LAND USE CHANGE DETECTION WITH LANDSAT-2 DATA FOR MONITORING AND PREDICTING REGIONAL WATER QUALITY DEGRADATION

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16. Abstract

The overall objective of this research investigation was to compare LANDSAT-1 and -2 imagery for land use change detection in Arkansas that might be indicative of variations in water quality.

Comparison between LANDSAT-1 and -2 imagery of Arkansas provided evidence of significant land use changes during the 1972-75 time period; (historical water quality data were not available in areas of maximum change.) Analysis of Arkansas historical water quality information has shown conclusively that whereas point source pollution generally can be detected by use of water quality data collected by state and federal agencies, sampling methodologies for nonpoint source contamination attributable to surface runoff are totally inadequate. The expensive undertaking of monitoring all nonpoint sources for numerous watersheds can be lessened by implementing LANDSAT change detection analyses. However, what is urgently needed is initiation of LANDSAT water quality monitoring programs in which specific sampling considerations are given to the storm hydrograph.

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PREFACE

This Type III Report covers the contract period from 27 January 1975 to 27 July 1976, and fulfills the requirements as outlined in Article I, Item B for NASA Contract NAS 5-20810, "Land Use Change Detection with LANDSAT-2 Data for Monitoring and Predicting Regional Water Quality Degradation."

OBJECTIVE

The overall objective of the research program was to compare gross water quality data with gross changes in land use.

The specific objective of this research investigation was to compare LANDSAT-1 and -2 imagery for land use change detection in Arkansas that may indicate variations in regional water quality. The long-term objective was to provide insight into the feasibility of using LANDSAT-derived land use mapping for monitoring and predicting gross or regional degradation of water quality.

SCOPE

The hypothesis of this LANDSAT research proposal was that the quality of surface water at any given point within a watershed might be recognized as an excellent indicator of land use above that point. Conversely, the updating of LANDSAT-derived land use maps would provide a technique for defining, monitoring, and predicting changes in regional water quality.

Surface water quality data published by federal, state, and local agencies provide a readily available source of information that could be used in conjunction with LANDSAT-derived land use changes. LANDSAT imagery was analyzed for changes in land use during the 1972-1976 time period, and corresponding water quality records were evaluated. A converse approach also was used whereby historical water quality data were processed for anomalous trends, which were then correlated with changes in land usage.

CONCLUSIONS

Comparison between LANDSAT-1 and -2 imagery of Arkansas provided evidence of significant land use changes; however, water quality records were not available in areas of maximum change.

Processing of all Arkansas water quality data published since 1944 revealed that only 7 percent of more than 200 stations have been in continuous operation since 1964, and those having sufficient historical records in the 1972-75 time frame provided data on parameters that have little relevance in identifying nonpoint source pollution.

Water quality sampling programs conducted concurrently with the LANDSAT investigation provided conclusive evidence as to the extremely variable nature of the rate and quality of land runoff. Among the more important variables that control runoff water quality are rainfall intensity and duration, antecedent conditions, and the type of land use. A few monthly samples taken without regard for rainfall, positioning on the stream hydrograph, and more importantly the parameters indicative of surface runoff tell very little about the water quality of a stream.

SUMMARY AND RECOMMENDATIONS

Land usage now is recognized as the dominant overall influence affecting the quality of surface waters for much of the United States. Land and water no longer are considered to be independent components of the landscape. Though point source pollution has received considerable public attention in the past two decades, the more complex diffuse or nonpoint pollution has been essentially ignored. With the exception of specific inputs such as irrigation return flows, surface mine drainage, and subsurface flow, most of the total contribution of nonpoint pollutants results from surface runoff. If greater attention is not given to land use as a component of any water quality management system, the benefits of tertiary and advanced waste treatment may be offset by pollution from surface runoff.

Nonpoint sources of pollution can be enormously great in number, yet rarely are cited as pollution sources to streams and rivers. The expense of monitoring all nonpoint sources in all river basins can be lessened by monitoring land use changes with LANDSAT imagery. What is urgently needed is initiation of water quality - LANDSAT monitoring programs in which specific considerations are given to the hydrograph. The design of a monitoring network based on point sources alone can provide only partial information. Stormwater quality analyses should be undertaken on those stream segments where land usage indicates a significant impact. The consideration of storm runoff is essential for determining critical conditions.

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RESEARCH PLAN

1.1 INTRODUCTION

Land and water now are being recognized as mutually dependent components of the environment. Yet only recently have the full implications of land use for water resources management begun to unfold. Though the quality of surface waters can be influenced by many factors, the more important parameters dominating water composition generally are the mineralogy of surface soils, geochemical composition of the subsurface, and biological and physical characteristics within the watershed. However, land usage now is recognized as the dominant overall influence affecting the quality of surface waters for much of the United States. Certainly urbanization and related industrial growth in the last two decades are the major causes of increased point source pollution and associated degradation of the quality of the nation's surface waters. The more complex diffuse or nonpoint pollution from land runoff, though not well understood, also is caused mainly by some form of human activity. Because of the very nature of pollution from land runoff, the problem has received little response beyond mere recognition. However, the lowering of the environmental quality of surface waters has become a source of considerable public and governmental concern. This concern is manifested in the Federal Water Pollution Control Act Amendments of 1972, the objective of which is to restore and maintain the chemical, physical, and biological integrity of U.S. surface waters.

Recognition of the complex interrelationships between land usage and environmental factors is essential for recognition of the impact of nonpoint source pollution. For example, though nonpoint pollutants often are recognized as organic and inorganic materials entering surface and groundwater from nonspecific or unidentified sources in sufficient quantity to constitute a pollution problem, these same components in minor amounts may provide the nutrients essential for productive aquatic ecosystems. Natural processes on watersheds can contribute their share of any pollution load and in many cases this share may be substantial. In fact, if greater attention is not given to land use in water quality management, the benefits of advanced treatment may be offset by pollution from land runoff. It is mandatory, therefore, not only to establish the natural or background water quality during low flow in order to assess the effects of increased inputs caused by human activities, but also to monitor stream characterics during times of maximum surface runoff.

Because land use changes can be expected to affect the water quality of an area, variations in regional surface water quality data collected by state and federal agencies should be correlative with gross land use changes detected by LANDSAT image analysis. The updating of land use maps in conjunction with analyses of historical water quality data should provide a technique for defining, monitoring, and predicting regional water quality. As a general hypothesis for such a LANDSAT investigation, the quality of water at any point within a watershed might be recognized as an excellent indicator of land use above that point. Conversely, emphasis should be placed on determining how various land use activities may influence water quality.

1.2 SCOPE OF STUDY

The State of Arkansas was a pioneer test region for the U.S. Geological Survey's National Standard Land Use Classification System. The first regional computerized land use mapping program in the United States, aimed at monitoring urban growth, was completed in 1975 for approximately 52,000 square miles of the Ozarks Region, much of which was the State of Arkansas. Computerized land use maps generated mostly from high altitude photographs (1972-73 acquisition) and supplementary LANDSAT-1 imagery represent a comprehensive data collection program designed to satisfy a great number and variety of user groups. Of particular significance to the overall problem defined for this investigation was the feasibility of updating these land use maps by LANDSAT-2 analysis, and comparing significant changes in land use with pertinent historical water quality records.

Ground truth data proved to be available in the form of water quality information for Arkansas surface waters which has been collected and published annually (since 1944) by the U.S. Geological Survey, Arkansas Geological Commission, and other state and federal agencies. In addition to the governmental compilation of regional water quality data, two intensive water quality monitoring programs, in distinctly different watersheds, were conducted in Arkansas during the period of investigation. These two long-term comprehensive collection and monitoring investigations, sponsored by the National Park Service (Buffalo National River) and Corps of Engineers (Caddo River and DeGray Reservoir), provided water quality data that could be correlated with a multitude of environmental parameters.

In the fields of land use and water resource management, remote sensing technology and applications are of particular importance in two areas, resource inventory and analysis and the monitoring of man's manipulation of the environment. Thus contrasting changes in land use from LANDSAT-1 and LANDSAT-2 maps should provide gross or regional change detection patterns. The extent to which land use change detection from LANDSAT imagery can be used for monitoring and predicting regional water quality degradation was the fundamental issue to be resolved by this investigation.

1.3 OBJECTIVES

1.3.1 Short Term

1. Compare LANDSAT-1 and LANDSAT-2 images for changes in gross land use patterns within selected Arkansas watersheds.

2. Compare surface water quality data gathered during LANDSAT-1 and LANDSAT-2 overflights for changes in gross water quality.

3. Evaluate and compare detailed water quality monitoring data and land use changes in specific areas (Buffalo National River and DeGray Reservoir) with the regional data obtained from LANDSAT-1 and LANDSAT-2.

4. Analyze water samples from selected Arkansas watersheds for which no post-LANDSAT-1 and/or LANDSAT-2 data are available.

5. Analyze water samples from selected Arkansas watersheds in order to correlate with USGS-derived data.

1.3.2. Long Term

The long-term objective is to provide insight into the feasibility of using LANDSAT-derived land use mapping for monitoring and predicting gross or regional degradation of water quality. Should this method prove feasible in Arkansas, applicability should hold for the entire United States.

Computerized land use maps, updated with LANDSAT type inputs, may provide a near-real-time capability of assessing regional water quality, independent of political boundaries. The long-term objective of the study is to evaluate an emerging remote sensing technology, ultimately to be combined with computerized image processing as a system for monitoring water quality conditions on a spatial, continuous, almost-real-time basis.

SECTION 2

BACKGROUND INFORMATION

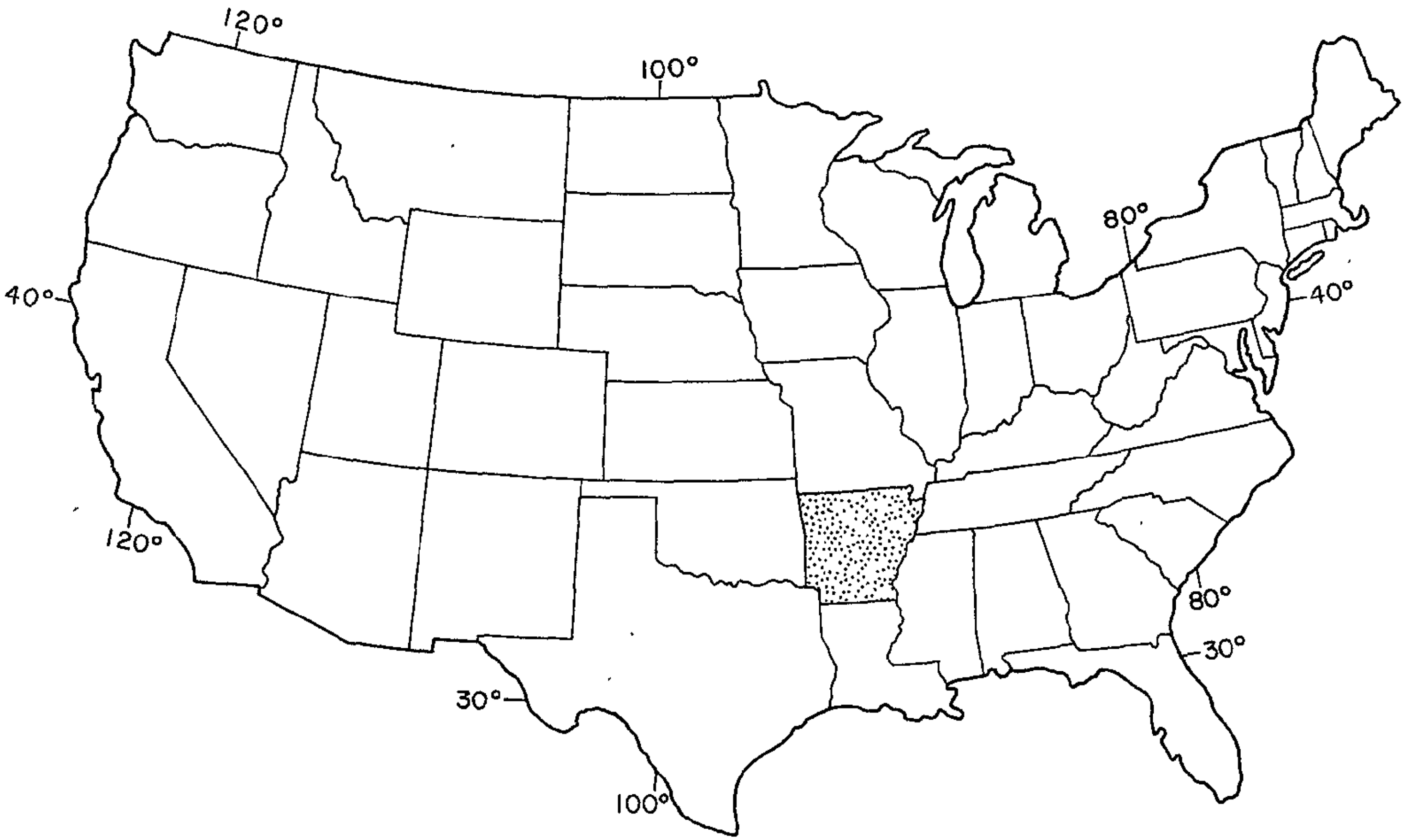
2.1 LOCATION AND BACKGROUND

2.1.1 Location

Arkansas is in the south-central United States (Fig. 1), adjoining Missouri on the north, Oklahoma and Texas on the west, Louisiana on the south, and Mississippi and Tennessee on the east. Arkansas' latitudinal location between 33° and 36°30'N is in the humid subtropics near their poleward edge, or the lower middle latitudes. Because of this location Arkansas is affected primarily by the Westerlies, a wind belt carrying cyclones and anticyclones which produces greatly varying weather. Arkansas' longitudinal location, from approximately 90° to 94°30'W, is in the mid-section of the nation and just east of the semiarid lands which begin near the 100th meridian.

2.1.2 Physiography

Parts of two major physiographic regions of the southern United States are within the boundaries of Arkansas, the Gulf Coastal Plain which covers the southern and eastern sections of the state and the Interior Highlands encompassing the northern and western part (Fig. 2). Physiographically Arkansas is divided into two nearly equal areas, the highlands in the northwestern half and the lowlands in the southeastern half. The Interior Highlands can be subdivided into Ozark Plateaus and Ouachita Mountains provinces. The Ouachita Mountains province consists of two subdivisions, the Arkansas Valley and Ouachita Mountains regions or sections.

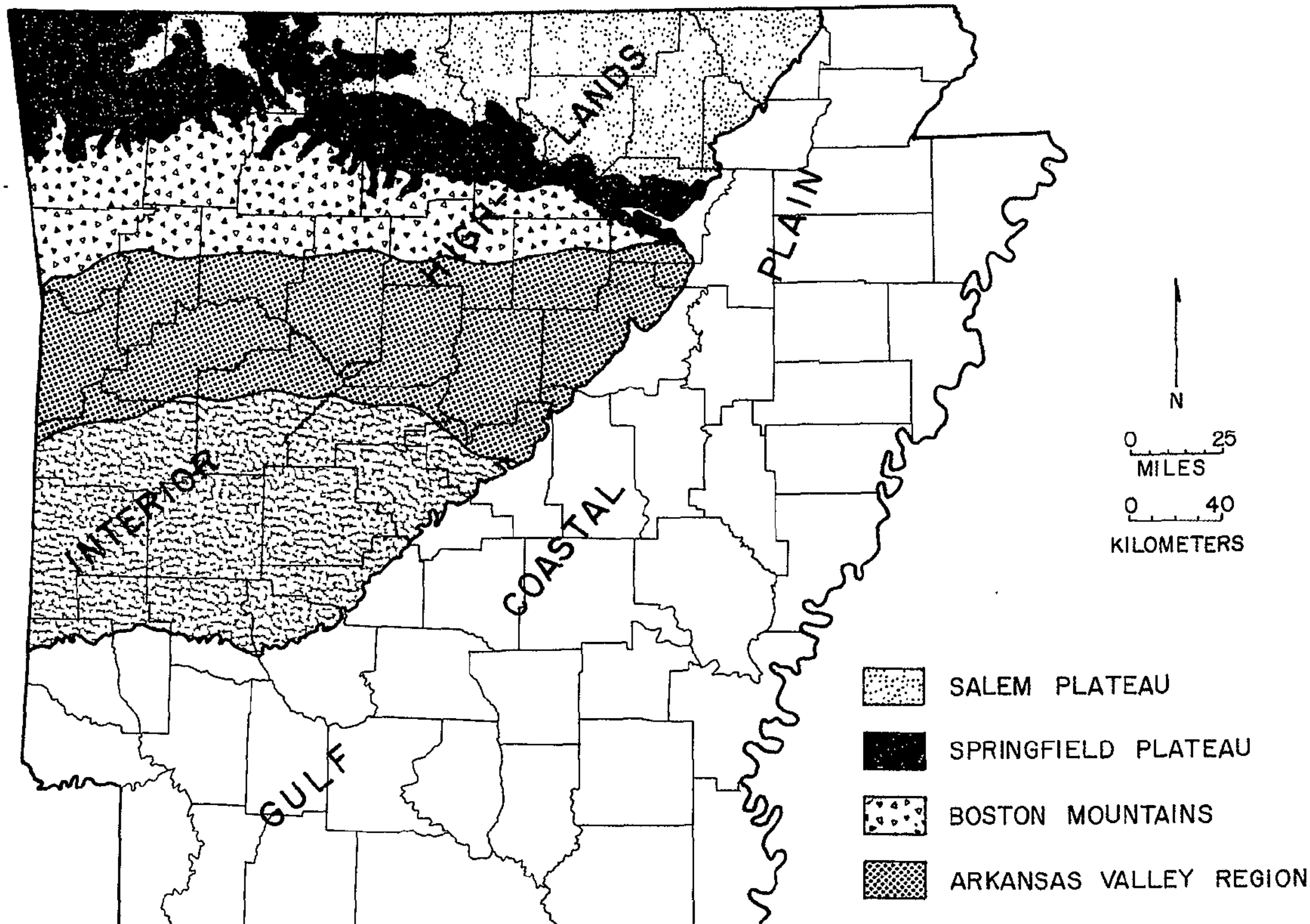


ARKANSAS IN RELATION TO THE UNITED STATES

(after: Arkansas Department of Planning, 1973).

Figure 1. Arkansas in relation to the United States

ARKANSAS PHYSIOGRAPHIC REGIONS



(after: Arkansas Department of Planning, 1973).

Figure 2. Arkansas physiographic regions

The Ozark Plateaus covers northern Arkansas and consists of three well-defined steplike surfaces, the Salem Plateau, Springfield Plateau, and Boston Mountains. Rock types in the plateaus are sedimentary and the units are relatively undeformed. The Salem Plateau is characterized mainly by elevations of 500 to 1,000 feet above sea level. Streams are gradually dissecting the broad uplands and the area is undulating to hilly, relief generally not exceeding 200 feet. In the Springfield Plateau elevation generally ranges from 1,000 to 1,500 feet. The Boston Mountains are the higher southern edge of the Ozarks. The mountains are primarily flat-topped summit ridges representing the original erosion surface of the plateaus. Great stream dissection has created steep-sided mountains and deep narrow valleys. Elevation generally ranges from 1,500 to 2,200 feet but in places exceeds 2,500 feet. Relief is mainly within the 500-1,000-foot range but in places exceeds 1,600 feet. The northern boundary is well marked by a retreating escarpment in most areas. On the south, the mountains descend rather abruptly to the Arkansas Valley region.

The Ouachita Mountains in the west-central part of the state also are composed of sedimentary rocks, but they have been folded into generally parallel ridges and valleys in an east-west orientation. Most of the mountain ridges are narrow with steep slopes; crests tend to be sharp; valleys are generally rather broad. Within the Ouachita Mountains province, subdivisions are distinguished mainly by the spacing of the folds. The Arkansas Valley region, for example, is from 30 to 40 miles wide and is characterized by widely spaced ridges straddling the Arkansas River which flows from northwest to southeast. Within the core area of the Ouachita Mountains, elevations of 2,000 feet are common with an associated range of relative relief from 300 to 900 feet. The southern flank of the

Ouachitas is characterized by an undulating surface with few elevations of more than 500 feet.

The Gulf Coastal Plain is between 100 and 500 feet above sea level, with local relief of less than 100 feet. The gently rolling surface is only moderately dissected by streams. Much of the surface material is unconsolidated sand deposited in the sea which once covered the area. Crowley's Ridge is a striking irregularity in the Northeastern Coastal Plain. This feature is 3 to 12 miles wide, rising 200 feet above the plain on the north and 100 feet on the south.

2.2 GEOLOGY

The Interior Highlands of Arkansas is underlain by rock of Paleozoic age, dominated by limestone and dolomite in the north plateaus areas and gradually changing to sandstone and shale in the south. The Gulf Coastal Plain is underlain by rock of Cretaceous, Tertiary, and Quaternary age composed of claystone, sandstone, conglomerate, chalk, and marl. Table 1 provides an indication of the general geologic age groupings of rock units, and Figure 3 gives more specific details about the geologic units at the surface.

2.3 SOIL ASSOCIATIONS

A soil survey and soil associations map provide valuable information to anyone interested in land use - water quality studies. In Arkansas, the USDA Soil Conservation Service, Forest Service, and the University of Arkansas Agricultural Experiment Station cooperate in soil survey mapping, research on soils, development of reports for publication, classification of soils, and interpretation studies for various uses. Figure 4 shows the

ARKANSAS SURFACE GEOLOGY

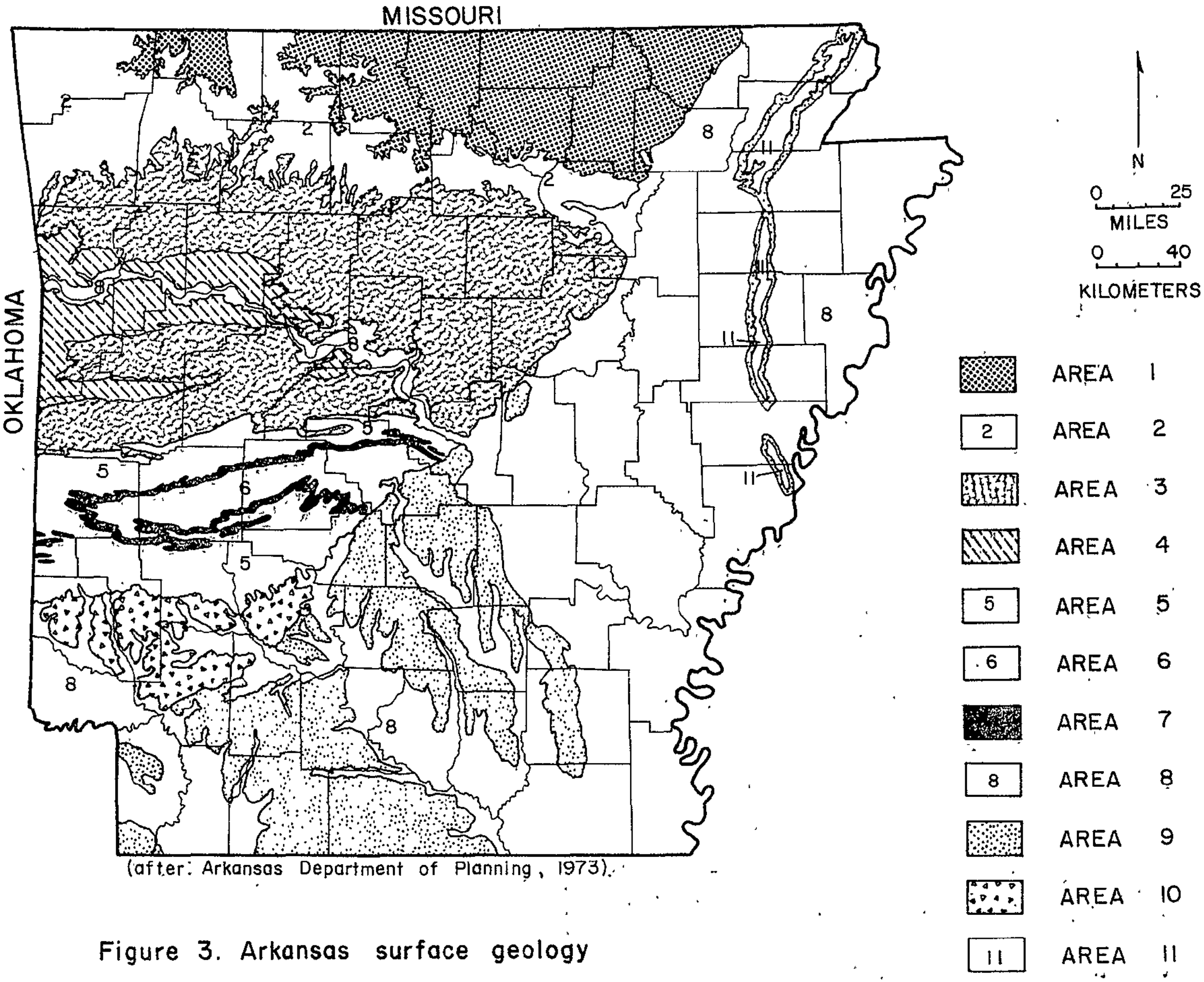


Figure 3. Arkansas surface geology

EXPLANATION
SURFACE GEOLOGY

AREA 1

The surface rocks of the Salem Plateaus are the oldest of the Ozark Plateaus, younger ones having been removed by erosion. They are largely of Ordovician age, and are predominantly dolomite and limestone with some sandstone and shale. The Cotter Dolomite of Early Ordovician age, a massive formation up to 500 feet thick, covers most of the east and north of this region. The Everton Limestone is the predominant rock in the western and southern areas.

AREA 2

This area is primarily the Springfield Plateau. The Boone Formation, consisting of limestone and chert of Early Mississippian age, is the surface rock. Weathering easily reduces the limestone, leaving large pieces of chert which are especially prominent on hillsides where the finer materials have been eroded away. Outliers of the Boston Mountains are especially common in the western part of the region. They consist largely of sandstone and shale found in the Boston Mountains.

AREA 3

The Boston Mountains and the eastern part of the Arkansas Valley are surfaced in sandstone and shale of Pennsylvanian age. The massive Atoka Formation, more than 1,500 feet thick, is the most prominent. The Atoka Sandstone forms the bluffs at the top of the Boston Mountains.

AREA 4

The western part of the Arkansas Valley is surfaced in Upper Pennsylvanian rock, consisting of sandstone and shale. The numerous natural gas fields in this region produce a dry gas.

AREA 5

Mississippian rocks surface most of the northern flanking Ouachita Mountains. The Jackfork Sandstone is particularly important in the major mountain ridges. The Stanley Shale is the most widespread unit.

AREA 6

The Central Ouachitas are closely folded ridges and valleys of Ordovician and Silurian sandstone and shale. Two major units are the Crystal Mountain Sandstone and the overlying Mazarn Shale.

AREA 7

Arkansas novaculite is exposed along the outer edge of the Central Ouachitas, also referred to as the Novaculite Uplift. The novaculite is of Devonian age and underlies the Hot Springs Sandstone. It is a very hard, fine-grained rock of silica, used as an abrasive stone and as a silica source in manufacturing.

AREA 8

Recent alluvium and terrace deposits cover much of the lowlands in the southeastern half of the state. Particularly, they provide the surface materials in the Mississippi Alluvial Valley and along the rivers of the Gulf Coastal Plain. The terrace deposits are generally older, commonly Pleistocene, and represent former levels of bottomland below which streams now have cut.

AREA 9

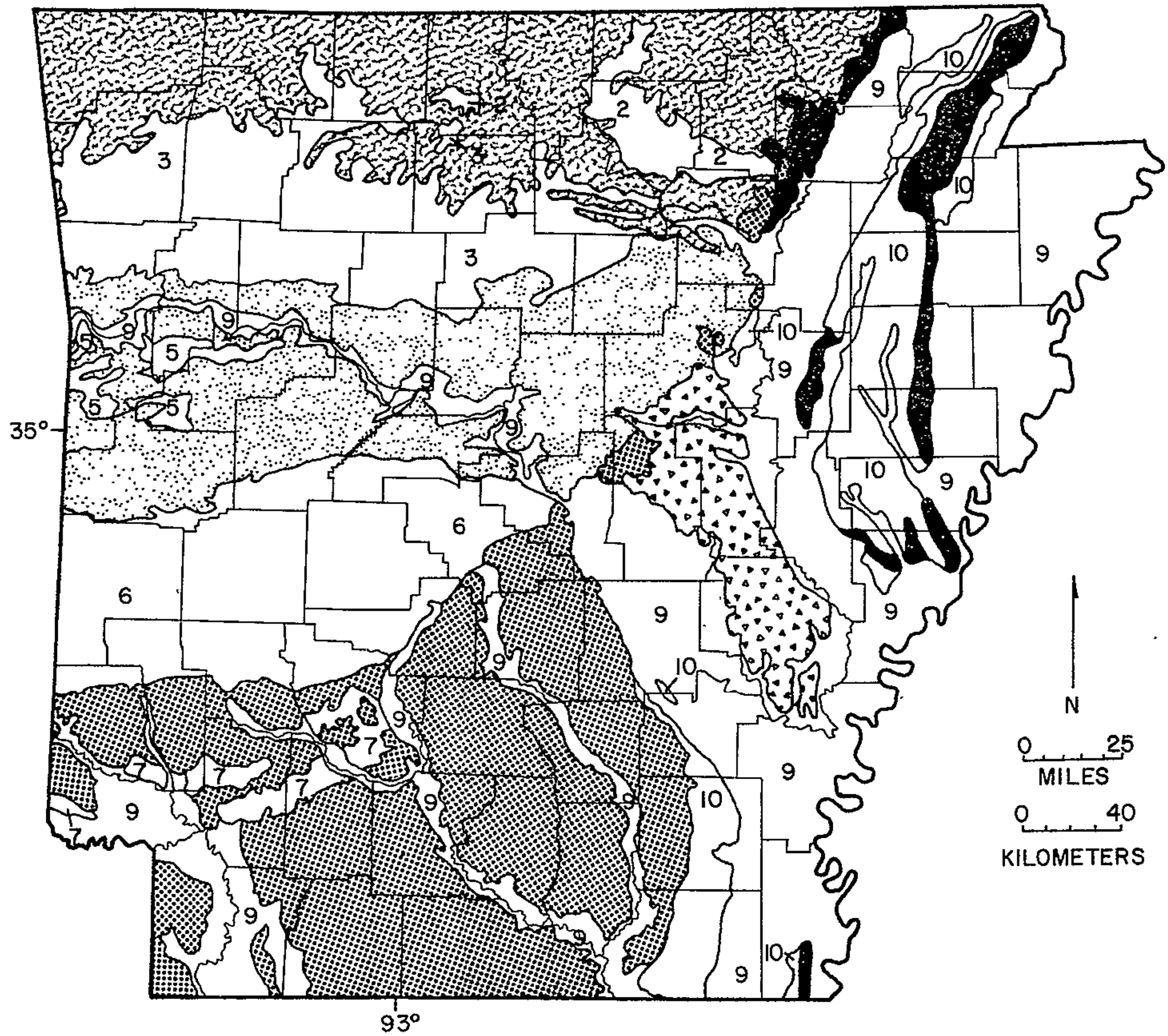
The edge of Crowley's Ridge and a large area of the Gulf Coastal Plain are surfaced with the Claiborne, Wilcox, and Mickey Formations of Eocene age. The area in the Coastal Plain is interrupted by the more recent alluvial deposits of the major rivers. Generally, the surface materials are poorly consolidated sand and clay. There are scattered deposits of lignite. The bauxite deposits of Pulaski and Saline Counties are in this surface area and the oil and gas deposits of South Arkansas are in older and much deeper rocks below the Coastal Plain.

AREA 10

Scattered Cretaceous units occupy the inner edge of the Gulf Coastal Plain from the Oklahoma line to Clark County. Most of the beds are coarse sand, clay, or gravel.

AREA 11

Loess caps the higher parts of Crowley's Ridge. It is a fine, windblown silt derived from the alluvial deposits west of the ridge. The prevailing westerly winds picked up the dried alluvium which had been deposited mainly during the Pleistocene and carried it eastward, dropping it when forced to rise. The bluffs on the east side of the Mississippi Valley from Cairo, Illinois, southward also are capped with loess.



ARKANSAS SOIL ASSOCIATIONS

- OZARK HIGHLANDS LIMESTONE SOILS
- 2 OZARK HIGHLANDS SANDSTONE-LIMESTONE SOILS
- 3 BOSTON MOUNTAINS SOILS
- ARKANSAS VALLEY SOILS
- 5 CHEROKEE PRAIRIES SOILS
- 6 OUACHITA MOUNTAINS SOILS
- 7 BLACKLAND PRAIRIES SOILS
- FORESTED COASTAL PLAIN SOILS
- 9 BOTTOMLAND AND TERRACE SOILS
- 10 LOESSIAL PLAINS SOILS
- EASTERN PRAIRIE SOILS
- LOESSIAL HILLS SOILS

Figure 4. Soil associations

(after: Arkansas Department of Planning, 1973).

EXPLANATION
SOIL ASSOCIATIONS - GENERAL LAND USE

Group 1

Ozark Plateaus Limestone Soils. These soils have developed chiefly on the limestones of the Springfield and Salem Plateaus. Elevation ranges from 500 to 1,500 feet and most of the land is in slope. Soils have developed chiefly under deciduous forest but some prairie is present in the westernmost area. Subsoils are slowly to moderately permeable, grayish brown to yellowish brown clays. Soils are mainly silt, loam, relatively deep in the valleys and on flatter areas, but very thin on the steeper hillsides. They are used for general farming, especially grazing of beef cattle; and for orchards and vineyards.

Group 2

Ozark Plateaus Sandstone-Limestone Soils. The hills and valleys are eroded from interbedded sandstone and limestone on the Salem Plateau. Clay and sandy loam subsoils are overlain by loamy grayish brown and yellowish brown soils. Mixed hardwoods and shortleaf pine are the natural vegetation and general farming predominates.

Group 3

Boston Mountain Soils. The Boston Mountains are the southernmost edge of the Ozarks where much of the area is very rugged, and relatively level land is confined to ridgetops. Most of the area is heavily forested, chiefly with deciduous trees but with shortleaf pine in the east and south. The Ozark National Forest is in the middle of the area. The soils are sandy loams and clay loams, medium textured, and generally well drained. Woodland and pasture with some general farming are major uses.

Group 4

Arkansas Valley Soils. Sandstone and shale are the parent materials for soils on the narrow ridges and in the wide valleys of the Arkansas Valley section of the Ouachitas. Deciduous forest with some prairie and stands of shortleaf pine increasing southward are the natural vegetation. Soil conditions vary considerably from valley floor to hillside, but most soils are slowly to moderately permeable and of medium texture. Sandy, silty, and clay loams range from brown to yellow and red in color. Pasture, general farming, and some specialty crops occupy the non-forested land.

Group 5

Cherokee Prairies Soils. These soils occupy scattered areas in the western Arkansas Valley, developing over sandstone and shale and under prairie. The soils are deep and of medium texture and are a dark silt loam. Grazing is the major use.

Group 6

Ouachita Mountains Soils. Shale, sandstone, novaculite, and quartzite are common surface rocks. The soils are of medium texture and moderate permeability. The area is forested; pines and bottomland hardwoods predominate. Soils are mainly silty clay and silty loam, deep in the valleys and very shallow and stony on the ridgetops. The Ouachita National Forest comprises considerable acreage. Elsewhere, livestock grazing and general farming are the chief agricultural pursuits and there is much timber harvesting.

Group 7

Blackland Prairie Soils. In southwestern Arkansas, scattered prairies occupy areas of chalk and calcareous marls. Gray clay subsoils are overlain by deep, dark clay and silt loam soils. Pasture and field crops are the chief uses.

Group 8

Forested Coastal Plain Soils. Central south Arkansas consists of a sandy coastal plain of rolling terrain broken by stream valleys. Most of the area is gently to moderately sloping and pine forest dominates except along streams. Most subsoils are sandy or silty clay loams, relatively deep. Soils are largely sandy loams with some silt and clay loams. There is considerable harvesting of both pines and hardwoods. Pastures and truck and field crops are major agricultural uses.

Group 9

Bottomland and Terrace Soils. This soil association is found along all major streams. The deep alluvial material ranges from coarse to fine in texture and thus from rapid to slow in permeability. The land is level to only gently undulating and there is much wetland. Bottomland hardwoods are the major natural vegetation. Chief agricultural uses are for cotton, rice, soybeans, and pasture.

Group 10

Loessial Plain Soils. In some areas of eastern Arkansas, especially on the west side of Crowley's Ridge, are broad alluvial plains capped with wind-deposited silt. Most of the soils are deep, medium textured, and slowly permeable. The subsoils are mainly clay and commonly compact. A variety of crops, but chiefly cotton and rice, are raised and pastures are extensive.

Group 11

Eastern Prairie Soils. The prairies of eastern Arkansas have nearly level terrain. The clay subsoils are generally compact. The silt loam soils are used for rice, cotton, soybeans, and pasture.

Group 12

Loessial Hills Soils. Crowley's Ridge and smaller ridges of eastern Arkansas are capped with windblown silt ranging in depth from a few to as many as 70 feet. The area is in moderate slope and there has been much soil erosion. The largely silt loam soils are deep, of medium texture, and moderately permeable. Pasture is the chief use.

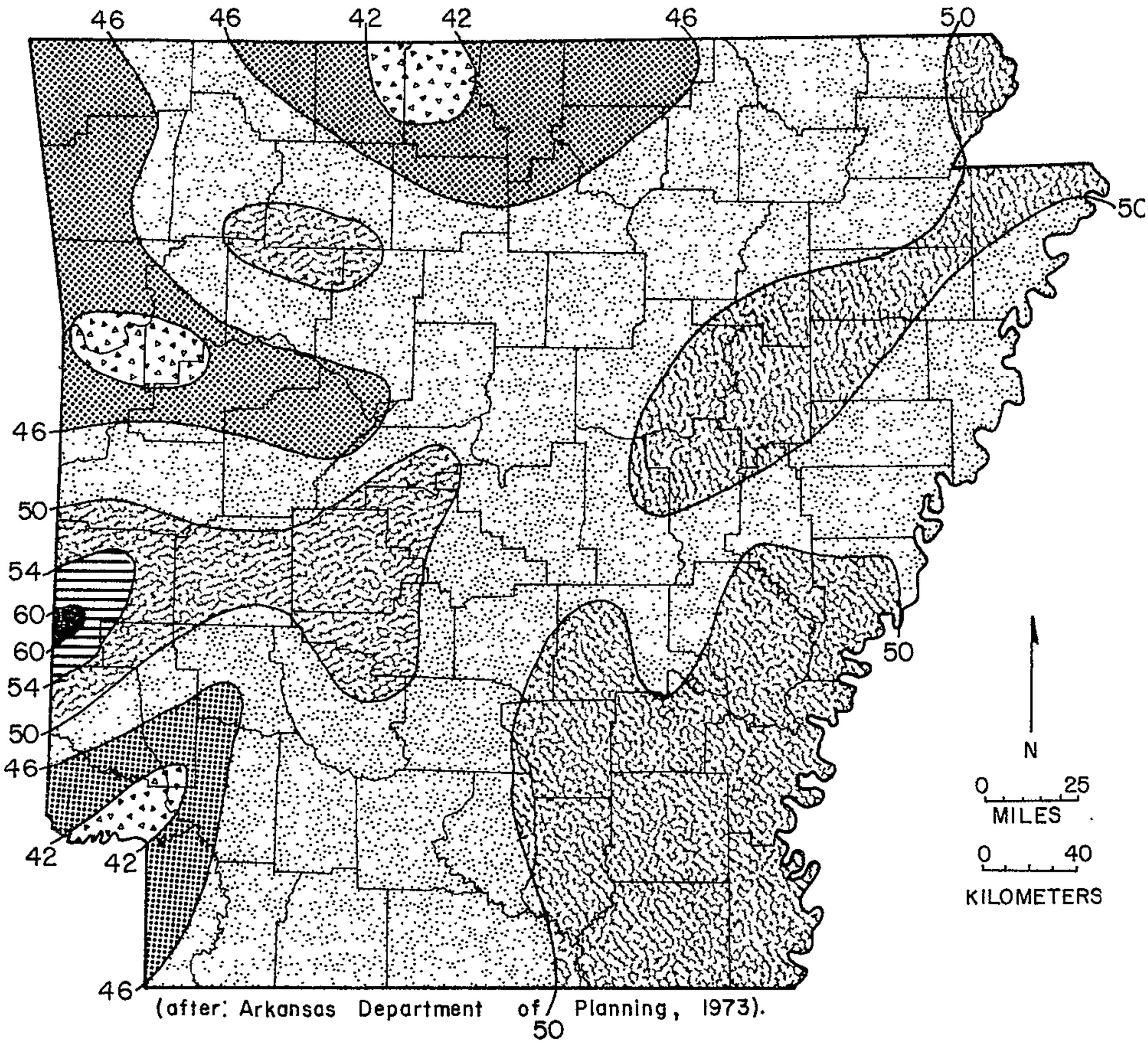
Table 1. Geologic Age Relationships

ERA	PERIOD	EPOCH	APPROXIMATE AGE (in years before present)
CENOZOIC	QUATERNARY	Recent (Holocene)	10,000
		Pleistocene	1,000,000
	TERTIARY	Pliocene	13,000,000
		Miocene	25,000,000
		Oligocene	36,000,000
		Eocene	58,000,000
		Paleocene	63,000,000
MESOZOIC	CRETACEOUS		135,000,000
	JURASSIC		180,000,000
	TRIASSIC		230,000,000
PALEOZOIC	PERMIAN		280,000,000
	PENNSYLVANIAN		310,000,000
	MISSISSIPPIAN		345,000,000
	DEVONIAN		405,000,000
	SILURIAN		425,000,000
	ORDOVICIAN		500,000,000
	CAMBRIAN		600,000,000

major soil associations for Arkansas and the explanation includes a brief description of each land use resource area and respective association.

2.4 PRECIPITATION AND CLIMATE

The mean annual precipitation ranges from about 40 inches in the western Arkansas River Valley to about 60 inches in the western Ouachitas (Fig. 5). Most precipitation in Arkansas is of frontal origin, occurring along the zone or "front" where two unlike air masses meet. Locally in highland areas precipitation amounts are increased by orographic action which occurs when moist air is forced to rise over a landform barrier. This process is common in the area of the Ouachitas that has the highest mean annual precipitation in the state. Most precipitation is in the form of rain. Snowfall occurs throughout the state, but nowhere is it great enough to add significantly to the precipitation total. Snowfall in the south is usually very light; in some years only a trace is recorded.



MEAN ANNUAL PRECIPITATION IN INCHES

Figure 5. Mean annual precipitation in inches

Because most of the state's precipitation is of the frontal or cyclonic type, the locations of the major storm tracks in the area are important factors in Arkansas' precipitation. Three major storm tracks affect the state. The most important is the South Pacific track which crosses the state diagonally from the southwest to the northeast. The effects of this track can be seen on the map as the area having the greatest annual precipitation through the center of the state. As a low, or cyclone, moving along this track reaches the central part of the nation, it draws warm, moist air toward it from the Gulf of Mexico, thus creating precipitation in Arkansas.

The Texas storm track passes south and east of the state. Lows following this track are able to draw considerable moisture up from the Gulf. The track comes closest to the southeast corner of Arkansas, and is evidenced by the area with more than 50 inches of precipitation in that region of the state.

The third track, and the least important to the state, is the Colorado storm track which passes north of Arkansas through southern and central Missouri. This track is farther from the moisture source of the Gulf and thus has less effect on the precipitation in the state. However, the Colorado track is responsible for some of the precipitation received in northwest Arkansas.

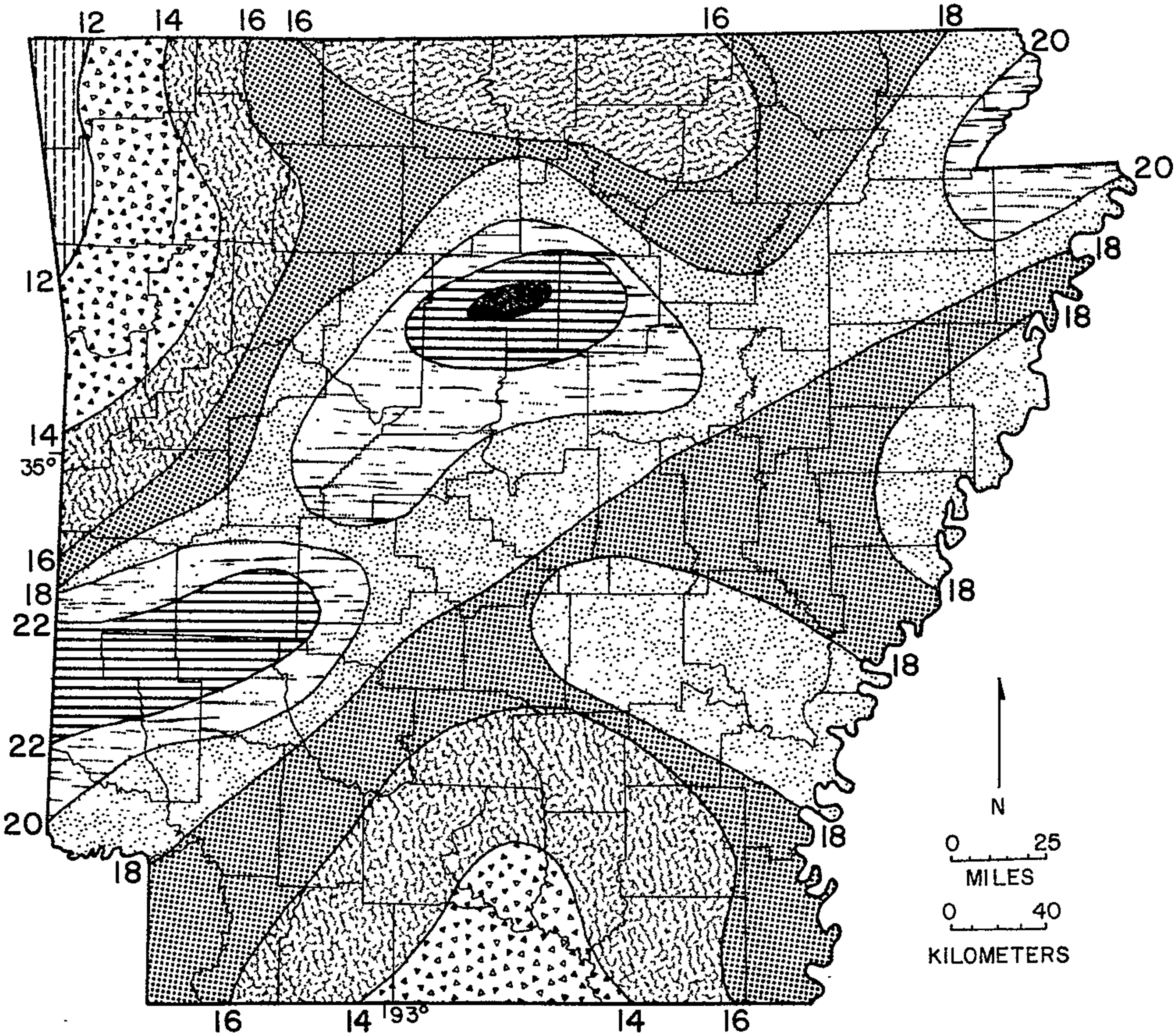
2.5 STREAM RUNOFF

Stream runoff is water that drains from the land by means of surface streams. These streams are supplied by surface flow and by drainage from groundwater sources. Basically, runoff is the water remaining from precipitation after losses to evaporation, transpiration, soil moisture, and groundwater.

Many variables regulate the amount of runoff. Precipitation is the most basic regulator. Amount, duration, intensity, and frequency of precipitation all affect it. If precipitation amounts are small, or if it is infrequent or comes as light showers, runoff will be small. Runoff will be greater if precipitation comes in large quantities in a short period of time. Vegetative cover is another factor that determines the amount of runoff. A thick ground cover will retain precipitation and slow surface runoff. Soil conditions are also a factor. If the soil is loose and porous, water can percolate into the ground to become part of the soil moisture or the groundwater, thus slowing the rate and decreasing the amount of runoff. A hard-packed soil increases the amount of runoff, and the porosity of the subsoil and bedrock also can influence it. Slope has a significant effect. A steep slope decreases the time in which water can soak into the ground, thus increasing runoff. All these factors must be considered together to understand properly the pattern of runoff in Arkansas.

A few examples of the factors affecting runoff aid in interpreting the mean annual data provided in Figure 6. Heavy precipitation, considerable slope, and shallow soil with rather impervious bedrock are probable reasons for the large annual runoff in southwestern Arkansas. Similar factors possibly are present in the area with the greatest amount of runoff in the state; however, methods of data collection may have exaggerated the size of this area somewhat. Dense forest vegetation, little slope, and a combination of various other factors result in a small amount of runoff in southernmost Arkansas. Not reflected by the map data (Fig. 6) are urban areas where large paved expanses increase runoff markedly.

In general, stream runoff characteristics for all of Arkansas can be correlated roughly on the basis of physiography, the Highlands in the



(after: Arkansas Department of Planning, 1973).

MEAN ANNUAL RUNOFF IN INCHES 1940-1960

Figure 6. Mean annual runoff in inches, 1940-1960

northwestern half and the Lowlands in the southeastern half. The words "high" and "low" readily bring to mind how a river or lake would look in these two parts of the state. Highland rivers are generally flashy, fast running, and clear; Lowlands rivers are sluggish and generally muddy. Lakes and reservoirs in the Highlands are relatively deep with steep irregular shorelines. Lowland lakes and reservoirs are relatively shallow and small quantities of water will flood large areas of land in comparison with equal quantities of water in a lake in the Highlands (Sniegocki and Bedinger, 1969).

2.6 LAND USE

The State of Arkansas was a pioneer test region for the proposed National Standard Land Use Classification System. The first regional computerized land use mapping program in the United States, aimed at monitoring urban growth, was completed in 1975 for about 52,000 square miles of the Ozarks, including the entire State of Arkansas. Computerized land use maps generated from high altitude photographs represent a comprehensive data collection program designed to satisfy a great number and variety of user groups. Of particular significance to the overall objectives of this investigation was the feasibility of updating these land use maps with LANDSAT-2 imagery to make possible monitoring of land use changes which might have a direct influence on the gross degradation of water quality.

2.6.1 USGS Mapping Program*

The Ozarks Project was undertaken after an investigation by the Geography Program to determine an area in which a test and demonstration

*Summarized from a report released in 1975 by The Ozarks Regional Commission in cooperation with the USGS; Ozarks Pilot Land Use Data Base Test and Demonstration Final Report, Little Rock, Arkansas, 33 p.

could be conducted. Selection was based on the availability of source material for the region, the availability within the region, and the enthusiasm of the states' agencies for the program.

2.6.1.1 Data Base Parameters

The first meeting with personnel of the Ozarks Regional Commission was held in Little Rock, Arkansas, in October 1971. At this meeting, U.S. Geological Survey personnel displayed the Pheonix, Arizona, land use map, computer plots, and statistical data. The Ozarks Regional Commission favored investigating the possibility of the development of a similar system for the Ozarks Region. The U.S. Geological Survey and Ozarks Regional Commission personnel believed that it was necessary, before entering into a commitment, to brief the individual states' members of the Commission; i.e., the members from Missouri, Arkansas, Oklahoma, and Kansas. The purpose of the briefings was to ascertain that the land use data base would provide meaningful data that could be used for resource management activities in the region. These briefings emphasized the need for such a system and provided input for further system development.. Upon agreement by the states as to the need for such a land use data base system, individual 1:250,000-scale map sheets to be compiled were selected.

This project provided the Ozarks Regional Commission with a computerized land use data base system having the following features.

1. A set of maps in the standard 1:250,000-scale topographic map series format.
2. All data encoded and put into the computer for statistical data development.
3. Provision for updating and/or expanding by the inclusion of new and diversified data.
4. Programs available for data manipulation and statistical tabulation.

2.6.1.2 Data Base Products

The land use data base contains the following items for each 1:250,000-scale topographic map sheet within the selected area.

1. Lithographic copy of the topographic map at a scale of 1:250,000.

2. A transparent overlay keyed to the topographic map showing Level II land use, delineated in accordance with U.S. Geological Survey Circular 671 and certain amendments (Table 1 provides the land use classification).

3. A transparent overlay keyed to the topographic map sheet showing the political boundaries.

4. A transparent overlay keyed to the topographic map sheet showing the drainage areas.

5. A transparent overlay keyed to the topographic map sheet showing the federal- and state-owned land to a minimum area of 40 acres.

6. A transparent overlay keyed to the topographic map sheet showing census county subdivisions by census tracts within the standard metropolitan statistical areas and the minor civil divisions elsewhere.

The flow diagram (Fig. 7) illustrates the progressive tasks accomplished in the compilation of the data base.

All of the data, with the exception of the topographic map sheet, are encoded on computer cards and stored on tape for manipulation by the computer. Two types of computer items are produced, a tape to drive a plotter which will plot, as a map graphic, various types of data stored, and a tabulation of data which result from a specific data manipulation.

2.6.1.3 Land Use Map Preparation

The acquisition of source material was the first step in the compilation of the land use data base map. The criteria for selection of source material had to allow the extraction of Level II land use as described in USGS Circular 671 (Table 2).

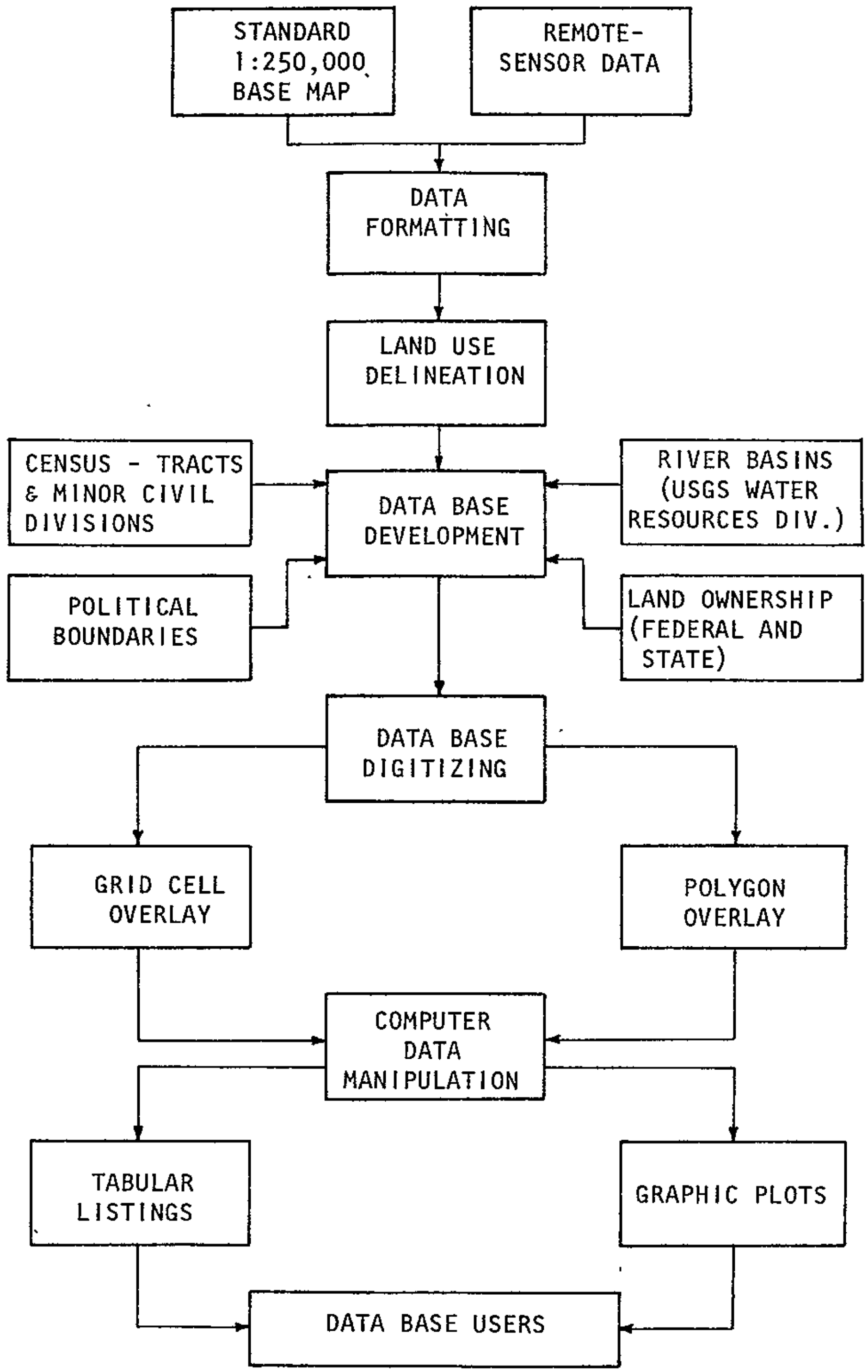


Figure 7. Land use data base system flow diagram.

Table 2. Land Use Classification System for Use With Remote Sensor Data - Ozarks Regional Commission Program*

Level I	Level II
01. Urban and Built-Up Land	
	11. Residential
	12. Commercial and services
	13. Industrial
	14. Extractive
	15. Transportation, communications, and utilities
	16. Institutional
	17. Strip and clustered settlement
	18. Mixed
	19. Open and other
02. Agricultural Land	
	21. Cropland and pasture
	22. Orchards, groves, bush fruits, vineyards, and horticultural areas
	23. Feeding operations
	24. Other
03. Rangeland	
	31. Grass
	32. Savannas (palmetto prairies)
	33. Chaparral
	34. Desert shrub
04. Forest Land	
	41. Deciduous
	42. Evergreen (coniferous and other)
	43. Mixed
05. Water	
	51. Streams and waterways
	52. Lakes
	53. Reservoirs
	54. Bays and estuaries
	55. Other
06. Wetland	
	61. Forested
	62. Nonforested
07. Barren Land	
	71. Salt flats
	72. Beaches
	73. Sand other than beaches
	74. Bare exposed rock
	75. Other
08. Tundra	
	81. Tundra
09. Permanent Snow and Icefields	
	91. Permanent snow and icefields

*From USGS Circular 671, with modified wetland coding.

The 1:250,000-scale topographic map series was used as the base map for the compilation of the land use overlay and other overlays. A composite positive at 1:250,000-scale was made for each map sheet showing only the border information, the culture, and the open water features. This film positive was enlarged to compilation scale of approximately 1:125,000. The 1:125,000-scale enlargement was used as the base map for all data base overlays. The 1:125,000-scale data base overlays were reduced in the final reproduction phase to fit the original 1:250,000-scale film positive base.

Auxiliary sources of information useful in the compilation of land use and other data base overlays were obtained by the Geography Program. This source material consisted of land use or other types of maps supplied by the U.S. Geological Survey, Department of Transportation, Department of Agriculture, Department of Housing and Urban Development, and state and local agencies. The cartographic specifications for compilation were:

1. The delineations of all features other than water categories will be in straight line segments approximating actual land use polygon boundaries.

2. All water features will be delineated by curved lines that follow the shoreline of the water feature being delineated.

The areas of the polygons delineated are of two minimum sizes. All Urban and Built-up Land and Water polygons have a minimum area of 10 acres. All other polygons of land use have a minimum area of 40 acres. These minimum areas are derived from the minimum lengths of line. The minimum ground dimension of polygons is 660 ft. (200 m.) for all Urban and Built-up Land and Water Categories, and 1320 ft. (400 m.) for all other categories. At a map scale of 1:250,000 these minimum dimensions would be about 1/32 (0.8) and 1/16 inch (1.6 mm), respectively. These minimum width considerations preclude the delineation of very narrow long tracts. Triangles or other polygons are acceptable for delineation if the base of the triangle or polygon satisfies the minimum width criterion for the appropriate minimum area.

2.6.1.4 Computer Applications

Having the computer provide both map and statistical data requires that the information developed during the compilation be converted to a computer-acceptable format. For the original agreement (USGS and Ozarks Regional Commission), the conversion was accomplished by using Universal Transverse Mercator (UTM) coordinates and encoding the information by square-kilometer cells. The encoded data were keypunched into computer cards and read into the computer for data manipulation and plotting. Although the data were encoded by individual map sheets, the data were combined in the computer and stored on magnetic tape so that complete county, regional, or state data can be generated. The program used to produce statistics in the computer has a subroutine which produces the data necessary to drive the plotter in such a way that the data can be plotted at any scale for an area of any size.

The term "encoding" refers to the means by which the graphic data base maps can be quantified for adaption to computer manipulation. The encoding of all overlay data was completed for all areas of the agreement, with reference to the Universal Transverse Mercator grid which allowed the use of a rectangular grid throughout the area. Each map sheet contains more than 20,000 cells, each cell representing one square kilometer. A computer card for each square-kilometer cell contains data base information in the following format.

Col.	1-3	UTM grid zone
Col.	4-5	100,000-km grid box designator
Col.	6-7	East km^2 grid number (row)
Col.	8-9	North km^2 row number (column)

Col. 14-15	State number
Col. 18-20	County number
Col. 21-26	Census minor civil division or tract number
Col. 29-32	Drainage number
Col. 33-36	Data
Col. 38-39	Land ownership code
Col. 41-42	Land use code

2.6.1.5 Updating

Updating of material for both graphic and computer input is possible in this land use data base. From available source material, the new graphic land use overlay is prepared by interpreting the source and delineating the areas which require updating or changes on a clear overlay keyed to the original compilation map. This technique applies to all of the overlays involved in the data base. Once the changes have been determined and plotted, the 1- km^2 grid is overlayed on the change sheet; those 1- km^2 cells where changes have occurred are noted and new cards are prepared for each cell, showing the changed data of the overlay being updated. The new cards replace the old cards in the original deck and the newly constituted deck is read into the computer.

2.6.2 USGS Mapping Versus Change Detection

Coincidentally with the LANDSAT investigation, land use - water quality studies were conducted in the Buffalo National River and Caddo River watersheds. In addition to the land use maps prepared by the USGS for these two watersheds, land use mapping was done at the University of Arkansas by use of large-scale (1:20,000) panchromatic photographs* in combination with LANDSAT-1 imagery. Comparison of the University of Arkansas and USGS land use maps revealed a problem that had not been

*Photographs furnished courtesy Arkansas Highway Department.

anticipated during the initial phases of the investigation. The USGS polygonal land use boundaries only approximated the actual "real-world" outlines. The computer-compatible polygons tend to average irregularities, and this averaging necessarily leads to a reduction in the accuracy of final map categories. Because the original data base used by the USGS has been classified (secret) since the day it was obtained, change detection by comparing real-world boundaries and updating of the computerized land use maps were not feasible. However, particulars related to the water quality monitoring for both the Buffalo National River and Caddo River watersheds are provided in sections 5.2 and 5.3, respectively.

SECTION 3

PREVIOUS INVESTIGATIONS

3.1 INTRODUCTION

The use of mathematical models for simulating the response characteristics of a watershed has been firmly established and a comprehensive review of progress in surface runoff modeling is provided by Schaake (1975). Attempts to model the effects of land use on surface runoff have met with varying degrees of success; however, in most of these studies the emphasis has been on surface water hydrology (flow regime) rather than surface water quality. Research related to the association between land use and surface water hydrology can be categorized into two main areas of concern, (1) the effects of urban development on flood events and (2) the effects of deforestation or vegetation on water yield and flood events.

3.2 EFFECTS OF URBANIZATION

A comprehensive summary of the hydrologic effects of urbanization in the United States has been prepared by McPherson (1972). Espy and Winslow (1974) provide a state-of-the-art report in which a correlation between physiographic, urban, and climatic factors is used to estimate urban flood frequency characteristics. The effects of urbanization on water quality are summarized by Shubinski and Nelson (1975), and Gluck and McCuen (1975) describe a method for estimating land use characteristics for hydrologic models. Lehmann (1975) provides a bibliography with abstracts concerning the effect of land use and urbanization on water resources. The current interest of most of these investigators is the application of computer techniques to the simulation of the hydrologic response of urbanized watersheds.

3.3 EFFECTS OF DEFORESTATION AND VEGETATION

The hydrologic consequences of changing land use have become obvious in areas of deforestation. Rothacher (1970) found that increases in water yield after timber harvest vary in proportion to the area cleared; he has shown that clear-cut logging can increase annual surface runoff in the Oregon Cascades by 18 inches. Hewlett and Helvey (1970) studied storm hydrographs at a test site in the southern Appalachians and found an 11 percent average increase in stream runoff. Most recently, hydrologists have related their efforts indirectly to overall water quality. Mansue and Anderson (1974) recognize that stream sediments degrade water quality for nearly every water use. They point out that sediment interferes with aquatic life processes, affects heat balance in streams by shading lower water levels, and abrades constructural features in the stream channels. Mansue and Anderson used multiple regression analysis to model storm event streamflow values associated with sediment load, and they recognized changing land use as a probable factor contributing to sediment increases. Harr et al. (1975) summarize the more recent studies concerned with changes in storm hydrographs after road building and clear-cutting. Blackwood (1974) concludes that water quality varies greatly from storm to storm and that the factors causing these variations are too numerous to permit the use of simple prediction techniques. However, Darby et al. (1976) suggest a method of discriminant analysis which precludes extensive monitoring programs to gather comprehensive water quality data, and conclude that even with limited stream sampling data indicators of watershed characteristics can be used both to estimate overall water quality of a stream and to predict individual problem parameters.

SECTION 4

RESEARCH PROCEDURES

4.1 INTRODUCTION

Initially it was proposed to correlate land use change and water quality changes in Arkansas by multivariate analysis. However, it was not possible to match land use change areas with areas for which historical water quality data were available. Therefore it was necessary to modify the initial objective to the correlation of different land usage with water quality at several sites in Arkansas.

4.2 DATA COLLECTION

All available water quality data for the state of Arkansas were collected. Included were water quality records of the U.S. Geological Survey, U.S. Corps of Engineers, and the Arkansas Department of Pollution Control and Ecology.

Difficulty was immediately encountered in finding stations with an acceptable record length. Although water quality data for Arkansas have been published annually since 1944, only 15 of the present stations (about 200) have data back to 1964 and even fewer stations have continuing (i.e., at least monthly) records back to the initiation of data collection. An additional difficulty was a critical lack of data for the parameters most useful in monitoring pollution, especially nonpoint source pollution (McElroy et al., 1975). For example, there were virtually no phosphate, insecticide, pesticide, or heavy metal data and sparse nitrate and bacteria data--parameters sensitive to nonpoint source pollution.

Still another problem in selecting the data records to be used was that in many cases different sets of data were measured at different sample times. This discrepancy virtually eliminated the possibility of using multivariate data analysis. For example, a close examination of the 41 stations in the White River basin and the 18 stations in the Illinois River basin with periods of record from 1968 to 1974 revealed only three stations for which parameters and measurement frequency were sufficient to warrant further analysis.

After an extensive evaluation of all data, seven stations finally were selected for detailed study on the basis of having the most complete water quality data available in terms of period of record, sample frequency, and number of parameters measured. Three of the stations selected have the same terraine environment and are near each other in northeastern Arkansas. These similarities permitted cross-checking of data and interpretation. The other four stations represent two additional distinctly different land usages and different locations.

4.3 ENVIRONMENT OF STATIONS SELECTED

The locations and environments of the seven stations are depicted grossly in Figure 8 and Table 3. St. Francis station on the St. Francis River; the Cache River station at McDougal, and the Black River station at Corning are all in the northeasternmost corner of Arkansas (Fig. 8). The St. Francis and Black Rivers have headwaters in the St. Francois Mountains of Missouri and flow onto the Gulf Coastal Plain, whereas the Cache River drainage basin consists only of Recent alluvium (Figs. 3, 8). The rocks of the St. Francois Mountains include Precambrian granite and felsite, Cambrian dolomite and glauconitic shale, and Ordovician sandstone. Although

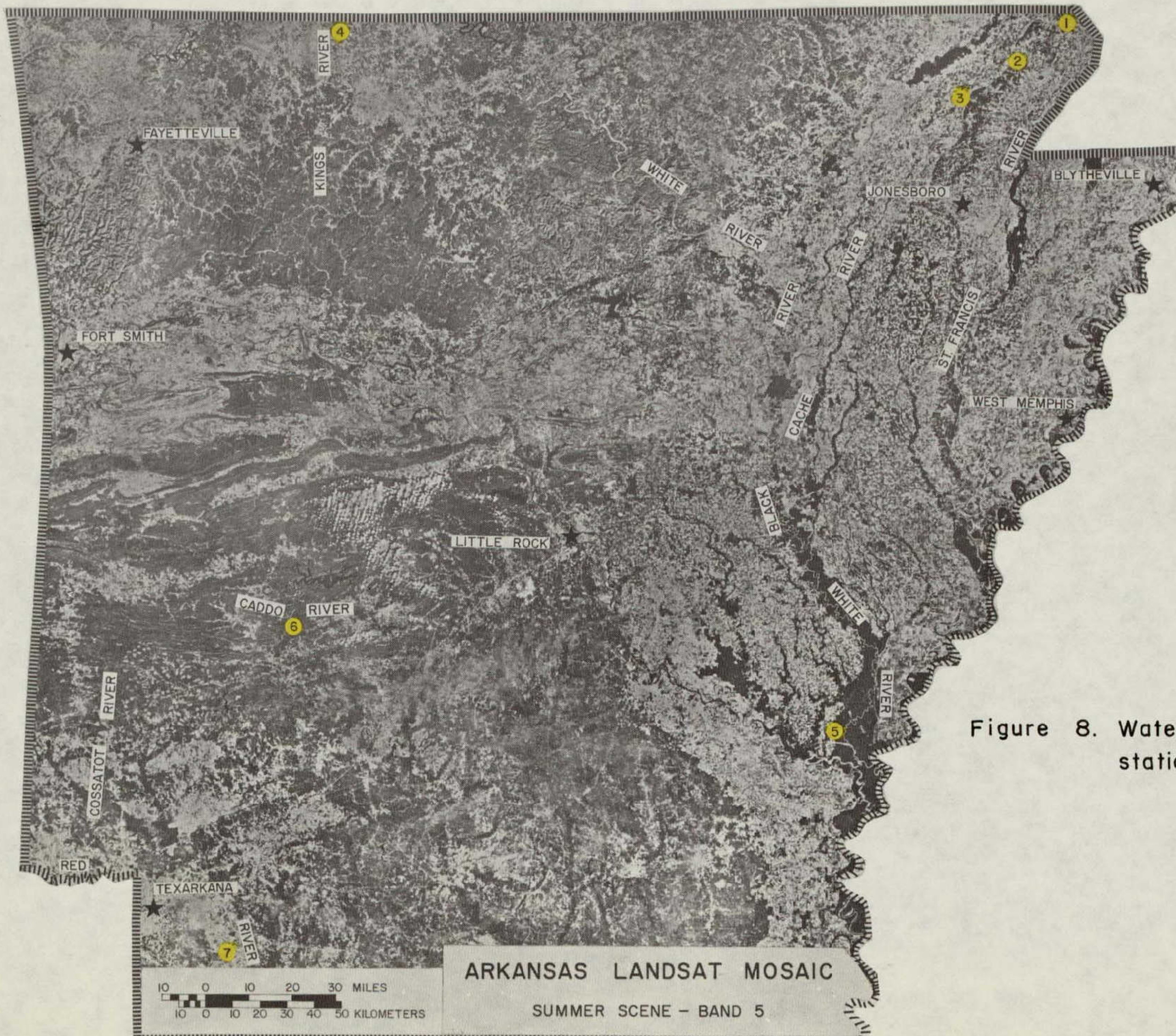


Figure 8. Water quality station locations.

Table 3 Environment of Selected Water Quality Stations

	Station Number	Longitude-Latitude	Physiographic Provinces	Major Rock Types	Major Land Use
1.	St. Francis River at St. Francis	90°08'13"W 36°27'21"N	St. Francois Mountains Gulf Coastal Plain	granite, felsite, dolomite, limestone, sandstone, alluvium	agriculture
2.	Cache River at McDougal	90°22'24"W 36°26'05"N	Gulf Coastal Plain	alluvium	agriculture
3.	Black River at Corning	90°32'26"W 36°24'07"N	similar to St. Francois	similar to St. Francis station	agriculture
4.	Kings River near Berryville	93°37'15"W 36°25'36"N	Ozark Region	limestone, shale, sandstone	pasture, forest
5.	White River at Lock and Dam No. 1	91°11'08"W 34°01'35"N	Ozark Region Gulf Coast Plain	alluvium	agriculture
6.	Caddo River at Glenwood	93°25'00"W 34°17'12"W	Ouachita Mountains	shale, sandstone, novaculite, and chert	forest
7.	Red River at Doddridge	93°05'36"W 33°05'36"N	Ouachita Mountains Gulf Coastal Plain	sand, lignite, red clay, alluvium	agriculture

these stations are on different rivers, the environments within each watershed are very similar. Land use in the areas of all three stations is agriculture (Fig. 8), the geologic settings (Figs. 3, 4) are similar and, because of the close spacing of the stations, climate (Fig. 5) is essentially the same.

Farther south in the White River basin is the Lock and Dam No. 1 station on the White River (Fig. 8). It is similar to the three described above in that the major land use in the area is agriculture. This station is in Recent alluvium in the Gulf Coastal Plain; however, a significant part of the White River drainage is in the Ozark Region. The Doddridge station on the Red River in the southwestern corner of the state (Fig. 8) is in a predominantly agricultural area and also is in alluvium of the Gulf Coastal Plain. However, the headwaters of the Red River drain sand, lignite, and red clay areas in Oklahoma.

The Caddo River station at Glenwood and the Kings River station near Berryville (Fig. 8) offer major differences in comparison with the other stations, not only geologically (Fig. 3) but also in land use (Table 3). The Kings River station near Berryville is surrounded by pasture-forest lands and the Glenwood area is mainly forest. The Kings River is in northwestern Arkansas in the Ozark Region and the Caddo River is in the Ouachita Mountains in west-central Arkansas (Fig. 2). Thus, these seven stations offer diversity in terms of location, climate, geology, land use, and size of drainage basin for the State of Arkansas.

4.4 PARAMETERS ANALYZED

The parameters analyzed for the seven stations are shown in Table 4. As mentioned, most of these are <u>not</u> the parameters most sensitive to land

Table 4. Explanation of major water quality parameters

TERM	DEFINITION
Biochemical Oxygen Demand (BOD)	BOD is a measure of the nonliving organic demand for oxygen imposed by various kinds of wastes; a high BOD may temporarily or permanently so deplete oxygen in water as to kill aquatic life.
Cubic Feet per Second	CFS is the rate of discharge representing a volume of one cubic foot passing a given point during one second and is equivalent to 7.48 gallons per second or 448.8 gallons per minute.
Dissolved Oxygen (DO)	DO is the concentration of oxygen dissolved in stream water; the DO concentration of unpolluted water varies directly with atmospheric pressure and inversely with temperature. Nonliving organic matter depletes dissolved oxygen in water creating stress for aquatic life.
Milligrams per Liter (mg/l)	mg/l is a unit for expressing the concentration of chemical constituents in solution; milligrams per liter represents the weight of solute per unit volume of water and can be expressed as parts per million (ppm).
Micrograms per Liter (µg/l)	Unit expressing the concentration of chemical constituents and can also be expressed as parts per billion (ppb). One thousand micrograms per liter is equivalent to one milligram per liter.
pH	pH is the measure of hydrogen-ion activity in solution and is the negative logarithm of the number of hydrogen ions in solution; pH is expressed on a scale of 0 (highly acid) to 14 (highly basic); pH 7.0 is neutral being neither acid nor basic.
Specific Conductance	Specific conductance is literally specific electrical conductance (or electrical conductivity), and is a measure of the capacity of water to conduct an electric current under standard test conditions: specific conductance increases directly with increased concentrations of dissolved and ionized constituents. Commonly, the amount of dissolved solids (in mg/l) is about 65 percent of the specific conductance (measured in micromhos).
Total Coliform	Coliform organisms are a group of bacteria used as an indicator of the sanitary quality of the water; the number of coliform colonies per 100 milliliters is determined by the immediate or delayed-incubation membrane-filter method.
Total Hardness	Hardness of water is a physical-chemical characteristic attributable to the presence of alkaline earths (principally calcium and magnesium) and is expressed as equivalent calcium carbonate ($CaCO_3$) in the raw water sample.
Total Iron	Iron in the raw water sample
Total Nitrate	Nitrogen in the form of nitrate in the raw water sample
Total Residue	Sum of the suspended and dissolved materials in a water sample. The sample is evaporated and heated to 103-105°C.
Turbidity	Turbidity is the capacity of materials suspended in water to scatter light; turbidity is measured in arbitrary Jackson turbidity units (JTU); highly turbid water is often called "muddy", although all manner of suspended particles contribute to turbidity.

use or nonpoint source pollution. However, these parameters are the only ones for which record length and measurement frequency are sufficient to warrant detailed analysis.

4.5 DATA ANALYSIS

Although multivariate analysis initially was planned, those parameters considered to affect water quality (i.e., rainfall, soil saturation, etc.) were either not available or not available in sufficient quantity or detail for multivariate analysis. Therefore, in lieu of multivariate analysis, multiple variable analysis (see Appendix A) was carried out on the sparse data available. Only at four stations were several parameters measured simultaneously on the same date. For one station there were 16 such dates but only during a 2-year period, for another there were 8 dates in a 4-year period, for another 7 dates in a 3-year period, and for the last station 5 dates in a 4-year period. Although sufficient data are not available for truly meaningful multivariable analysis, the results for these stations are presented in Appendix A. This information is useful, however, in indicating that streamflow, as expected, is a dominant factor in the control of water quality. It should be noted that one would expect a general correlation of streamflow and other factors, such as rainfall, soil moisture, and season. High rainfall, especially in a short period or associated with saturated soil conditions, usually will increase streamflow. Warm summer months correlate with overall low streamflow, yielding general season-streamflow correlation and temperature-streamflow correlation. During winter, lack of vegetation cover tends to increase runoff and groundwater storage which increase streamflow.

In summary, streamflow was selected as a simple basis for characterizing water quality and each parameter was plotted against streamflow to depict graphically changes in water quality. Basic statistics used in data analysis are the mean, standard deviation, coefficient of variation, correlation coefficient, and linear regression. The number of measurements, correlation coefficient, and the 90% significance level are indicated on all graphs by N,C, and S, respectively. If initial regression did not yield significant trends, removal of one or two anomalous points (which might represent data errors or unusual contamination) or separation of the data into rising or falling water level sets (if possible) in some cases provided significant results. In all cases the 0.90 significance level was applied, i.e., the chance of the correlation being fortuitous is 10%. Several parameters yielded significant correlation with streamflow, but many yielded significant correlation coefficients when correlated with the logarithm of streamflow. Correlation coefficients up to 0.98 thus can be obtained. It should be noted that a high correlation coefficient does not necessarily imply that streamflow controls or causes water quality changes, but simply indicates a correlation which can be used in water quality modeling.

4.5.1 Discussion of Parameter - Flow Variation

The parameters analyzed can be divided into three groups, those that correlate with flow (1) linearly, (2) logarithmically, and (3) randomly. The first group consists of those parameters expected to be controlled by runoff--turbidity and suspended solids. The second group consists of total dissolved solids, hardness, specific conductance, and pH which are controlled mainly by groundwater at maximum values (baseflow) and also are affected by storage flow (infiltration) and runoff (dilution) at greater flow values. The third group includes those parameters that may be controlled by suspended and dissolved material--total residue, total iron, total nitrate, and total coliform.

4.5.1.1 Turbidity

Turbidity generally is correlated linearly with flow (e.g., Fig. 9); however, complex relationships are noted for the St. Francis and Black River stations. The Red, Caddo, and Cache Rivers' stations offer diversity in the environment and river characteristics, yet all three exhibit the turbidity-flow relationship expected.

The White River station shows an unexpected decrease in turbidity with increasing flow (Fig. 10). However, the river characteristics for this station, located just upstream from the White River's confluence with the Arkansas River which creates the effect of a small impoundment, are considerably different from those of any of the other stations. An explanation for the anomalous behavior of turbidity is that during high flow the turbid White River water flows under the less dense, clear "impounded" water. Therefore sampling of the upper layers of the water at the station would not indicate an increase in turbidity with increasing flow, but rather a decrease. The higher turbidity values at low flow probably represent runoff from the station area.

The Black River and St. Francis River stations' turbidity values versus flow values do not have statistical significance, but there is a general increase in turbidity with increase in flow. By expansion of essentially low flow data and omission of anomalous points, the Black River station yields a significant increase in turbidity with increased flow (Fig. 11); however, the St. Francis River station is much more sensitive

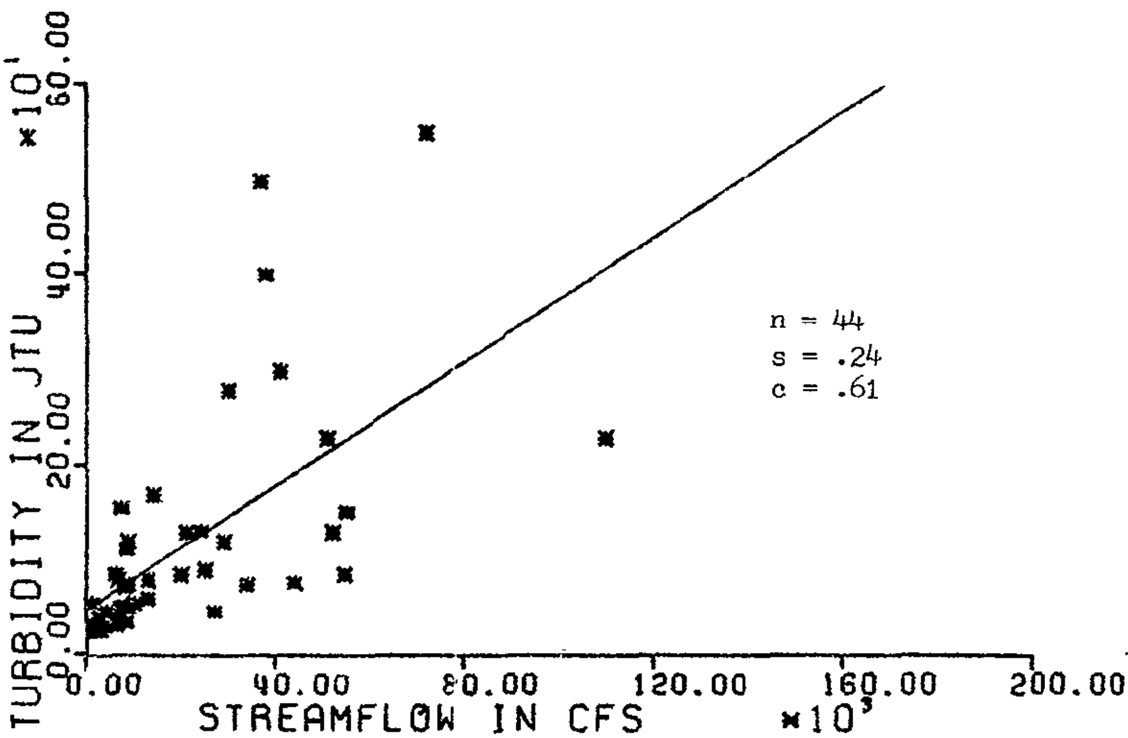


FIGURE 9. RED RIVER AT DODDRIDGE

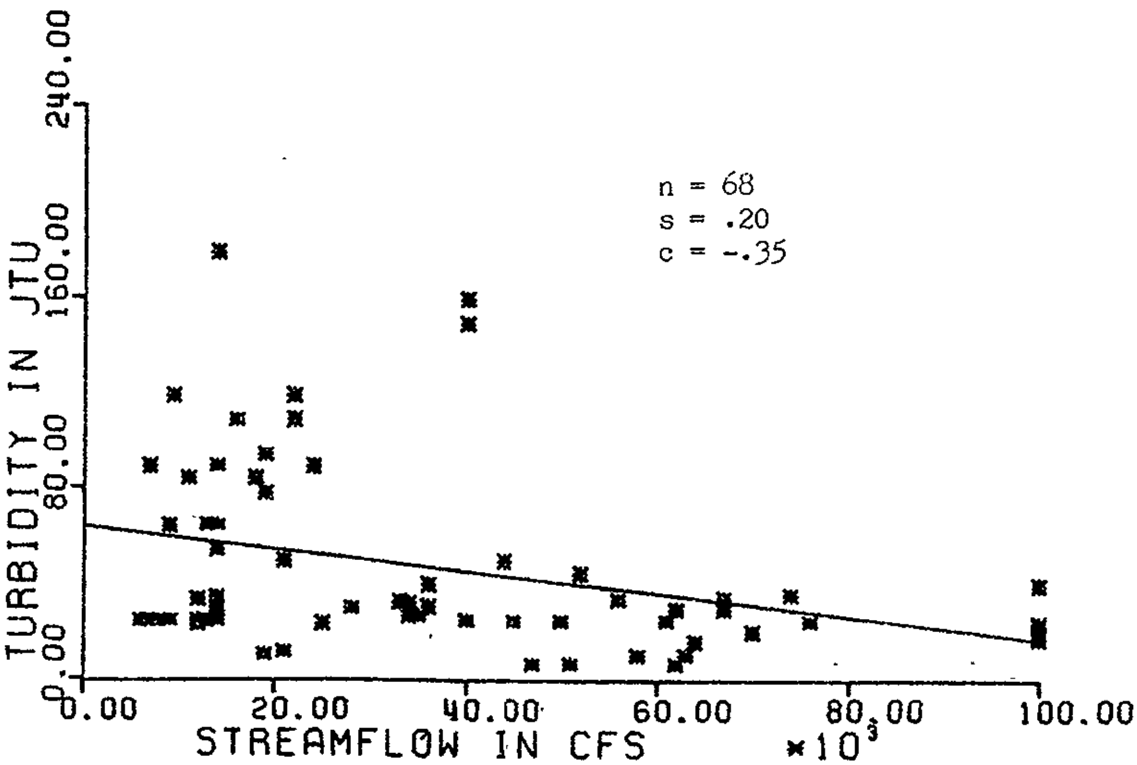


FIGURE 10. WHITE RIVER AT L&D * 1

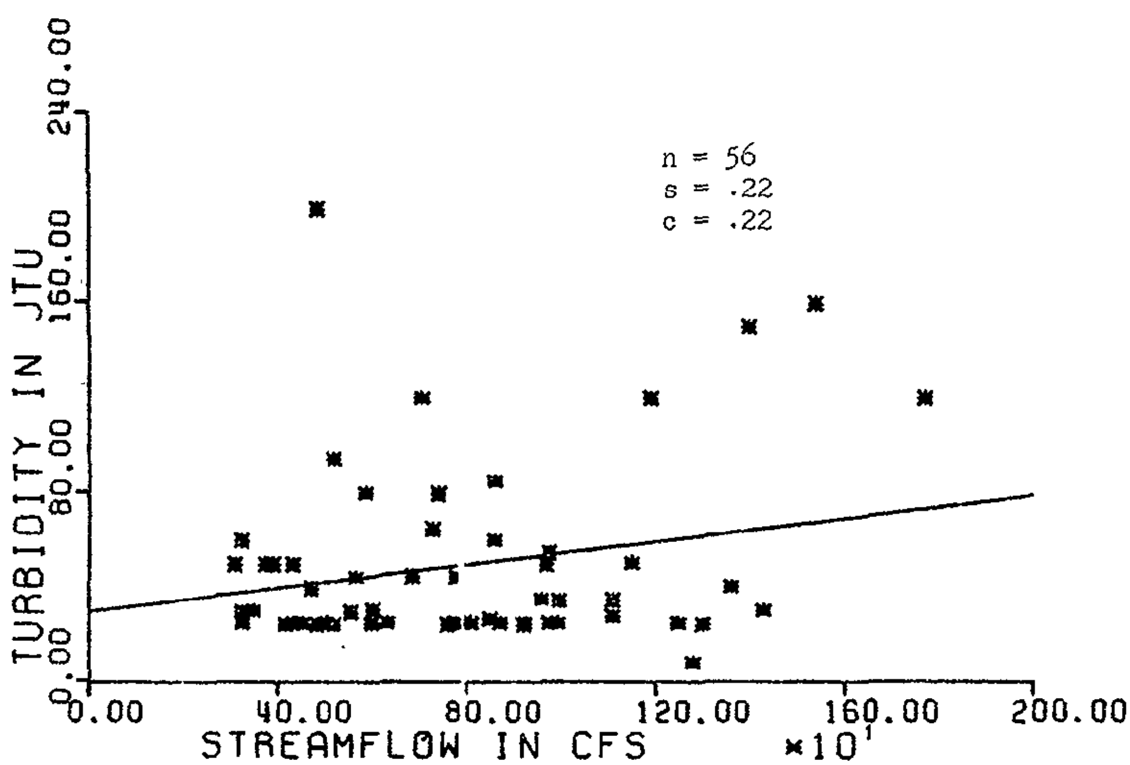


FIGURE 11. BLACK RIVER NEAR CORNING

to this effect than the other stations.

4.5.1.2 Specific Conductance, pH, and Hardness

All stations indicate a negative correlation of specific conductance, pH, and total hardness with increasing flow at the 90% significance level, except for specific conductance at the Kings River station. However, specific conductance is correlated negatively with flow for the Kings River station at the 85% significance level. Interestingly, the correlation for all of these parameters is higher with log of flow than with the arithmetical value (Figs. 12-14). The negative logarithmic correlation is attributed to dilution of dry period baseflow (groundwater) by less concentrated runoff and infiltration water and more dilute wet period baseflow. Because the infiltration water contains more dissolved material and has a longer period of flow than the runoff, there is a "tapering" effect on concentration. The Kings River station is unusual in that it exhibits linear correlations of decreasing specific conductance and pH with increasing flow that have slightly higher coefficients than the correlations with log of flow (Figs. 15 and 16). This situation suggests that these parameters are not controlled mainly by simple dilution with increased runoff.

4.5.1.3 Total Residue

Total residue is the sum of the dissolved and suspended material present, and thus may behave differently from one station to another depending upon the relative proportions. If total residue is mainly dissolved material, one would expect a decrease in concentration with increasing flow; however, if suspended material is dominant total residue would increase with increasing flow. Scatter could result from variation (or gradation) of the dissolved/suspended solid ratio. Fluctuation in this ratio could be the

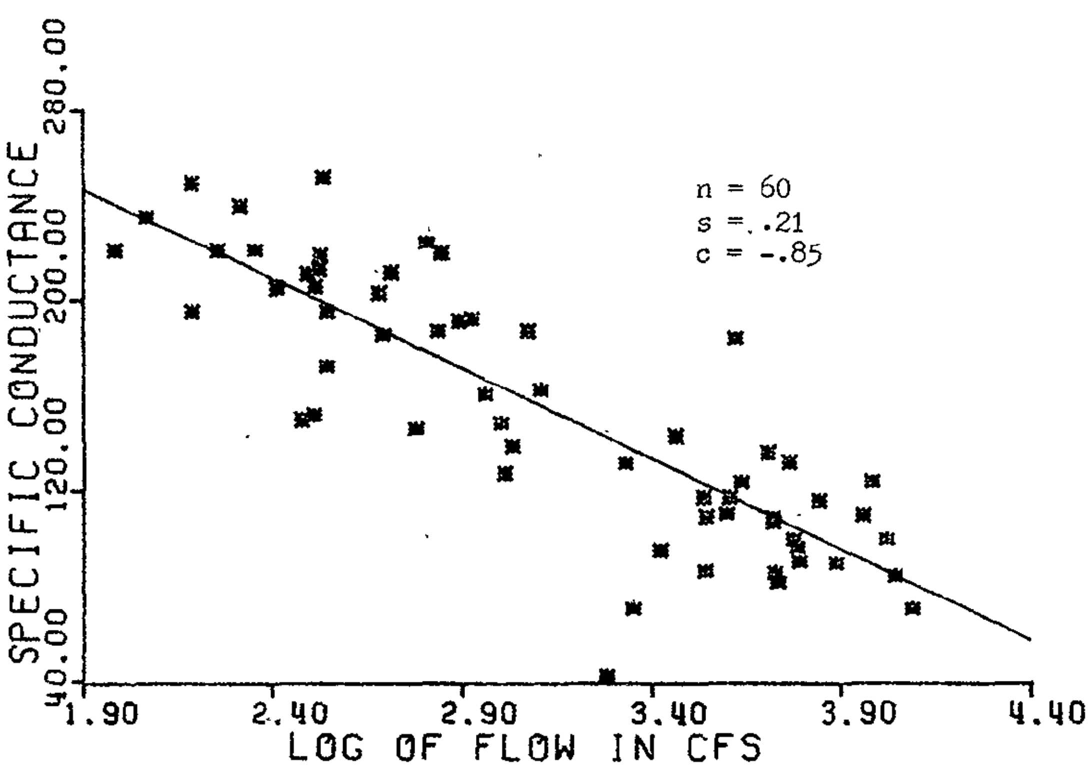


FIGURE 12. ST FRANCIS RIVER AT ST FRANCIS

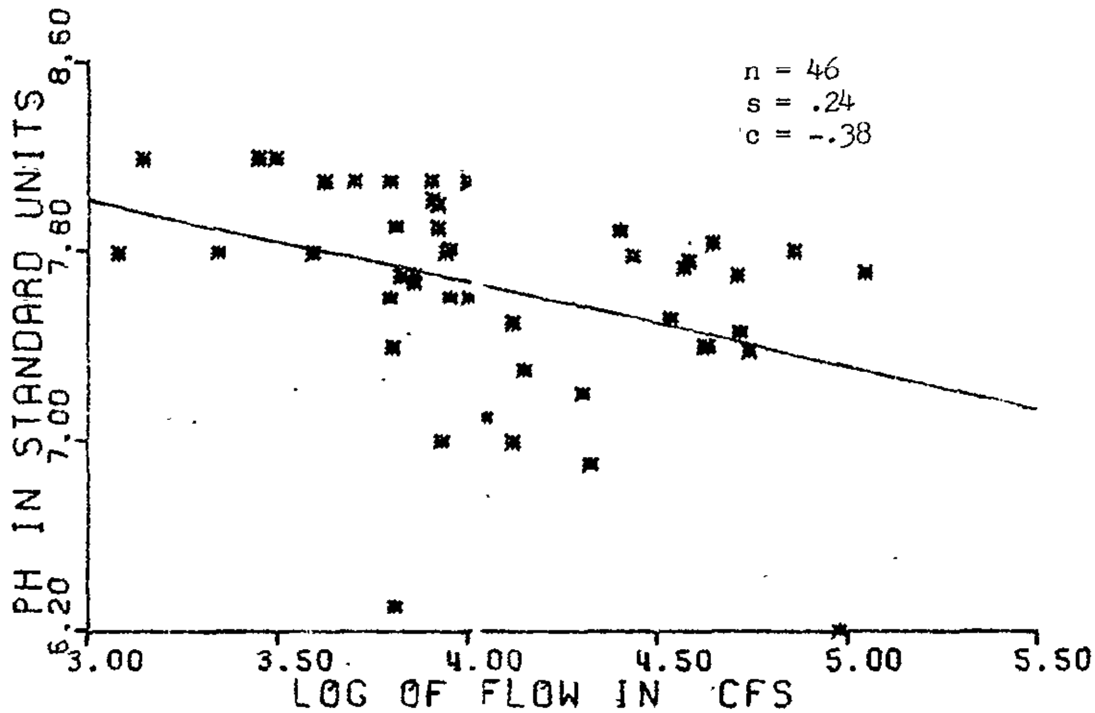


FIGURE 13. RED RIVER AT DODDRIDGE, ARK.

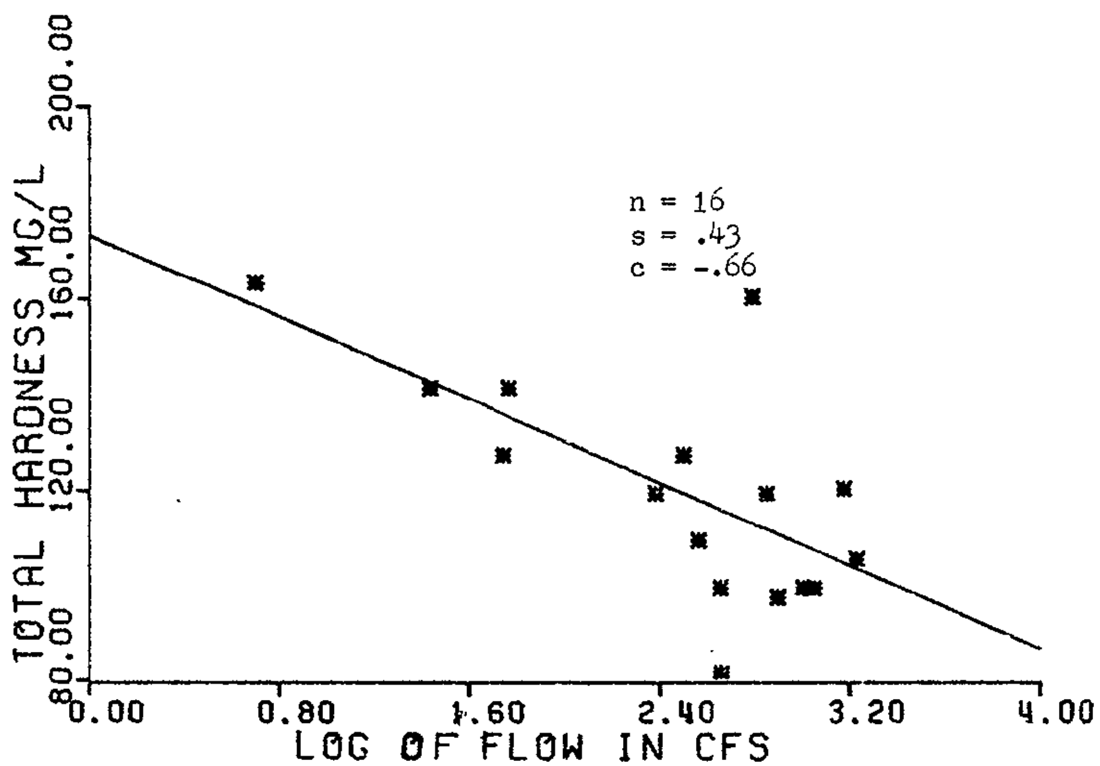


FIGURE 14. KINGS RIVER AT BERRYVILLE

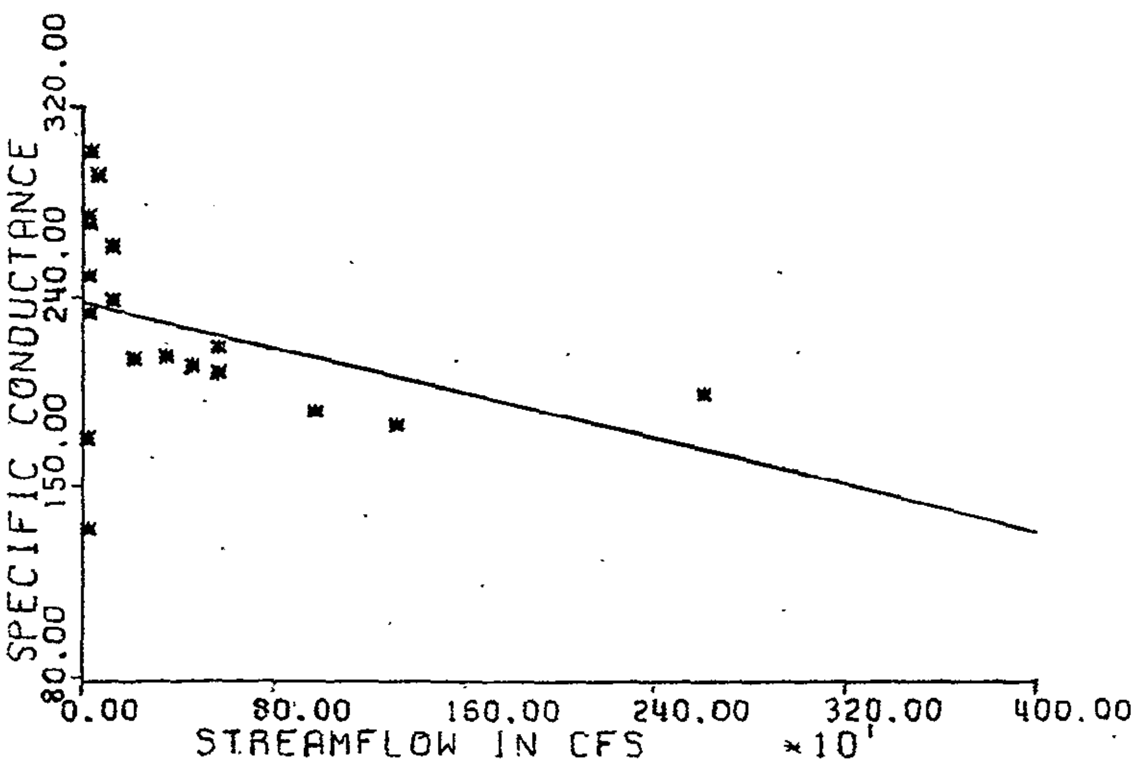


FIGURE 15. KINGS RIVER AT BERRYVILLE

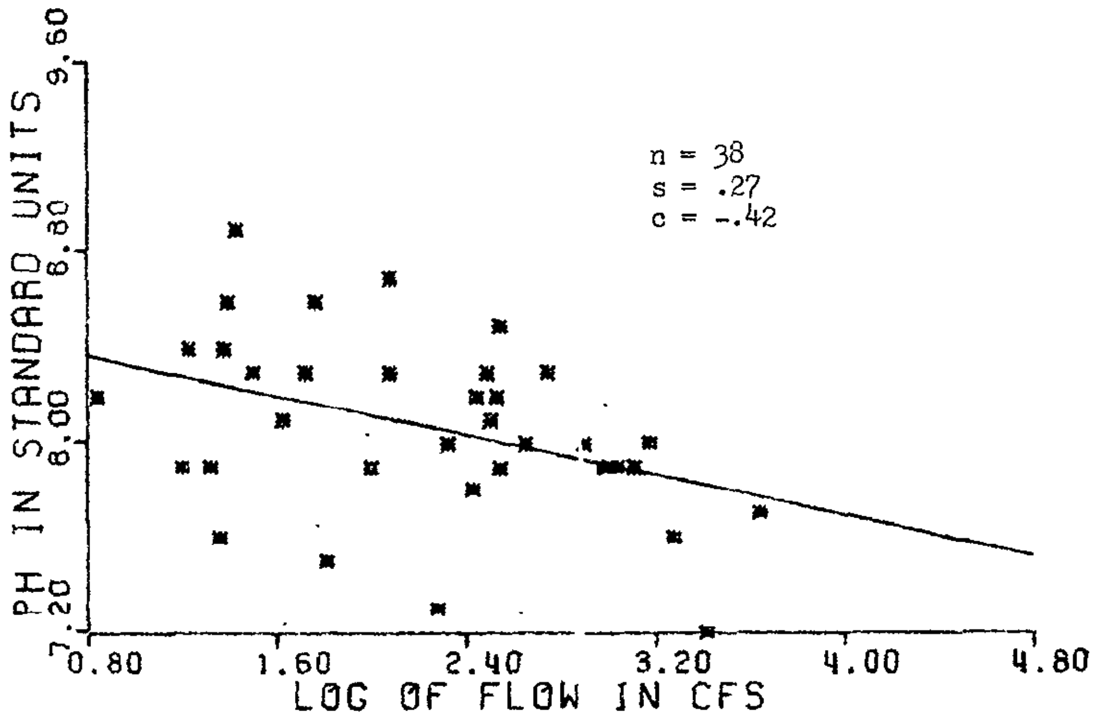


FIGURE 16. KINGS RIVER AT BERRYVILLE

result of the proximity of rainfall which causes increased flow to the station. For example, a significant part of the suspended material contributed by runoff may settle out if the rainfall area is very far from the station. Other factors, such as ground cover (e.g. season) and land use (e.g. time of plowing) can also affect total residue.

The fact that the White, Kings, St. Francis, and Black Rivers' stations all exhibit decrease in total residue with increasing flow (e.g., Fig. 17), suggests that the dominant contribution to the total residue for these stations is the dissolved load. The sparse data available indicate that the dissolved solids normally comprise about 60% of the total residue for these three stations; however at high flow as little as 10% of the total residue is dissolved solids. Therefore, these trends appear to represent dilution. Johnson and Needham (1966), Keller (1970), Pinder and Jones (1969), and Singh and Kalra (1972) all have noted similar dilution effects. The trends showing an increase in total residue with increase in flow for the Red River and Cache River stations (e.g. Fig. 18) are not significant statistically and probably reflect local station environment characteristics.

4.5.1.4 Total Iron

Total iron would be expected to follow a pattern similar to that of total residue because it can be present as suspended or dissolved material. However, only one station, Red River, has a total iron versus flow plot that is statistically significant (Fig. 19). The best trends are for the Red River and Cache River stations which also have the highest iron concentration. The increase of total iron with increasing flow indicates that the dominant amount of iron is present with the suspended solids, at least at high flow, or that greater amounts of dissolved iron are added by infiltration waters at high flow.

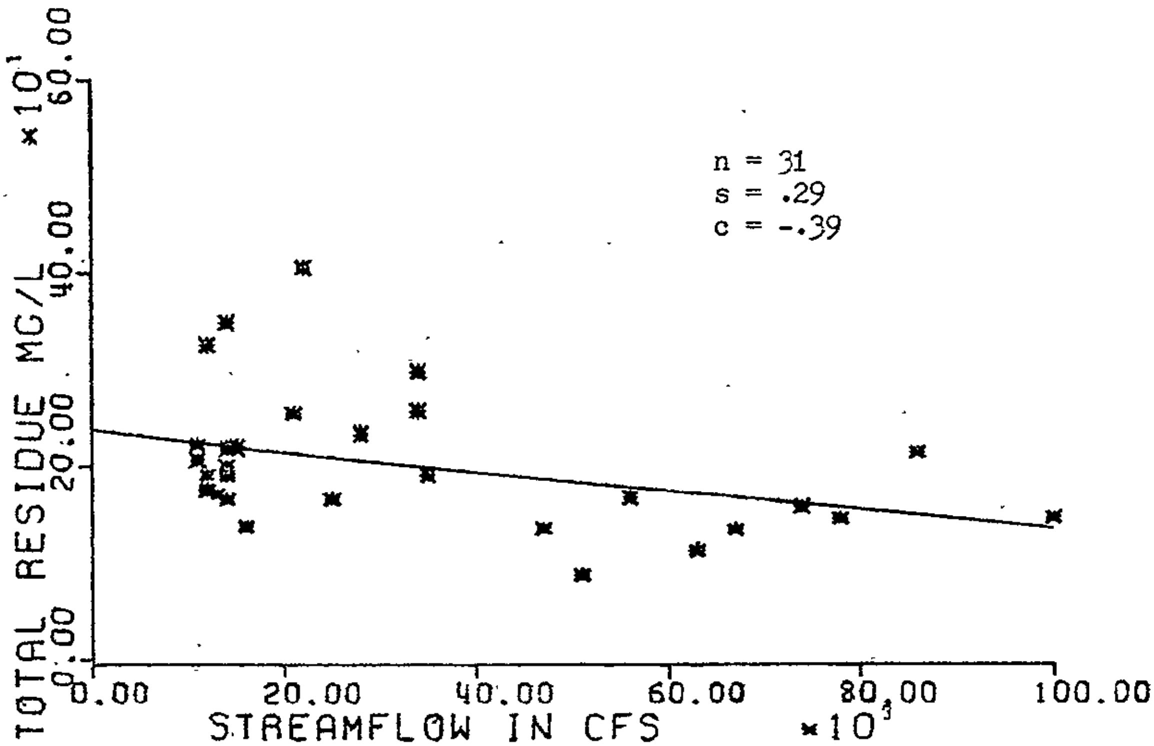


FIGURE 17. WHITE RIVER AT L&D - 1

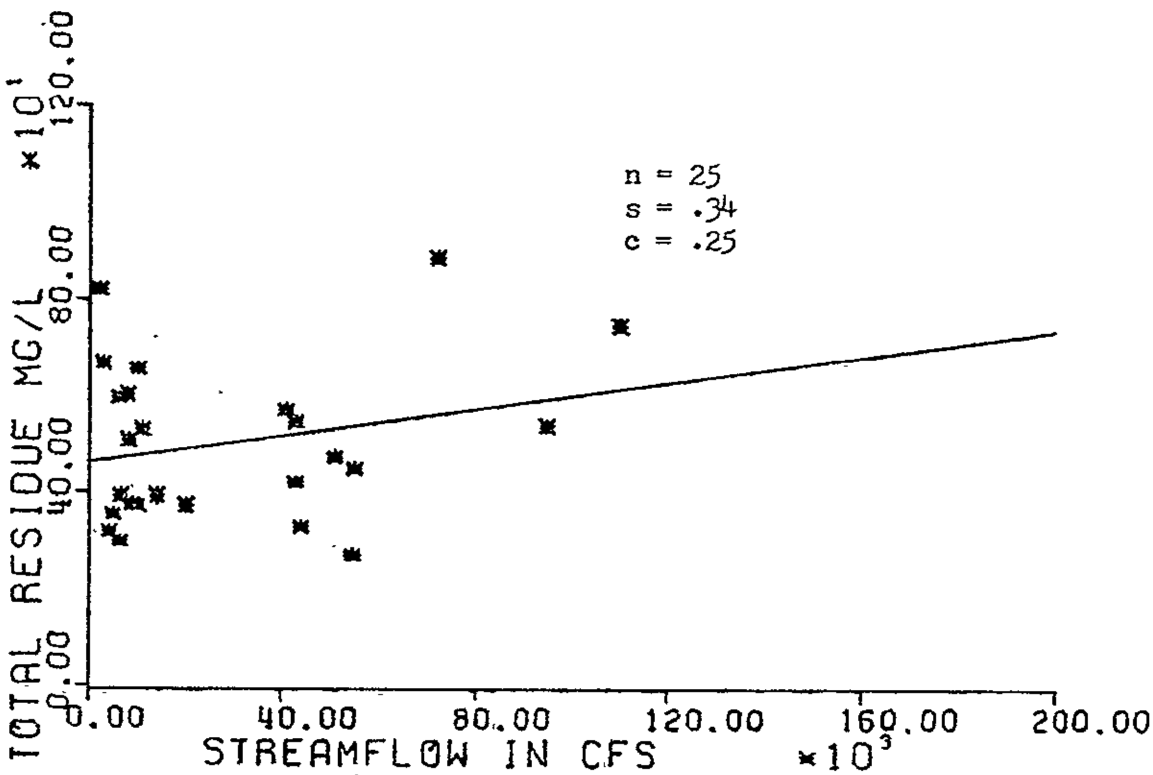


FIGURE 18. RED RIVER AT OODORIDGE

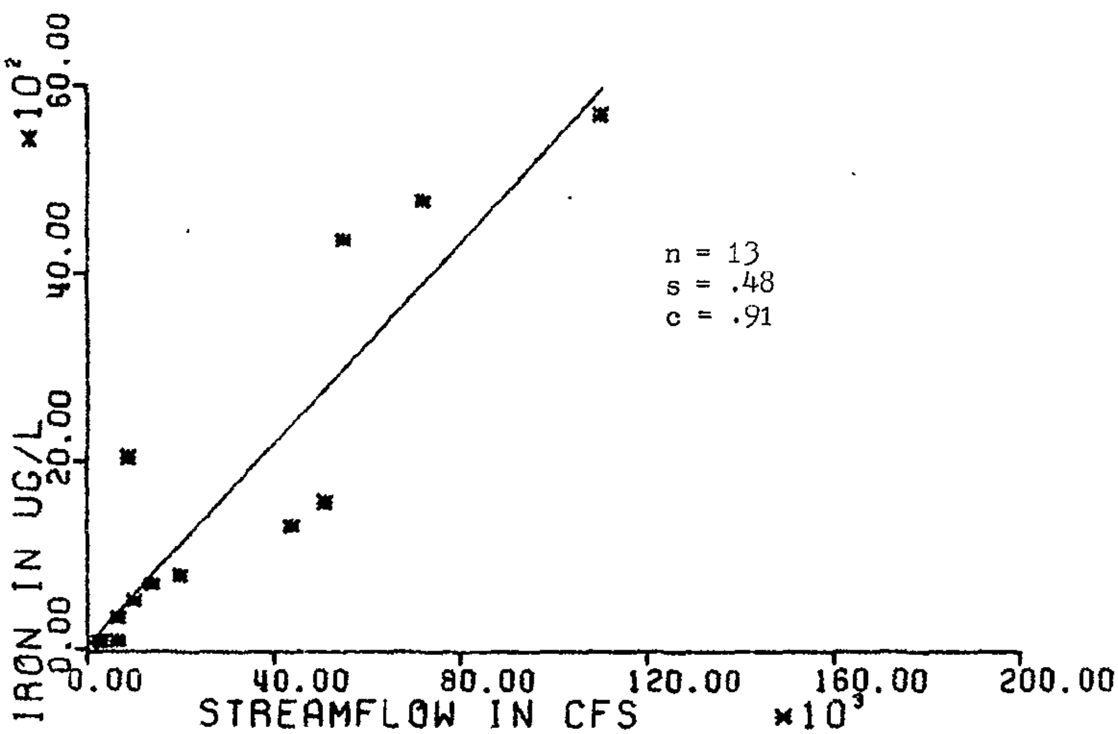


FIGURE 19. RED RIVER AT DODDRIDGE

4.5.1.5 Total Nitrate

Total nitrate includes nitrate from suspended and dissolved solids, and the explanation of its increase with increasing flow is similar to that for iron except dissolved nitrate in runoff is likely. Runoff water which increases flow may dissolve nitrate (natural organic nitrate or nitrate in fertilizer). One of the problems in interpreting the nitrate values is lack of sufficient data. By omission of one anomalously high point, six nitrate values give a statistically significant trend at the 90% significance level for the Kings River station (Fig. 20). The Red River, White River, and Cache River stations all show increasing nitrate trends with increasing flow which approach the 90% significance limit. The Black River and St. Francis River stations show decreasing nitrate values with increasing flow, but the trends have very poor, unacceptable correlation coefficients.

4.5.1.6 Total Coliform

Although total coliform versus flow for the Kings River station has a 0.98 correlation coefficient, the graph has essentially only two points with a cluster of four low value points and one high value; thus little real meaning can be attached to this trend. The Red River, Cache River, and Black River stations (e.g., Fig. 21) all show increasing total coliform counts with increasing flow, but none are significant statistically. The White River and the St. Francis River (e.g., Fig. 22) both show overall decreases of coliform bacteria with increasing flow; however, neither of these trends is significant at the 90% level. Lack of data combined with multiple source of the bacteria (runoff and infiltration water, i.e., rising or falling hydrograph) leads to scatter of coliform counts versus flow.

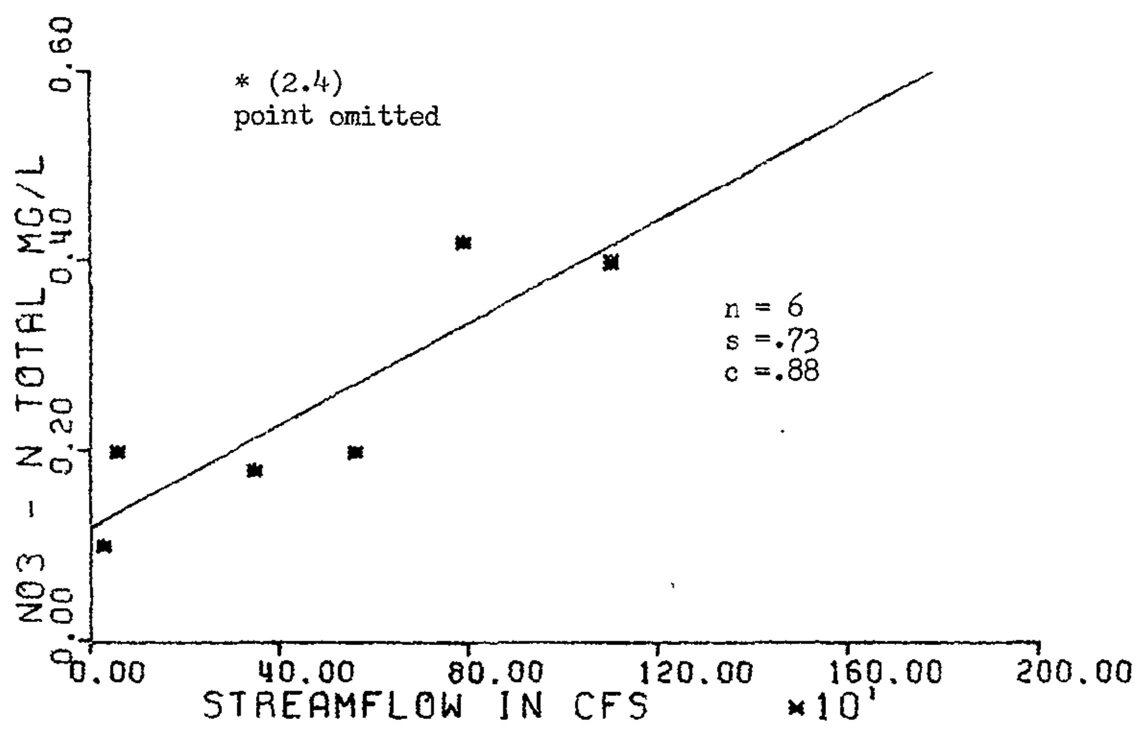


FIGURE 20. KINGS RIVER AT BERRYVILLE

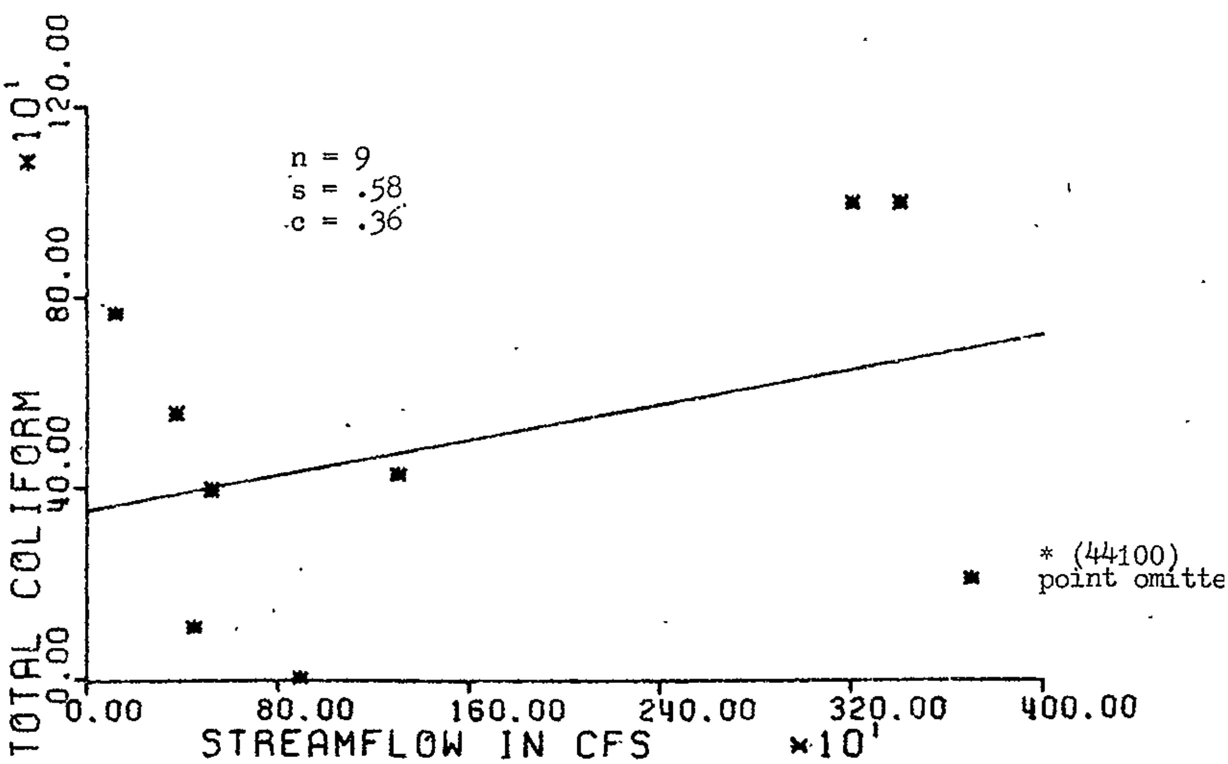


FIGURE 21. BLACK RIVER NEAR CORNING

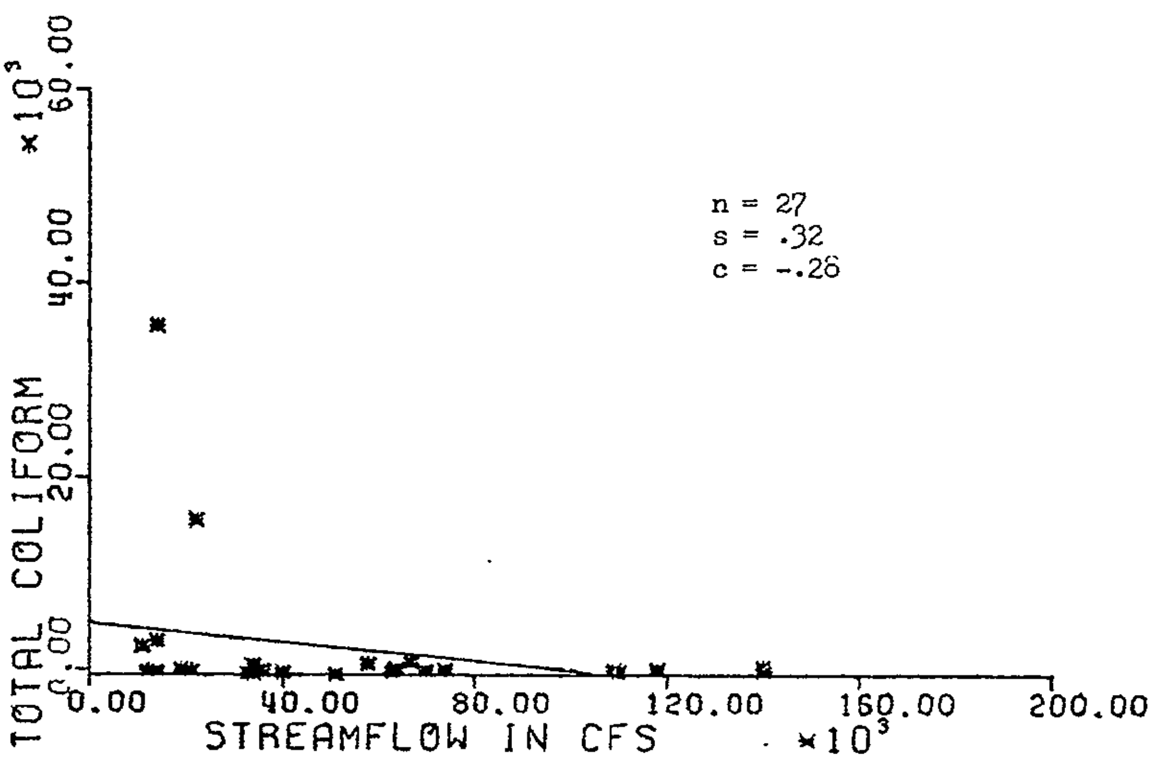


FIGURE 22. WHITE RIVER AT L&D # 1

4.5.1.7 Dissolved Oxygen

Dissolved oxygen shows increase with increasing flow at the Red River, Black River, and Caddo River stations (e.g. Fig. 23); however, only the Red River trend is significant at the 90% level. The White River exhibits a statistically significant trend of decreasing dissolved oxygen with increasing flow rate (Fig. 24). This trend may be related to the fact that at high flow dense turbid water which is also highly oxygenated flows under the less oxygenated quiet water at the sampling station. The Cache River has essentially constant dissolved oxygen (8 ppm). This lack of variation could indicate a significant input from the groundwater system or a complex mixture of oxygen demand by runoff materials that balances the increased dissolved oxygen due to runoff. The Kings River also shows relatively constant dissolved oxygen values (10 ppm); however, this pattern is attributed to the characteristics of the Kings River. The Kings River is a riffle-pool stream in which the dissolved oxygen is recharged and approaches saturation as the water passes through the riffles. Another problem in correlating dissolved oxygen with streamflow is the dissolved oxygen temperature dependence (higher dissolved oxygen at lower temperature). Thus, although runoff waters may have high dissolved oxygen values, they may also have low dissolved oxygen values because of the presence of oxygen-depleting materials. Temperature effect is additive to these effects.

4.5.1.8 Biological Oxygen Demand (BOD)

The Kings River (with the omission of one extremely high flow value), White River, Red River, and St. Francis River stations yield statistically significant trends of BOD with streamflow (e.g., Fig. 25). However, it should be noted that there is a great variation in BOD for a particular flow value. This variation undoubtedly is dependent upon the type of material

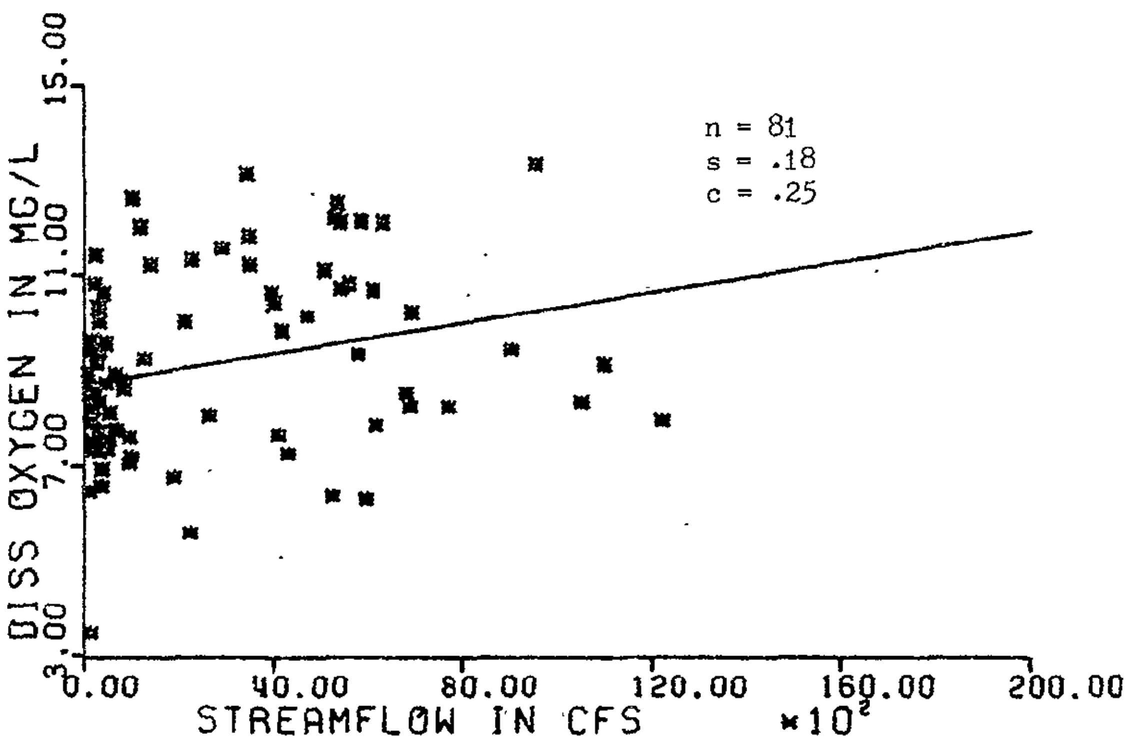


FIGURE 23. RED RIVER AT DODDRIDGE, ARK.

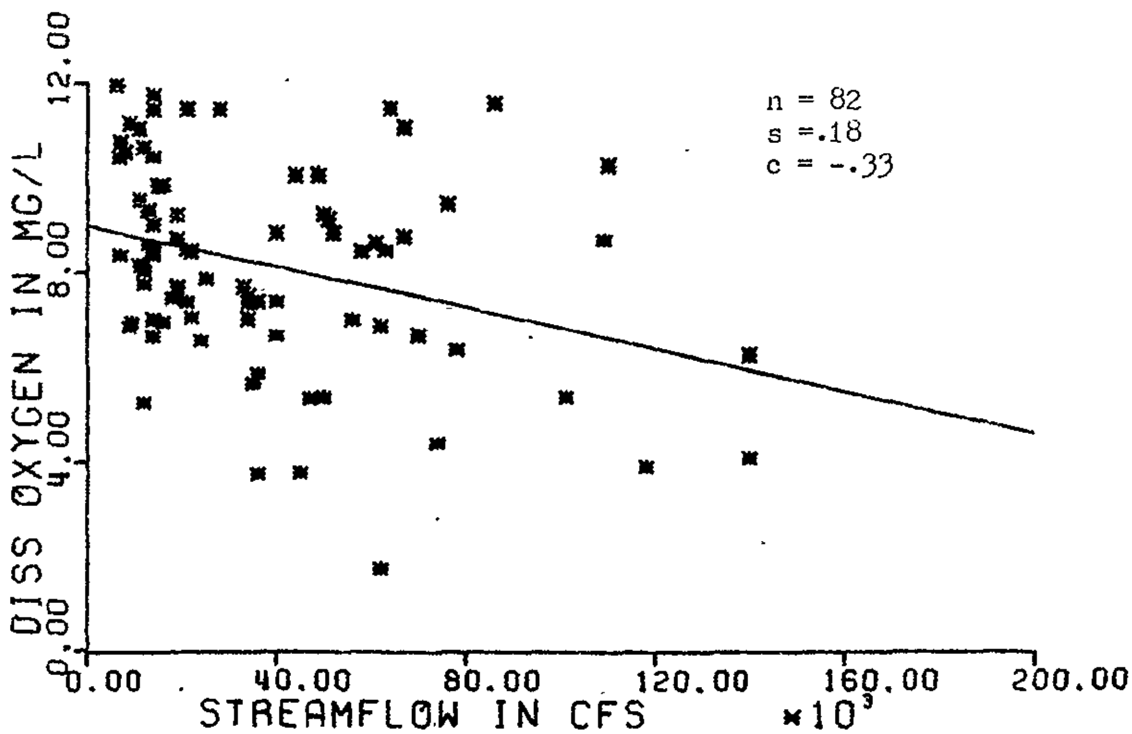


FIGURE 24. WHITE RIVER AT L&D # 1

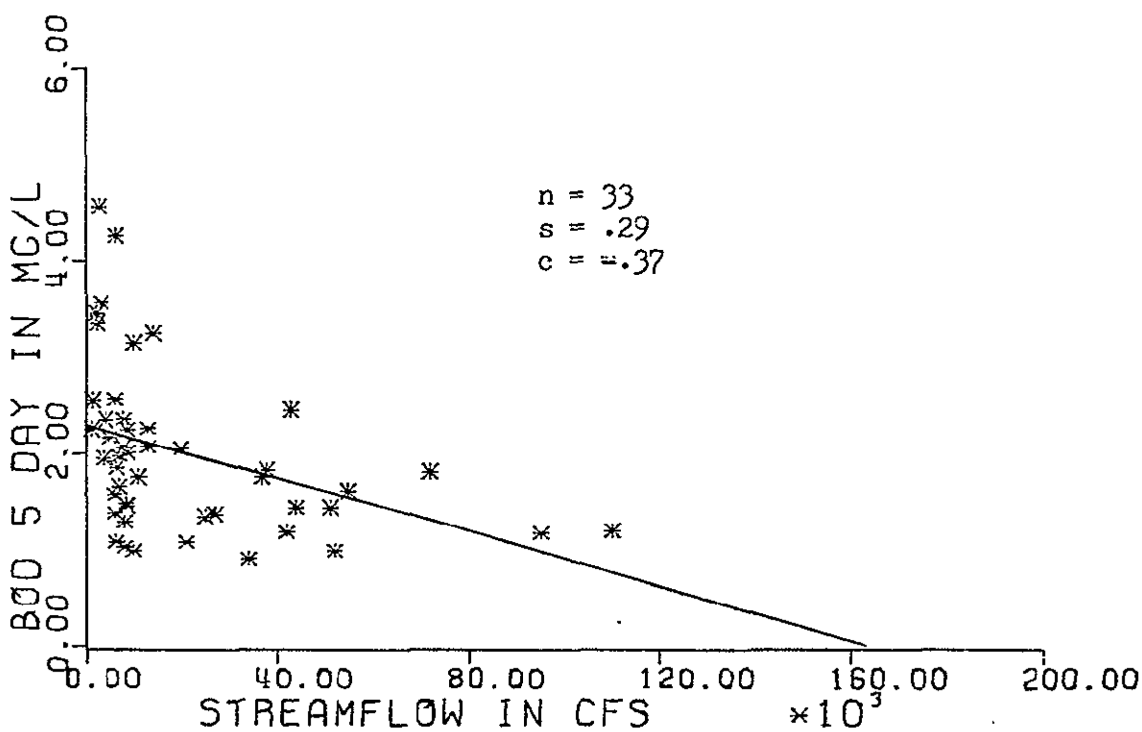


FIGURE 25. RED RIVER AT DODDRIDGE, ARK.

present in the runoff and the infiltration waters. The Black and Cache Rivers especially show great variation in BOD values.

4.6 IMPORTANCE OF HYDROGRAPHIC DATA TO WATER QUALITY

A hydrograph is a chronological graphic representation of the discharge of a stream. Figure 26 is a schematic representation of a seasonal hydrograph with individual storms removed. The higher streamflow values for winter and spring are attributable to greater runoff and greater groundwater flow in comparison with the lesser groundwater flow and runoff associated with the drier summer and fall months. Greater evapotranspiration concentration in the summer also may help to differentiate values for these periods. This type of low flow (i.e. nonstorm) water quality data is available; however, data for fluctuations caused by individual storms are lacking.

Figure 27 is a schematic representation of a storm hydrograph. The rising side and crest of the hydrograph reflect basin characteristics and the nature of the storm or rain event which caused the rise. The falling side of the hydrograph reflects the presence of various types of flow storage--surface runoff, infiltration water, and groundwater (baseflow)--and is generally independent of the characteristics of the particular storm or rain event. During periods of no rainfall, the total flow of the stream is composed of baseflow and the hydrograph assumes a shape uniquely characteristic of the particular basin (Dracup et al., 1973).

The best storm hydrograph data with corresponding water chemistry data for Arkansas are from the Caddo River station at Glenwood. Figure 28 shows a storm hydrograph for the Caddo River which exhibits a very short rise time of only about six hours followed by a sharp rise in water levels resulting from a second rain event. The hydrograph for the gauging station at Glenwood, Arkansas, shows that for the period of December 1974 to November

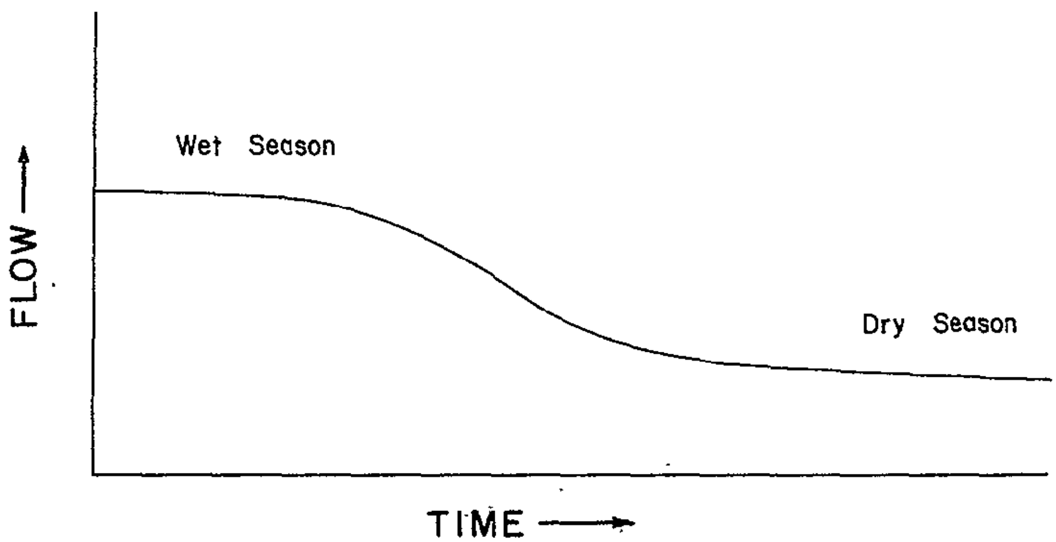


Figure 26. Schematic diagram of a seasonal hydrograph.

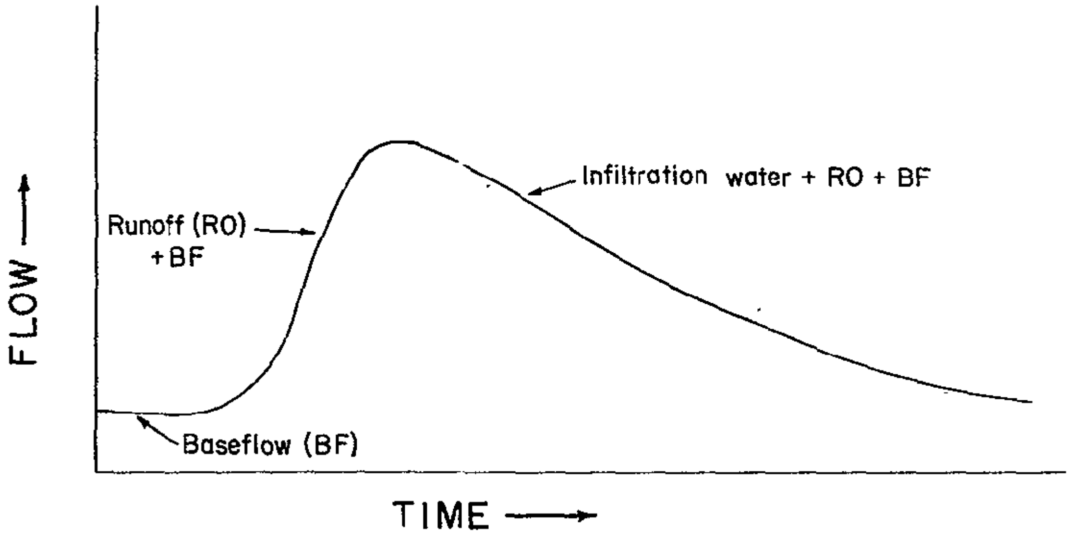


Figure 27. Schematic diagram of a storm event hydrograph showing the importance of baseflow, runoff, and infiltration water.

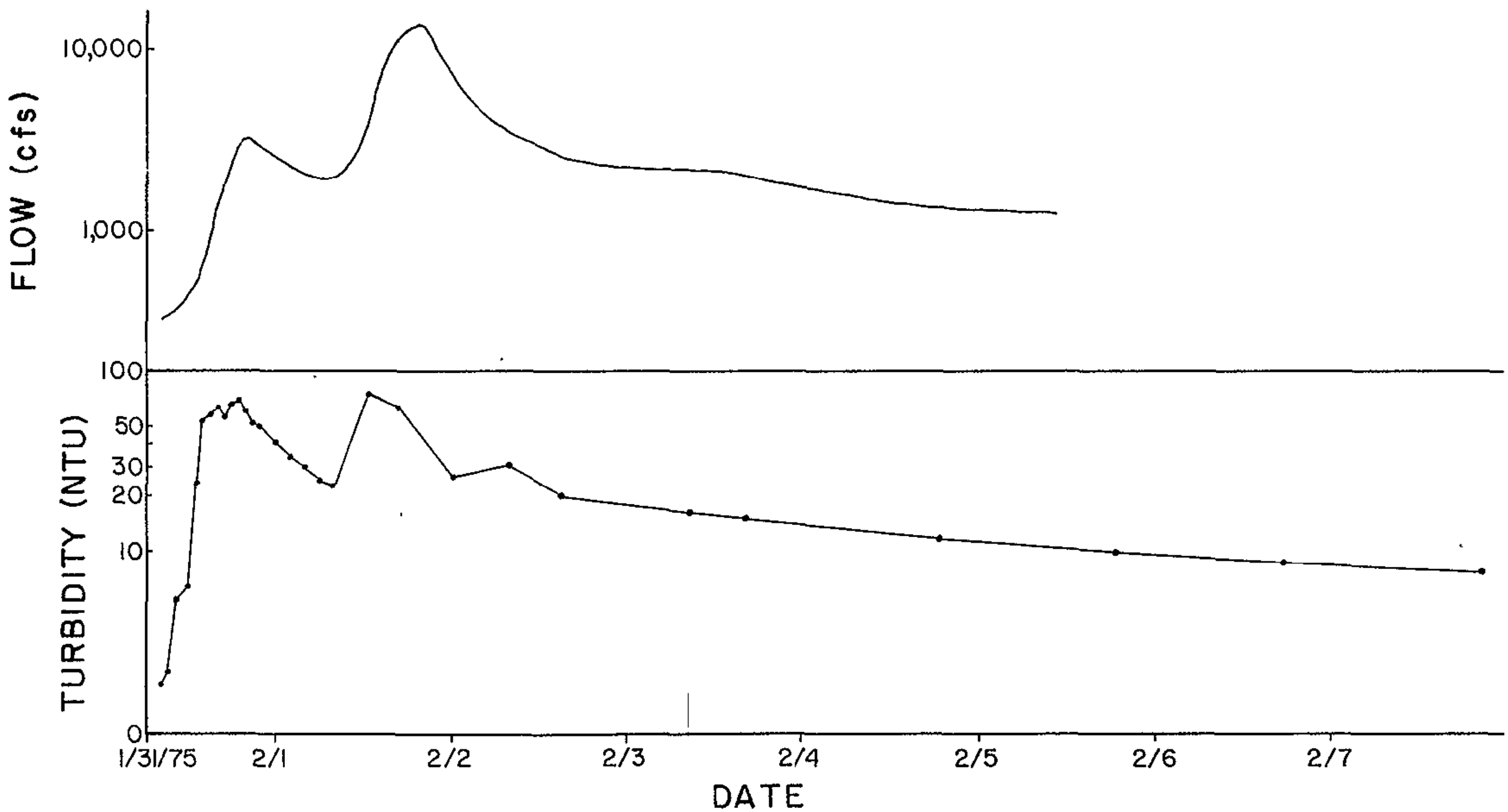


Figure 28. Storm hydrograph and turbidity values for the Caddo River (from Nix et al., 1975)

1975 water was rising for 383 of 7800 hours (i.e., 4.8 percent of the time). The average rise time for each event was about seven hours, and of the 54 total rise events many lasted less than three hours. One can see from these data how easily a rising event can be missed in water quality sampling, especially because about half of the rise events occur at night.

Complete modeling of water quality should include the ascending part of the hydrograph as well as the descending part, but essentially all of the historical water quality data are for baseflow and some represent the descending side of the hydrograph. Complete modeling would require continuous monitoring of flow in order to characterize a sample as representing baseflow, rising hydrograph, or falling hydrograph because the water quality can be affected greatly by the relation of the water sample to the hydrograph.

Nix et al. (1975) observed the effect of a storm hydrograph at the Glenwood station on the Caddo River in 1975. They noted dilution effects for calcium, pH, and specific conductance, as well as plug flow or first flush effects (small peaks) for Ca and specific conductance (Fig. 29). They also noted increases in turbidity, bacteria counts, suspended sediments, total Kjeldahl nitrogen (TKN), dissolved TKN, total phosphorus, and suspended solids caused by increased runoff associated with the rising hydrograph (Figs. 28-32). These graphs emphasize the need for rising hydrograph data in order to compare water quality accurately with land use. Sufficient flow data were available for two stations, St. Francis and Black River, to designate periods of rising and falling water levels. However, corresponding water quality data are meager, total residue and turbidity being most abundant. These parameters were plotted against rising and falling water level flow for the St. Francis station and reasonable correlation coefficients were obtained for total residue and turbidity (Figs. 33-36). The

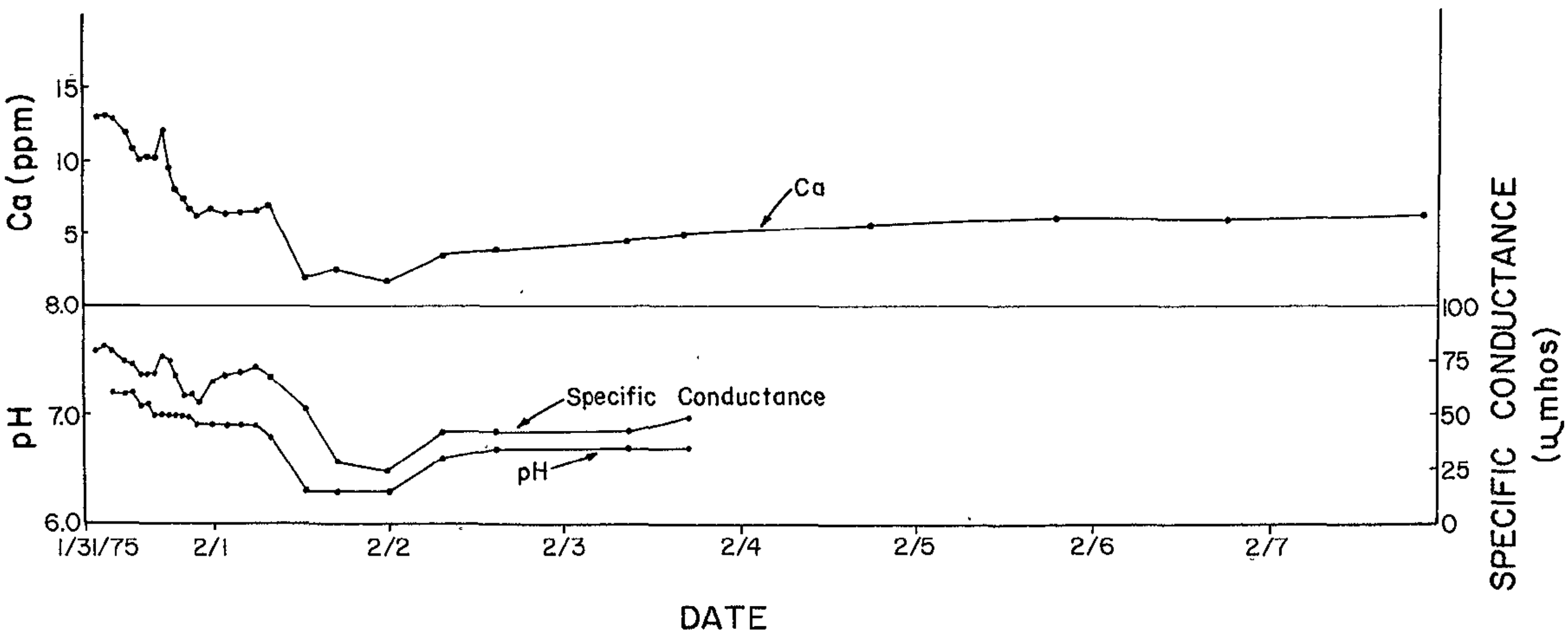


Figure 29. Calcium and pH values corresponding with the storm hydrograph for the Caddo River (from Nix et al., 1975).

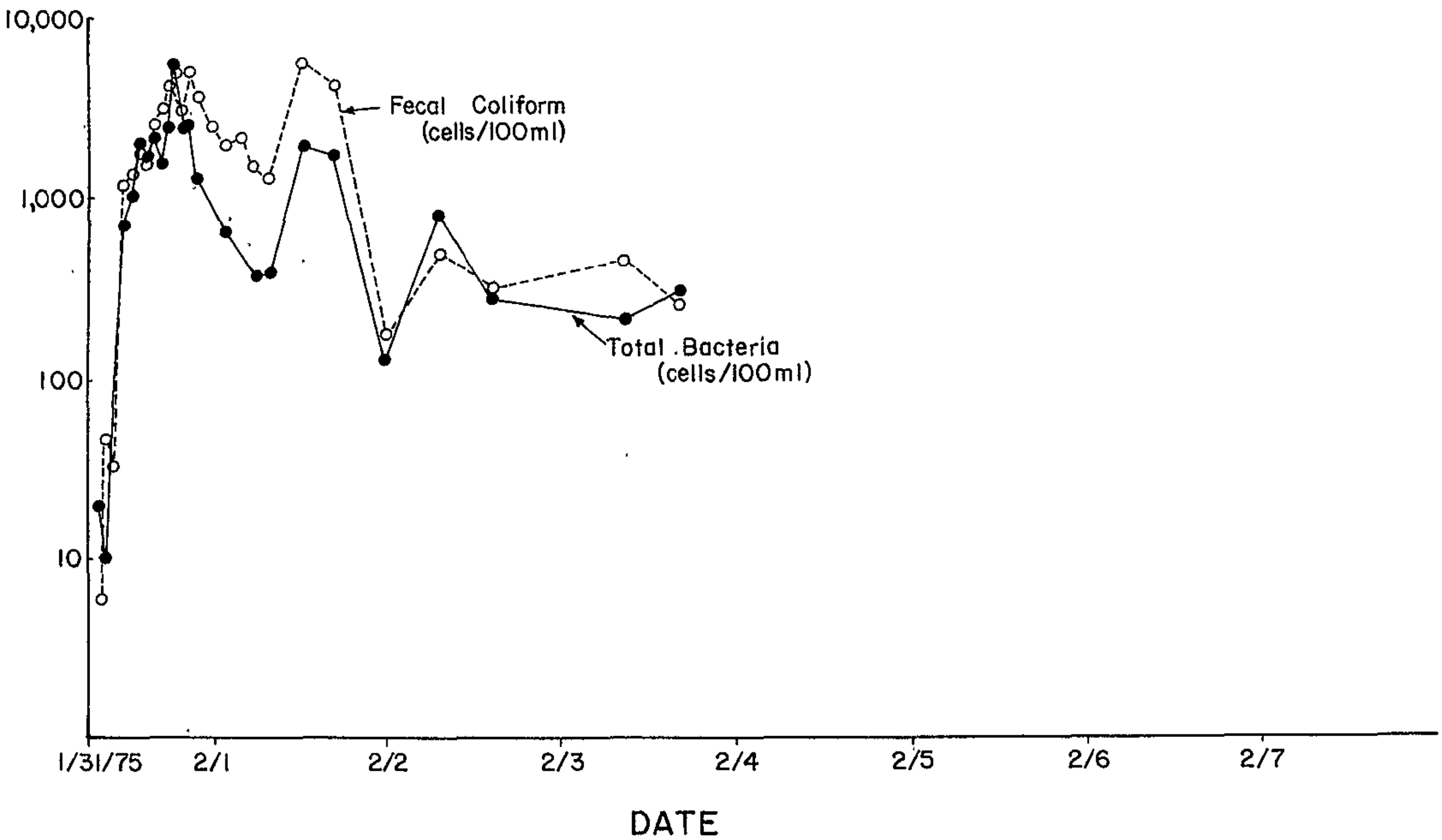


Figure 30. Fecal coliform and total bacteria data corresponding with the storm hydrograph for the Caddo River (from Nix et al., 1975).

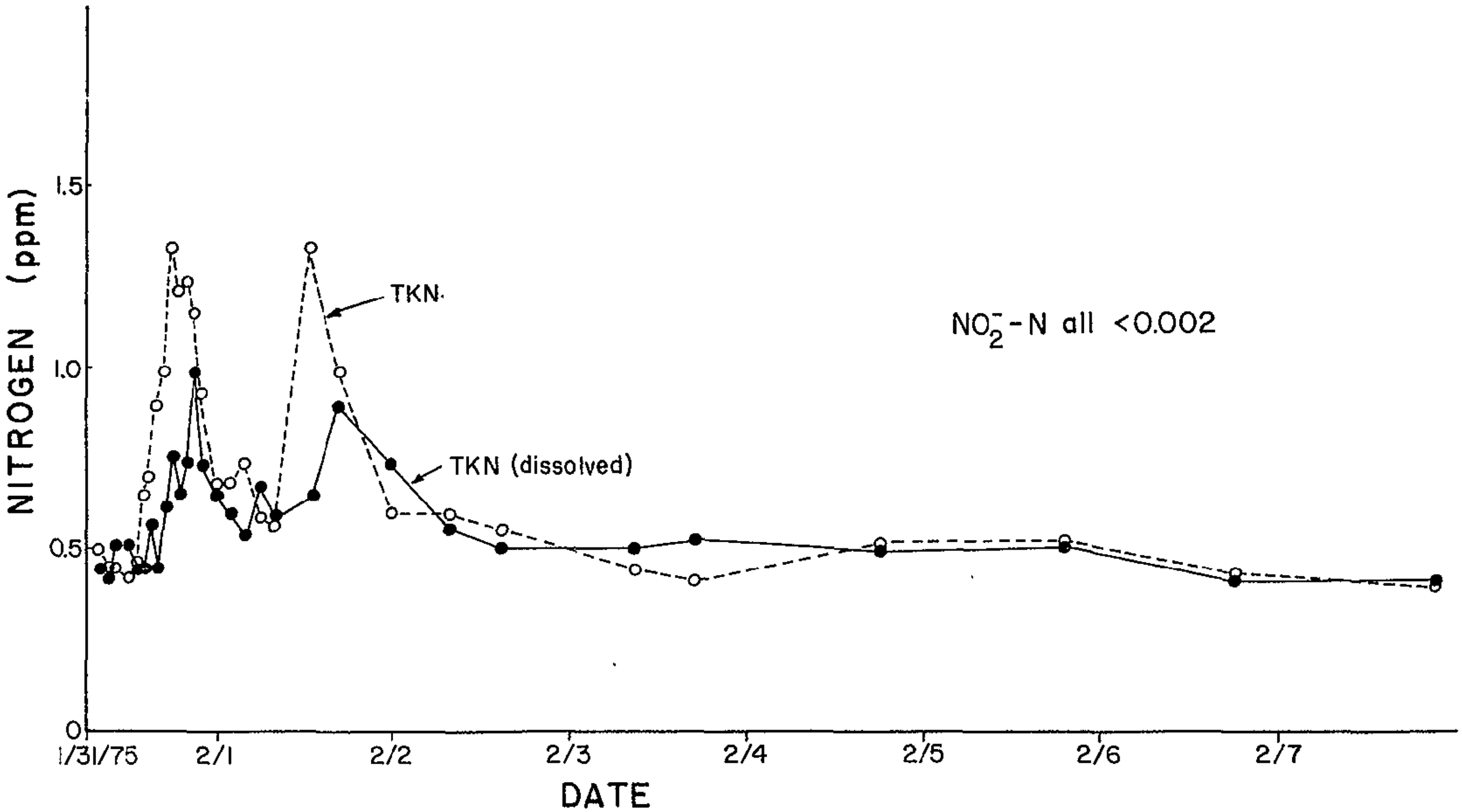


Figure 31. Total Kjeldahl nitrogen and total Kjeldahl nitrogen dissolved values corresponding with the storm hydrograph for the Caddo River (from Nix et al., 1975).

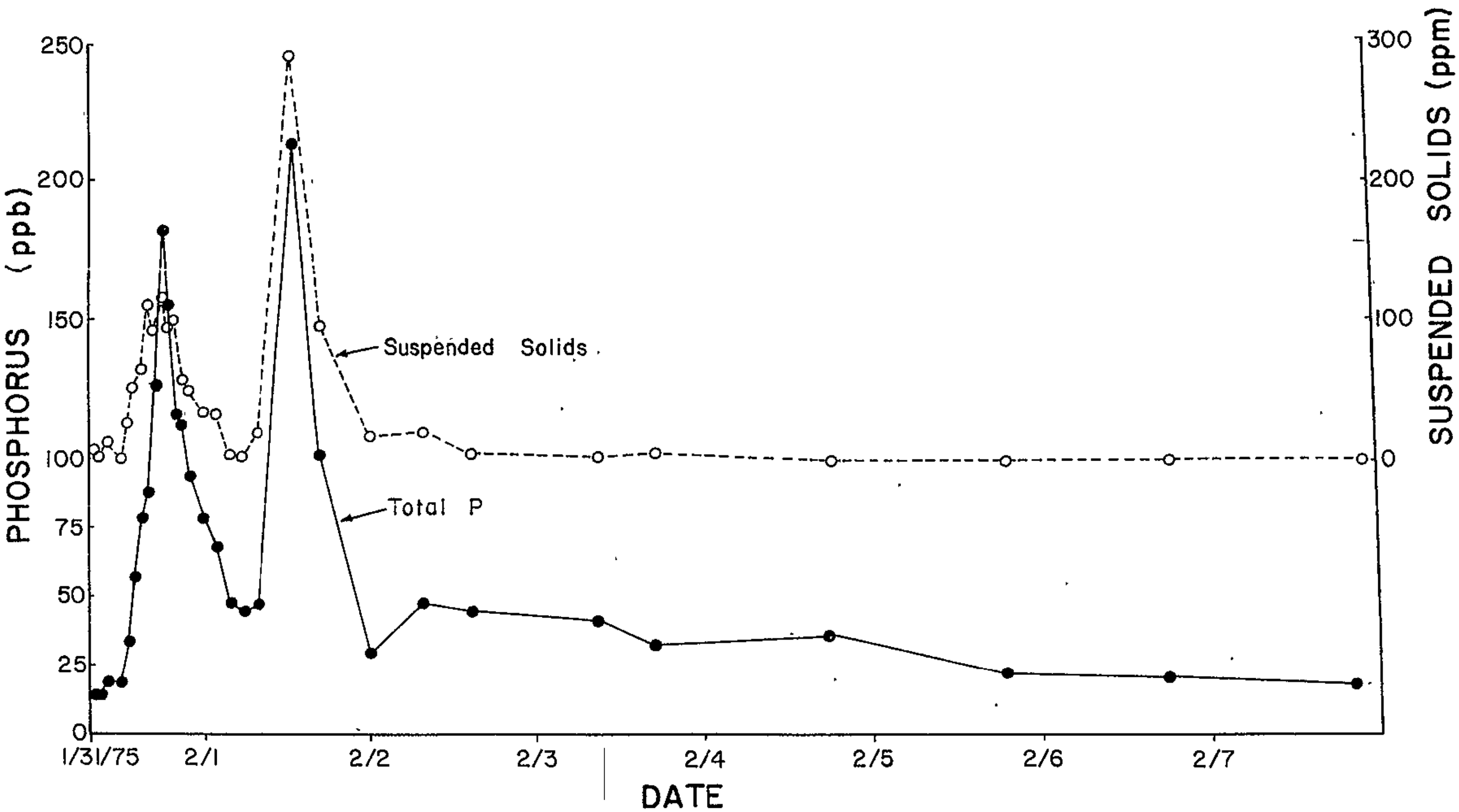


Figure 32. Total phosphorus and suspended solids data corresponding with the storm hydrograph for the Caddo River (from Nix et al., 1975).

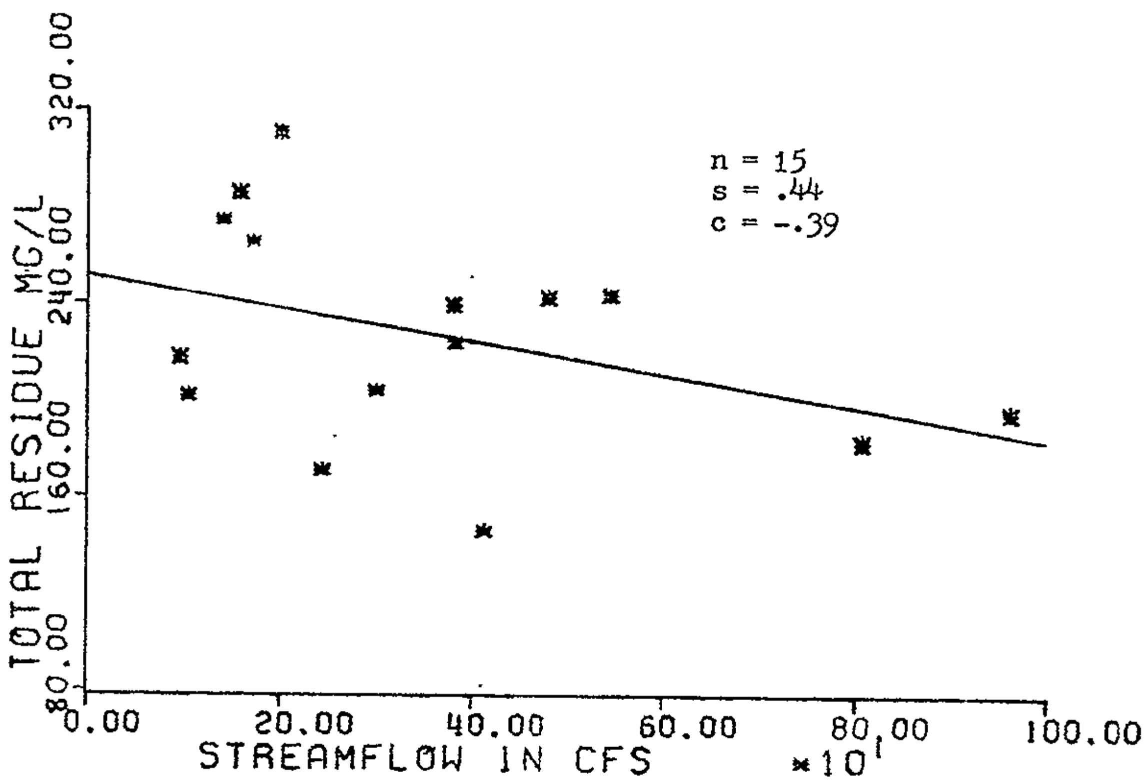


FIGURE 33. WATER FALLING AT ST FRANCIS

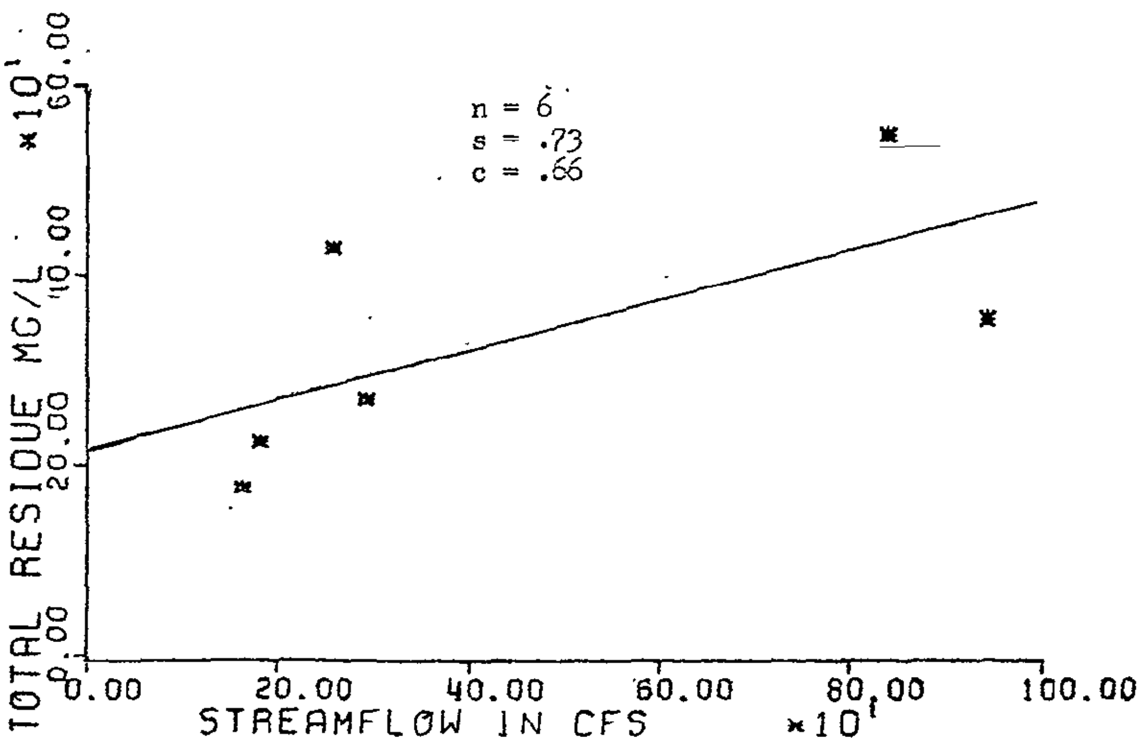


FIGURE34. WATER RISING AT ST FRANCIS

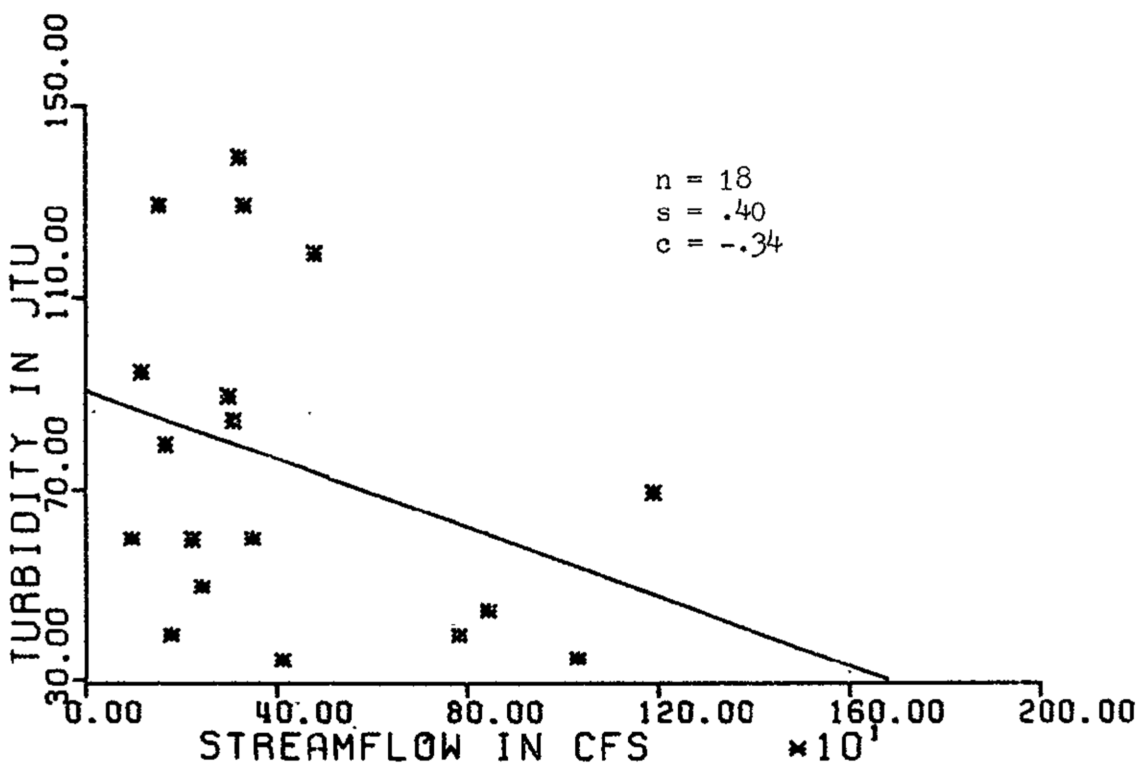


FIGURE 35. WATER FALLING AT ST FRANCIS

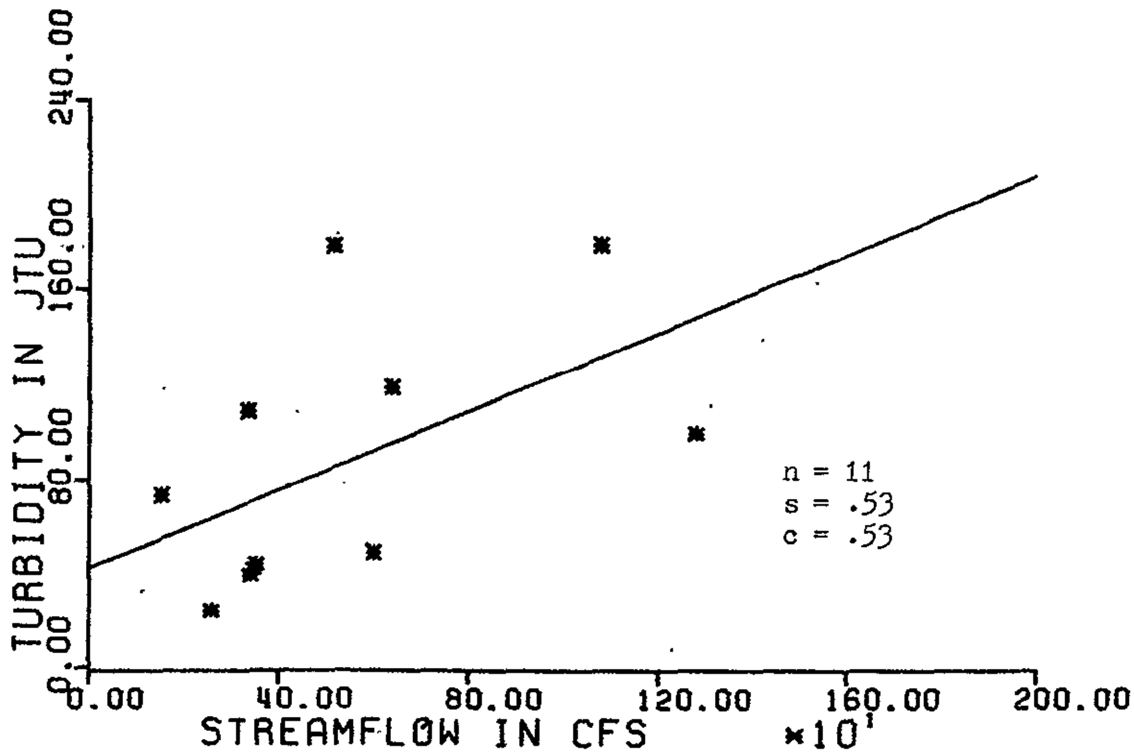


FIGURE 36. WATER RISING AT ST FRANCIS

Black River station yielded similar results (Figs. 37-40) except for very poor results in the cases of falling water levels for turbidity (Fig. 40) and rising water levels for total residue (Fig. 38). The separation of rising and falling water level data often markedly improves correlation with flow in comparison with the total data available (Figs. 41-44).

4.7 SUMMARY AND CONCLUSIONS

Total hardness, specific conductance, and pH tend to decrease (be diluted) with increased streamflow. Turbidity tends to increase with increased streamflow because of a corresponding increase in stream velocity which adds to the suspended sediment load of the stream. The effect of streamflow on total residue and total coliform is variable. If the dissolved load of the stream is dominant over the suspended load, increased streamflow dilutes the dissolved solids and total residue will decrease if no great quantity of suspended sediment is introduced. However, the reverse can happen, i.e., total residue can increase with increasing streamflow, if the suspended sediment load is dominant. Total coliform present in the water can be decreased by dilution or increased by runoff from contaminated areas. The same is true for total iron and nitrate. In the spring the latter could be introduced by runoff from agricultural areas and increased runoff from spring rains. However, without a contaminating source and aside from the first flush effects, increased flow should dilute iron and nitrate. Dissolved oxygen is dependent on temperature and oxygenating characteristics of the river which can be related to streamflow, i.e., increased surface area during flooding, aeration because of turbulent flow, etc. Biological oxygen demand is dependent mainly upon factors affecting dissolved oxygen--coliform, nitrate, phosphate, and organic materials. It

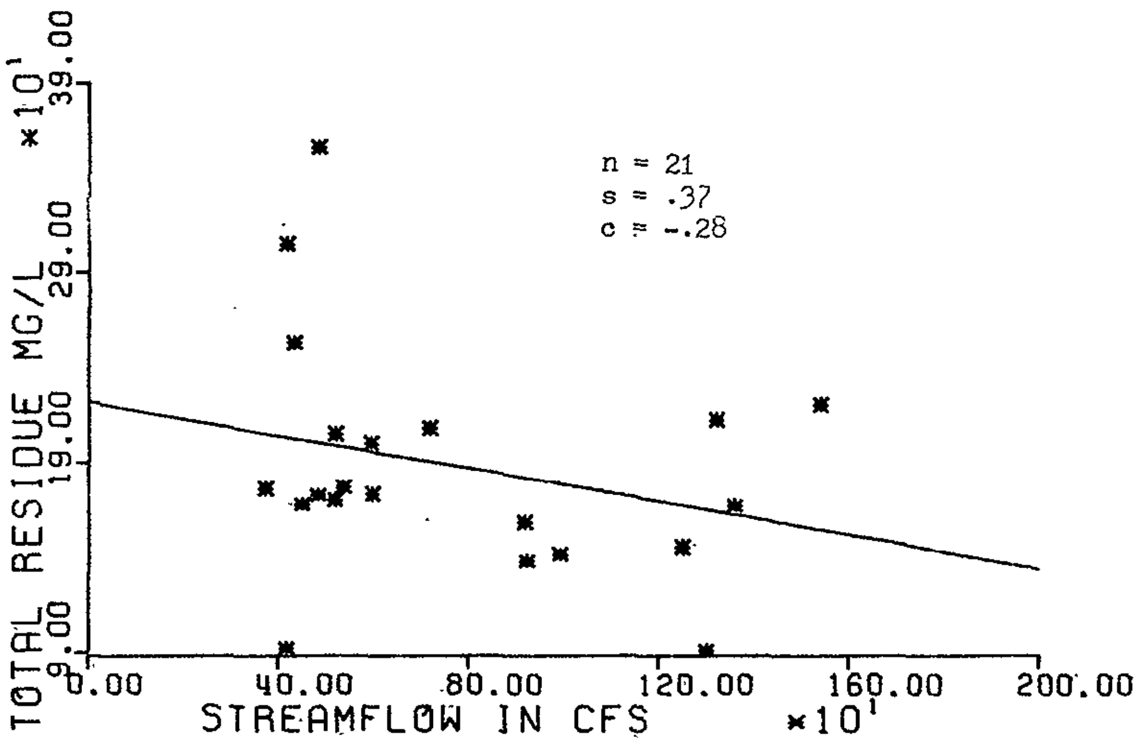


FIGURE 37. WATER FALLING AT CORNING

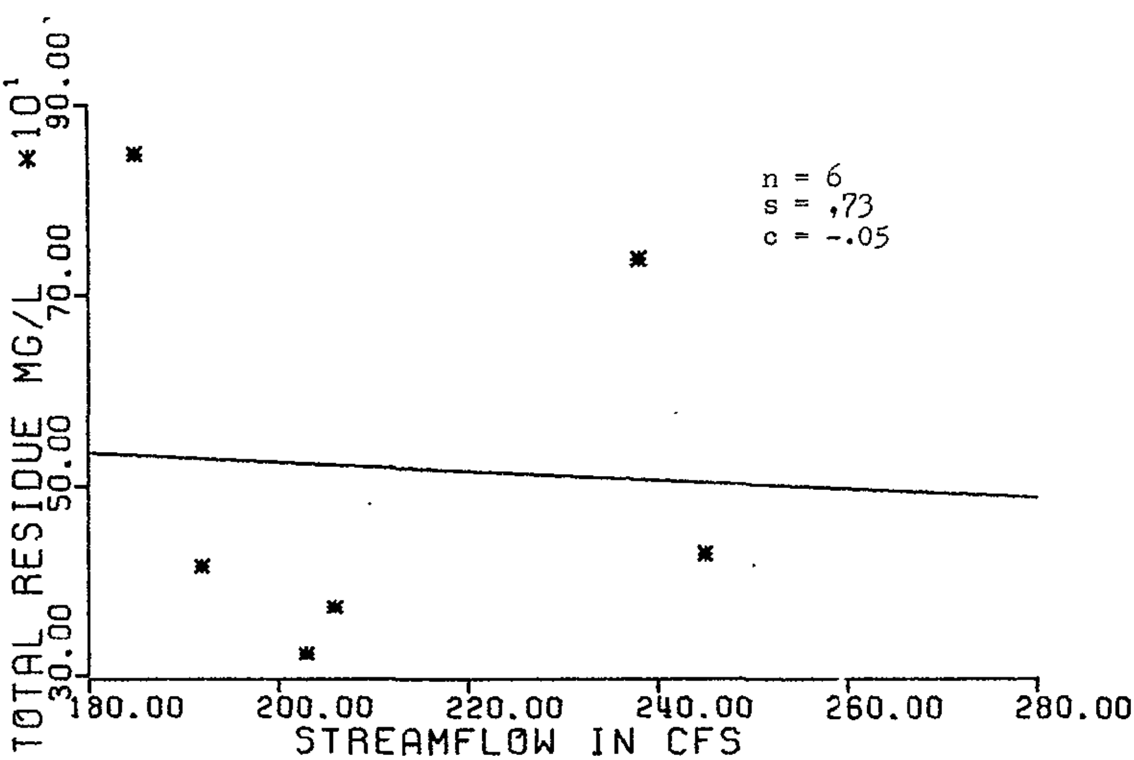


FIGURE 38. WATER RISING AT CORNING

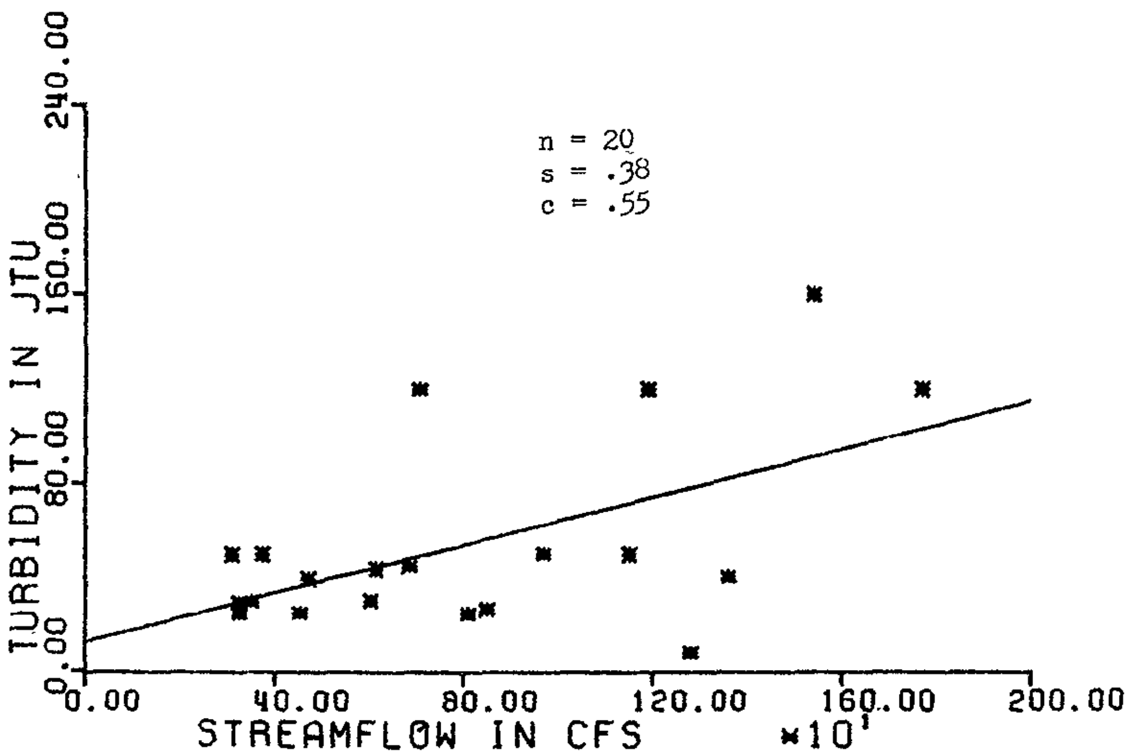


FIGURE 39. WATER RISING AT CORNING

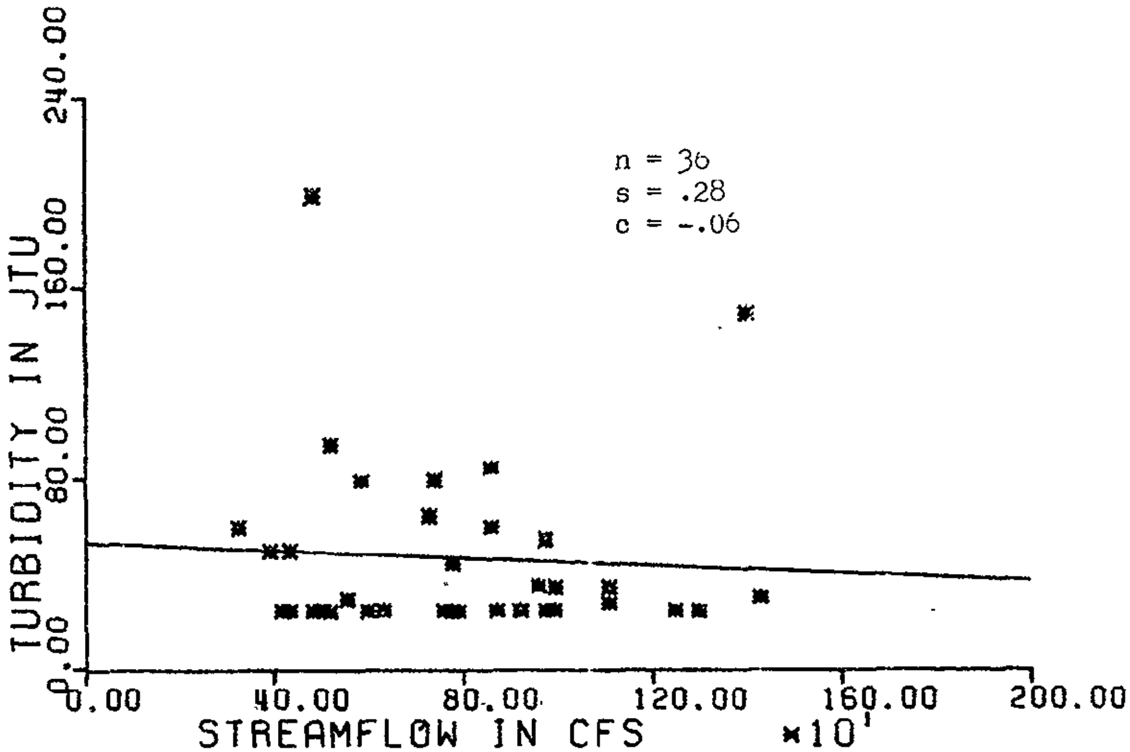


FIGURE 40. WATER FALLING AT CORNING

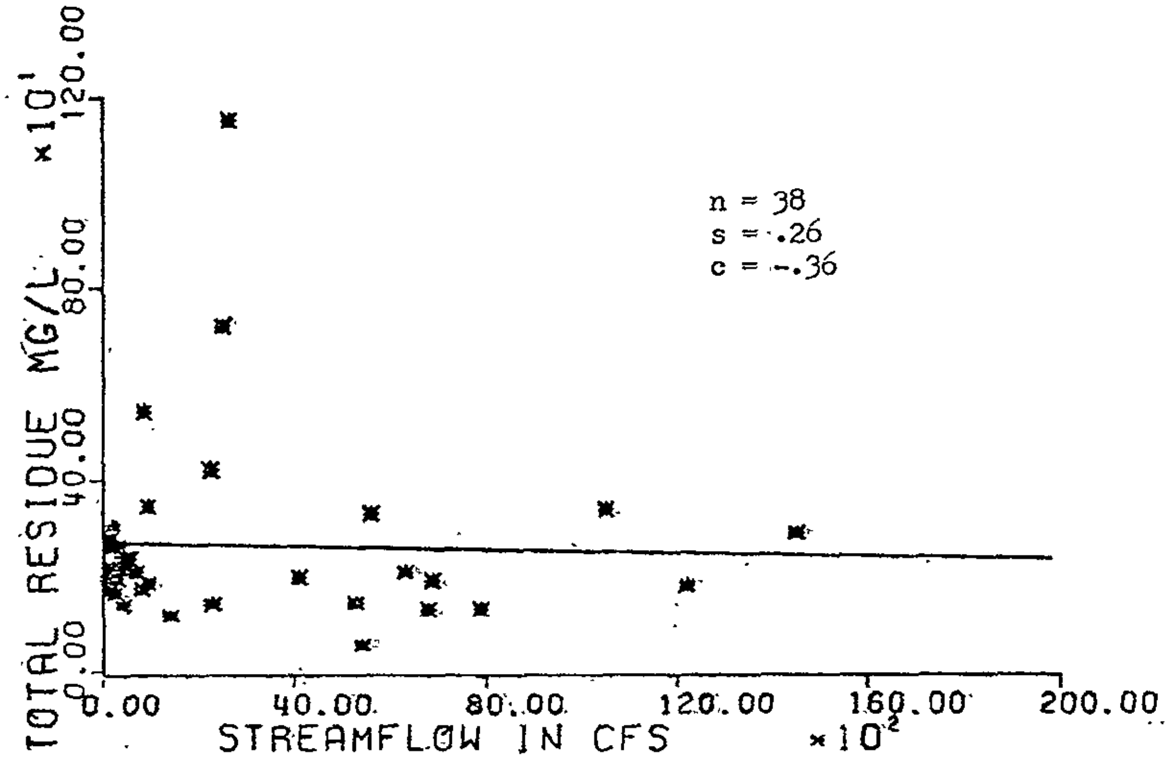


FIGURE 41. ST FRANCIS RIVER AT ST FRANCIS

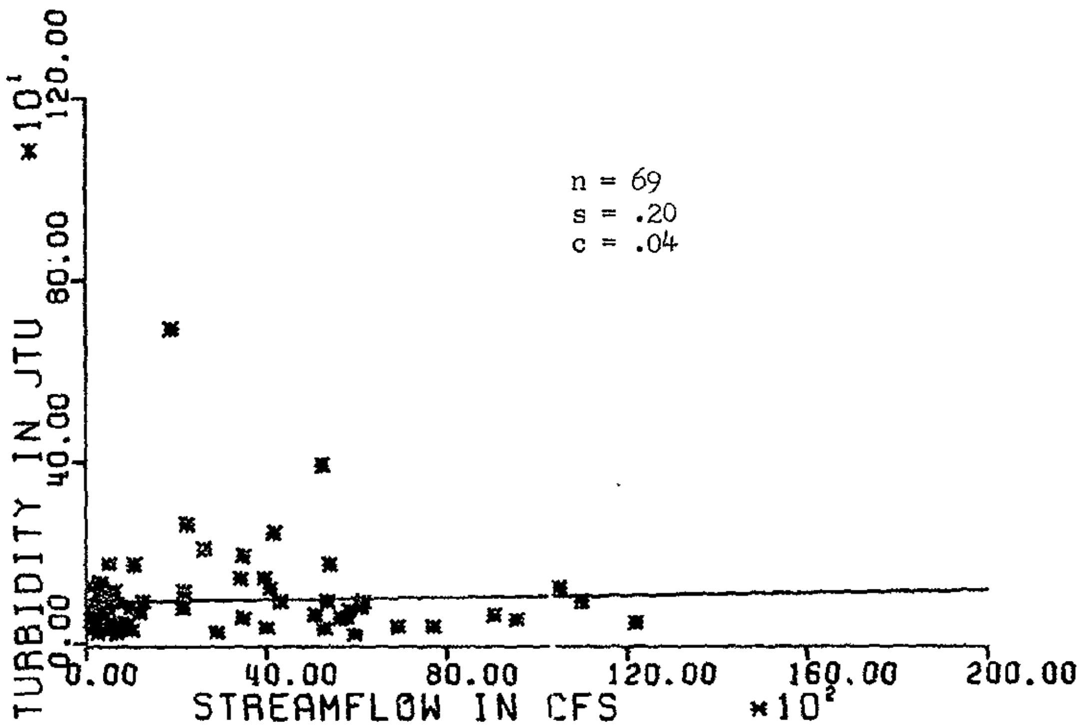


FIGURE42. ST FRANCIS RIVER AT ST FRANCIS

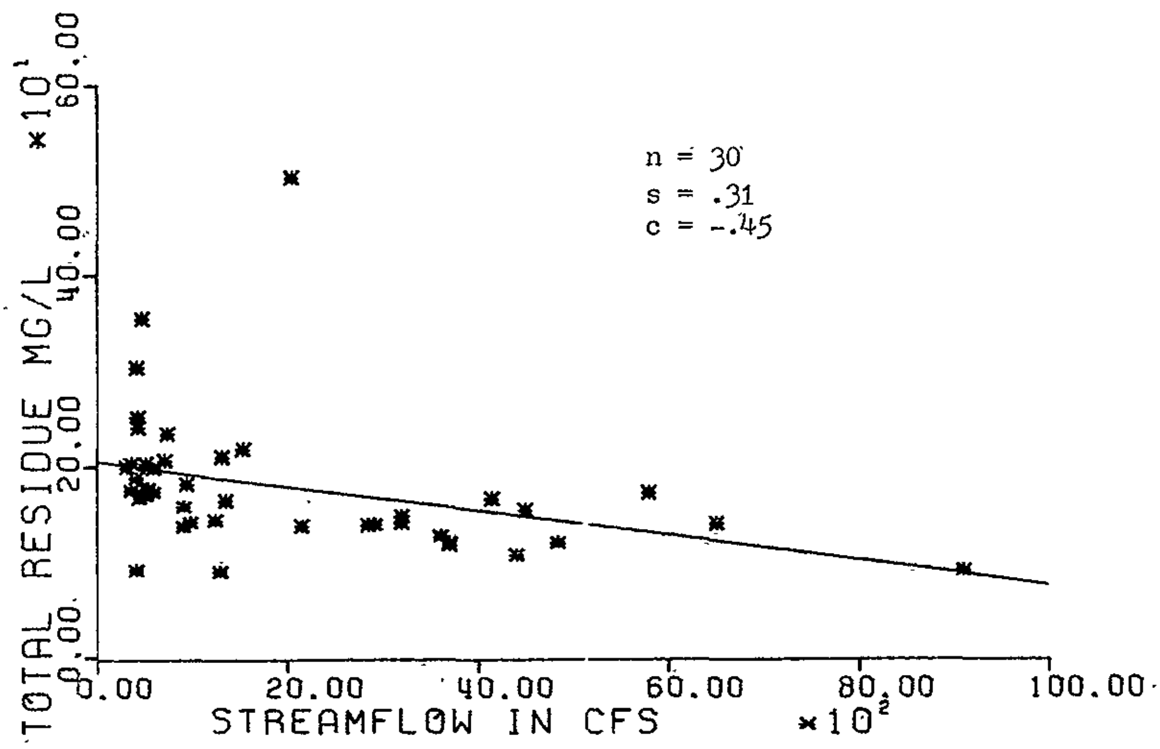


FIGURE 43. BLACK RIVER NEAR CORNING

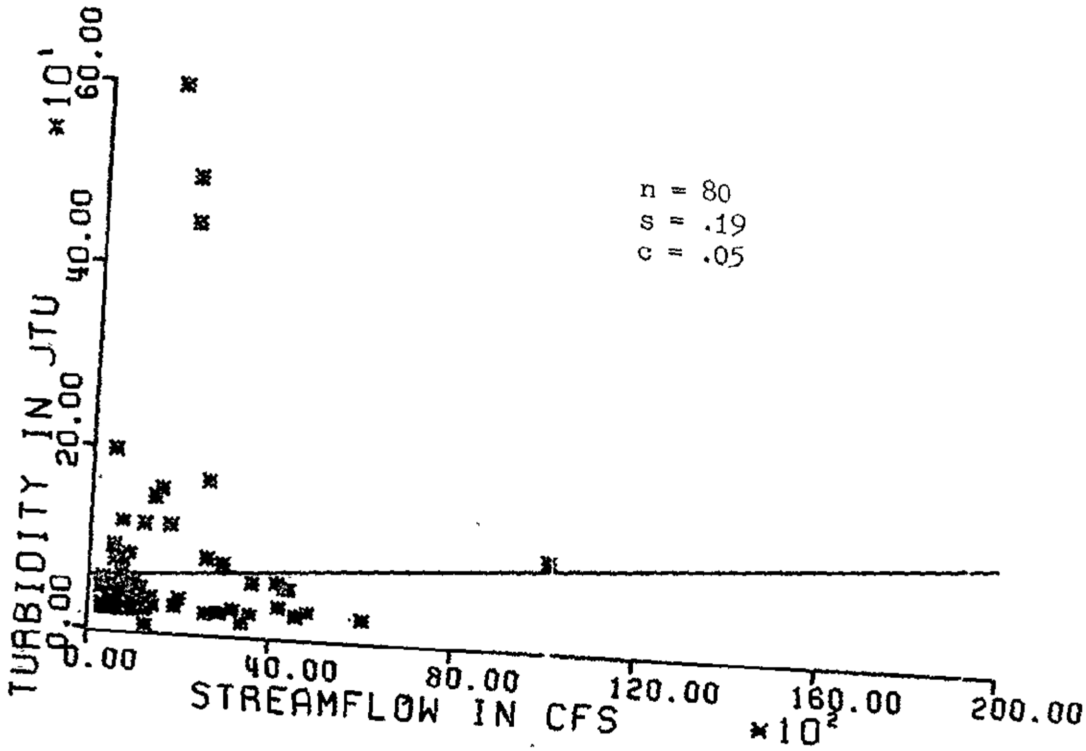


FIGURE 44. BLACK RIVER NEAR CORNING

may increase or decrease with increasing flow, depending upon the concentrations of the organic material and nutrients. Temperature has only minimal effect on biological and chemical reactions which affect parameter concentrations (except for bacteria, dissolved oxygen, and biological oxygen demand) because the total annual temperature range for these seven stations small (0-35°C).

Correlation of land use and water quality was not feasible because of the scarcity and infrequent measurement of parameters, especially those sensitive to nonpoint source pollution. Although data are limited, it is apparent that the hydrograph controls water quality and that to monitor land use effects, water collection time with respect to the hydrograph must be known. The rising side of the hydrograph represents mostly runoff, whereas the falling side shows the contribution of infiltration water as runoff becomes less important. Data from both sides of the hydrograph peak thus yield information concerning the land surface and its soil (i.e., land use). Water quality data as now collected are totally inadequate as a basis for monitoring nonpoint source pollution.

SECTION 5

WATER QUALITY MONITORING

5.1 COSSATOT RIVER WATERSHED

5.1.1 Introduction

LANDSAT imagery was used in an attempt to determine changes in land use in the Cossatot River watershed of southwest Arkansas during the period October 1972 - April 1975. Clearcutting operations in an extensive commercial timber forest accounted for the major land use change detected. A 6.9 percent decrease in total forest cover in the entire watershed was noted on LANDSAT 2 imagery; however, a concomitant increase of 181 percent in clearcut areas also was determined. Interpretation of the clearcut areas was made on the basis of distinctive color and pattern characteristics on color composite imagery. Some difficulty was encountered in distinguishing certain clearcut lands from stands of strictly deciduous vegetation in the surrounding mixed forest. Nevertheless, a field investigation of part of the watershed confirmed the extreme accuracy of the interpretation of clearcut lands. The land use map created from LANDSAT imagery was found to compare favorably with maps of the same area generated from high altitude aircraft imagery. A lack of adequate historical water quality records, combined with a lack of access to the area, prevented water quality monitoring during the research program.

5.1.2 Location and Description of Watershed

The Cossatot River of southwest Arkansas is a southward flowing tributary of the Little River, itself a major tributary of the Red River. The

Cossatot is approximately 70 miles long and its watershed is 529 mi^2. Lands drained by the Cossatot are predominantly in mixed deciduous and pine forests; most of the cleared agricultural land is in the southern half of the watershed. Population also is concentrated in the downstream part of the area, the towns of Horatio (852) and Lockesburg (620) being the largest communities in the entire watershed. The towns of Gillham (200), Grannis (177), and Wickes (409), each on the western divide along U.S. Highway 71, are the only sizable communities in the northern half of the watershed.

For the purpose of this report, the Cossatot watershed is divided into three separate areas: upper, middle, and lower watersheds. Though land use change data were compiled for each of the three areas, the upper part of the watershed received special attention, being the subject of a field check conducted to confirm the accuracy of LANDSAT land use classification assignments.

5.1.2.1 Upper Cossatot

The upper Cossatot watershed is defined as the land drained by the river north of the Duckett Bridge in sec. 9, T.6S., R.30W., an area of 218 mi^2. Approximately half of this area is within the Ouachita National Forest, where the river has its source, and the remaining territory (below the mouth of Brushy Creek) provides somewhat different land usage. Rock exposed in the National Forest consists primarily of alternate beds of nonresistant shale and very resistant chert (the Arkansas Novaculite of Devonian age). West-northwest trending folds have resulted in a series of narrow, ridge-topped mountains which rise as much as 800 to 1000 feet above adjacent valleys. The forest, which accounts for at least 95 percent of the land cover, is composed mostly of deciduous vegetation though pine commonly is present on the gentler slopes at lower elevations. No appreciable amount of forest clearing activity is now being conducted within the National Forest; however, a minor portion of the land is in pasture or other agricultural use. In the National Forest, the Cossatot is a cold, clear shallow stream, flowing over a river bed choked in many places with cobbles of novaculite. As the river flows south and southwest, it is joined by several small lateral tributaries, and just south of the forest boundary the Cossatot is joined by Brushy Creek, another south-flowing mountain stream of approximately the same size.

Below the mouth of Brushy Creek the Cossatot passes into a somewhat different type of watershed area. Here the bedrock is composed of mostly shale and sandstone. East of the river the topography is generally much more subdued than in the National Forest, relief within single sections rarely exceeding 200 feet. West of the river the topography is somewhat more rugged, especially in the Cross Mountains area, where the Arkansas Novaculite again is exposed. Agricultural land use is more important in this piedmont area than in the National Forest; however, the principal land use is commercial timber production. Most of the forest is of a mixed variety with relatively few stands of strictly deciduous or coniferous forest. It is in this part of the upper Cossatot watershed that clearcut locations were noted on LANDSAT imagery, areas which later were checked in the field.

5.1.2.2 Middle Cossatot

The middle Cossatot watershed includes the land above the U.S. Highway 70/71 bridge east of De Queen, Sevier County, and south of the upper watershed. Included in the middle watershed is the Gillham dam and reservoir site. A short distance below the dam site the Cossatot enters a typical

Gulf Coastal Plain terrain, composed mostly of Quaternary alluvium. This area supports substantial agricultural activity. North of the coastal plain boundary, small farms are numerous west of the river, whereas the eastern part of the watershed here is almost exclusively in commercial forest.

5.1.2.3 Lower Cossatot

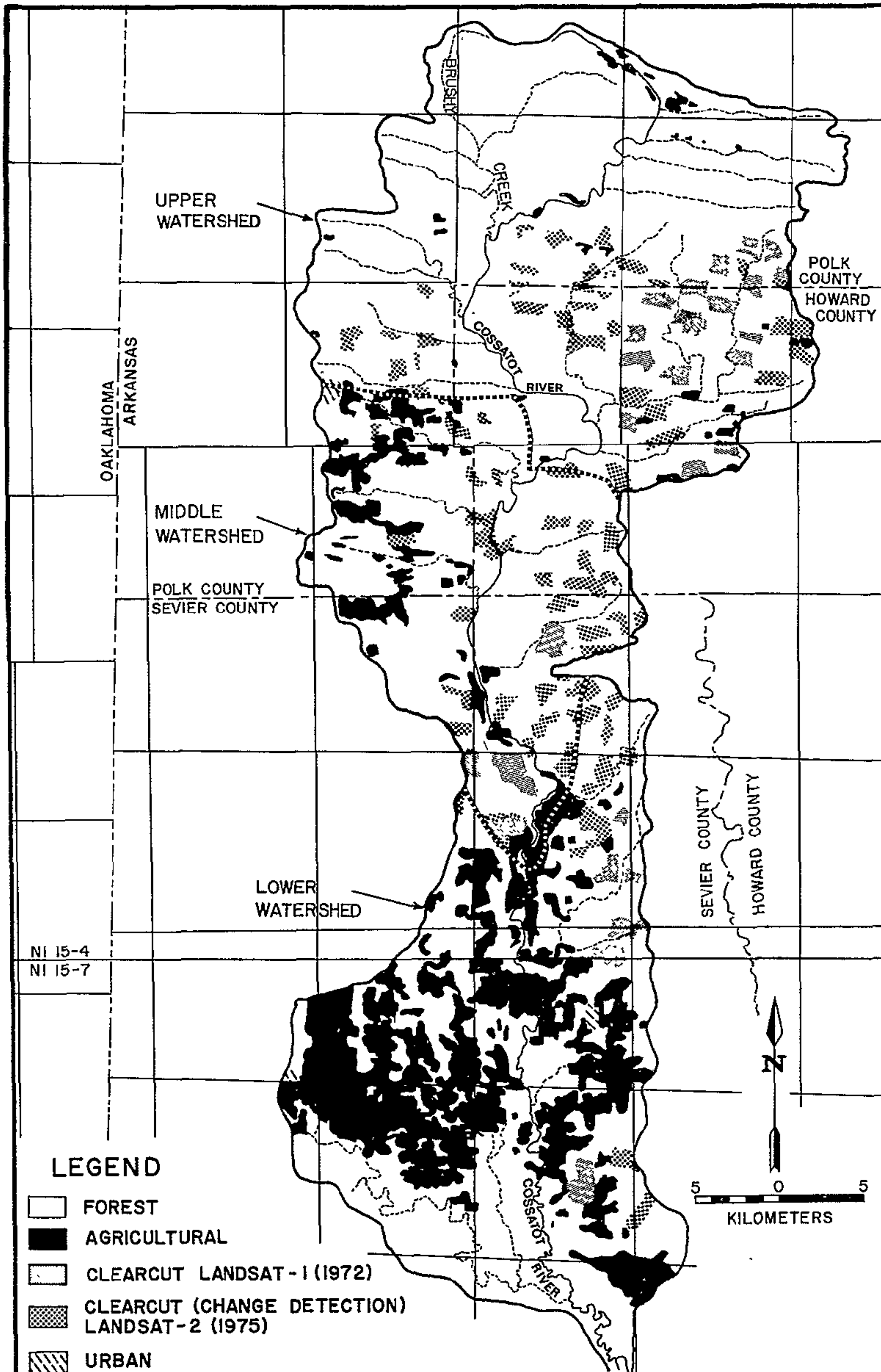
The lower Cossatot watershed consists of those lands drained by the river south of the Highway 70/71 bridge. In this part of the watershed commercial timbering is less important than agricultural activity, which is carried out on both the Gulf Coastal Plain and the adjacent uplands where favorable soils are present. Surrounding the mouth of the river is an extensive area of poorly drained deciduous woodland which supports neither agriculture nor the timber industry. This area is below the top level of the flood control pool of the Millwood Reservoir on Little River.

5.1.3 Imagery Interpretation and Field Check

Increases in the extent of forest removal in the Cossatot watershed, as detected on LANDSAT imagery for the period 1972-1975, are illustrated in Figure 45. The classification scheme used in the construction of the land use map is discussed in section 5.1.4.1. Detailed land use inventory data appear in Table 5.

5.1.3.1 Imagery Employed

Data for the land use map of the Cossatot watershed first were drafted from a NASA color composite LANDSAT-1 image acquired on October 4, 1972 (81073162335G200). An enlargement of the Cossatot area as it appears on the MSS Band 5 image of this scene is shown in Figure 46. Land use change detection was accomplished by drafting data from a LANDSAT-2 image with an



LAND USE MAP

COSSATOT WATERSHED, ARKANSAS

Table 5. Cossatot watershed land use.

Watershed Division		Urban			Agricultural			Forest			Clearcut			Total	
		Acres	Sq Mi	Percent	Acres	Sq Mi	Percent	Acres	Sq Mi	Percent	Acres	Sq Mi	Percent	Acres	Sq Mi
Upper	1972	128	0.2	<1	3,520	5.5	2.5	130,944	204.6	93.7	5,120	8.0	3.7	139,712	218.3
	1975	128	0.2	<1	3,520	5.5	2.5	123,584	193.1	88.5	12,480	19.5	8.9		
Middle	1972	704	1.1	<1	11,456	17.9	14.6	63,936	99.9	81.7	2,176	3.4	2.8	78,272	122.3
	1975	704	1.1	<1	11,456	17.9	14.6	55,488	86.7	70.9	10,624	16.6	13.6		
Combined Upper & Middle	1972	832	1.3	<1	14,976	23.4	6.9	194,880	304.5	89.4	7,296	11.4	3.3	217,984	340.6
	1975	832	1.3	<1	14,976	23.4	6.9	179,072	279.8	82.1	23,104	36.1	10.6		
Lower	1972	1,408	2.2	1.2	33,088	51.7	27.4	83,328	130.2	69.1	2,752	4.3	2.3	120,576	188.4
	1975	1,408	2.2	1.2	34,048	53.2	28.2	80,000	125.0	66.3	5,120	8.0	4.2		
Totals for entire Watershed	1972	2,240	3.5	<1	48,064	75.1	14.2	278,208	434.7	82.2	10,048	15.7	3.0	338,560	529.0
	1975	2,240	3.5	<1	49,024	76.6	14.5	259,072	404.8	76.5	28,224	44.1	8.3		

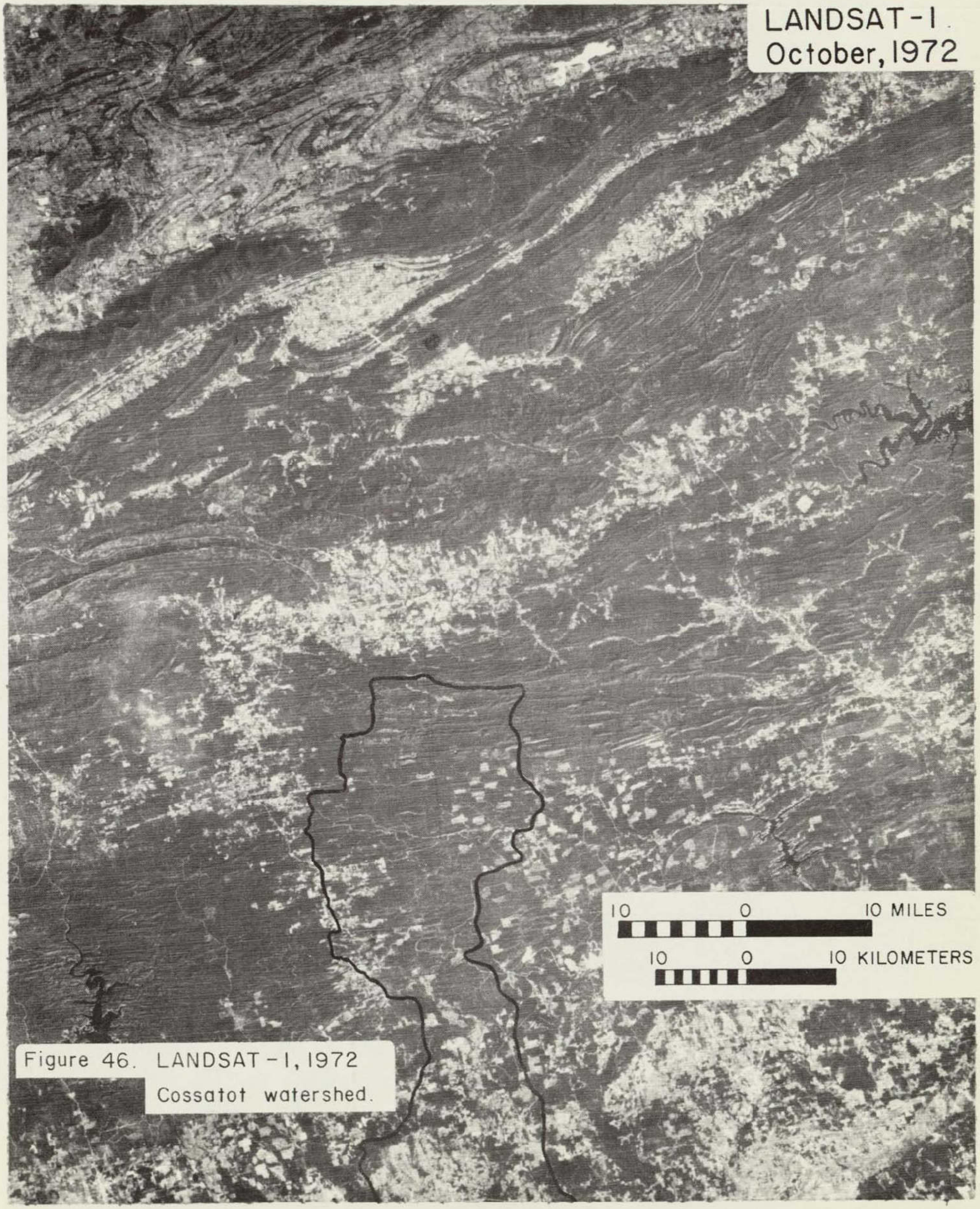


Figure 46. LANDSAT-I, 1972
Cossatot watershed.

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acquisition date of April 19, 1975 (82087161225N000) (see Figure 47). By the Diazo process, an IR color composite for this scene was constructed in the University of Arkansas Remote Sensing Lab by use of positive transparencies of MSS Bands 4, 5, and 7. Additional reference occasionally was made to a snow-cover Landsat-2 scene of the Ouachita region acquired on March 14, 1975 (82051161225G000).

5.1.3.2 Image Characteristics and Mapping Techniques

Examination of the Cossatot watershed on both the 1972 and 1975 false color composites shows an area generally dominated by the red hues of healthy forest vegetation. Slight variations in darkness appear to indicate distinctions between deciduous and evergreen forest. In a few areas it is possible to delineate stands of either strictly deciduous trees (light red) or strictly evergreen trees (dark red). However, most of the forest has an intermediate hue which appears to be characteristic of a mixed forest. Scattered throughout the forest are areas where the tree cover appears to have been altered drastically. On both the 1972 and 1975 images, land cleared for agricultural purposes, generally for pasture, has a distinctive bright orange hue.* Recognition of agricultural lands is facilitated by the fact that such land often is cleared in regular blocks which follow U.S. Land Survey system patterns. Agricultural lands can be distinguished from other, somewhat irregular blocks which have a variable hue. On the 1972 image these areas are characterized mostly by a pronounced gray color. A few of the sites, however, appear simply as pale areas within the

*The orange hue is due to nearly complete light transmission in agricultural areas on the Band 7 IR-Cyan component of the composite, with some interception by the Yellow (Band 4) and Magenta (Band 5) films. Clearcut areas are much darker than agricultural areas on Band 7.

Figure 47. LANDSAT-2, 1975
Cossatot watershed.

forest, distinguished from the surrounding vegetation by only a slight difference in hue. Both types of areas were delineated as forest clearcuts on the land use map of the watershed. During the field check, it was discovered that controlled burning is used to deaden remaining deciduous cover after the harvesting of pines in the mixed forest. This burning apparently accounts for the gray color noted in most of the areas. The 1975 image has no areas of pronounced gray color, but does include several additional sites with colors ranging from pale gray-red to a bright off-white. These sites have the irregular block pattern of presumed clearcuts noted on the 1972 image.

Mapping of clearcut and agricultural areas was fairly uncomplicated because the aforementioned image characteristics could be used for discrimination. However, large stands of deciduous vegetation in the midst of the generally mixed forest were, in a few cases, difficult to distinguish from clearcuts, especially if these areas appeared to have a definite pattern. Classification of these areas was made by considering their extent, their apparent accessibility, and their position in relation to geomorphic features and to other areas believed definitely to be clearcuts. Most finally were placed in the undisturbed forest category.

The upper Cossatot watershed initially was mapped entirely by an uncertain, time-consuming manual sketching procedure. Acquisition of a Bausch & Lomb Zoom Transfer Scope provided the means by which the initial mapping could be checked, and by which mapping of the rest of the watershed was accomplished rapidly. The Zoom Transfer Scope allowed the transferral of imagery data directly to the 1:125,000-scale county highway maps initially used as the base maps.

5.1.3.3 Field Check

A field check of the commercial timber area in the upper Cossatot watershed was conducted during early August 1975. Previously 53 separate areas had been designated as suspected clearcut locations in the upper watershed. During the field investigation, 28 of these sites were visited. The other areas either were not readily accessible or their location on the ground could not be pinpointed with sufficient accuracy with the available maps. Of the 28 forest sites visited, 27 were found to bear evidence of recent harvesting activity. General accuracy of interpretation thus was confirmed, allowing satisfactory assurance that the map produced for the entire watershed reflects fairly closely the ground conditions in the forests at the time of image acquisition. In addition, confirmation of the correct assignment of certain areas to the agricultural land category was achieved at several points, but those areas were not checked systematically.

The single misidentification detected was accompanied by one confirmed omission of a clearcut area. In the case of the misidentification, a 320-acre stand of strictly deciduous forest vegetation was placed in the clearcut category because of its light tone and well defined pattern on both the March and April 1975 images. A smaller area which is, in fact, a recent clearcut was omitted from the LANDSAT-derived map and placed in the forest category after being interpreted as a stand of mature deciduous vegetation. The difficulties in the classification of these areas point up the need for caution in the interpretation of early spring imagery of a mixed commercial forest. If a strictly deciduous area which appears in light tones on the imagery also has the characteristic outline of a clearcut, discrimination becomes difficult, particularly because many of the clearcut areas actually have some deciduous cover remaining after harvesting. It is possible that this problem can be overcome by use of imagery obtained somewhat later in the growing season, when spectral reflectance from undisturbed deciduous forest is at a maximum. At this time, discrimination from disturbed areas should be less uncertain.

5.1.4 Changes in Land Use, 1972-1975

5.1.4.1 Land Use Categories

The land use map accompanying this section of the report (Figure 45), drafted from LANDSAT imagery, shows the extent to which recognizable changes occurred in the Cossatot watershed during the 30-month period of October 1972 - April 1975. Four separate categories of land use were delineated on the LANDSAT imagery. Urban and built-up land is the smallest of these, and is restricted to the five small communities mentioned in section 5.1.2. No change was detected in this category. A nearly static condition also prevailed in the extent of agricultural lands, only a slight increase being noted. Additions to this category are restricted to the lower watershed and are not designated separately on the watershed map.

The principal land use change in the Cossatot watershed during this time period was the result of timber harvesting activity in the commercial forest. Forest lands are defined here as those areas in which undisturbed stands of trees so completely cover the ground as to produce a characteristic tone on the LANDSAT image, one which is generally darker than that produced by surrounding cleared areas. Clearcut areas comprise the fourth category. Some recent clearcuts have only a low weed cover remaining on the site after harvesting. However, as has been noted, many clearcut areas have a certain amount of deciduous cover, either as residual (usually deadened) hardwoods or as a secondary growth of shrubbery ("browse"). In general, a clearcut area is defined here as an area formerly in the forest category which has been disturbed drastically in the recent past by commercial timber harvesting. Areas which were recognized as clearcuts on the 1972 imagery are considered to remain in that category for the 1975 land use inventory. In Figure 45, these older areas are distinguished from other clearcuts which were detected only on the 1975 imagery.

5.1.4.2 Land Use Inventory

Land use data for each of the Cossatot watershed divisions are presented as area estimates and as percentage total in Table 5. Table 6 provides a summary of the percentage changes in the forest and clearcut categories in each of the watershed divisions.

Table 6. Land use change detection 1972-1975.

	Upper Watershed	Middle Watershed	Combined Upper & Middle Watersheds	Lower Watershed	Entire Watershed
Percentage forest	-5.6	-13.2	-8.1	-4.0	-6.9
Percentage clearcut	144	388	217	86	181

5.1.5 <u>Comparison with High Altitude Aircraft Imagery-Derived Map</u>

Figure 48 is a representation of land use data for the Cossatot watershed obtained from high altitude aircraft (U-2) imagery. The maps used in the drafting of Figure 48 are the land use overlays for the McAlester and Texarkana 1:250,000 Topographic Quadrangles as prepared by the U.S. Geological Survey (discussed in section 2.6.1). Mapping was done from U-2 color IR photographs (March 1974) on an image scale of approximately 1:125,000. The classification scheme used was that described in USGS Circular 671. The original map data were presented entirely at the proposed

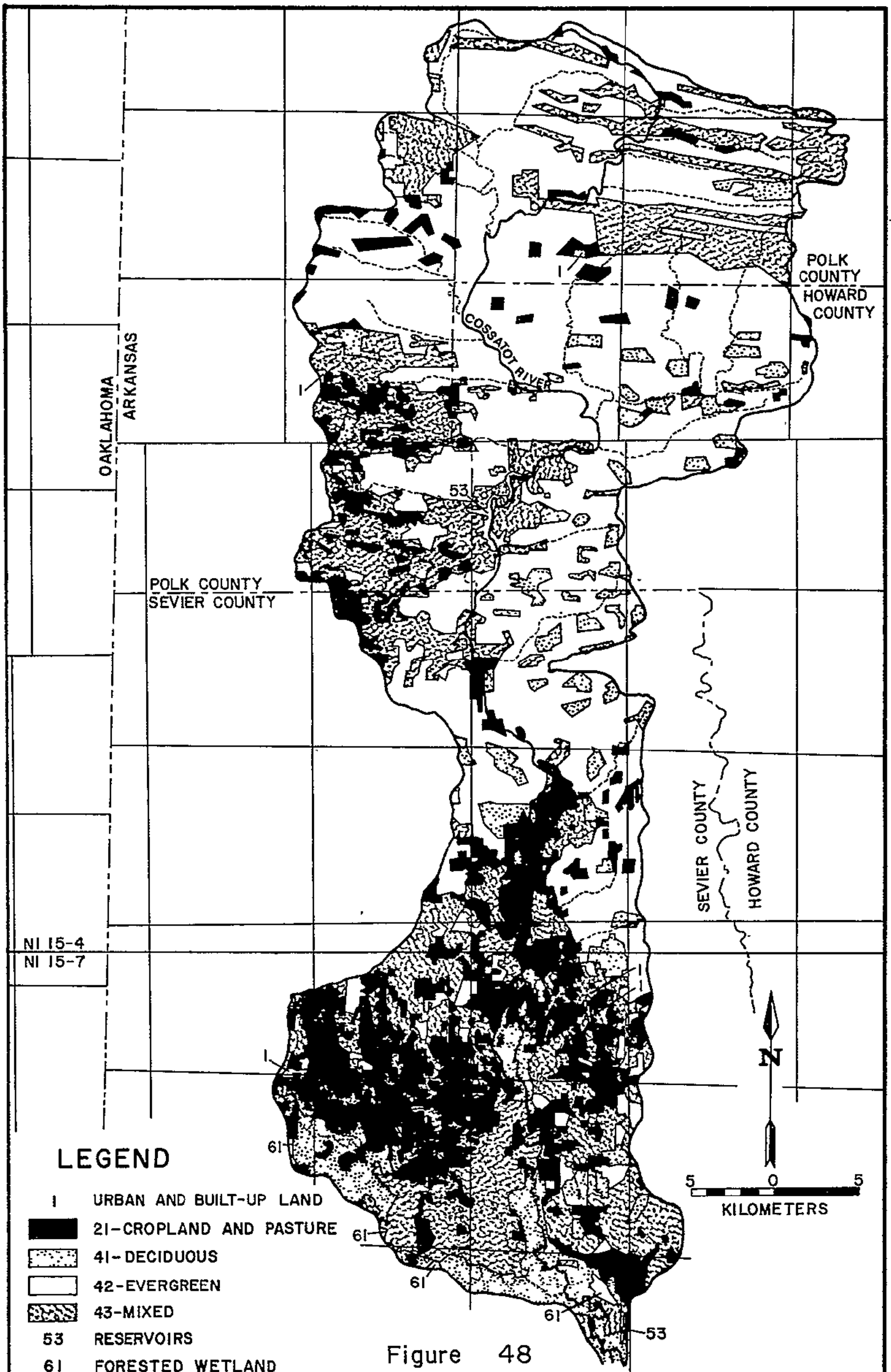


Figure 48

LAND USE MAP

U.S.G.S. OZARKS REGION PROJECT-1974

classification Level II, the level judged best suited for high altitude imagery-derived data. Figure 48 simplifies this classification scheme only within category 01, Urban and Built-Up Land. These lands all are designated at classification Level I, whereas all other lands appear as shown on the original Level II maps of the area.

The LANDSAT imagery-derived land use map in Figure 45 can be compared with Figure 48. In Figure 45, no attempt was made to delineate forest types, or to distinguish among the various Level II categories of urban lands. With these differences recognized, the LANDSAT-derived map compares favorably with the Level II mapping represented by Figure 48. In particular, it is apparent that the proposed USGS classification scheme does not include a separate Level II category which embraces clearcut lands. When they are recognized (Figure 48) such lands generally are placed in the deciduous forest category. Agricultural lands are approximately equal in total extent on the two maps, whereas the exact positioning of these lands is somewhat less precise on the LANDSAT-derived map. Finally, on the original USGS overlays from which Figure 48 was drafted, land use boundaries are drawn as straight lines, with an averaging of irregularities, so that acreage data within each category can be processed readily by computer techniques. This practice necessarily leads to a reduction in the accuracy with which the boundaries are portrayed on maps. This loss of accuracy can be seen in certain of the clearcut areas, most of which have an irregular outline on the ground. Within these areas at least, land boundaries are portrayed more realistically on the LANDSAT-derived map than on the maps derived from U-2 photographs.

The favorable comparison with aircraft imagery-derived data is suggestive of the accuracy and sensitivity to detail which can be expected from

LANDSAT mapping in forested areas. The capability for the detection of land use change on LANDSAT imagery can be seen readily by comparing Figures 46 and 47, enlargements of the Cossatot area as it appears on the 1972 and 1975 images, respectively. The increases in the amount of clearcut lands detailed in Tables 5 and 6 are immediately apparent on the 1975 image. The detailed tabulation of clearcut lands, documenting a 181 percent increase in this category for the entire watershed, included some areas no larger than 50 acres. A small increase in the amount of agricultural lands, distinguished from clearcuts by their color and pattern, also was recorded effectively in the LANDSAT data.

5.1.6 Water Quality in the Cossatot River Watershed

The Cossatot River watershed initially was selected for study as a result of a preliminary examination of LANDSAT imagery which suggested that a substantial land use change had occurred there. It was hoped that adequate historical water quality records for the Cossatot could be found which might be compared with more recent data. The search for water quality records centered on data collected by the U.S. Geological Survey and published in "Water Supply Papers - Quality of Surface Waters in the U.S." or in "Water Resources Data for Arkansas." These publications were checked for the years 1947 through 1973. During only one of these years, 1959, were samples from the Cossatot collected and analyzed systematically. In more than half of the years, no samples were gathered at all. In 1971, samples were collected on a one-time basis by the U.S. Army Corps of Engineers in the preparation of a "Final Environmental Statement, Gillham Lake, Cossatot River, Arkansas." Regularly scheduled water quality sampling of the Cossatot was not begun until May 1974 when the Arkansas Department of

Pollution Control and Ecology established a sampling point near Lockesburg in the lower watershed.

The lack of adequate historical water quality records for the Cossatot watershed precluded the possibility of showing a relationship between detected changes in land use and any changes in water quality. In addition, the commercial timber forests of southwest Arkansas, where the most distinct land use changes in the state have been detected on LANDSAT imagery, are more than 100 miles from the University at Fayetteville. This lack of proximity to the remote sensing facility effectively prevented the establishment of a systematic water quality monitoring program during the course of the project.

5.2 WATER QUALITY OF THE BUFFALO RIVER

5.2.1 Introduction

The Buffalo River of northern Arkansas originates in Newton County, 35 miles southeast of Harrison, Arkansas. It flows generally northeast 150 miles and ends 40 miles east of Harrison where it enters the White River at Buffalo City in Marion County (Fig. 49). Along most of its course it is characterized by meanders and steep bluffs 400 to 600 feet high. A mantle of white oak, pine, walnut, cedar, and other timber covers the hills surrounding the river. Because of its scenic beauty and fair fishing, the Buffalo River is very popular for canoe float trips. Recently under Public Law 92-237 the Buffalo River became a National River under the auspices of the National Park Service.

5.2.2 Geology and Land Use

Because elemental variation correlates with the rock types of the area,

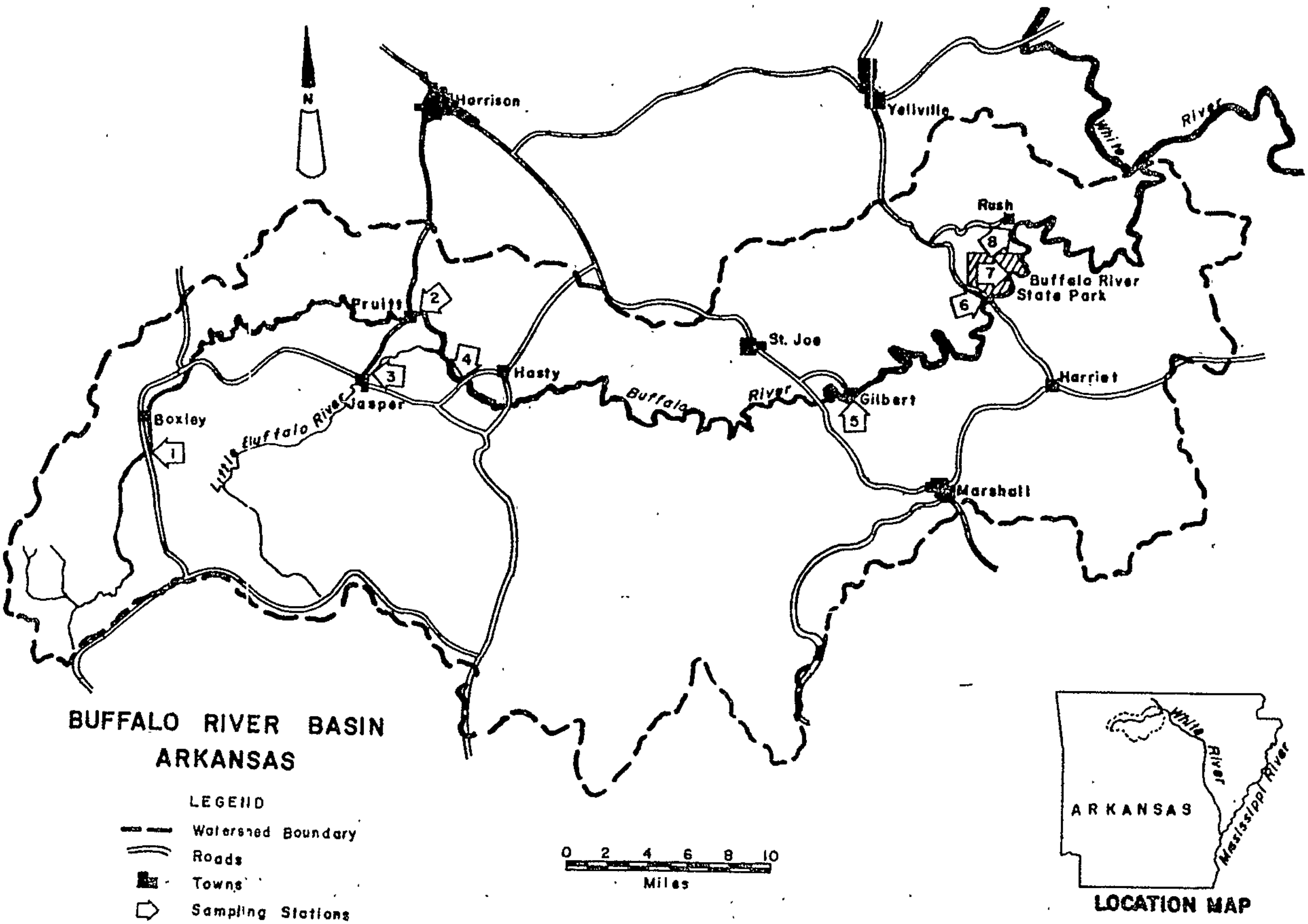


Figure 49. Location of sample stations. Location of Buffalo River is shown in inset.

it is helpful to summarize the geology of the Buffalo River. The Buffalo River flows northeast along the northern edge of the Boston Mountains. It dissects the Springfield Plateau and drops from an elevation of 2,000 feet at its source to 500 feet at its confluence with White River. Along much of its course it has cut from 400 to 600 feet below the Springfield Plateau and in its upper part in the Boston Mountains it is in a gorge 1,400 feet deep. The drainage area is characterized by a maze of long, narrow, fairly level-topped ridges of irregular pattern capped by the Boone Formation. Because of the canyonlike character of the valleys, spring and fall storms produce high floods. The Buffalo River at Gilbert on August 18, 1915, rose 54 feet above the low stage (McKnight, 1935).

All rocks of the Buffalo River area are of sedimentary origin and are mainly those of the Ordovician, Mississippian, and Pennsylvanian Systems. Units of Silurian and Devonian age are mostly absent as a result of erosion or nondeposition. Ordovician-age strata include the Cotter, Powell, Everton, Jasper, St. Peter, Joachim, Plattin, Kimmswick, Fernvale, and Cason Formations. Mississippian-age strata include the Boone, Batesville, Fayetteville, and Pitkin Formations. Early Pennsylvanian strata of the area include the Hale and Atoka Formations. As the Buffalo River flows downstream it passes from a shale, limestone, chert environment to a sandstone, limestone, dolomite environment.

The richer zinc ore deposits are present either in the Everton Formation of Early Ordovician age or in the Boone Formation of Mississippian age. The maximum thickness of the Everton is 400 feet and it is composed of limestone, dolomite, and sandstone. The Boone Formation is about 350 feet thick and is limestone and chert. Other mineralized strata are in the Cotter dolomite and Powell dolomite. The strata have a slight southward regional dip of about 0.5°. Faulting and gentle folding are present locally. The faults are normal and are in two major systems, one trending northeast and the other trending east-southeast. Many of the faults form grabens.

Many old mines and known deposits of zinc, lead, and copper dot the drainage area of the Buffalo River. These deposits are most extensive in the area from Gilbert to Buffalo City. One of the best known mining areas is along Rush Creek, a tributary of the Buffalo River 24 miles upstream from the White River. Mines, mills, and reduction plants were in use there as early as 1851, but were most active from 1914 to 1917. The Boxley-Ponca Lead District was mined intermittently from 1860 to 1920 (McKnight, 1935).

The Rush Creek area alone has produced more than 25,000 tons of concentrates, mainly zinc carbonate and a smaller amount of zinc silicate and sulfide. An old mill and its tailings pile stand today on the bank of Rush Creek at its confluence with the Buffalo River. Lead sulfide concentrates produced amount to less than 10% of the zinc produced in the northern Arkansas mining district. Along the Buffalo River lead ores are mostly in the headwaters region and one known deposit is near Water Creek, a tributary. Copper ore is much less common than lead and zinc in the Buffalo River area and is mostly along Tomahawk Creek, a tributary.

The dominant land use (70 percent) throughout the watershed of the Buffalo River is forestry, agriculture being only a minor component. Table 7 gives the specific land usage of the Buffalo River watershed.

5.2.3 Water Quality

There is a lack of water quality data for the Buffalo River. The U.S. Geological Survey operated a water quality station near Rush, Arkansas (about 23 miles from the mouth of the river) from 1949 to 1960 (U.S. Geological Survey). However, data were collected from this station only for 1950

Table 7. Buffalo River watershed land use.

Land Use	Sq. Miles	Acres
Agriculture	265.80	170,110
Urban	4.01	2,570
Forest Mixed	365.92	228,430
Forest Coniferous	11.16	7,145
Forest Deciduous	702.74	449,755
Total	1,349.63	858,010

(3 samples) and 1960 (9 samples) and partial analyses were made for 1951, 1952, 1953, and 1954 (2 samples for each of these years).

More recently the Water Resources Research Center of the University of Arkansas in conjunction with the National Park Service has begun a series of studies on the Buffalo River that include water quality investigations. The water quality investigations can be divided into two types of studies. One type involves seasonal monitoring of eight stations along the river (Parker, 1973, 1975; Rippey and Meyer, 1975; Steele et al., 1975). The second type is an "intensive look" at the water quality of the entire river at "a point" in time (Nix, 1973, 1975).

Before an assessment of water quality changes with land use can be made, it is necessary to examine the changes in water chemistry along the river and also chemical changes due to seasonal fluctuations. Nix (1973, 1975) made two intensive water quality studies, one for six days in May 1973 and another for six days during May-June 1974. Both studies were carried out by canoe and samples were collected at the same locations along the river. The 1973 sampling trip was cut short (about 10 miles upstream from the Rush station) by heavy rains. Nix (1975) relates changes in calcium, magnesium, and alkalinity concentrations with rock type changes along the river. These parameters as well as dissolved oxygen, specific conductance, sulfate, nitrate, phosphate, and zinc show little difference between the 1973 and 1974 background values. However, the anomalous peaks for nitrate, phosphate, and zinc for 1973 and 1974 are not the same (Figs. 50-52). The slightly lower phosphate levels in 1974 perhaps indicate phosphate addition in 1973 due to runoff. As shown in Figure 51, there is a trend of increasing phosphate concentration downstream. This loading of phosphate may be due to disturbed land throughout the watershed of the stream. The nitrate anomalies may be caused by agricultural activities and the lack of nitrate loading indicates that although nitrate may be introduced at points along the river, the elevated concentrations are quickly dissipated, probably by biological activity. Zinc anomalies may be the result of contamination by agriculture or by disturbance of old mine tailings. Calcium, magnesium, and alkalinity values are slightly lower for 1973 than for 1974 (Figs. 53-55), probably because of dilution by rains in 1973. The break in continuity of several of the parameters for 1973 near river mile 45 is caused by the presence of heavy runoff after rains, but the river had regained "normal" values at river mile 33.

There are major differences between the 1973 and 1974 values for sodium, potassium, chloride, and iron (Figs. 56-59). The 1973 values are considerably larger and show large fluctuations, whereas values for 1974 are very low and constant. This pattern suggests that the origin of the sodium, potassium, chloride, and iron is very different from that of calcium, magnesium, and alkalinity. The sodium, potassium, and iron determinations were made on raw water samples by atomic absorption spectrometry which would detect these cations' presence as suspended material, and as dissolved material.

The fact that suspended load would be greater after rain could explain

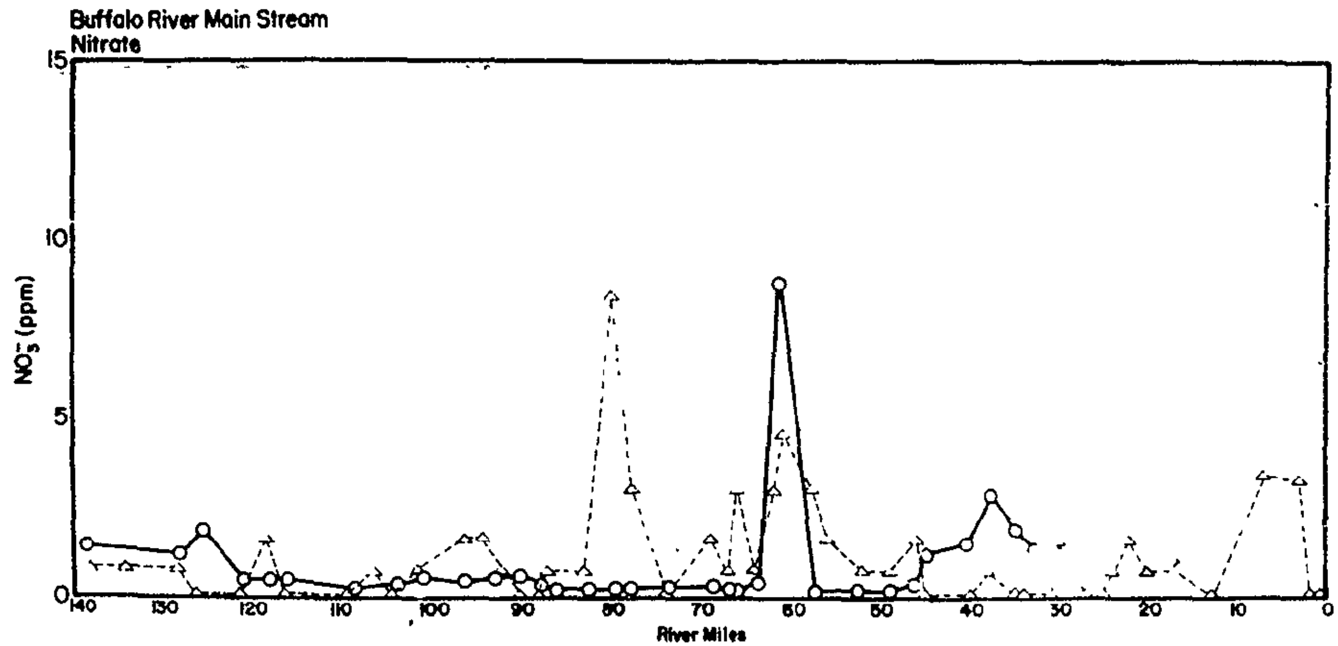


Figure 50. Nitrate concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

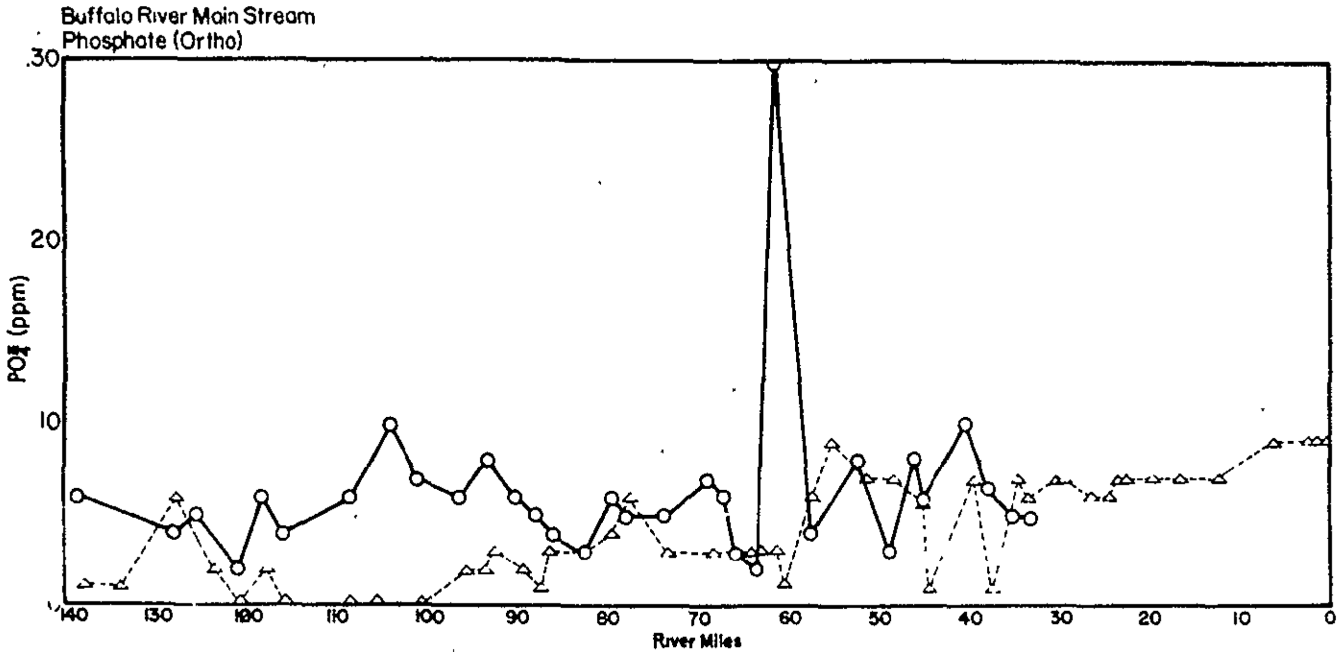


Figure 51. Phosphate concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

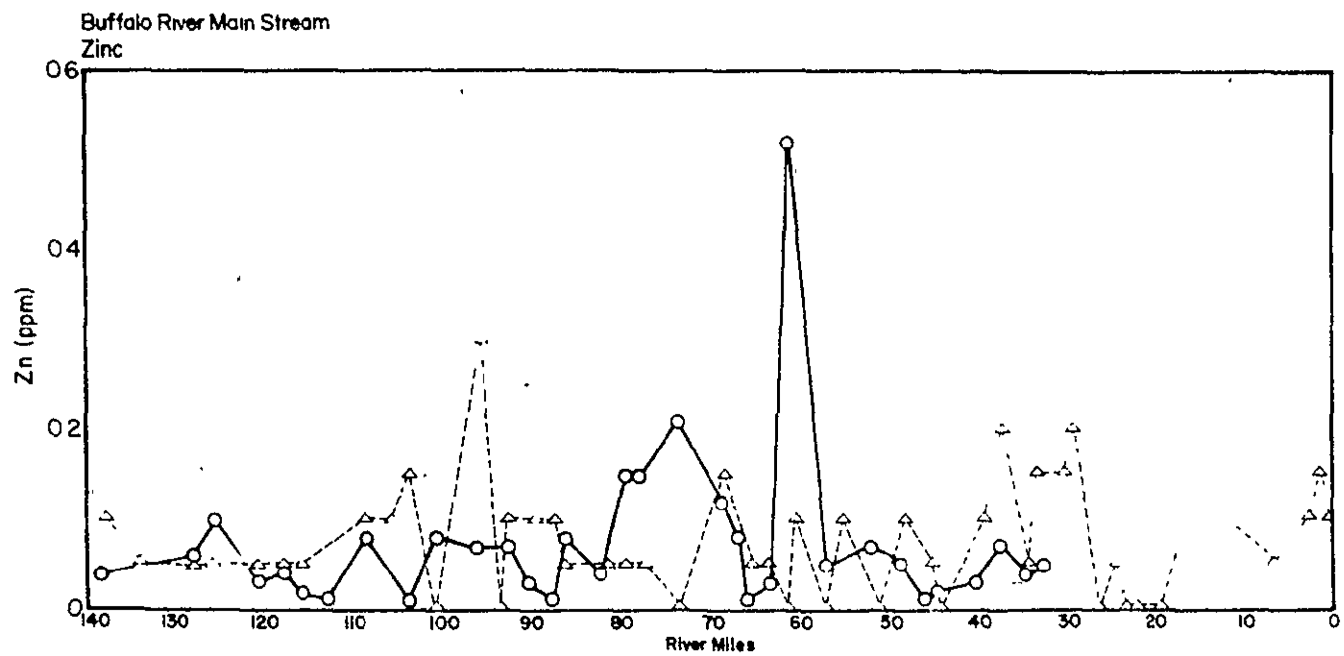


Figure 52. Zinc concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

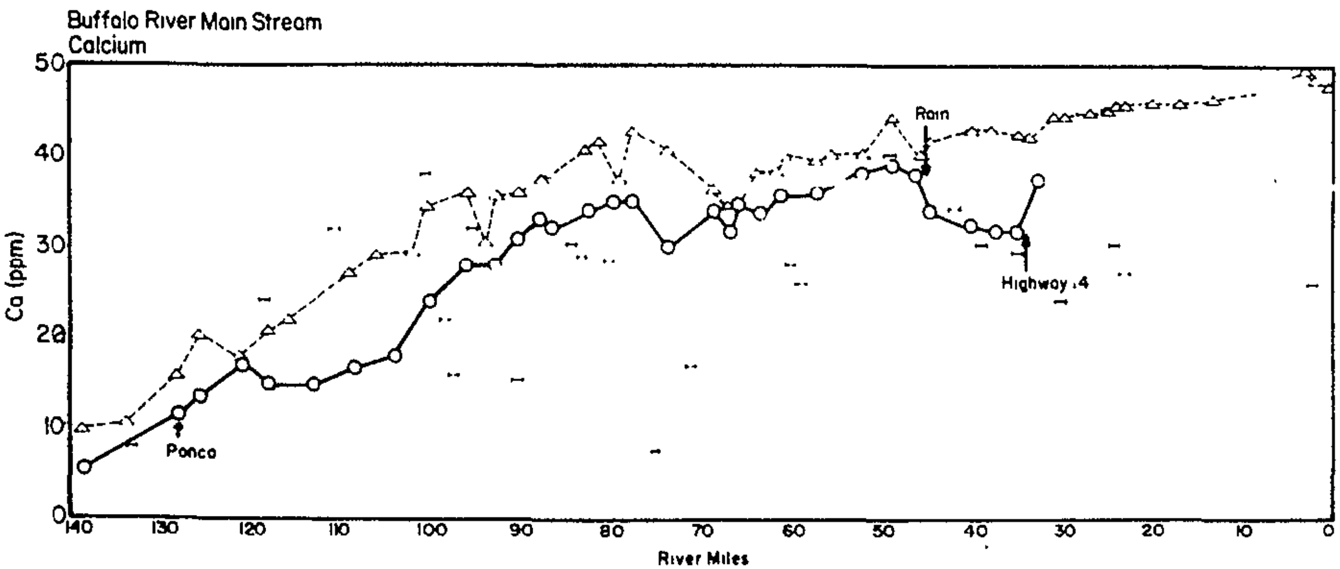


Figure 53. Calcium concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Bars represent calcium values for tributaries. Confluence of the Buffalo River with the White River is at zero river miles.

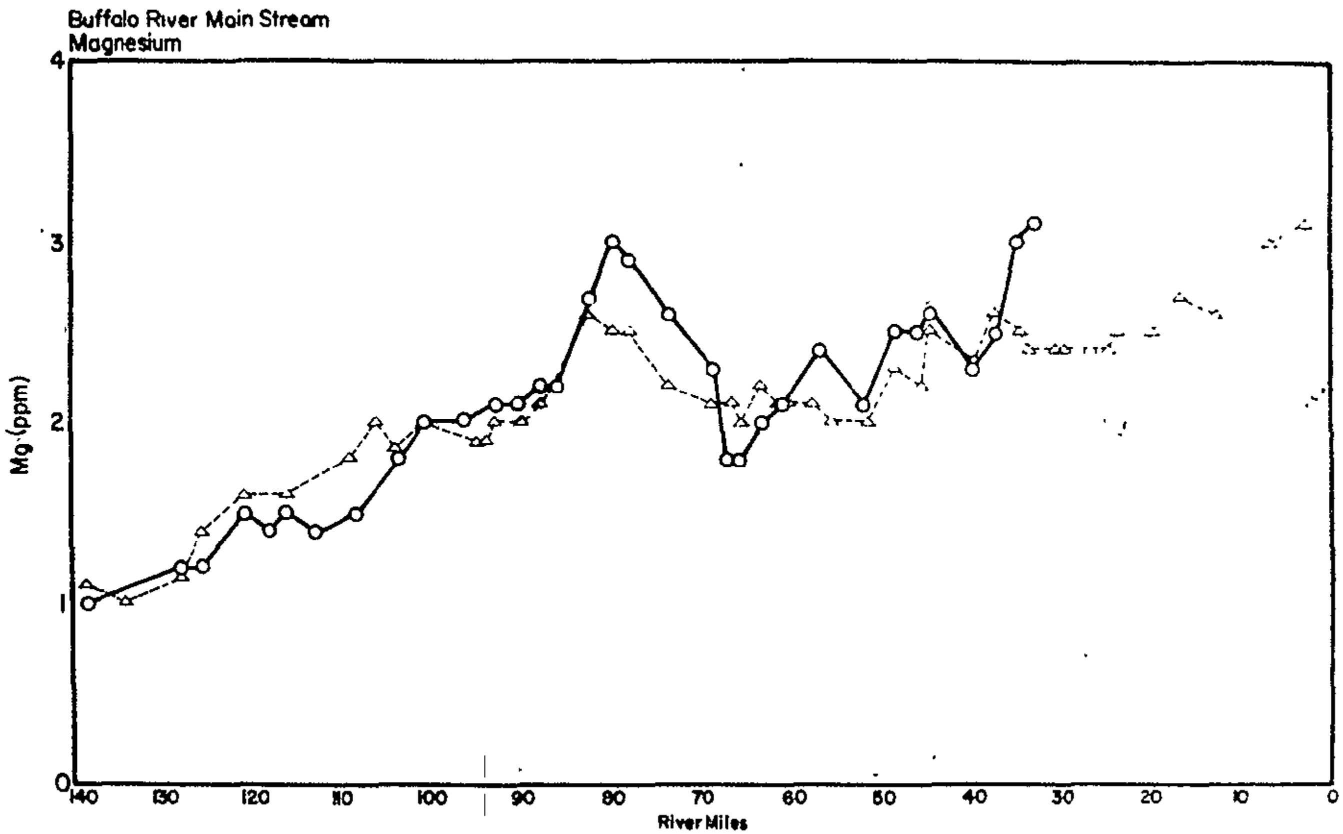


Figure 54. Magnesium concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

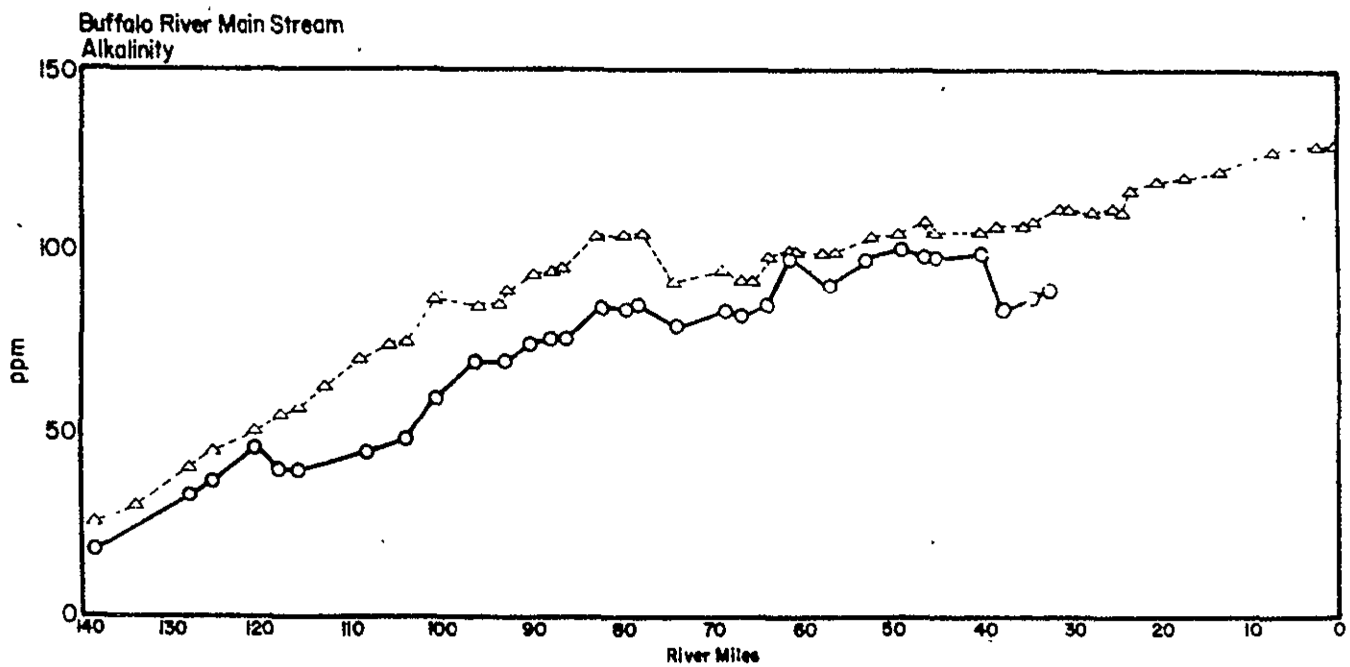


Figure 55. Alkalinity concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dasehd line). Confluence of the Buffalo River with the White River is at zero river miles.

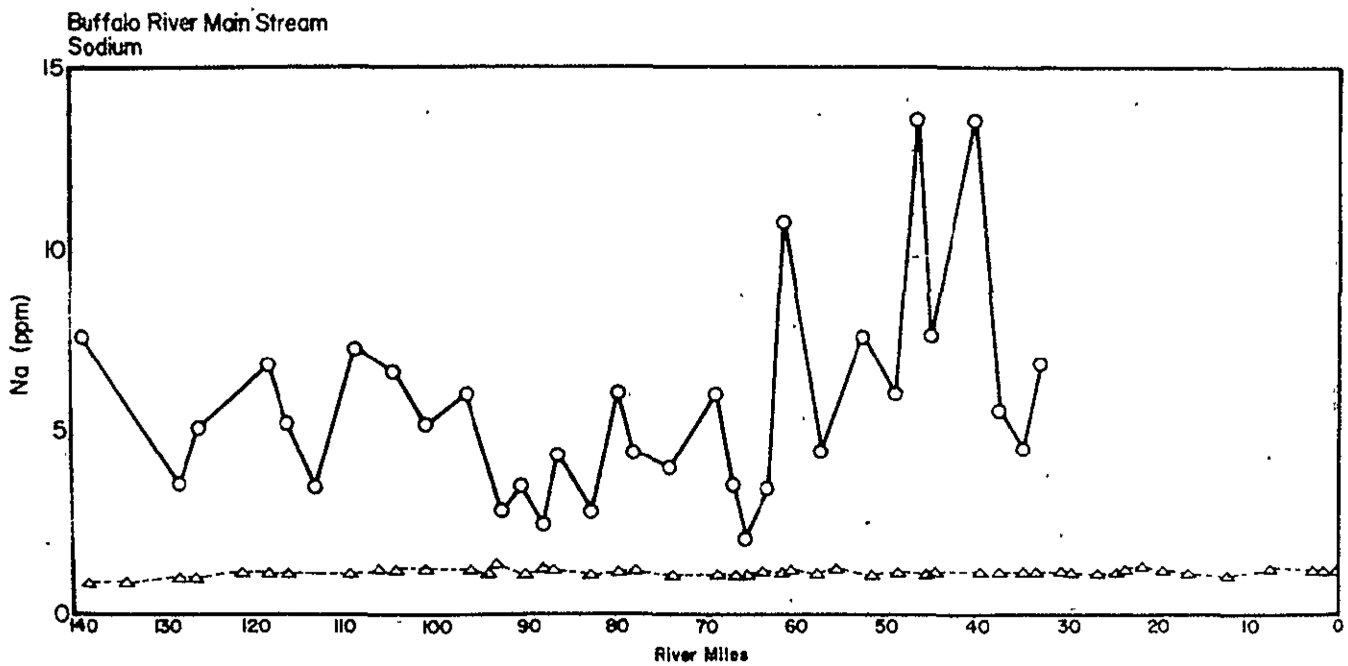


Figure 56. Sodium concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

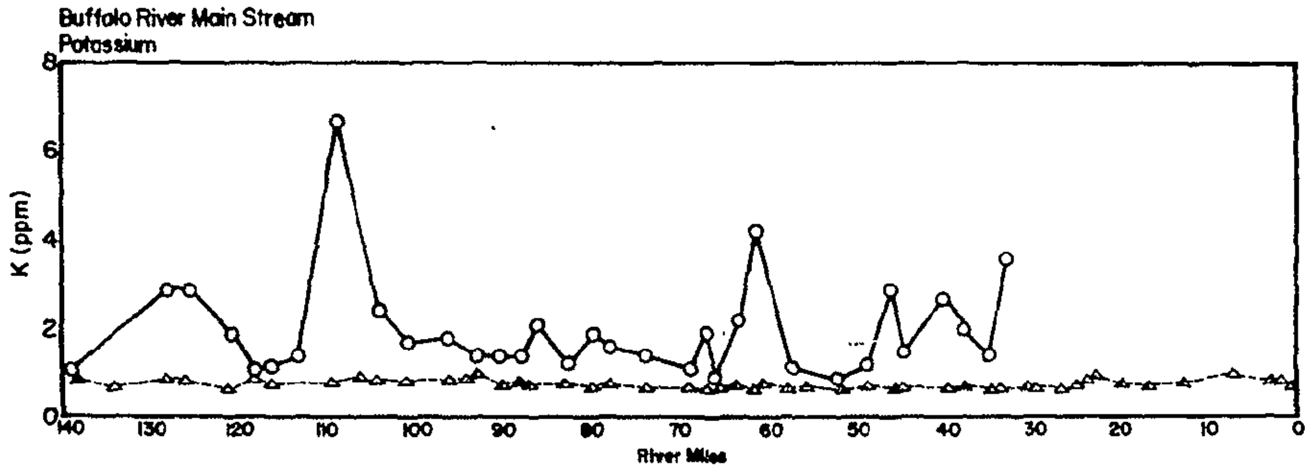


Figure 57. Potassium concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

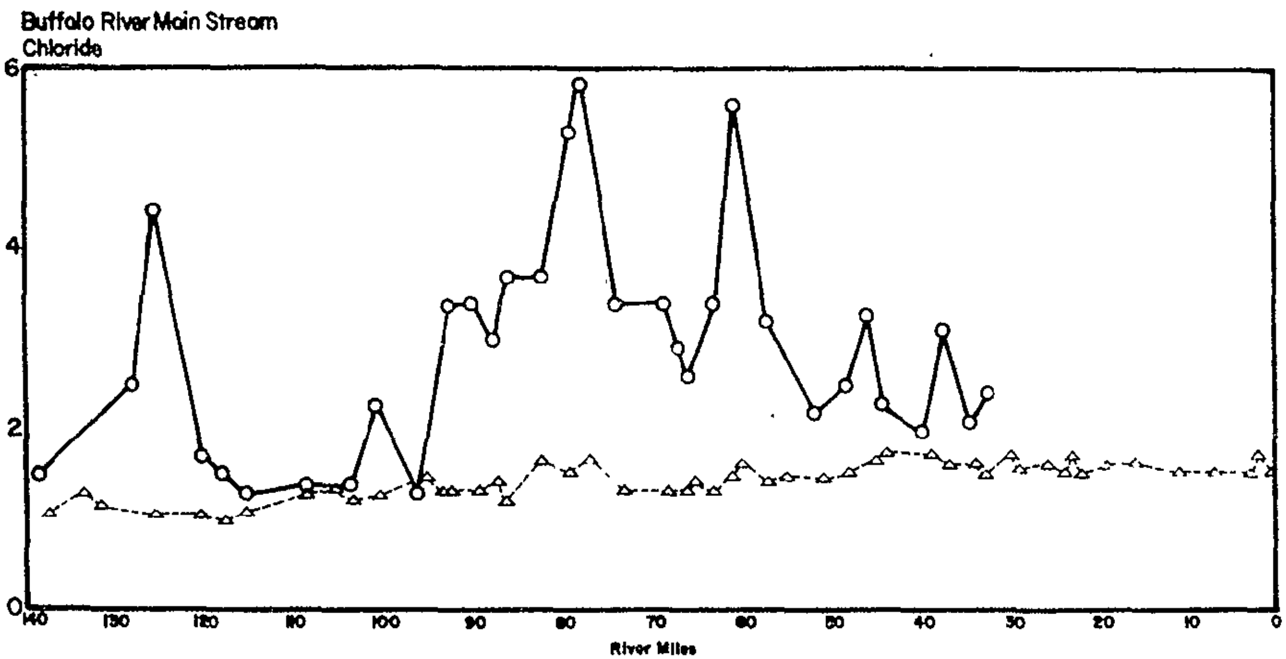


Figure 58. Chloride concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

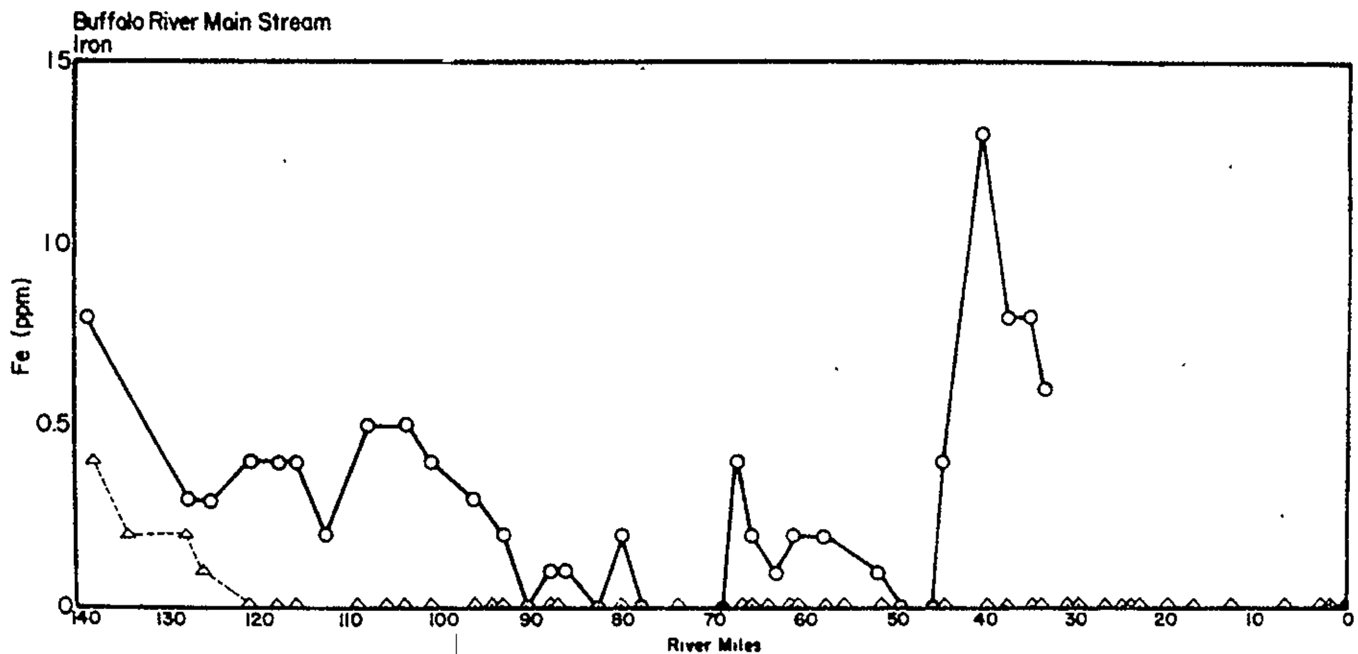


Figure 59. Iron concentration versus river miles for the Buffalo River 1973 (circles and solid line) and 1974 (triangles and dashed line). Confluence of the Buffalo River with the White River is at zero river miles.

the difference between the 1973 and 1974 values for these elements. Nix notes that the levels of such constituents as sodium may reflect the activities of man. Nix also concludes that during periods of runoff, the river may become heterogeneous with constituents such as sodium and potassium and that these constituents may originate in the watershed immediately adjacent to the stream. A summary of the ranges and means determined by Nix for each year for the entire river is given in Table 8.

The other type of water quality investigation carried out by the Arkansas Water Resources Research Center confirms the general parameter variation along the river noted by Nix (1973, 1975) but also gives seasonal variation. Parker (1975) indicates that alkalinity, hardness, and specific conductance increase downstream. These three parameters also show seasonal variation with the highest values in summer. Parker notes no other constituents that show a seasonal fluctuation. Rippey and Meyer (1975) investigated ammonia, nitrate, phosphate, and silica; however, biological activity apparently masks any major seasonal variation. Table 9 summarizes the ranges for each station and for the entire river determined by Parker (1975) and Rippey and Meyer (1975).

Steele et al. (1975) monitored eight stations and found that the major elements in the water (Tables 10, 11; Fig 60) generally reflect the geologic setting of the river as do the bottom sediments. Nix (1975) found similar relationships with close sampling of water along the river. However, it is important to note that Steele et al. used water filtered through a 0.45-micron filter for analyses. Calcium and Mg increase in concentration downstream where carbonate rocks (limestone and/or dolomite) are present. Although K and Na show very little variation along the river, they are clearly present in lower concentrations upstream. Shale, which is

Table 8. Buffalo River water data compiled from Nix (1975). Top figures are the ranges for the entire river and th bottom ones are the means. All values are given in ppm except pH and specific conductance (micromhos).

Date	pH	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Specific Conductance	Dissolved Oxygen	Phosphate (PO_4)	Zinc (Zn)	# of Samples and Collection Period
1974	7.0-7.8 7.6	0.05-0.40 0.06	10-50 36	1.0-3.1 2.1	0.9-1.4 1.3	0.6-1.9 0.9	26-118 93	3.1-15.6 7.4	1.0-1.8 1.5	-	0.0-0.5 0.1	68-317 229	8.0-11.0 9.5	0.00-0.09 0.04	0.00-0.03 0.01	34 SAMPLES 5/73
1973	7.0-7.8 7.6	0.0 -0.8 0.3	5.4-39.2 28.1	1.0-3.1 2.1	2.0-17.2 6.0	0.9-6.7 2.0	18-101 74	2.0-12.1 7.3	1.3-5.8 2.8	0.1-0.41 0.24	0.1-2.8 0.9	45-315 184	8.5-120 10.2	0.04-0.30 0.06	0.01-0.21 0.07	64 SAMPLES 5/74

Table 9. Buffalo River water quality data compiled from Parker (1973,1974). Ranges are given for each station and the entire river. All of the stations are on the river except station 3 which is on the Little Buffalo River, a tributary. All values are given in ppm except pH, specific conductance (microhmos), turbidity (Jackson Units), and fecal coliform (numbers per 100 ml of water).

Date	Station	pH	Silica (SiO_2)	Iron (Fe)	Total Alkalinity	Chloride (Cl)	Nitrate (NO_3)[1,2]	Dissolved Oxygen	Specific Conductance	Total Solids	Suspended Solids	Turbidity	Fecal Coliform (#/100ml)	Phosphate (PO_4)[2]	Hardness as $CaCO_3$[3]	# of Sample Collection Trips and Period
1973 1974	1	7.0-7.3 7.0-7.4	- -	- 0.05-0.40	25-42 27-29	0.5-2.8 1.4-3.0	0.08-0.20 0.22	7.5-8.4 9-12.3	90-160[4] 50-70	16-64 -	4.8-10.6 1.2-5.8	0-5 4-5[4]	0-200 0-43	0.05-0.80 0.009	43 26-48	
1973 1974	1A	- 7.0-7.6	-	- 0.011-0.40	- 35-108	- 0.9-4.5	- 0.20-0.28	- 7.7-11.9	- 72-189	- -	- 1.3-3.5	- 0-12[5]	- 4-130	- 0.006-0.074	- 40-120	3 SAMPLES PER STATION FOR 1973 (5/73-6/73)
1973 1974	2	7.5-7.7 7.0-7.8	-	- 0.01-0.30	70-100 63-132	1.0-2.8 0.9-4.0	0.10-0.26 0.18-0.24	8.0-10.0 7.4-12.2	40-220[4] 09-289	80-152 -	5.0-23.2 2.1-4.4	0-5 0-10	23-150 5-56	0.0-0.50 0.004-0.005	109 70-124	
1973 1974	3	7.5-7.6 7.0-7.7	-	- 0.004-0.03	78-98 58-124	1.5-2.8 0.9-5.5	0.18-0.25 0.20-0.34	7.4-8.0 8.1-10.8	40-220 15-201	72-111 -	5.0-7.4 2.0-4.4	0 5-10	190-16000 70-1460	0.05-0.40 0.006-0.224	95 64-130	6[6] SAMPLES PER STATION FOR 1974 (5/74-3/75) EXCEPT AS NOTED
1973 1974	4	7.4-7.5 7.3-7.9	-	- 0.009-0.30	70-106 74-131	1.5-2.8 0.9-5.0	0.06-0.09 0.24-0.27	7.5-8.5 7.7-12.8	40-200 21-205	75-176 -	5.0-39.6 1.7-6.9	0 0-30	4-2500 5-490	0.20 0.004-0.080	105 80-134	
1973 1974	5	7.6-7.9 7.2-7.9	-	- 0.03-0.20	95-123 83-121	1.0-2.8 0.9-4.0	0.06-0.12 0.16-0.34	8.5- 9.0 8.6-13.1	20-220 51-195	63-168 -	2.2-20.6 1.6-7.6[5]	0 0-7	0-50 2-160	0.05-0.20 0.005-0.033	111 88-124	
1973 1974	6	7.5-7.8 7.2-7.8	-	- 0.05-0.20	100-123 90-130	1.5-4.2 1.4-5.0	0.10-0.45 0.20-0.36	8.9-9.0 8.6-13.2	20-760 46-197	67-144 -	2.3-9.0 0.5-8.2	0 0-12	10-50[4] 1-130	0.05-0.20 0.004-0.013	117 94-150	
1973 1974	7	7.4-7.6 7.2-7.8	-	- 0.05-0.20	102-127 91-128	1.5-2.8 1.4-4.5	0.20-0.80 0.18-0.36	7.4-8.5 7.8-13.0	40-240 45-197	75-141[4] -	2.7-11.0 0.3-9.5	0 0-14	0-50 1-280	0.10-0.50 0.006-0.010	136 96-122	
1973 1974	8	7.5-7.6 7.0-7.8	-	- 0.00-0.20	112-140 97-132	1.5-2.8 1.4-5.0	0.60-1.20 0.16-0.32	7.2-8.0 7.5-12.6	40-250 66-283	67-152[4] -	1.4-8.0 0.4-142	0 0-18	0-130 0-590	0.10-0.20 0.010-0.036	148 102-240	
1973 1974	RIVER	7.0-7.9 7.0-7.9	- 1 - 7[7]	- 0.004-0.40	25-140 27-132	0.5-4.2 0.9-5.5	0.08-1.20 0.08-0.75	7.2-10.0 7.4-13.2	40-760 50-233	16-176 -	1.4-39.6 0.3-14.2	0-5 0-30	0-16000 0-590	0.0-0.80 0.0-0.354[8]	43-148 26-150	

1 Two samples per station in 1973.
2 One sample for station 1, three samples for stations 5, 6, 7, and 8, and three samples for all other stations.
3 One sample per station in 1973.
4 Two samples per station.
5 Four samples per station.
6 Maximum of three samples for station 1 and maximum of five samples for stations 5, 6, 7, and 8 in 1974.
7 Range for entire river - ten samples for period 6/74-4/75 (Rippey and Meyer, 1975).
8 Range for river includes data from Rippey and Meyer (1975).

Table 10. Buffalo River water data compiled from Steele et al. (1975). Range (top figures) and mean (bottom figure) given for six samples from each station (stations same as in Table 9). All values are in ppm except Fe and Zn which are in ppb.

Station	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Iron (Fe)	Zinc (Zn)
1	0.9–1.1 1.0	0.5–0.8 0.7	5–12 7	0.8–1.1 1.0	11–41 21	4–12 7
2	1.1–2.2 1.3	0.7–1.2 0.8	20–39 27	1.5–4.2 2.3	7–40 19	4–102 21
3	0.9–3.5 1.7	0.7–1.2 0.9	16–42 27	1.3–2.9 1.8	4–12 12	0.3–163 58
4	1.0–2.1 1.4	0.7–2.2 0.8	19–44 31	1.3–3.9 2.2	3–36 11	1.0–101 23
5	1.2–1.8 1.4	0.6–1.0 0.9	24–49 3[illegible]	1.4–3.5 2.5	1–30 9	1.0–147 62
6	1.3–1.9 1.4	0.6–1.1 0.8	24–49 36	1.8–3.3 2.9	3–54 18	1.0–41 18
7	1.3–2.0 1.5	0.6–1.1 0.8	26–50 36	1.9–4.0 2.9	1–27 10	1.0–43 15
8	1.3–2.0 1.5	0.7–1.1 0.9	30–48 37	2.9–8.9 4.2	1–16 8	1.6–348 64

Table 11. Buffalo River water data compiled from Steele et al. (1975). Range (top figures) and mean (bottom figure) given for each collection trip (8 samples) by date for entire river. Ranges for entire river for period last row. All values are in ppm except Fe and Zn which are in ppb.

Date	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Iron (Fe)	Zinc (Zn)
3/74	0.9-1.6 1.2	0.7-0.9 0.8	5-30 21	0.9-3.0 1.6	16-41 31	4-15 7
5/74	1.0-1.4 1.2	0.8-0.9 0.9	8-42 30	1.1-3.4 2.4	8-21 11	2-163 29
7/74	1.0-1.4 1.2	0.8-0.9 0.9	12-50 41	1.0-5.6 2.8	3-13 6	15-106 51
8/74	1.8-3.5 2.2	1.0-1.2 1.1	36-42 39	3.0-4.7 3.9	3-16 7	1-87 16
12/74	0.9-1.4 1.3	0.5-0.7 0.6	7-34 26	1.0-8.9 2.2	3-19 8	10.4-348 97
3/75	1.1-1.6 1.4	0.6-0.7 0.7	5-33 26	0.9-4.6 2.3	1-54 17	0.3-4.6 20
PERIOD	0.9-3.5	0.5-1.2	5-50	0.9-8.9	1.0-54.3	0.3-348

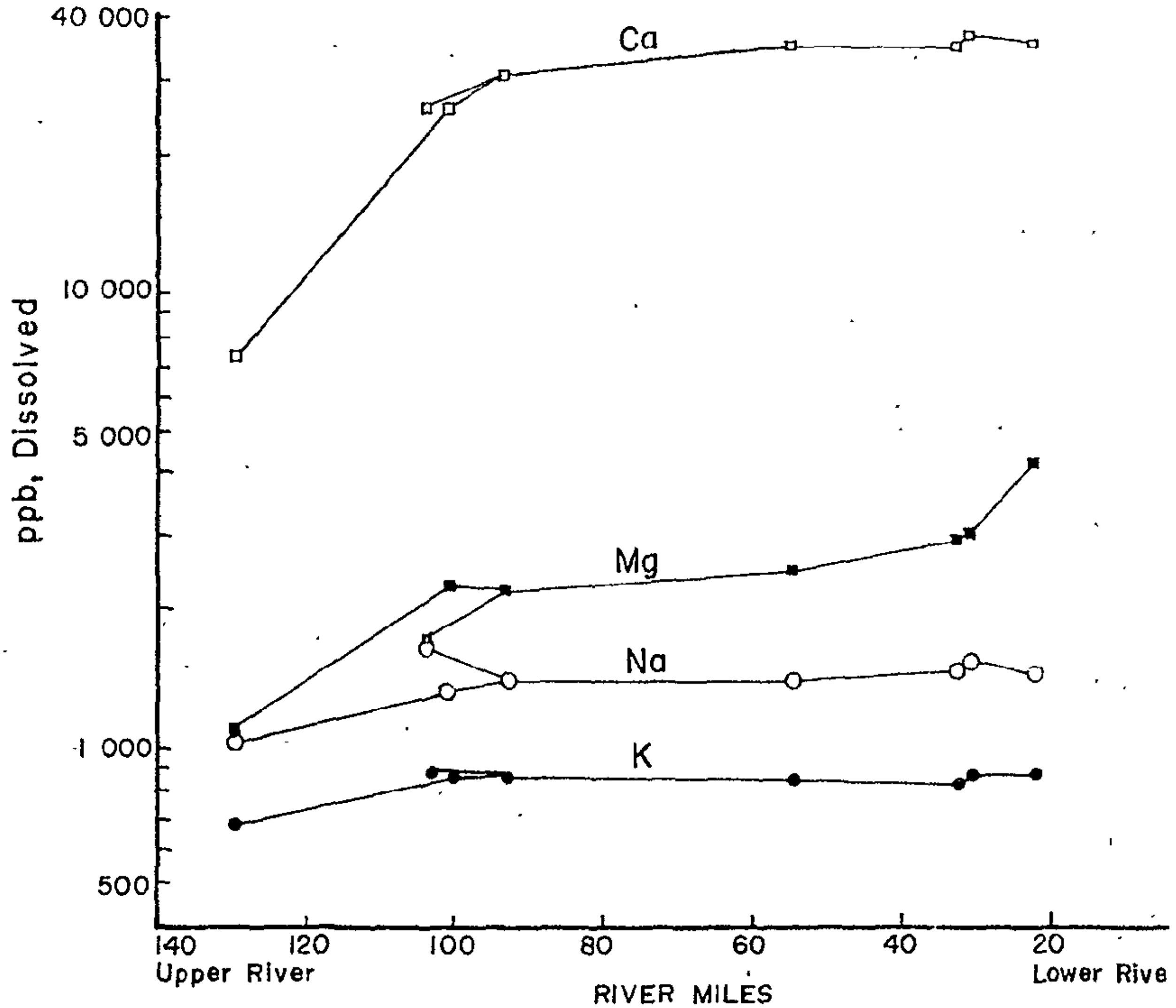


Figure 60. Dissolved river load (major elements) versus river miles. Average values for each station plotted.

relatively rich in these two elements compared with other rocks in the area, is present upstream. However, clay tends to scavenge Na and K from the water, sorbing them on its surface and between layers. Because of the presence of shale and clay particles in the bottom sediments upstream and possibly because of the presence of feldspar (a source of Na and K) downstream in sandstone, the trend for Na and K is a slight increase in concentration downstream.

Some of the minor elements follow trends similar to those of the major elements (Figs. 61, 62). Strontium substitutes for Ca in minerals, and is present in limestone. Strontium follows a trend similar to that of Ca, i.e., it increases in concentration downstream. A trend of decreasing Fe downstream is observed, probably because a major source of iron is the shale in the upper part of the drainage basin and the dissolved iron is diluted and precipitated downstream. Li concentration decreases downstream. Because of the larger size of the hydrated Li ion, it is not strongly adsorbed by clay and would not be expected to follow trends similar to those for Na and K. But because the shale is probably a major source of Li, the Li concentration is diminished downstream by dilution. Mn concentrations are relatively constant (4-9 ppb). The low value for dissolved Mn is at station 1 in an area where a large amount of Mn is present in the bottom sediments. The effectiveness of sorption processes there may be greater because of the large Fe and Mn concentrations, and thus a relatively greater amount of Mn may be removed from solution there than at other stations. Pb values are extremely constant, whereas Zn concentration is quite variable.

The major ions (Ca, Mg, Na, and K) fluctuate seasonally, the greatest concentration being during late summer (Fig. 63). This pattern correlates

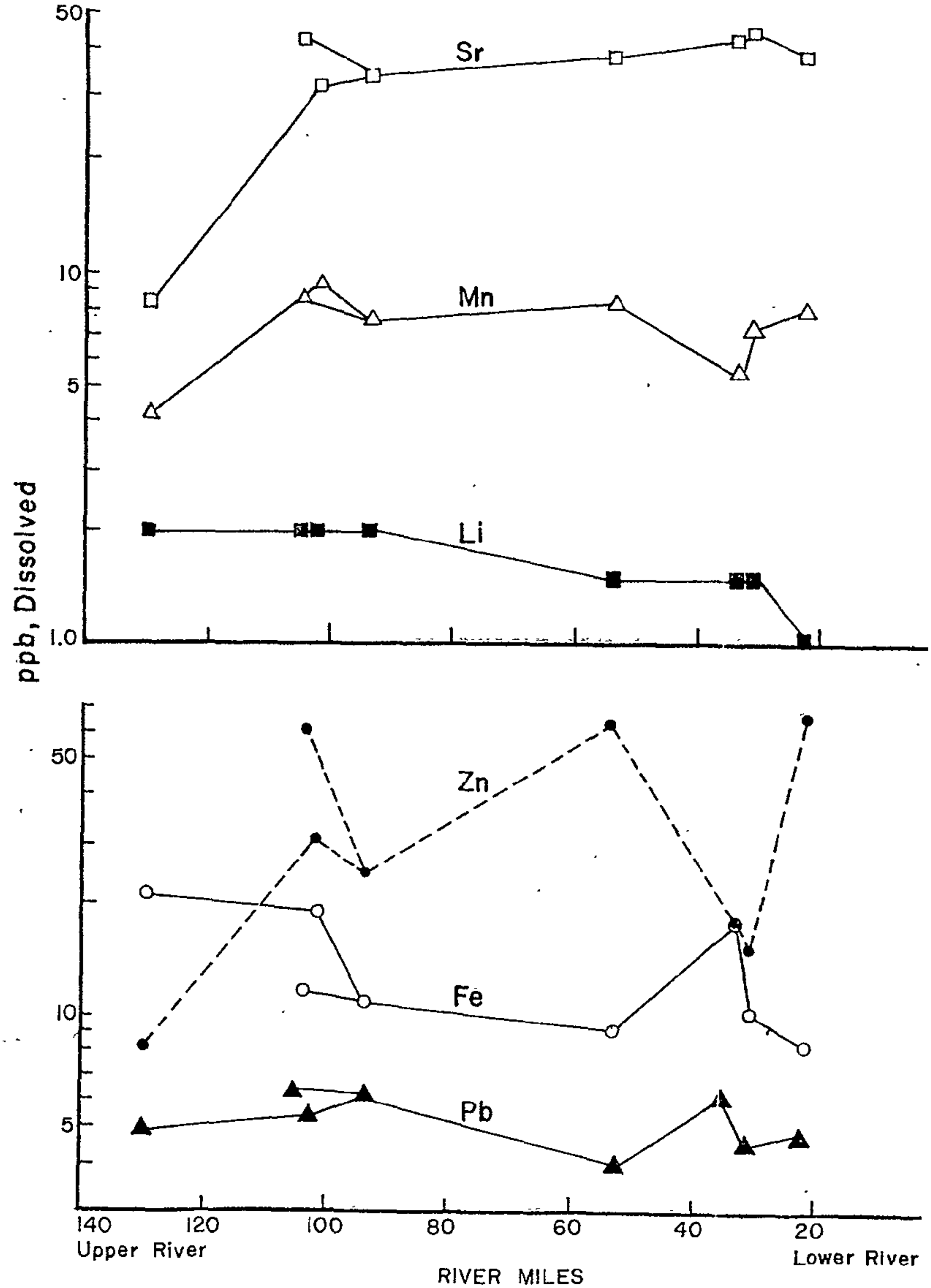


Figure 61. Dissolved river load (minor elements) versus river miles. Average values for each station plotted.

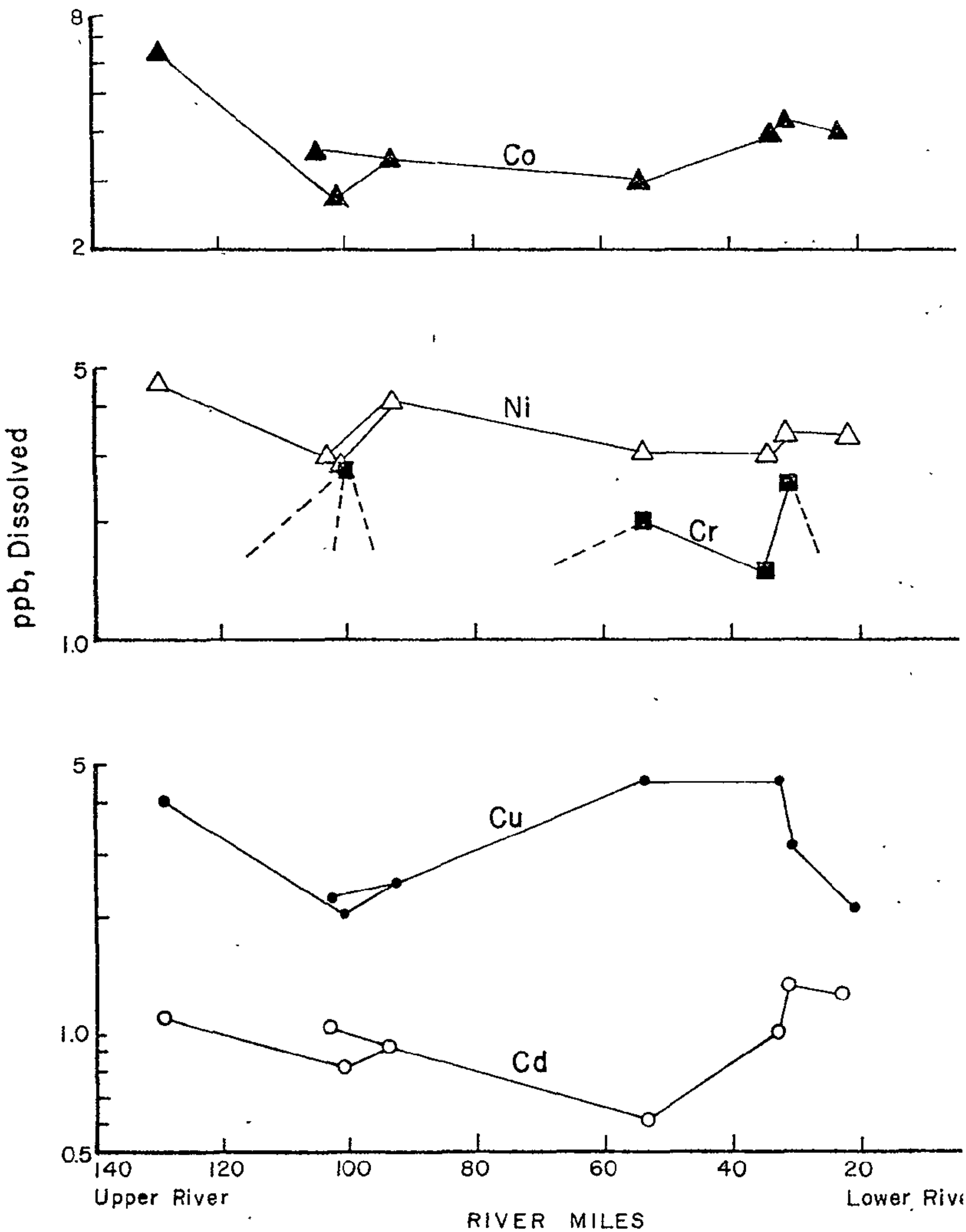


Figure 62. Dissolved river load (minor elements) versus river miles.

Average values for each station plotted.

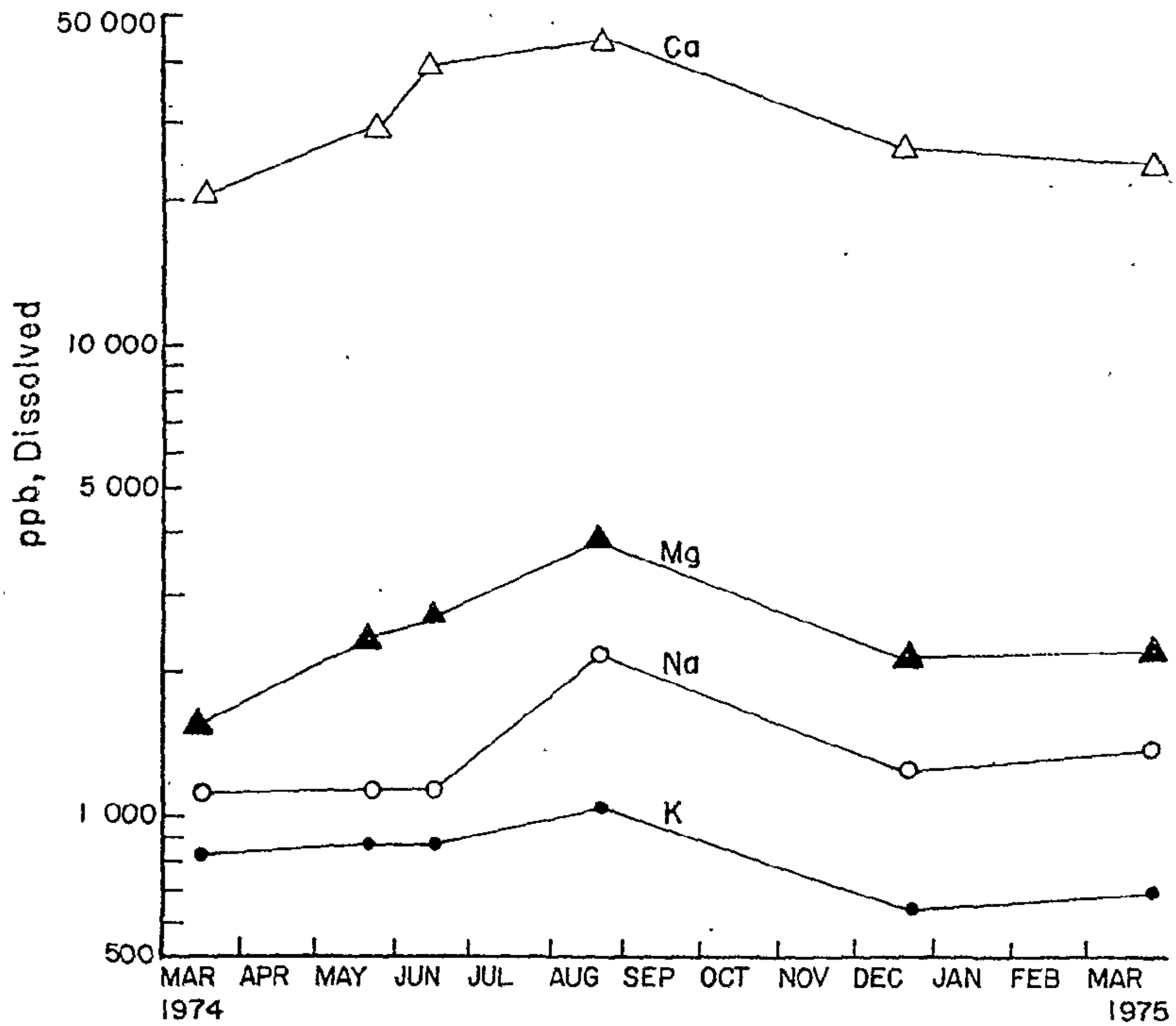


Figure 63. Dissolved river load (major elements) versus month of collection. Points are average values for eight stations.

with the flow pattern, the greatest concentration being during low flow for the river (Fig. 64). The correlation can be explained as the result of the concentration of the elements by evapotranspiration during periods of least rainfall (or lack of dilution by rain and runoff).

Of the trace metals, Pb shows a seasonal pattern (Fig. 65). The pattern closely matches that for temperature and bears an inverse relation to dissolved oxygen variation with time. As the dissolved oxygen content increases the Pb content decreases. Mn solubility apparently is not affected by the aforementioned factors--the Mn concentration of the river is very stable throughout the year. The other element variations with time are irregular and there is no correlation with flow, temperature, or dissolved oxygen.

Finally, it is possible to assess the changes in water quality for the Buffalo River on the basis of the nature of the station (i.e., whether it is anomalous) and seasonal fluctuations. The Rush station is apparently a "normal" site along the river because the parameter trends there follow those for the river as established by Nix (1973, 1975). From comparison of several years' data for the Rush station (Table 12) and consideration of seasonal fluctuations, it can be concluded that there has been no change in the concentration levels of these parameters since 1949. There is not only overlap of the ranges, but also nearly duplication of values for the ranges and means.

5.2.4 LANDSAT Analysis

Comparison between the land use map (completed 1972-73) and 1975-76 LANDSAT-2 imagery failed to reveal any significant changes.

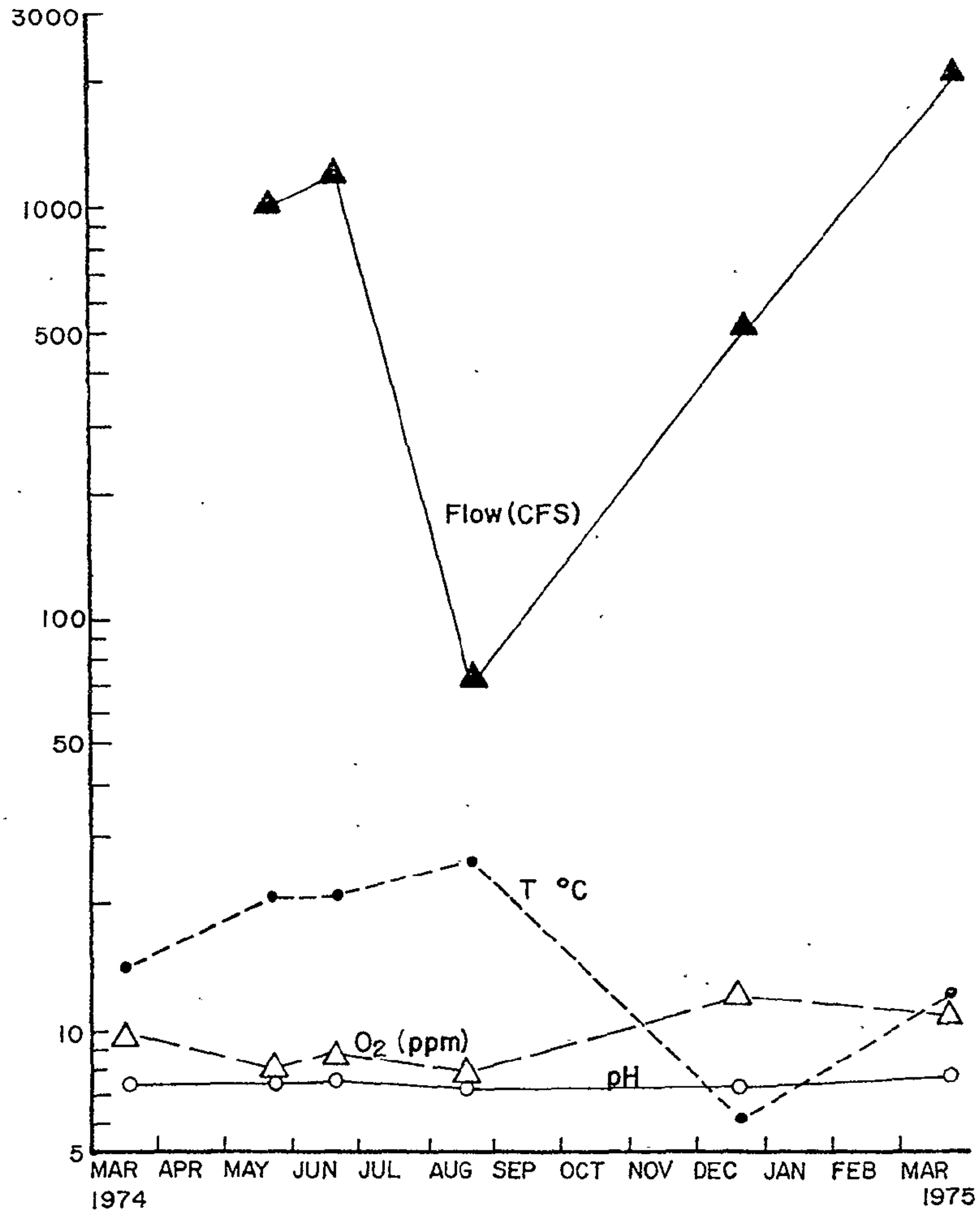


Figure 64. River water properties. Each point is an average value for the eight stations except flow, which is for a station near midpoint along the river (station 5)

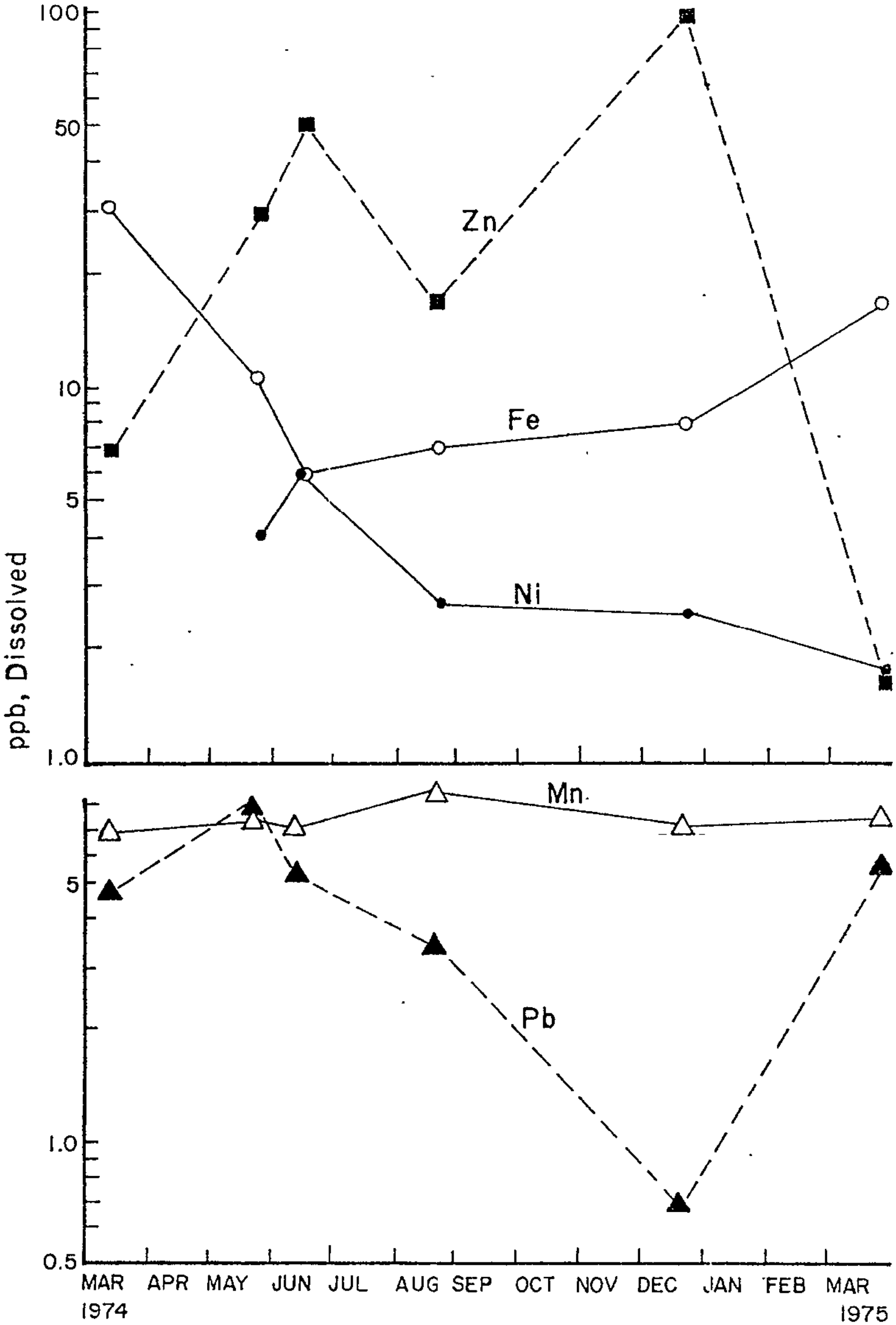


Figure 65. Dissolved river load (minor elements) versus month of collection. Points are average values for eight stations

Table 12. Comparison of water quality parameters at or near Rush, Arkansas from 1950 to 1974. All values are in ppm.

Source and Year	pH	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness $CaCO_3$	Hardness Non-$CaCO_3$	# of Samples and Period
USGS 1950	7.7-8.0 7.8	- 5.9	- 0.02	- 37	2.9-3.3 3.1	2.2-2.6 2.4	- 1.4	101-126 117	3.7-8.0 4.6	1.5-2.5 2.1	- 0.1	0.3-2.8 1.5	114-122 118	94-106 101	2-11 5	3 10/49-9/50
USGS 1951	- 8.3	- -	- -	- -	- -	- -	- -	95-129 112	5.0-7.0 6.0	2.0-3.2 2.6	- -	1.1-1.6 0.8	- -	83-117 100	5-11 8	2 1/51-10/51
USGS 1952	8.2-8.6	- -	- -	- -	- -	- -	- -	121-124 122	4.0-7.0 5.5	- 2.2	- -	0.4-1.0 0.7	- -	110-126 116	8-18 13	2 2/52-9/52
USGS 1953	8.2-8.3	- -	- -	- -	- -	- -	- -	96-113 105	3.0-4.0 3.5	2.5-4.5 3.5	- -	0.8-2.5 1.6	- -	84-102 93	4-5 4.5	2 2/53-9/53
USGS 1954	- 8.2	- -	- -	- -	- -	- -	- -	88-105 97	3.0-4.0 3.5	2.5-3.2 2.9	- -	0.7-2.6 1.6	- -	73-88 81	1-2 1.5	2 1/54-9/54
USGS 1960	7.8-8.1 7.6	- -	- -	33-46 37	1.9-5.3 3.5	1.0-2.0 1.6	0.5-0.9 0.7	107-158 126	4.2-9.6 5.8	1.2-2.8 2.2	- -	0.0-0.7 0.2	103-137 115	92-137 108	3-8 5	9 11/59-9/60
STEELE 1974	-	-	0.001-0.0016 0.008	30-48 37	2.9-8.9 4.2	1.2-2.0 1.5	0.7-1.1 0.9	-	-	-	-	-	-	-	-	6 3/74-3/75
NIX 1974	7.7	-	0.05	43	2.4	1.3	0.9	112	4.2	1.6	-	0.0	-	-	-	5/74[1]
NIX 1973	7.6	-	0.6	38	3.1	6.8	3.6	91	8.1	2.4	0.19	1.3	-	-	-	5/73[1]
PARKER 1973	7.5-7.6	-	-	-	-	-	-	112-140	-	1.5-2.8	-	0.60-1.20	-	148	-	5/73[3]-6/73
PARKER 1974	7.0-7.8	-	0.00-0.20	-	-	-	-	97-132	-	1.4-5.0	-	0.16-1.40	-	102-140	-	5/74[6]-3/75

USGS data from U.S. Geological Survey records for appropriate years.
Steele, 1974 - Data for station 8, Table 9, this report.
Nix, 1974 - Data for station 64, Table 22, Nix (1975).
Nix, 1973 - Data for station 59 (about 10 miles upstream from Rush), Table 6, Nix (1973).
Parker, 1973 - Data for station 8, 1973, Table 8, this report.
Parker, 1974 - Data for station 8, 1974, Table 8, this report.

5.2.5 Conclusions

Recent data (1973-1974) for water quality along the entire Buffalo River indicate no anomalous values that can be related to land use changes along the river. The differences along the river are related to changes in the type of rock in the drainage basin--there is more shale upstream. Data from recent (1973-1974) studies also have allowed annual ranges for parameters to be established which are necessary for the detection of any water quality changes. Although several parameters have wide ranges, they are related to seasonal (flow) fluctuations. Finally, comparison of all historical data in light of the foregoing two points indicates that there has been no change in water quality for the Buffalo River since 1949.

5.3 CADDO RIVER - DEGRAY RESERVOIR

5.3.1 Introduction

The Caddo River, which has its source in the mountains of Montgomery County, Arkansas, flows southeastward 78 miles to its junction with the Ouachita River in the vicinity of Arkadelphia, Arkansas, where an impoundment forms the DeGray Reservoir. A water quality monitoring program along the Caddo was initiated in 1966 prior to impoundment, and has continued through the time frame of the LANDSAT project. Because land use mapping of the entire watershed was completed in 1972-1973 by means of large scale photography, this test site was particularly well suited for change detection analysis.

5.3.2 Location

The DeGray Reservoir is on the south flank of the Ouachita Mountain Region of central Arkansas on the Caddo River. The rocks of the area consist chiefly of shale and sandstone of Paleozoic age with lesser exposures of novaculite and chert. Very shallow soils cover the hillsides and slightly deeper soils are present on mountain ridges and in the valleys. Recent alluvial deposits are present along the Caddo River. Most of the Caddo River watershed (approximately 449 mi^2) is mountainous with elevation ranging from 2201 feet above mean sea level near the headwaters to 194 feet at the mouth. Forestry is by far the dominant land use, and agricultural and urban uses are subordinate.

The DeGray Dam was constructed on the Caddo River, Arkansas, approximately 7 miles north of Arkadelphia, Arkansas. Impoundment of the river began upon closure of the diversion tunnel on August 8, 1969. In December 1971 the reservoir reached normal pool elevation of 408 feet, at which the pool area is 18.3 mi^2. The reservoir extends west to northwest approximately 20 miles (Fig. 66). The maximum depth of water when the reservoir is at normal pool elevation is about 187 feet. The lower half of the impoundment is characterized by relatively large open water whereas the upper half of the reservoir is narrower. The DeGray project is unique in that it is the first major upper level release dam in Arkansas.

A pre-impoundment water quality study of the Caddo River (Nix, 1967) involved the collection and analysis of samples from the Caddo River and representative tributaries during the period from August 1966 through July 1967. After impoundment of the Caddo River, the Office of Water Research and Technology, U.S. Department of the Interior, in cooperation with the Arkansas Water Resources Research Center, sponsored a project to study the water chemistry of DeGray Reservoir (Nix, 1974). This project extended from July 1970 through June 1972. A second project was established which essentially provided for the continuation of studies initiated in the earlier project. The period of this project was from

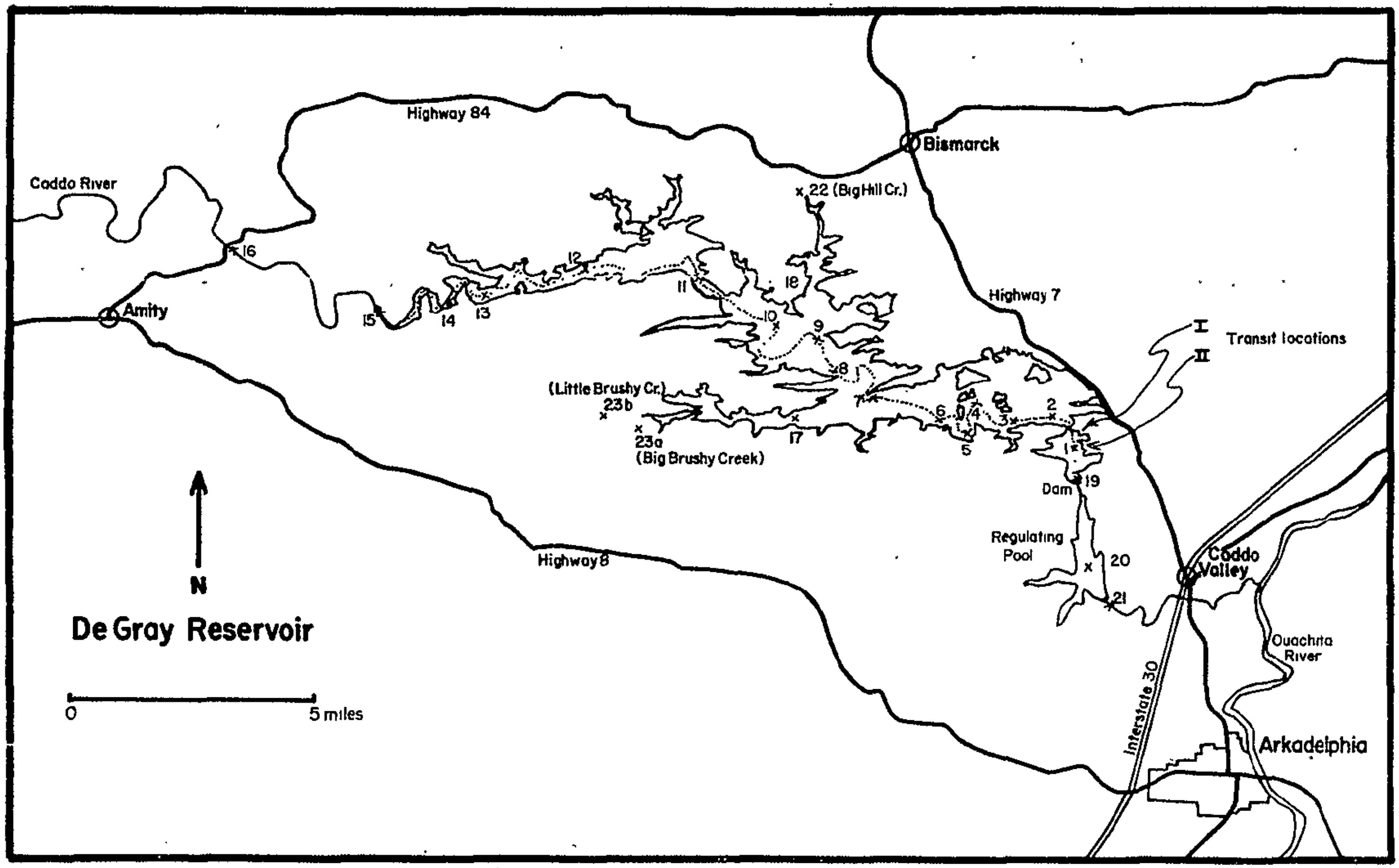


Figure 66. Location map of DeGray Reservoir.

July 1972 through July 1975 (not published).

In March 1974, the National Reservoir Investigation Program of the U.S. Fish and Wildlife Service established a branch station on the campus of Ouachita University for the purpose of investigating the fishery of DeGray Lake. This group also will be involved in studies to determine distribution and seasonal variations of plankton populations.

The DeGray Lake and the Caddo River have been used as a prototype for a reservoir/watershed ecosystem modeling study by the Waterways Experiment Station, Vicksburg, Mississippi, since 1973 (Nix et al., 1974, 1975).

5.3.3 Geology and Land Use

The Caddo River drains part of the southeastern flank of the Ouachita Mountains in west-central Arkansas. The drainage area is characterized by forested hills and narrow valleys. Slopes are commonly very steep and rocky. The headwaters of the Caddo River drain a terrain of mainly shale and sandstone. Near the dam site, the river enters alluvium which persists to the confluence of the Caddo River with the Ouachita River. Runoff from the alluvial section enters the Caddo River downstream from DeGray Dam. The dominant land use throughout the watershed of the Caddo River is forestry, agriculture being only a minor component. Table 13 gives the specific land usage of the Caddo River watershed.

5.3.4 Station Selection

Sampling stations were selected to provide a representative description of the reservoir during filling and after stabilization of the system (Fig. 66). Reservoir stations were located directly over the former river channel. Studies on DeGray Reservoir have indicated that three transitional areas or sectors can be used to describe the impoundment. Sampling

Table 13. Caddo River watershed land use.

Land Use	Sq. Miles	Acres
Agriculture	73.60	47,104.0
Urban	3.02	1,932.8
Lake	18.33	11,731.2
Forest Mixed	174.66	111,782.4
Forest Coniferous	145.87	93,356.8
Forest Deciduous	33.84	21,657.6
Total	449.32	287,564.8

of multiple stations within each sector of the reservoir during the FY 1974 study (Nix et al., 1974) indicated that although some intrasector water quality variations did occur, the changes were minor and sector characteristics were clearly definable. One station therefore was chosen to represent each of the three major sectors: station 12, station 10, and station 1 (Fig. 66).

5.3.5 Discussion of Water Quality

Water quality data on DeGray Reservoir and the Caddo River have been collected from September 1969 to the present. The results of chemical analysis of samples taken from DeGray Reservoir have helped to establish seasonal trends as well as distributions of the constituents in the reservoir.

Lateral distribution of most water quality parameters is uniform at each of the sampling stations. Gradients of some parameters were observed from the lower end of the lake to its headwaters. Reduced species (iron and manganese) are present in the oxygen-depleted hypolimnion. The chemical constituents which appear to be the most dynamic are calcium, alkalinity, silica and, in the hypolimnion, iron and manganese. Calcium and alkalinity vary in an apparent response to the flow of the river.

Total bacteria populations were observed to fluctuate considerably during the period of study. Larger populations generally were observed in the upstream section of the reservoir and are believed to be related to bacteria associated with suspended sediment during periods of high runoff. Moderately large total bacteria populations were observed in the downstream section of the lake after periods of rain.

Station 12 represents the upstream sector of the reservoir which is characterized by a relatively narrow channel and is influenced directly by the chemical content of the Caddo River. During periods of high runoff, turbid water was observed throughout this sector. Complete flushing of this sector has been observed during the period when the reservoir is mixed. Turbid runoff water observed through the entire water column indicates "plug" flow through this sector. During the early spring and late fall, runoff may disrupt stratification. Interflow and/or overflow of runoff may occur when the lake is rigidly stratified. Nix and his coworkers suggest that water entering the lake during periods of elevated flow travels into the reservoir as an interflow near the top of the thermocline or, as winter approaches and the temperature of the runoff decreases, the interflow changes to an underflow and carries water containing dissolved oxygen into the oxygen-depleted hypolimnion.

The midlake sector is influenced directly by the Caddo River after periods of high runoff. This section of the reservoir is characterized by open water with several side pockets. The interflow of turbid runoff into station 10 usually is observed as an interflow, even when disruption of stratification has occurred at station 10. During the period of summer stratification, the turbid water usually enters this compartment as an interflow near the top of the thermocline.

The downstream sector of the reservoir is represented by station 1. This sector is principally open water, much of which is relatively deep. Effect of high runoff rarely is observed this far downstream in the reservoir. Turbid water originating from the Caddo River after major storm events has been observed in this part of the reservoir only after extended periods of heavy rain and then only as a confined interflow.

5.3.6 Changes in Water Quality

Table 14 gives annual ranges for water quality parameters measured at the surface and at 66-foot depth at station 1. Although the reservoir becomes stratified in the summer, note that the ranges for most parameters are similar at the surface and at the 66-foot depth for any given year. On the basis of this information it was concluded that despite stratification, interflow, overflow, and underflow, the surface samples can be used as a measure of long-term water quality changes.

Table 15 compares the annual ranges for water quality parameters based on surface samples for the three compartments of the reservoir. The number of months and the period of sampling vary from year to year; thus, caution must be used in interpreting differences in parameter values as change in water quality. It appears that the orthophosphate, nitrate, and calcium values have decreased with time. Nix (1974) noted the significant decrease in orthophosphate during the first two years of impoundment of DeGray Reservoir. He attributes the relatively large quantities of phosphate during the early period of impounding to the decomposition of organic matter flooded by the reservoir. Nix (1974) also noted the decrease in calcium concentration from 1970-1972. He suggests deposition of calcium in the reservoir because pre- and postimpoundment calcium

Table 14. Comparison of annual ranges of water quality parameters at 0 and 66-foot depths at station 1. All values are in ppm.

Year	Depth	pH	Total Alkalinity	Ortho-phosphate Soluble (PO_4)	Nitrate (NO_3)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Temperature °C	Potassium (K)	Biological Oxygen Demand	Ammonia (NH_4)	Silica (SiO_2)	Total Dissolved Solids	Specific Conductance (micromhos at 25°C)	Turbidity	Dissolved Oxygen	Chloride (Cl)
1970	0	6.7-8.0	-	0.09-0.25	1.0 -1.5	4.1- 7.3	1.1-1.6	1.7-2.0	-	1.1-1.3	-	-	-	-	-	-	-	0.75-5.6
	66	6.3-7.4	-	0.09-0.27	1.4- 2.0	5.6- 8.3	1.6-2.0	1.6-2.0	-	1.2-1.6	-	-	-	-	-	-	-	1.2 -6.9
1971	0	6.5-7.3	27.1-35	0.07-0.19	0.2 -1.1	8.2- 9.8	1.6-2.3	1.9-2.3	8.3-31.0	1.5	-	-	-	-	-	-	-	1.5 -6.9
	66	6.3-6.8	29.9-33	0.05-2.0	0.5 -2.0	7.7- 9.1	1.7-2.1	1.8-3.0	7.1- 8.5	1.4-2.4	-	-	-	-	-	-	-	1.8 -3.2
1972	0	6.4-7.6	33 37	0.03-1.5	0.3 -2.1	7.8- 9.6	1.8-2.0	2.1-2.4	-	1.0-1.9	-	-	-	-	-	-	-	0.3 -3.4
	66	6.4-6.7	33 38	0.02-1.6	0.3 -1.9	8.5-10.0	1.8-2.0	1.9-2.5	-	1.1-1.6	-	-	-	-	-	-	-	0.8 -4.3
1973	0	6.7-7.6	20 23	0.0 0.015	0.09-0.32	3.2- 5.6	0.8-1.4	1.6-1.7	10.0-30.5	0.8-1.6	-	0.03-0.06	0.1-5.8	-	-	-	-	-
	66	6.3-6.8	18 25	0.0 -0.04	0.1 -0.9	4.3- 5.2	1.0-1.4	1.0-1.4	6.6-10.3	1.1-1.2	-	0.04-0.05	-	-	-	-	-	-
1974	0	6.6-7.8	19 36	0.0 -0.002	0.1 -0.3	3.8- 5.4	1.1-1.5	1.0-2.2	7.0-26.3	1.0	0.0-7.5	0.14-1.0	1.4-5.8	26-55	41-63	67-83	7.2-10.6	-
	66	6.3-6.8	18 25	0.0 -0.04	0.1 -0.9	4.3- 5.2	1.0-1.4	6.6-1.4	6.6-10.3	1.1	0.0-3.9	0.7 -1.2	5.2-6.9	27-60	39-75	50-78	0.9- 7.9	-
1975	0	6.6-6.9	21 23	0.0 -0.012	0.2 -0.3	4.7- 4.8	1.2-1.3	1.5-1.6	8.0-12.8	-	1.0-2.0	0.4 -0.6	4.0-6.3	16-43	41-45	77-84	8.0-10.8	-
	66	6.6-6.8	21	0.0 -0.009	0.2 -0.4	4.1- 5.0	1.2-1.3	1.3-1.6	7.9- 8.1	-	0.0-2.0	0.4 -0.7	4.9-5.3	27-52	42-51	68-89	8.5- 9.5	-

Table 15. Comparison of annual ranges of water quality parameters for stations 1, 10, and 12. All values are in ppm.

Station	Year	pH	Total Alkalinity	Ortho-phosphate Soluble (PO_4)	Nitrate (NO_3)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Temperature (°C)	Potassium (K)	Biological Oxygen Demand	Ammonia (NH_4)	Silica (SiO_2)	Total Dissolved Solids	Specific Conductance (micromhos at 25°C)	Turbidity	Dissolved Oxygen	Chloride (Cl)
1	1970	6.7-8.0	-	0.09-0.25	1.0 -1.5	4.1- 7.3	1.1-1.6	1.7-2.0	-	1.1-1.3	-	-	-	-	-	-	-	-
	1971	6.5-7.3	27.1-35	0.07-0.19	0.2 -1.1	8.2- 9.8	1.6-2.2	1.9-2.3	8.3-31.0	1.5	-	-	-	-	-	-	-	-
	1972	6.4-7.6	33 37	0.03-1.5	0.3 -2.1	7.8- 9.6	1.8-2.0	2.1-2.4		1.0-1.9	-	-	-	-	-	-	-	-
	1973	6.7-7.6	20 24	0.0 -0.015	0.09-0.32	3.2- 5.6	0.8-1.4	1.6-1.7	10.0-30.5	0.8-1.6		0.03-0.06	0.1-5.8			62	9.4-10.8	0.75-5.6
	1974	6.6-7.8	19 36	0.0 -0.002	0.1 -0.3	3.8- 5.4	1.1-1.5	1.0-2.2	7.0-26.3	1.0	0.0-7.5	0.14-1.0	1.4-5.8	26-55	41-63	67-83	7.2-10.6	1.5 -2.7
	1975	6.6-6.9	21 23	0.0 -0.012	0.2 -0.3	4.7- 4.8	1.2-1.3	1.5-1.6	8.0-12.8	-	1.0-2.0	0.4 -0.6	4.0-6.3	16-43	41-45	77-84	8.8-10.8	0.3 -3.4
10	1970	6.8-7.5		0.10-0.26	0.7 -2.2	4.9-13.4	1.1-2.3	1.7-2.4	-	1.1-1.7	-	-	-	-	-	-	-	-
	1971	6.7-7.3	27.1-39	0.05-0.11	0.2 -1.3	8.4-11.0	1.6-2.0	2.0-2.4	4.1-30.0	0.9-2.2	-	-	-	-	-	-	-	-
	1972	6.6-7.3	22 34	0.05-1.5	0.2 -2.0	6.1- 8.8	1.6-2.0	1.6-2.5		0.9-1.6	-	-	-	-	-	-	-	-
	1973	7.1-8.5	23	0.01	0.16	4.5	0.9	1.7	4.4-30.7	0.9		0.08	2.2-9.3			65	9.7- 9.8	1.3 -5.4
	1974	6.6-7.9	18 32	0.0 -0.032	0.07-0.5	3.9- 7.0	1.2-1.4	1.0-1.8	7.4-27.0	0.7	0.0-3.4	0.2 -1.1	2.4-7.2	29-65	39-76	36-76	6.4-11.2	1.8 -3.2
	1975	6.7-6.9	19 21	0.0 -0.015	0.2	3.8- 4.4	1.1	1.4-1.5	8.8-13.3	-	1.9-2.6	0.5 -0.6	4.6-5.8	21-43	39-42	8-56	10.1-10.4	1.1 -3.6
12	1970	7:2-8.0		0.09-0.22	0.0 -2.0	0.0-17.0	1.2-2.3	2.0-2.4		0.7-2.5	-	-	-	-	-	-	-	-
	1971	6.7-7.3	25.4-41	0.04-0.4	0.0 -1.1	9.0-13.3	1.5-9.0	1.9-2.3	2.4-30.5	0.7-1.6	-	-	-	-	-	-	-	-
	1972	6.9-7.8	28 35	0.03-1.6	0.2 -2.1	7.2- 9.1	1.4-5.4	2.0-2.6		0.6-1.6	-	-	-	-	-	-	-	-
	1973	7.2-8.5	24 27	0.00-0.025	0.14-0.23	3.7- 5.0	1.1	1.4-1.7	9.0-30.5	0.8-1.1	-	0.06-0.08	2.2-9.3	-	-	67	10.0-11.8	1.25-7.5
	1974	6.7-8.5	20 30	0.0 -0.03	0.07-0.4	4.4- 7.3	1.2-1.7	1.0-1.8	7.0-27.2	0.6	0.0-2.8	0.1 -1.6	3.8-7.9	38-63	42-81	12-68	7.5-11.5	1.5 -2.9
	1975	6.8-7.0	18 25	0.0 -0.012	0.1 -0.4	3.9- 5.5	1.0-1.3	1.2-1.6	7.1-13.3	-	1.3-2.4	0.4 -0.6	5.3-7.0	27-37	39-53	15-51	10.0-10.6	1.8 -3.8

concentration of the Caddo River is about 10 ppm. Apparently this process continued for a short time and now has stabilized. The 1970 values for nitrate are relatively high in comparison with those of subsequent years and this trend also may be attributable to decomposing organic matter during filling of the reservoir. Despite the different collection times, the other parameters appear to have remained essentially constant.

5.3.7 LANDSAT Analysis

Comparison between the land use map (completed in 1972-73) and 1975-76 LANDSAT-2 imagery failed to reveal any significant changes.

5.3.8 Conclusions

Aside from changes in a few water quality parameters attributable to stabilization of the reservoir, there is no indication that there have been changes in water quality of DeGray Reservoir. Changes in land usage from 1972 to 1975 are not evident on LANDSAT imagery. It should be noted that Nix et al. (1975) reported vast increase in concentration of several parameters during high flow storm events on the Caddo River. Detailed discussion of the Caddo River storm event data is presented in section 4.6.

5.4 RURAL TEST SITE

5.4.1 Introduction

The primary objectives of this part of the study were to determine the effects of rural land use practices on water quality conditions in northwestern Arkansas and to attempt to depict optimum monitoring conditions for the collection of pertinent surface water quality data.

Rural watersheds similar in size, topography, and geology were selected for a comparative water quality study on the basis of their contrasting land use practices. A control watershed representing a near-pristine area and two test watersheds which are influenced by rural development were monitored during both high flow (storm events) and low flow periods. The test watershed was divided into two segments for comparison with the control. The upper segment, the primary test watershed, is compared directly with the control watershed. Data collected on the lower segment, the secondary test watershed, are used only to view the effect of similar land use on a larger area.

By the evaluation of collected samples, present water quality conditions can be determined. If substantial water quality variation is found between the two watersheds, after consideration of both the amount and intensity of precipitation, a correlation between land use and water quality probably can be inferred. A comparison of collected water samples should help justify this assumption.

5.4.2 Location

The study area is in southwestern Benton County approximately 8 miles east of the town of Siloam Springs. Both watersheds are within the Robison 7.5-minute quadrangle, on opposite sides of the Illinois River (Fig. 67). The area is easily accessible by State Highway 68 and local graded roads.

The control watershed is within the Ozark National Forest south of the community of Pedro in sec. 16, T.16N., R.32W. Stream samples were collected at the boundary between privately owned and National Forest lands at lat 36°08'52"N., long 94°24'27"W.

The primary test watershed is approximately 3 miles north of the community of Logan in Palmer Hollow within sec. 21, T.16N., R.32W. Samples

LOCATION MAP

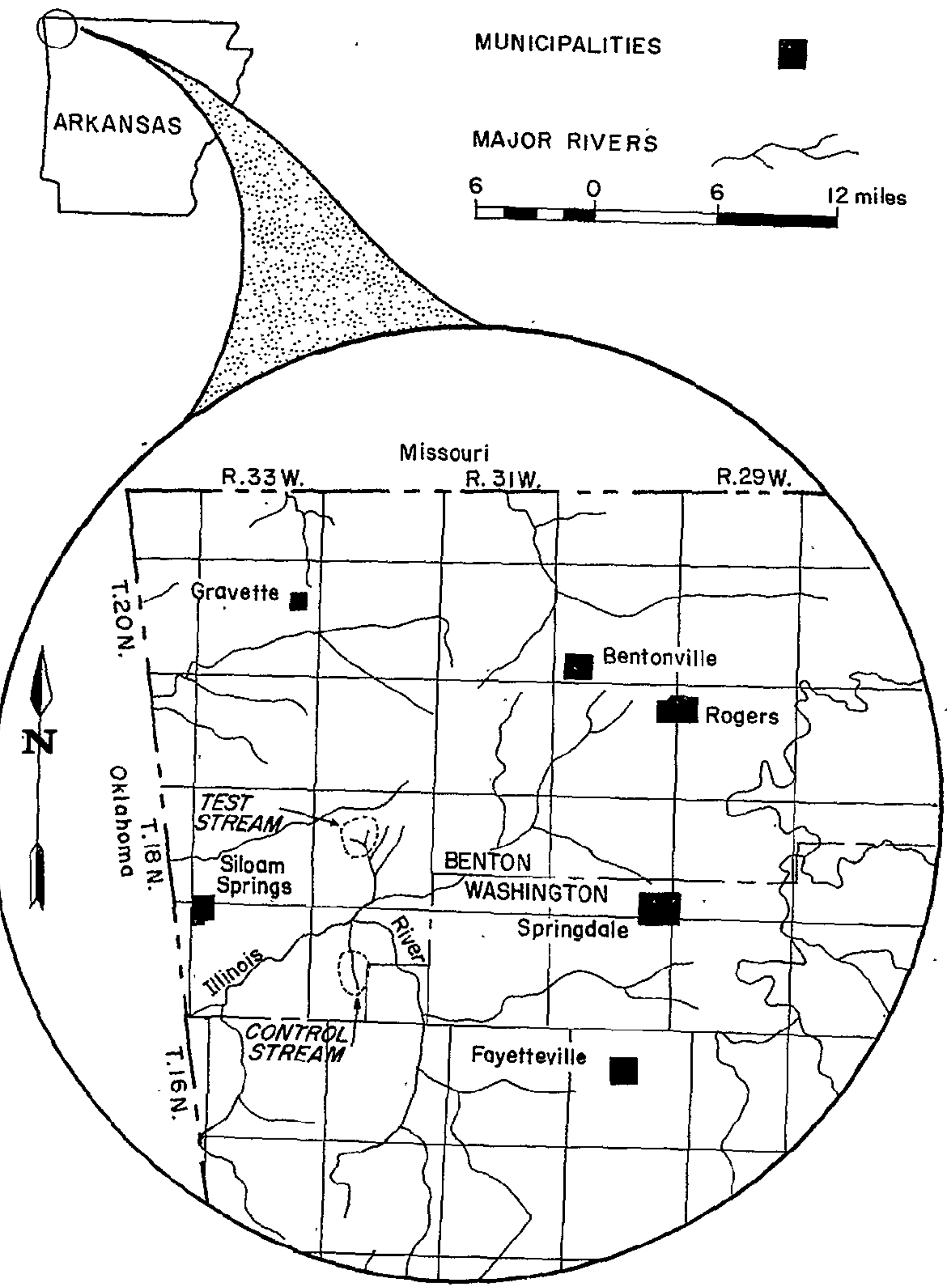


Figure 67. Rural test site location.

were collected at a point north of the bridge at lat 36°13'40"N., long 94°24'16"W.

The secondary test watershed is merely a southern extension of the primary test watershed, sec. 27, T.16N., R.32W. Samples were collected west of the bridge at lat 36°11'50"N., long 94°25'59"W. before the intersection with the Galey Hollow watershed.

5.4.3 Physiography and Topography

The watersheds are in the Springfield Plateau of the Ozark Physiographic Province, which is characterized by moderate to steep slopes, rolling hills and entrenched valleys. Major streams are perennial and have a dendritic drainage pattern.

The control stream has a 940-acre watershed and is approximately 1.7 miles long. The relief between the headwaters and the sampling point is 220 feet (elevation 1280-1060 feet). The stream flows northward into the Illinois River.

The primary test stream drains a 1,008-acre watershed and is approximately 1.8 miles long. Relief is 230 feet (elevation 1320-1090 feet) between the headwaters and sampling point. The primary test stream is the upper segment of the secondary test stream.

The secondary test stream drains a 3,404-acre watershed and its approximately 3.2-mile length includes the upper segment. Relief is 310 feet (elevation 1320-1010 feet) between the headwaters and sampling point. Flowing southeast, the stream enters Osage Creek which is a tributary of the Illinois River.

5.4.4 Geology

The study area is underlain by marine sedimentary rocks ranging from

Mississippian to Devonian in age. The control and test watersheds are within the Boone Formation of early Mississippian age. The Boone Formation constitutes the most extensive surface exposure in northwestern Arkansas. Appearing gray on fresh surfaces and reddish brown on weathered surfaces, the Boone is composed of finely to coarsely crystalline, thick-bedded limestone with interbedded chert. It is approximately 300 feet thick, extensively fractured, and very susceptible to weathering. Containing 30 to 60 percent chert by volume, the limestone weathers chemically, leaving mostly insoluble chert fragments (Horn and Garner, 1965). These fragments form a thin regolith covering the entire land surface. Transported downslope, regolith commonly fills stream channels at lower elevations.

5.4.5 Soils

Soils within the area are composed of cherty limestone residuum from the Boone Formation. They are of medium texture and contain large quantities of chert fragments. Area soils can be divided into two classes on the basis of their topographic location. Upland soils are in association with gently sloping ridge tops and steep-sided slopes, whereas lowland soils are along floodplains and terraces. Both soils have low organic content; cultivated soils contain less that 1 percent whereas forested soils contain as much as 4 percent organic material. Chert residuum ranges from 20 to 80 percent by weight, the larger amounts being on slopes and along stream beds. The soils are acid and of low to medium fertility (Horn and Garner, 1965).

Upland soils are characterized by grayish-brown cherty silt loam soil over yellowish to red cherty, silty clay or clay subsoil (Horn and Garner, 1965). The depth to bedrock is approximately 2 to 5 feet. Upland soils are well to moderately well drained and are of moderate to low permeability.

Lowland soils are brown, gravely, silt loam surface soils over yellowish-brown gravely, silty clay loam subsoil (Horn and Garner, 1965). They are derived from alluvium washed down from upland areas. Lowland soils are moderately to moderately well drained and are of moderate to low permeability.

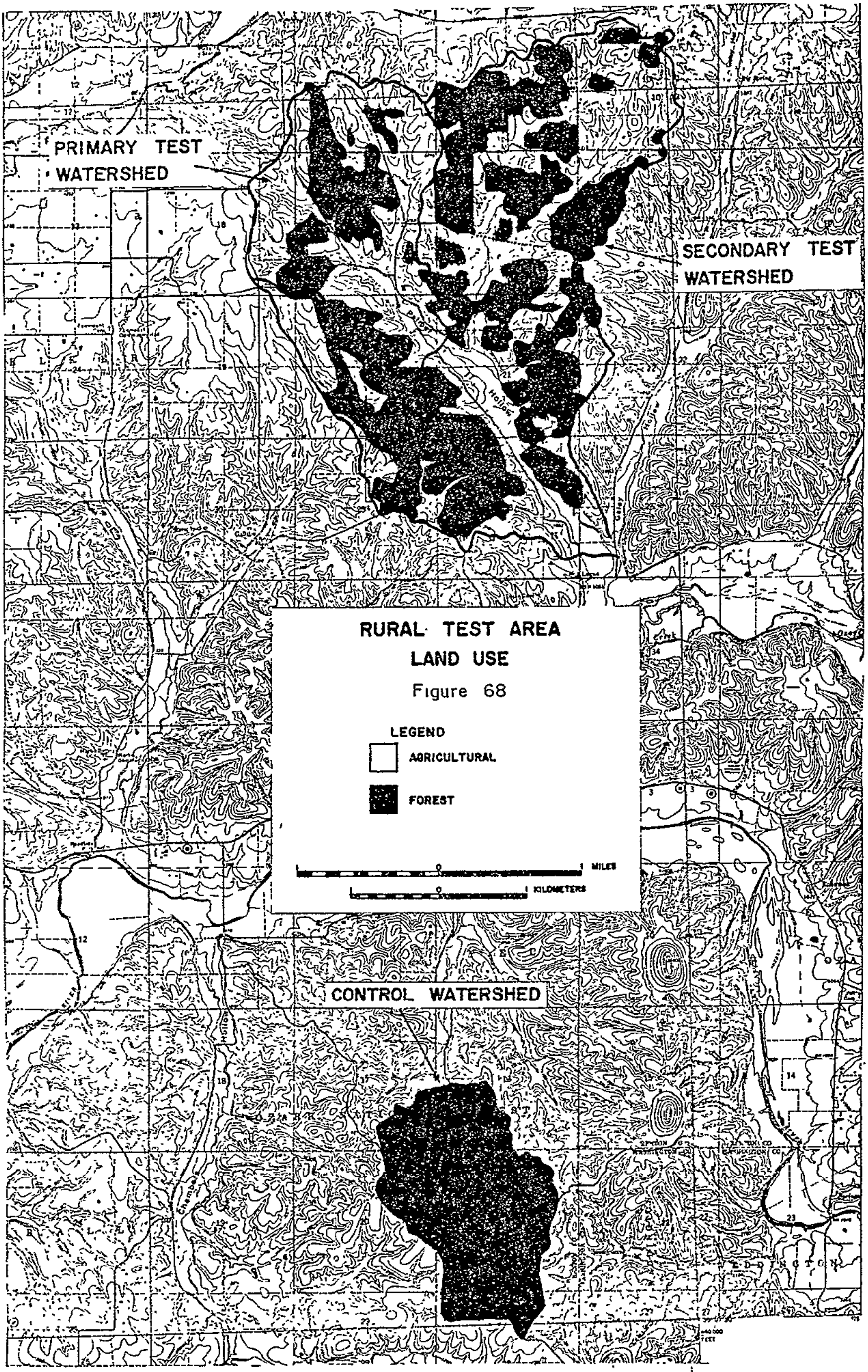
According to the U.S. Department of Agriculture's soil classification for Benton County (1971), most of the study area is composed of the upland soil type. Lowland soils are present only along the lower elevations of the primary and secondary test streams.

5.4.6 Land Use

Two major types of land use are found within the study area. Land is either covered by hardwood forest or cleared for agricultural use. Major agricultural practices are cattle and poultry raising and there is little or no cropland activity. Stream valley and hilltop land cleared for pasture is the land most suitable for agricultural use, whereas land along steep-sided slopes is predominantly wooded.

The control watershed is within the Ozark National Forest and is completely covered with deciduous trees. Lacking developed recreational facilities, the control watershed is relatively undisturbed. The only human influence in the 940-acre watershed is a county road which provides limited travel into the area.

Percentages of land use are relatively similar in the primary and secondary test watersheds (Fig. 68). The primary test watershed contains 354 acres of forest land, 35.2 percent, and 654 acres of cleared land, 64.8 percent. The secondary test watershed contains 1,389 acres of forest land, 40.8 percent, and 2,015 acres of cleared land, 59.2 percent.


PRIMARY TEST WATERSHED
SECONDARY TEST WATERSHED
RURAL TEST AREA
LAND USE
Figure 68
LEGEND
AGRICULTURAL
FOREST
MILES
KILOMETERS
CONTROL WATERSHED

5.4.7 Rainfall

Daily rainfall data for Fayetteville, Arkansas, were gathered by the National Oceanic and Atmospheric Administration. Monthly values of total rainfall between May 1975 and May 1976 are given in Figure 69. During the October 1975 to June 1976 study period, total monthly rainfall ranged from 0.46 inches in January to 7.16 inches in April. The lowest monthly totals were recorded in June and February and a substantial increase in precipitation followed during March, April, and May.

5.4.8 Methodology

Samples were collected at selected points on each watershed during high flow (storm events) and low flow periods. During storm events, samples were collected in conjunction with initial rise in stream flow. Because of differences in lag time, intensity of rainfall, and distances between sampling points, the collection of samples during the initial rise in flow could only be approximated. In contrast, low flow samples were collected during prolonged dry periods when collection time was of little importance.

Flow rates in cubic feet per second were recorded on the control and primary test streams. Stream velocity was measured by timing the passage of floats along selected stream sections. The average depth and width of each section were recorded. The information was then placed in Embody's formula to determine the rate of flow (Welch, 1948).

Specific conductance, stream temperature, and pH values were obtained during collection. Specific conductance values were determined by use of a Hach DR-EL/2 portable test kit. Samples also were analyzed immediately upon return to the laboratory with a YSI Model 31 conductivity

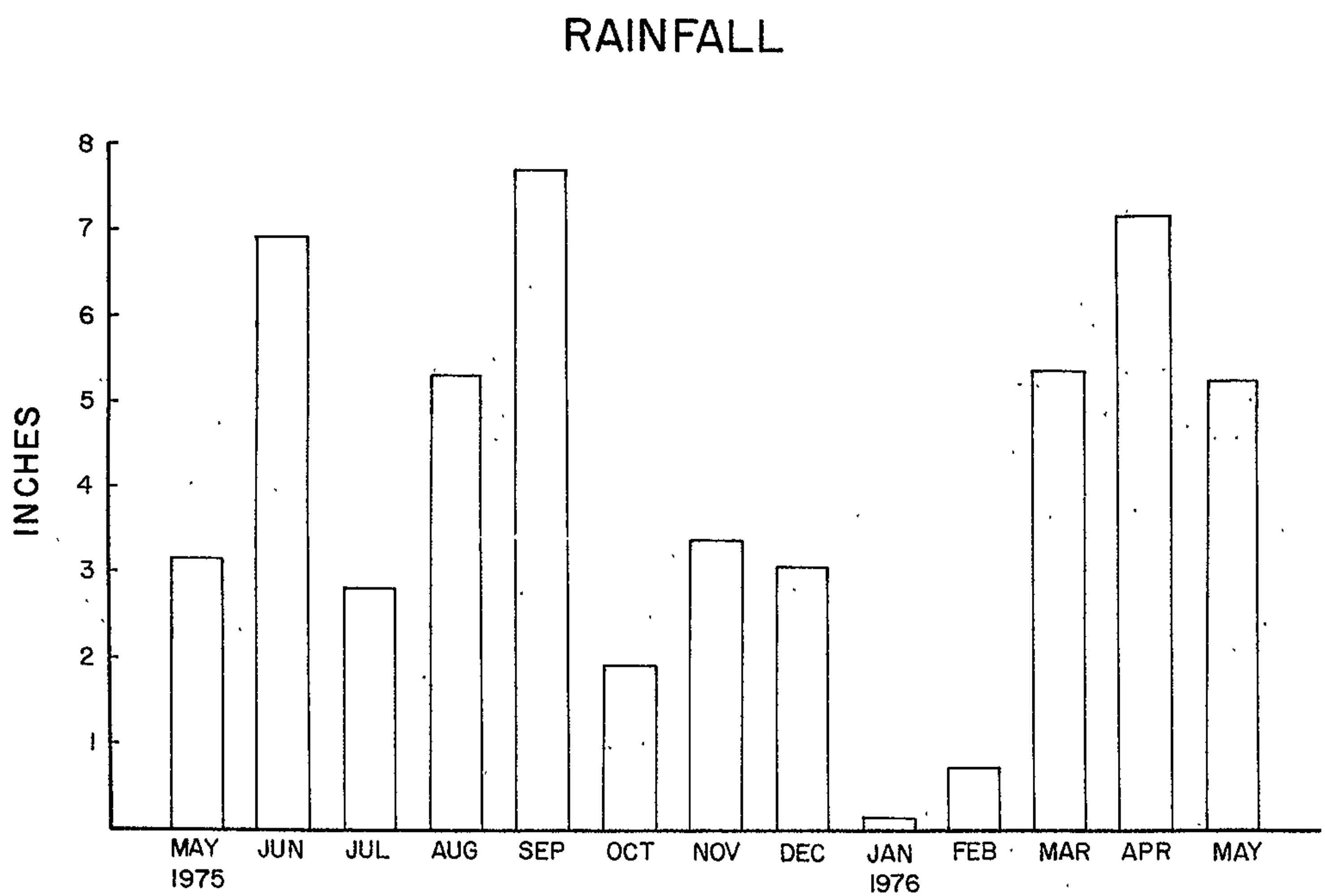


Figure 69. Monthly values of total rainfall, May 1975-May 1976, Fayetteville, Arkansas.

bridge; however, little variation was found between the two specific conductivity measurements. Stream temperature and pH values were determined by use of an Orin Model 407 pH meter and a centigrade thermometer.

A 500-ml water sample was collected and passed through 0.45-micron membrane filters for determination of alkalinity, nitrate-nitrogen, orthophosphate, chloride, and sulfate concentrations. The samples were collected in polyethylene containers and were iced for later laboratory analysis. Analyses were performed with a Hach Model DR-EL/2 by methods outlined in the Hach DR-EL/2 Methods Manual (1972).

A liter sample was collected for the analysis of turbidity and nonfilterable solids. Turbidity concentrations were determined by the method outlined in the Hach DR-EL/2 Methods Manual (1972). Analysis of nonfilterable solids was conducted in accordance with the FWPCA Methods for Chemical Analysis of Water and Wastes (1969).

After collection for fecal coliform determination, samples were placed on ice and analyzed immediately upon return to the laboratory. Fecal coliform analysis was accomplished by the membrane filter method given in Standard Methods for the Examination of Water and Waste Water (APHA, 1971).

A 50-ml sample was collected for atomic absorption analysis. Upon collection, samples were filtered and preserved with five drops of 1:1 nitric acid. A Perkin-Elmer Model 303 atomic absorption spectrophotometer was used to determine concentrations of calcium, magnesium, sodium, iron, manganese, potassium, and arsenic. Analyses were conducted by procedures in the 1970 Perkin-Elmer Handbook.

5.4.9 Data Interpretation

Stream samples were collected between October 5, 1975 and June 12, 1976 during five low stream flows and four storm events. Samples from the April storm event were collected at peak discharge rather than during the initial rise in stream flow. Therefore data gathered during the April sampling date are thought to be influenced by dilution.

The data are listed in the order collected for easy evaluation (Table 16). For interpretation, data were grouped into five categories--physical, micro-, macro-, nutrient, and biological parameters. Data collected on the primary test stream, designated test stream A, are compared directly with those from the control stream. The secondary test stream, designated test stream B, is different in size and is not compared directly with the control.

5.4.9.1 Physical Parameters

The values for pH were generally higher on the test streams during the study period (Fig. 70). The values correlate well with those found by Kittle et al. (1974) on the Illinois River adjacent to the study area. The average value was 7.2 for the control stream and 7.5 for test stream A. Values of pH seemed to be inversely proportional to stream flow on both the control and test watersheds. During low flow conditions, the control stream was found to be more acid than the test streams. The control watershed contains a large amount of decaying matter in the form of leaf litter which lowers stream pH.

In all instances, stream temperatures were found to be higher on the test streams than on the control (Table 16). The difference is most likely due to the greater exposure of the test streambeds, because the control stream is protected by vegetative cover. Absorption of solar

Table 16. Sample data for control stream, test stream A and test stream B.

Date of collection	Time of collection	Location	Flow (cfs)	Fecal Coli-form (#/100ml)	Temperature (°C)	Specific Conductance (micromhos at 25°C)	Turbidity (FTU)	Nonfilterable Solids	pH	Total Alkalinity	Chloride (Cl)	Sulfate (SO_4)	Orthophosphate soluble (PO_4)	Nitrate (NO_3) as N	Sodium (Na)	Potassium (K)	Magnesium (Hg)	Calcium (Ca)	Iron (Fe)	Manganese (Mn)	Arsenic (As)
10/17/75	3:30pm	control	1.20	0	15.0	154	0.70	0.00	7.5	100	15.0	5.0	0.03	0.13	4.77	0.69	0.83	37.0	<0.010	<0.002	<0.50
		Test A	1.40	350	18.0	135	6.60	14.40	8.0	90	10.0	5.0	0.08	0.95	2.67	1.68	1.16	35.14	0.046	0.029	<0.50
		Test B	-	25	18.0	145	2.20	1.65	8.2	80	15.0	5.0	0.05	1.22	5.22	0.50	1.21	28.63	<0.010	<0.002	<0.50
10/31/75	4:00pm	control	1.15	0	15.0	152	0.75	0.00	7.2	100	10.0	5.0	0.03	0.10	4.09	0.62	0.86	34.64	0.012	0.004	<0.50
		Test A	1.32	880	17.0	120	1.25	0.00	7.6	90	10.0	5.0	0.09	1.00	4.09	1.58	1.11	27.32	0.029	0.002	<0.50
		Test B	-	120	17.0	130	0.90	0.55	7.7	100	10.0	5.0	0.07	1.35	3.07	1.13	1.18	31.54	0.017	0.008	<0.50
11/9/75	2:30pm	control	1.65	50	17.0	150	0.50	0.81	7.2	90	10.0	4.5	0.11	0.35	2.80	0.76	0.73	28.54	0.026	<0.002	<0.20
		Test A	3.20	37,450	18.0	155	1.75	4.06	7.5	85	19.0	8.0	0.18	1.80	3.77	2.95	1.41	26.05	0.527	0.204	<0.20
		Test B	-	28,500	18.0	165	1.20	2.45	7.6	80	16.0	6.5	0.21	2.15	-	-	-	-	-	-	-
2/5/76	10:45am	control	1.10	0	8.5	163	0.60	0.16	7.8	90	12.0	8.0	0.20	0.27	2.96	0.93	1.79	34.30	<0.010	<0.005	<0.20
		Test A	1.30	500	10.0	149	1.25	1.67	7.8	70	15.0	4.0	0.06	1.00	3.94	1.18	1.12	28.20	0.014	<0.005	<0.20
		Test B	-	10	10.0	156	1.50	1.79	7.8	85	5.0	2.0	0.05	2.15	3.28	0.88	1.26	35.60	<0.010	<0.005	<0.20
3/26/76	2:35pm	control	1.20	0	14.0	152	-	-	7.3	85	7.5	4.0	0.01	0.15	2.33	0.69	0.71	32.70	<0.014	<0.006	<0.20
		Test A	1.37	1,200	15.0	133	-	- -	7.5	75	5.0	5.0	0.027	0.12	3.38	1.21	1.06	28.40	<0.014	<0.006	<0.20
		Test B	-	850	15.0	139	-	-	7.5	90	5.0	2.5	0.008	0.17	1.82	0.48	0.88	34.70	<0.014	<0.006	<0.20
3/29/76	1:30pm	control	1.80	97	14.5	140	8.00	6.20	7.2	70	10.0	4.0	0.01	0.06	1.84	0.61	0.56	26.50	0.054	0.006	<0.20
		Test A	3.10	4,200	15.0	169	16.00	6.30	7.6	70	7.5	4.0	0.04	0.17	3.16	1.59	1.03	26.29	0.036	0.008	<0.20
		Test B	-	3,250	15.0	161	18.00	14.7	7.6	90	7.5	5.0	0.02	0.20	2.59	1.69	0.88	32.50	0.032	0.006	<0.20
4/20/76	6:30am	control	4.80	82	14.0	136	15.00	11.00	6.1	10	2.5	0.0	0.15	0.33	0.63	0.81	0.69	2.05	0.051	0.012	<0.20
		Test A	6.20	25,400	15.5	212	80.00	472.00	6.5	20	5.0	5.0	0.16	2.80	1.70	3.13	1.20	9.08	0.105	0.033	<0.20
		Test B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5/23/76	3:15pm	control	2.50	120	15.0	145	4.60	4.100	7.0	94	43.0	10.0	0.02	0.45	6.47	0.90	1.75	32.61	0.011	0.017	<0.30
		Test A	4.20	22,100	16.0	180	40.00	252.00	7.4	75	15.0	12.0	0.18	1.40	7.21	2.87	1.29	24.56	0.094	0.071	<0.30
		Test B	-	35,625	16.0	180	67.00	200.00	7.3	56	8.0	12.0	0.19	1.10	1.63	2.26	0.92	19.38	0.937	0.053	<0.30
6/12/76	4:20pm	control	1.32	6	17.5	132	0.06	0.33	7.7	77	16.0	1.5	0.01	0.1	2.82	0.67	0.83	35.36	0.014	0.006	<0.30
		Test A	1.50	3,500	20.5	147	0.20	3.30	7.6	72	19.0	<1.0	0.07	0.74	3.76	1.97	1.31	29.69	0.006	0.006	<0.30
		Test B	-	480	20.5	147	0.24	3.72	7.8	61	8.0	<1.0	0.01	1.20	2.64	1.29	1.05	31.77	0.006	0.009	<0.30

Above data in mg/l unless otherwise indicated.

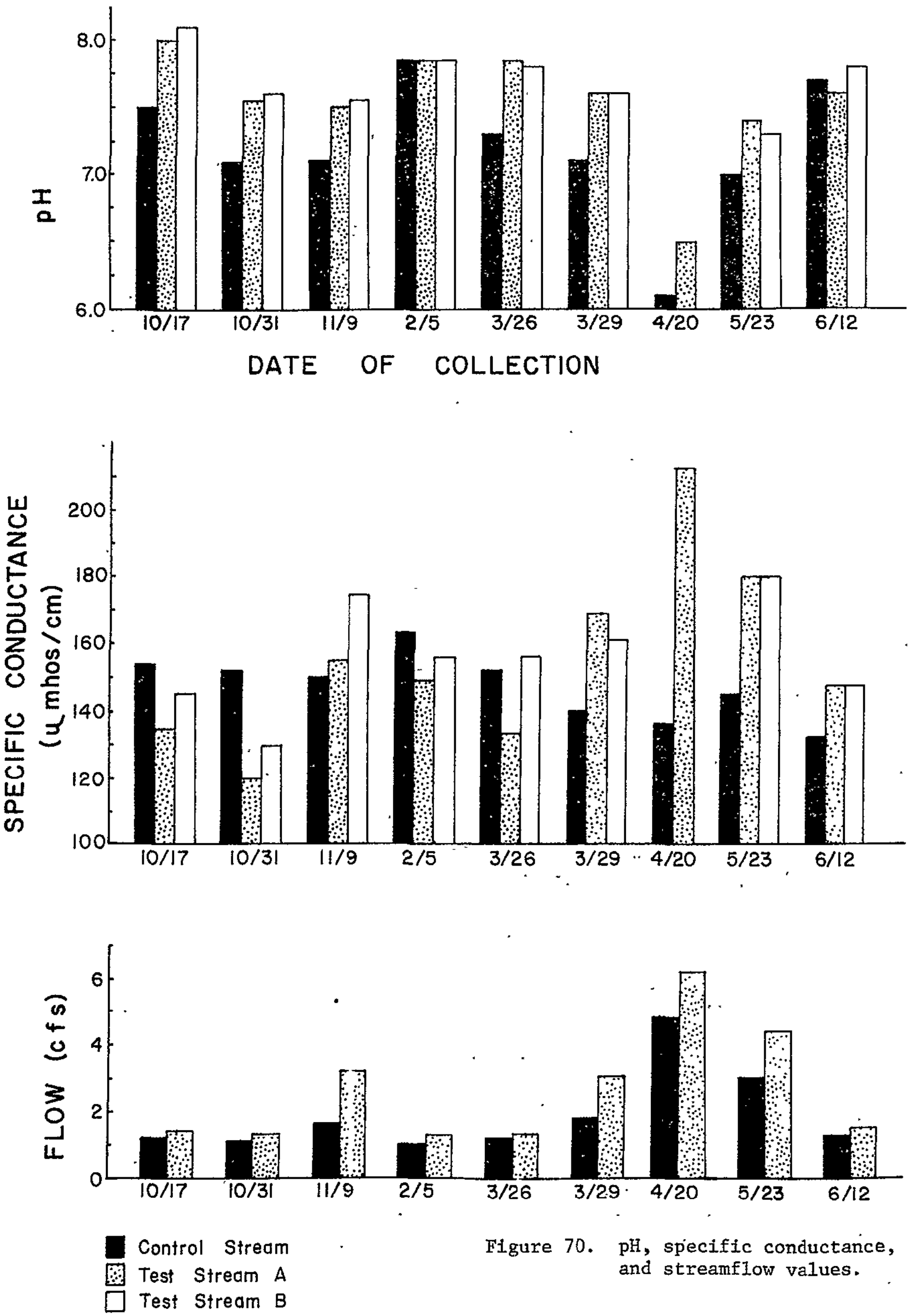


Figure 70. pH, specific conductance, and streamflow values.

energy by vegetation tends to minimize daily stream temperatures.

Turbidity and nonfilterable solids also were found to be higher on the test watersheds (Table 16). The data indicate that turbidity and nonfilterable solids vary directly with stream flow. The test watersheds, lacking heavy vegetative cover, are more susceptible to erosion than the control.

Except during the June sampling period, the control stream had higher specific conductance values during low flows (Fig. 70). The fact that the control stream had lower values during storm events suggests dilution. In contrast, the fact that the test streams had greater specific conductance concentrations during storm events suggests possible contamination by animal wastes.

Stream flows ranged from 1.1 to 6.2 cfs with an average difference of 0.18 cfs between the control and test stream A during low flow conditions (Table 16). Regardless of the times of stream gauging (low flows or storm events), relatively higher flows always occurred on test stream A (Fig. 70). These differences in stream flow are most certainly the result of contrasting land use between the control and test watersheds. The test watersheds, lacking a dense vegetative cover, cannot retain water as well as the heavily forested control, and thus a relative increase in surface runoff occurs.

5.4.9.2 Macroparameters

Chloride concentrations ranged from 2.5 to 43 mg/l on the control and from 5 to 14 mg/l on test stream A. The lowest chloride values were recorded during the April storm event. Although considerable fluctuations occurred, the average low flow chloride value was 10.7 mg/l for the control and 11.8 mg/l for test stream A. These values correspond well with the average chloride value of 10.5 mg/l given for the Illinois River adjacent to the study area (Kittle et al., 1974). Because of dilution, the time of collection is critical for valid chloride analysis. During storm events, samples should be collected after the initial rise in stream flow but before the hydrograph peak.

Sulfate concentrations ranged from zero to 12 mg/l with the greatest values recorded during the May storm event (Table 16). Sulfate values collected during low flow periods were similar for the control and test watersheds.

Aside from the diluted values of the April storm event, alkalinity concentrations were higher on the control stream throughout the study. Average alkalinity values ranged from 89 mg/l on the control stream to 78 and 80 mg/l on test streams A and B, respectively (Table 16). Because of considerable variation, correlation between stream flow and alkalinity cound not be determined.

5.4.9.3 Microparameters

In order of abundance, the major collected cations were calcium, sodium, magnesium, and potassium (Table 16). During low flows, calcium concentrations were higher on the control than on test stream A. Having greater flow, test stream A has a diluting effect on calcium concentrations. Samples collected during storm events had no detectable pattern on either the control or test streams. In general, low values for sodium, potassium, and magnesium were found on the control and higher values were found on the test streams (Fig. 71). The vegetative cover of the control stream tends to stabilize stream quality and flow characteristics, thus minimizing the effect of surface runoff.

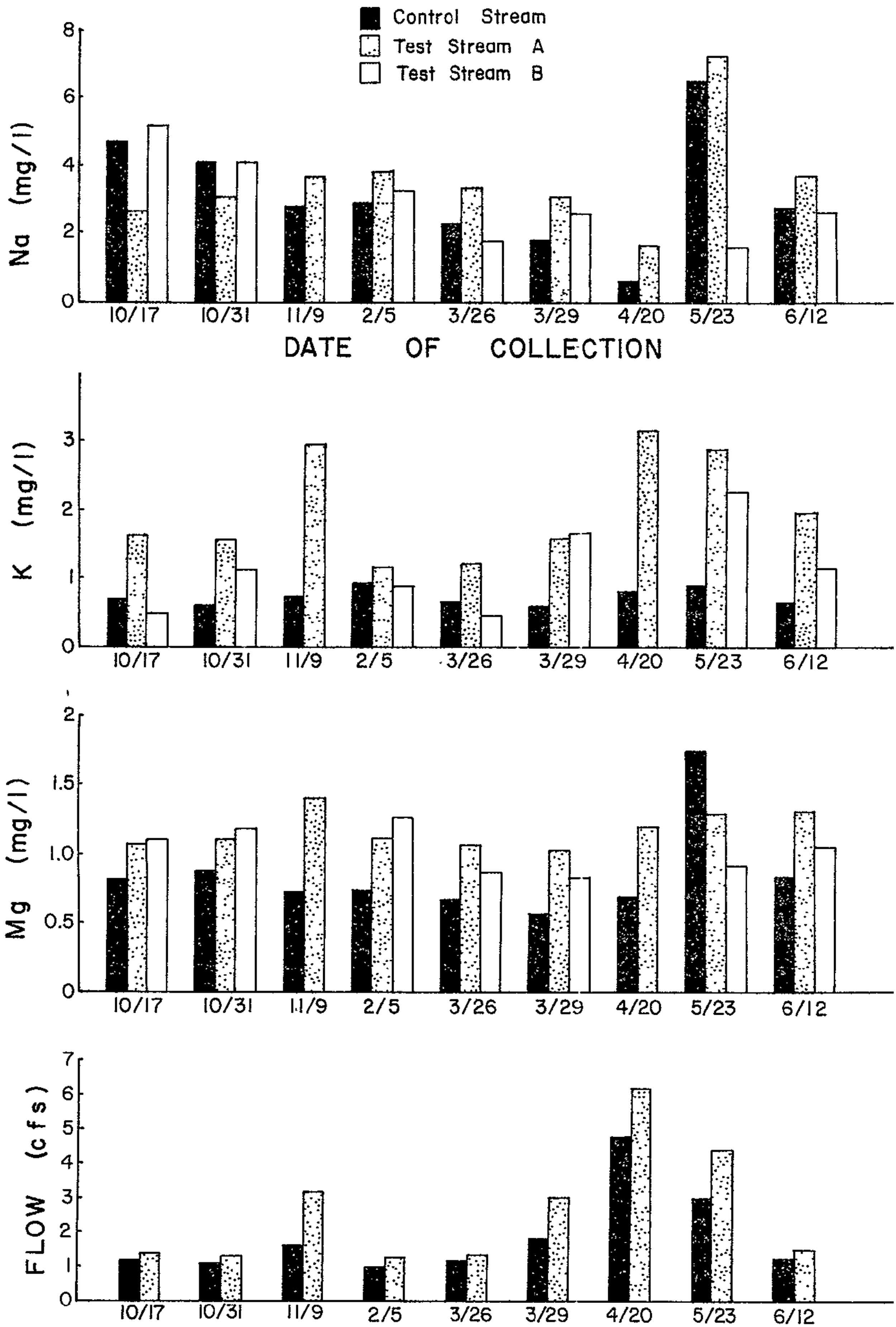


Figure 71. Sodium, potassium, and magnesium values.

Because of their small values and great variability, iron, manganese, and arsenic concentrations were not good indicators of water quality change. The highest iron and manganese values were recorded on the test streams during high flow periods (Table 16). Arsenic concentrations were below detection on all sampling dates (Table 16).

5.4.9.4 Nutrients

Water quality researchers believe that nitrogen and phosphorus are the major limiting nutrients in aquatic plant growth (Neas, 1966). Streams in undisturbed forested watersheds should have lower concentrations of nitrogen and phosphorus than streams in developed areas (Brown, 1972). Thus, phosphorus and nitrogen concentrations should be sensitive indicators of water quality change in relation to land use.

To evaluate the influence of different land uses on nutrient concentrations, orthophosphate and nitrate-nitrogen values were determined. The control stream had lower nitrate and phosphate values than did the test streams. Nitrate concentrations ranged from 0.12 to 2.8 mg/l on test stream A with higher values occurring during storm events (Fig. 72). Nitrate values did not exceed 0.45 mg/l on the control stream. Orthophosphate concentrations ranged from 0.03 to 0.18 mg/l on test stream A and averaged 0.063 mg/l on the control (Fig. 72). Values for both nitrate and phosphate generally increased during periods of increased stream flow. Loehr (1974) similarly observed that storm events contributed greater concentrations of nutrients than were present during low flow conditions.

Because samples were filtered before analysis, only soluble forms of nitrogen and phosphorus were analyzed. Southerland (1974) suggests that nutrients transported in surface runoff are primarily in the form of

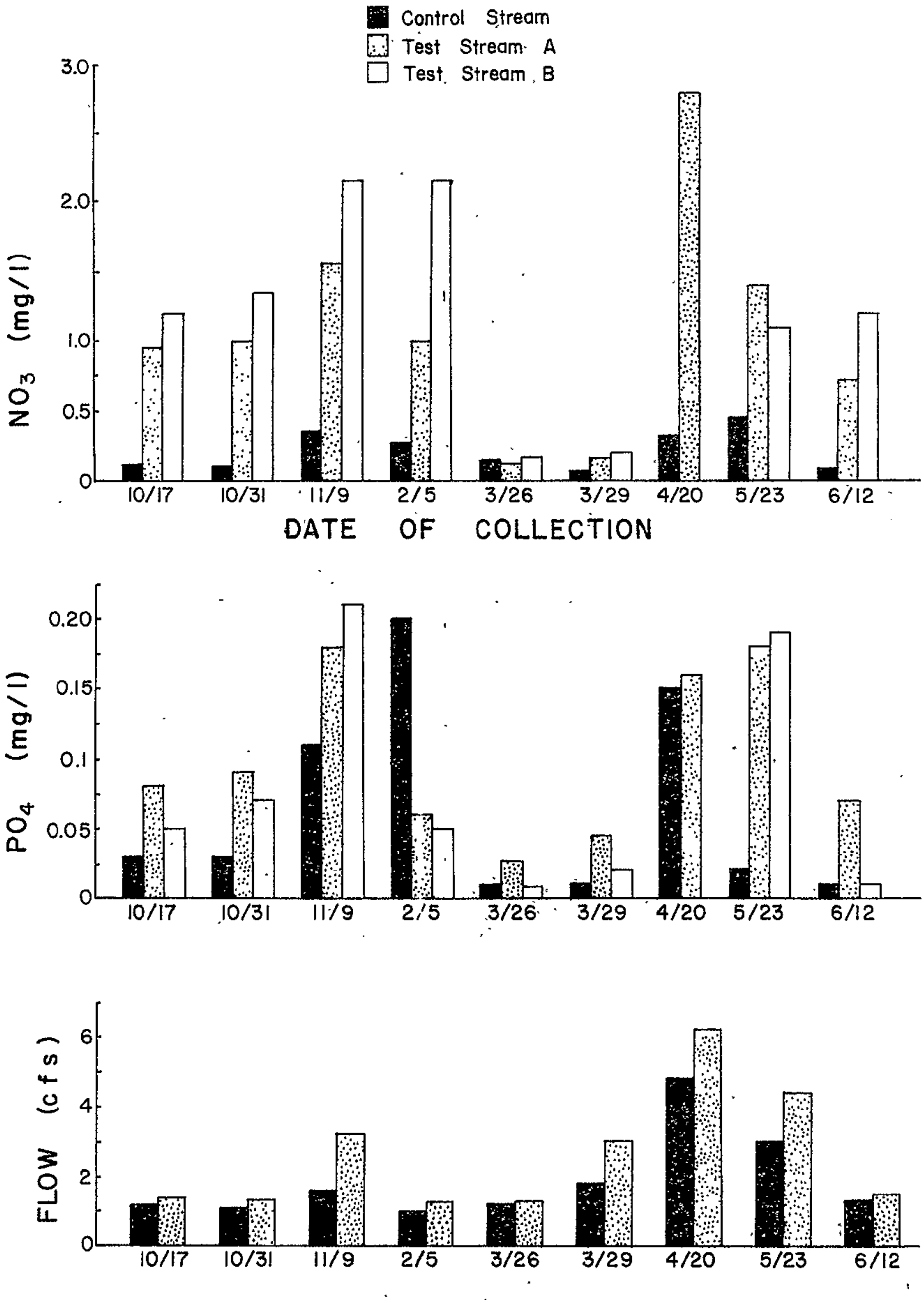


Figure 72. Nitrate and phosphate values.

particulate matter. Analysis of the nutrient data suggests that storm events produce greater concentrations of dissolved nitrate and phosphate than are present during low stream flows. Ryden et al. (1973) suggest that a more realistic measure of nitrate and phosphate concentrations during periods of surface runoff would be to sample both the dissolved and particulate forms, and the present analysis supports this assumption.

5.4.9.5 Biological Parameters

Fecal coliform concentrations in the control stream ranged from 0/100 to 120/100 ml and in test stream A ranged from 350/100 to 37,450/100 ml (Table 16). Geldreich et al. (1968) suggest that increased nutrients and temperature can be correlated with increasing survival rates of fecal coliform bacteria. Both the primary and secondary test streams, having greater nutrient and temperature values, had higher concentrations of fecal coliform than the control stream. The highest fecal coliform values on each stream were obtained during storm events (Fig. 73). Thus, the assumption can be made that with increasing stream flow an increase in fecal coliform concentrations should be observed.

In the evaluation of fecal contamination, fecal coliform values are considered better indicators than total coliform values (Geldreich, 1970). Gallagher and Spino (1968) suggest that if the total coliform standard is 5000/100 ml in recreational waters, corresponding fecal coliform densities for contact and non-contact recreational activity should be 150/100 ml and 750/100 ml, respectively. The Arkansas Department of Pollution Control and Ecology (1972) suggests a general-use total coliform standard of 5000/100 ml for the Upper White, Neosho, and Grand River Basins, including the study area, and a value of 1000/100 ml for recreational use. During storm events, samples collected on the test streams

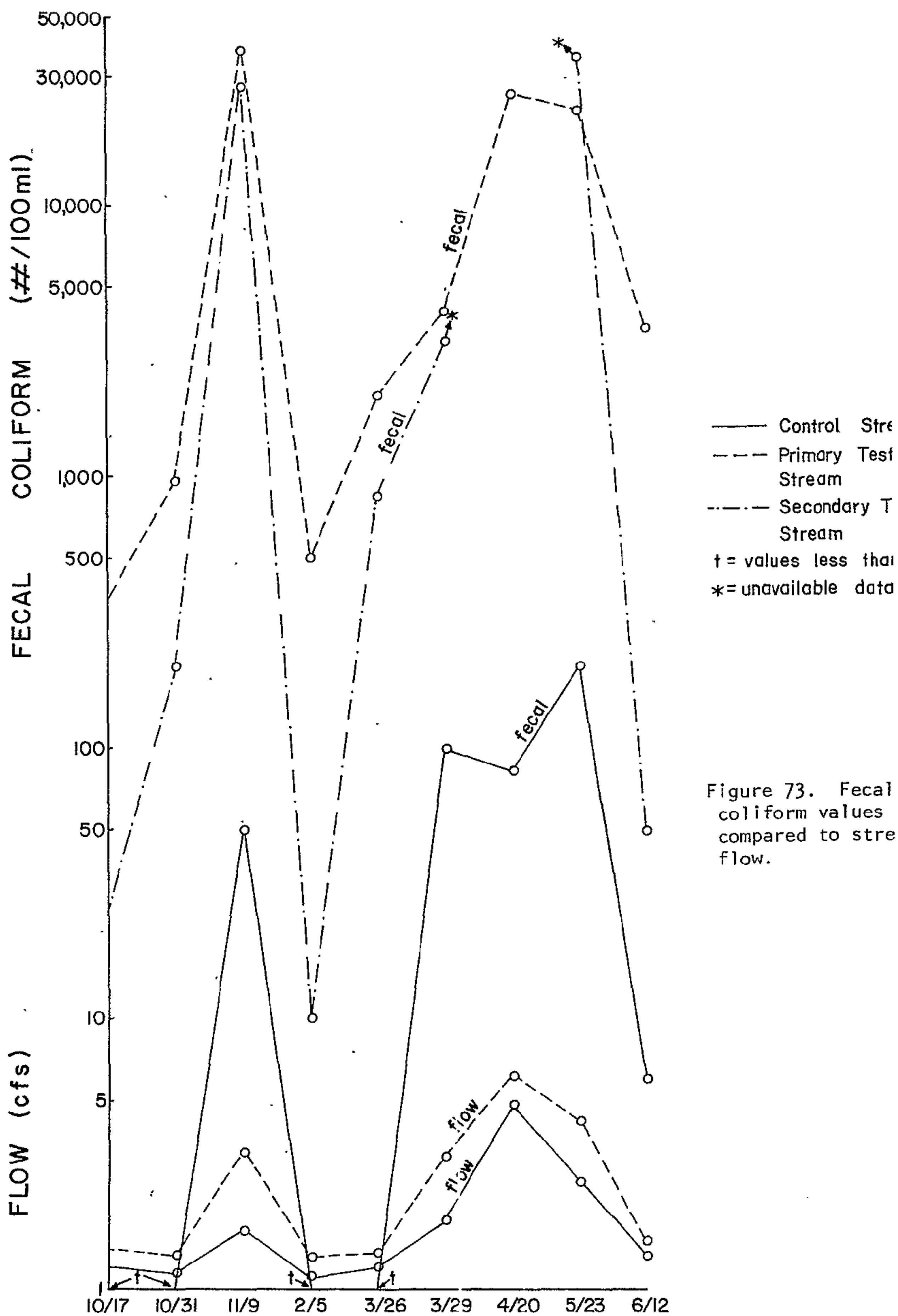


Figure 73. Fecal coliform values compared to stre flow.

exceeded both of the suggested standards and those given by the Arkansas Department of Pollution Control and Ecology.

Nonpoint source increases in rural coliform concentrations usually are associated with mechanical transfer of organisms from contaminated land surfaces. Betson and Buckingham (1970) recognize that samples collected during storms usually show higher fecal coliform concentrations. Coliform data from the present study suggest that random sampling without regard for stream flow can give an inaccurate estimate of fecal coliform concentrations.

5.4.10 Conclusions

The control watershed, being heavily forested and only minutely influenced by man, provided an indication of natural water quality conditions within the study area. The test watershed, influenced by human development, gave an indication of water quality conditions related to rural land use. As expected, rural land use has an important role in determining both quantity and quality of surface stream flows.

Considerable variation in water quality was found between the control and test watersheds. The selected physical, macro-, micro-, nutrient, and biological parameters proved to be good indicators of water quality variation. In many cases, collected data showed greater variation during conditions of increased surface runoff.

Higher fecal coliform and nutrient concentrations were found in the primary and secondary test streams than in the control stream. Both test streams are influenced by poultry and livestock wastes resulting from land use in the area. Concentrations of fecal coliform bacteria showed a substantial increase during high flow periods (Fig. 73). As was noted, random sampling without regard for stream flow can give an inaccurate estimate of water quality conditions.

Through data evaluation, a difference in water quality can be detected between the control and test watersheds. The amount of difference is apparently more pronounced during high flow periods. Because of similar topographic and geologic characteristics of the test and control streams within the same geographic area, water quality change seems to be related to land use in the study area.

5.5 URBAN TEST SITE

5.5.1 Introduction

During the last few years, the cities of northwest Arkansas have undergone a steady population growth (13 percent in 1975). The urban areas have expanded, incorporating farmland and forest and changing the land use to suit the needs of the people. Unfortunately, concomitant with urbanization are the associated changes in water quality. The purpose of this part of the overall investigation was to examine the relationship between changes in land use and water quality. To accomplish this, three watersheds were studied. Although the watersheds are similar in geology and topography; their land use is different. One watershed which drains a relatively unchanged forest area was used as the control site. The other two watersheds drain urban areas. They consist of a small watershed comparable in size to the control watershed and a much larger watershed which includes the small watershed.

Selected points on each watershed were sampled during times of high flow and low flow. By comparison of various parameters of the two watersheds, a change in water quality due to variation in land use could be determined.

5.5.2 Location

The watersheds are in north-central Washington County, Arkansas (Fig. 74). The control watershed contains 1172 acres and includes the southwestern part of the Elkins 7.5-minute quadrangle (T.16N., R.29W.). The large urban watershed contains 7552 acres and includes the southern part of the Fayetteville 7.5-minute quadrangle (T.16N., R.30W.). The small urban watershed contains 1125 acres.

The control stream (CS) is an unnamed eastern tributary of the West Fork of the White River. The control stream sampling site was at NW¼SW¼NE¼sec. 36, T.16N., R.29W. on an unpaved farm-access road.

The urban stream is Town Branch, a western tributary of the West Fork of the White River. Two sampling sites were maintained. One site (TC-71) is upstream from the junction of Cato Springs Branch with Town Branch. It is at NW¼SW¼SE¼sec. 20, T.16N., R.30W. on State Highway 16 West, and is within the small urban watershed. The other site (TC) is downstream from the junction of Cato Springs Branch with Town Branch. It is at NW¼SE¼SW¼sec.23, T. 16N., R.30W. on a partially paved farm-access road.

5.5.3 Physiography and Topography

The watersheds are within the Ozark Plateaus province of Arkansas, straddling the Springfield Plateau on the north and the Boston Mountains on the south. The low hills in which the headwaters of the control stream and the Cato Springs Branch of the test stream form are considered to be at the foothills of the Boston Mountains.

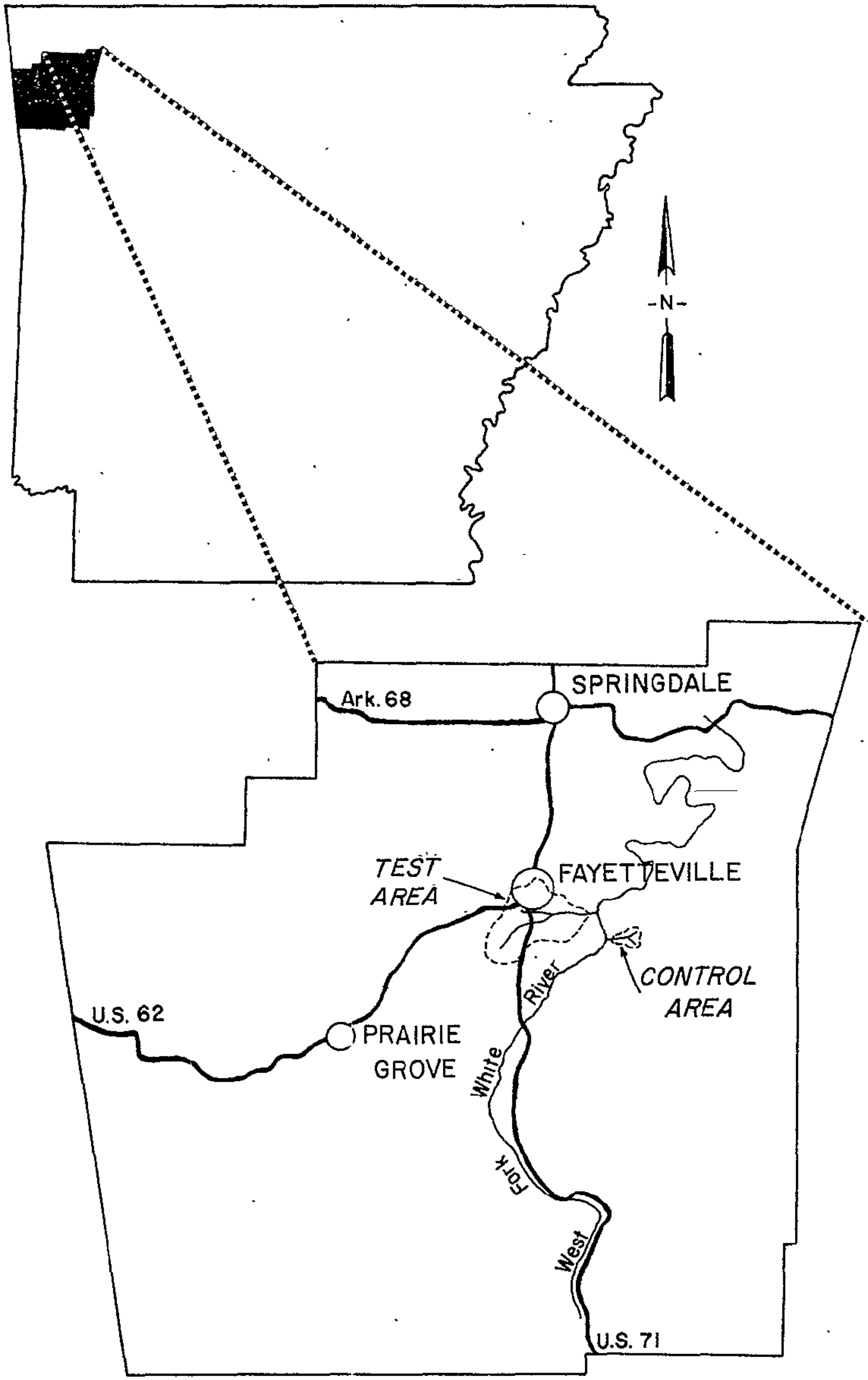


Figure 74. Urban test site location.

5.5.4 Geology

The chemical quality of most surface streams in northern Arkansas, at least during times of low flow, is determined largely by the distribution and mineral composition of the rock units in the drainage basins. The rock units that are exposed in the two drainage basins are primarily shale, sandstone, siltstone, and limestone.

In the control stream drainage basin, the rocks are of Late Mississippian age. The headwaters of the control stream are in the Pitkin Formation, a massive compact fossiliferous limestone, and the main stream body is in the Fayetteville Formation. The Fayetteville Formation can be described as consisting of clay shale containing pyrite, quartz, iron concretions, and a large amount of organic material, and a calcareous sandstone.

In the Town Branch drainage basin, the rocks are of Late Mississippian and Pennsylvanian age. The headwaters and main stream body of Town Branch are in the Fayetteville Formation. The Cato Springs Branch has its headwaters in the Pennsylvanian Atoka Formation which consists of siliceous sandstone and silty shale. The drainage then passes through the Bloyd Formation, consisting of silty shale, organic shale, organic siltstone, and sandy fossiliferous limestone. Farther downstream the Hale Formation is exposed which consists of silty clay shale, shaley siltstone, and organic sandstone. Finally Town Branch drainage traverses the Mississippian Pitkin Formation, ultimately joining Town Branch in the Fayetteville Formation.

5.5.5 Soils

The Soil Conservation Service has described the soils of Washington

County, and has defined them according to surface soil type, subsoil composition, soil depth, slope, acidity, runoff, erosion hazards, and available water capacity (USDA, 1969).

There are two surface soil types in the Town Branch drainage basin, silty loam found on 0-3 percent slopes and stony gravel loam found on 3-20 percent slopes. The silt loams have an average depth of 16 inches. The subsoil is plastic clay or silt loam which has an average depth of 12 inches. These soils are slightly to moderately acid. Flooding is an extreme hazard, as the soils are shallow, collect water and, because of the plastic clay subsoil, do not dry quickly. The stony gravel loams have an average depth of 8 inches. The subsoil is plastic clay or stony gravel silt loam which has an average depth of 60 inches. There is a large percentage of stone material in these soils and they are strongly acid. The runoff is rapid, the erosion hazard is severe to very severe, and the available water capacity is low because of the large amounts of rock material in the soils.

The soils of the control stream drainage basin are primarily stony loams with an average depth of 10 inches. The subsoils are clay loam, silt loam, or plastic clay with an average depth of 60 inches. The soils are strongly acid. Runoff is rapid and the erosion hazard is severe to very severe.

The depth to bedrock within the drainage basins is 3 to 10 feet with an average of 8 feet.

5.5.6 Land Use

Three types of land use in the study watersheds are detectable on LANDSAT imagery (Fig. 75): Level 1-01, Urban and Built-Up Land, Level 1-02, Agricultural Land, and Level 1-04, Forest Land.

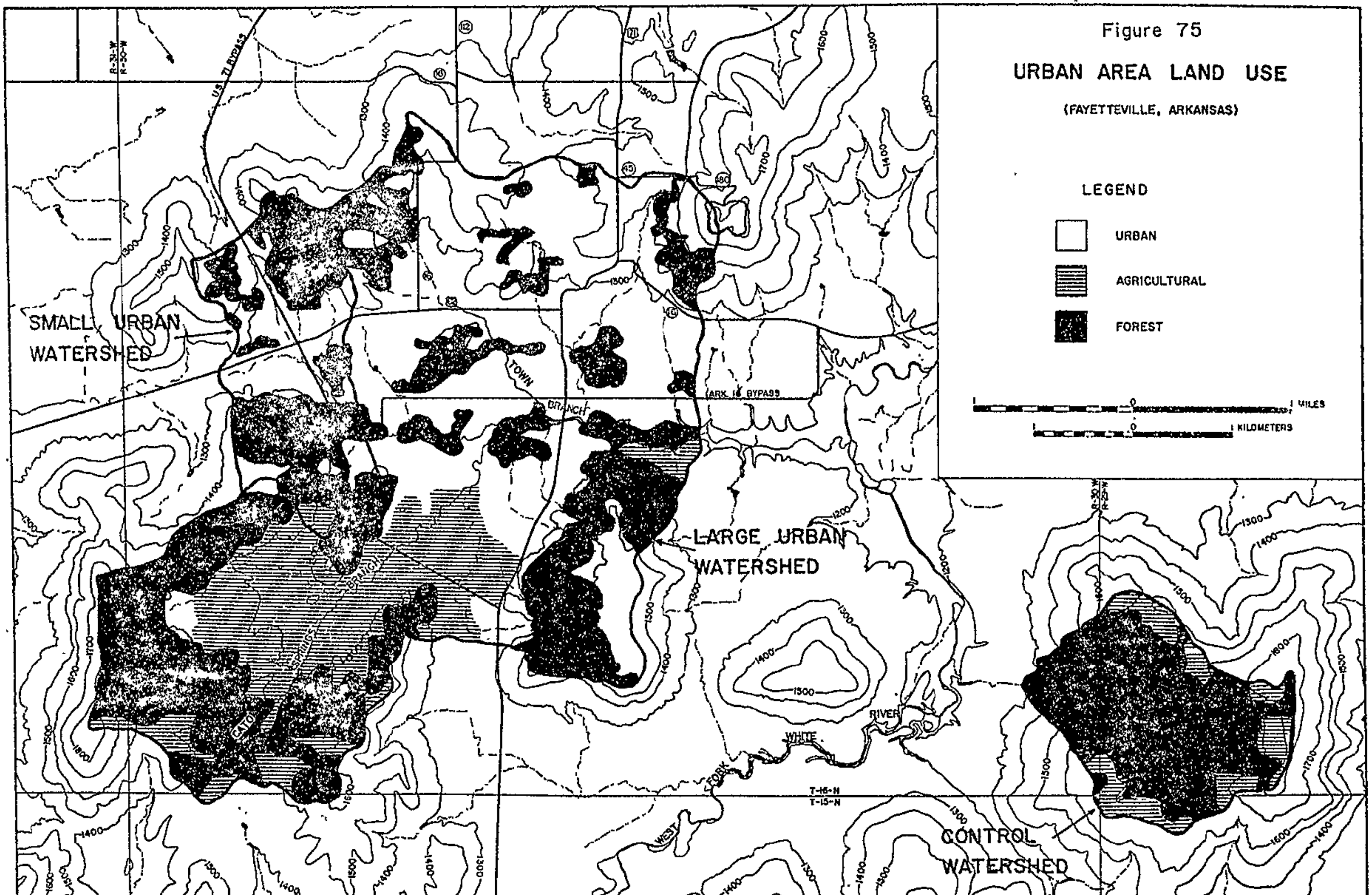


Figure 75
URBAN AREA LAND USE
(FAYETTEVILLE, ARKANSAS)

The control watershed contains 81 percent (948 acres) forest land and 19 percent (222 acres) agricultural land.

The small urban watershed contains 36.6 percent (401 acres) urban land, 0.2 percent (23 acres) agricultural land, and 63.2 percent (701 acres) forest land. The large urban watershed contains 35 percent (2,620 acres) urban land, 17 percent (1,310 acres) agricultural land, and 48 percent (3,622 acres) forest land.

5.5.7 Rainfall

Monthly rainfall values were gathered during the study period by the National Oceanic and Atmospheric Administration (see section 5.4.7 and Fig. 69).

5.5.8 Methodology

Samples were collected during storm events and at times of base flow. The sampling methods used were identical to those described in section 5.4.8. Sampling during storm events was attempted during the peak of flow but because of the difference in lag time at the three sites, the distance between the sites, and the rapid peak of flow at all sites, the samples usually were collected after the peak of flow.

5.5.9 Data Interpretation

Various water quality parameters (Table 17) were studied from collections made at the sampling sites at the control watershed (CS), large urban watershed (TC), and small urban watershed (TC-71).

In general, the urban watersheds yielded higher values for almost all water quality parameters. Samples collected during high flow periods were found to have greater values except when affected by dilution. On April 20, 1976, flooding of the West Fork of the White River made the

Table 17. Sample data for control stream (CS), large urban stream (C), and small urban stream (TC-71).

Date of collection	Time of collection	Location	Flow (cfs)	Fecal Coliform (#/100ml)	Temperature (°C)	Specific Conductance (micromhos at 25°C)	Turbidity (FTU)	Nonfilterable Solids	pH	Total Alkalinity	Chloride (Cl)	Sulfate (SO_4)	Orthophosphate soluble (PO_4)	Nitrate (NO_3) as N	Sodium (Na)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)	Iron (Fe)	Manganese (Mn)	Arsenic (As)
10/28/75	10:30am	control	<0.5	30	16.0	175	3.8	-	7.4	50	7.5	8	-	-	4.05	1.23	3.01	21.48	<0.010	<0.002	<0.5
		TC	1.3	2,950	17.0	260	8.4	-	7.5	120	20.0	12	-	-	16.70	4.39	8.24	55.69	<0.010	0.004	<0.5
		TC-71	<0.5	540	17.0	245	7.8	-	7.2	100	25.0	17	-	-	24.20	4.02	16.74	56.22	<0.010	<0.002	<0.5
11/3/75	11:00am	control	1.0	40	16.5	135	2.8	2.0	7.1	60	10.0	8	-	-	4.70	1.42	3.40	22.80	0.014	<0.002	<0.5
		TC	3.6	4,500	17.0	280	47.5	40.0	7.6	120	20.0	10	-	-	15.80	3.38	6.70	44.66	<0.010	<0.002	<0.5
		TC-71	1.6	1,200	18.0	480	2.4	4.0	7.1	110	27.5	11	-	-	28.90	4.29	19.53	63.47	0.012	<0.002	<0.5
2/5/76	3:00pm	control	<0.5	70	6.0	180	3.6	0.9	7.8	35	10.0	18	0.06	0.15	3.87	10.30	2.37	17.80	0.105	<0.005	<0.2
		TC	1.2	3,800	5.0	290	4.6	5.6	7.7	117	30.0	65	0.10	0.50	17.10	3.47	8.57	14.40	0.051	0.494	<0.2
		TC-71	0.5	650	5.0	260	5.0	13.5	7.6	75	35.0	225	0.35	0.26	34.80	2.49	18.30	14.40	0.279	0.189	<0.2
3/29/76	2:30pm	control	1.3	50	12.0	145	8.7	2.2	7.4	40	8.5	17	0.00	0.12	3.38	1.01	2.08	18.10	0.141	<0.006	<0.2
		TC	18.0	57,500	13.0	266	65.0	62.7	7.8	100	12.5	33	0.06	0.16	11.80	2.52	7.12	45.20	0.101	0.296	<0.2
		TC-71	6.0	2,160	15.0	285	52.0	21.2	7.6	50	10.0	37	0.02	0.08	14.80	1.55	9.70	28.70	0.126	0.076	1.1
4/20/76	2:30pm	TC	39.0	51,300	12.0	205	93.0	182.0	6.8	30	5.0	17	0.16	0.20	3.24	3.16	2.34	13.22	0.472	0.139	1.4
		TC-71	13.0	4,075	12.0	275	66.0	66.0	6.7	25	6.0	140	0.05	1.00	4.71	2.04	3.86	13.63	0.532	0.132	<0.3
5/23/76	7:30pm	control	1.1	300	16.0	160	18.0	15.0	6.9	44	8.0	38	0.03	1.75	3.38	1.11	2.27	16.82	0.185	0.025	2.8
		TC	4.2	29,800	17.0	230	65.0	351.0	7.4	88	21.0	200	0.37	20.00	11.29	2.56	6.63	40.11	0.034	0.146	1.4
		TC-71	1.9	980	17.0	270	5.3	15.0	7.2	88	21.0	200	1.70	0.33	31.78	2.82	17.21	52.11	0.037	.264	<0.3
6/14/76	2:30pm	control	<0.5	20	21.0	170	4.3	5.5	7.3	61	7.6	25	0.02	0.15	4.25	1.08	2.87	21.23	0.031	0.009	<0.3
		TC	1.3	3,500	21.0	280	12.0	16.5	7.6	117	20.5	68	0.04	0.48	29.62	2.66	7.34	44.11	0.031	0.241	<0.3
		TC-71	<0.5	440	21.0	255	11.0	24.5	7.3	108	14.4	237	0.03	0.58	14.98	3.05	18.68	56.11	<0.010	0.225	-

Data given in mg/l, unless otherwise indicated.

control site inaccessible.

5.5.10 Physical Parameters

The values of pH ranged from 6.7 to 7.8 with an average of 7.4. The large urban site generally had the highest values, and the small urban site had consistently low values, as would be expected upon consideration of the geology of the watersheds. The control stream had intermediate values (Fig. 76).

Specific conductance values ranged from 135 to 480 micromhos at 25^{o}C. The control site values were lower than those from the urban sites. Slight trends were observed in the urban watersheds. The large urban watershed had higher values than the small urban watershed during periods of low flow, and the small urban watershed had higher values than the large urban watershed during periods of high flow (Fig. 76).

Values for turbidity ranged from 2.8 to 66 FTUs. In all except two instances, the control site had lower values than the small urban site; the large urban watershed always had the largest values. The values had no pronounced patterns in relation to flow or between stations.

The values for nonfilterable solids ranged from 0.87 to 182 mg/l. The control values were lower than those from the urban sites. The inconsistant patterns possibly can be attributed to collection after peak storm flow.

The values for temperature ranged from 5 to 21^{o}C. The control values were generally 1 to 2^{o} lower than the values from the urban sites, perhaps because of foliage shading or the influence of groundwater.

Stream flow ranged from less than 0.5 to 39 cfs. The control value was equal to the small urban site value at base flow, and was less than

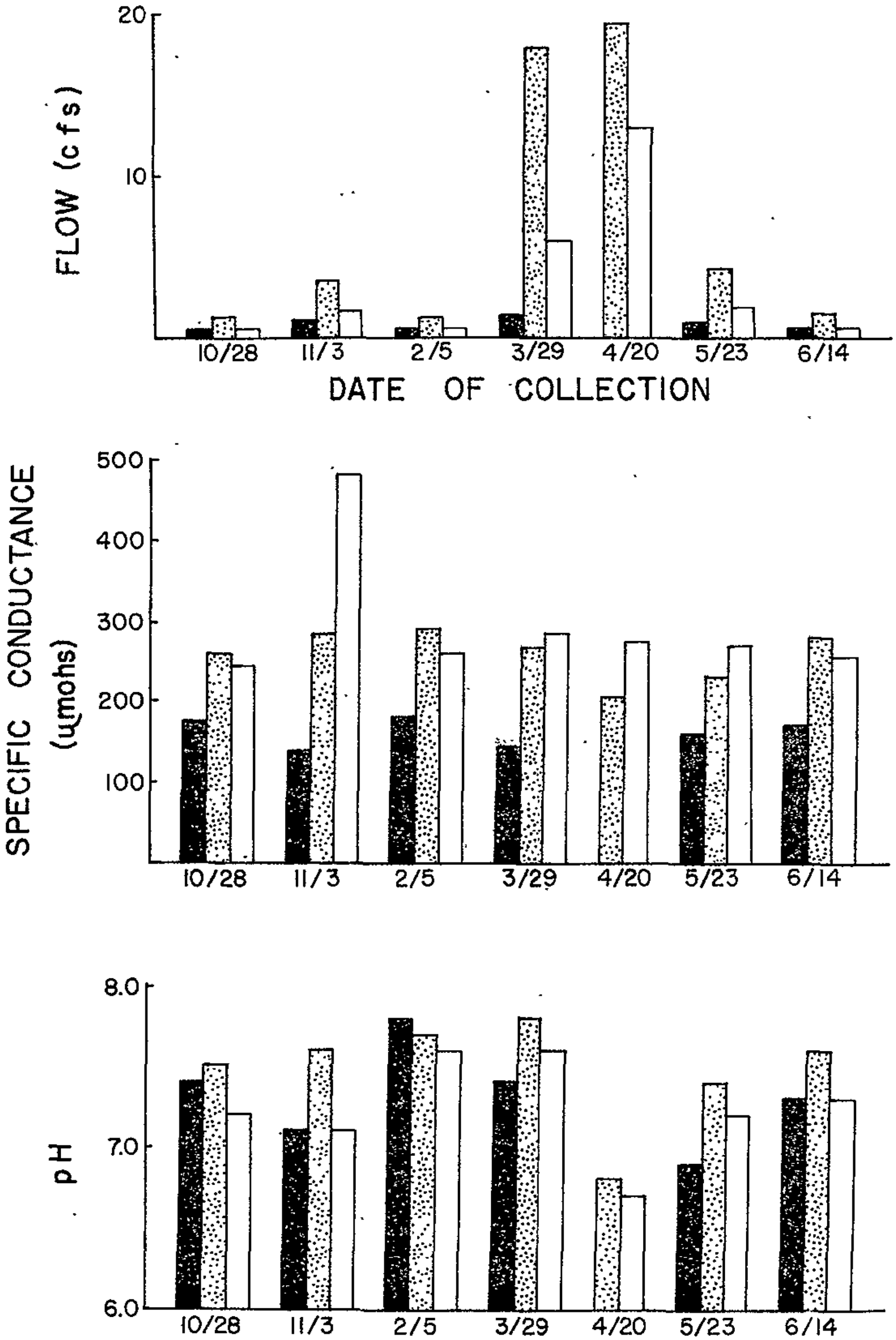
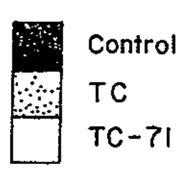


Figure 76. Streamflow, specific conductance, and pH values.



the small urban site value during storm events, as expected, even though the two drainage areas are approximately equal. The total urban watershed had the highest flow. The fact that the amount of runoff is greater in the urban test areas is attributable to the soil type and a smaller percentage of foliage there.

5.5.10.1 Nutrients

The range of values of orthophosphate (PO_4) was from 0.0 to 1.7 mg/1. The control value was lower than the urban test site values, although not always exceedingly lower. The values were not as high as expected for an urban area containing so much agriculture and maintained residential land, perhaps because of the percentage of agricultural area at the control contributing to the PO_4 content, and the collection of samples after peak storm flow (Fig. 77).

The values of nitrate (NO_3) were from 0.1 to 1.75 mg/1. There was no pronounced pattern for the data, as the control data were alternately low and high in comparison with the urban data, without regard to flow. This uncertainty was enhanced by the unavailability of data (Fig. 77).

5.5.10.2 Macroparameters

There was a wide range between the maximum and minimum values for total alkalinity, chloride (Cl), and sulfate (SO_4). For all three parameters, the control site values were lower than the urban site values. This finding is contrary to what would be expected for alkalinity, because the control watershed's geology suggests a calcium content higher than that in the small urban site. Urban-induced calcium is indicated. It is interesting to note that in the urban area streets are graveled with

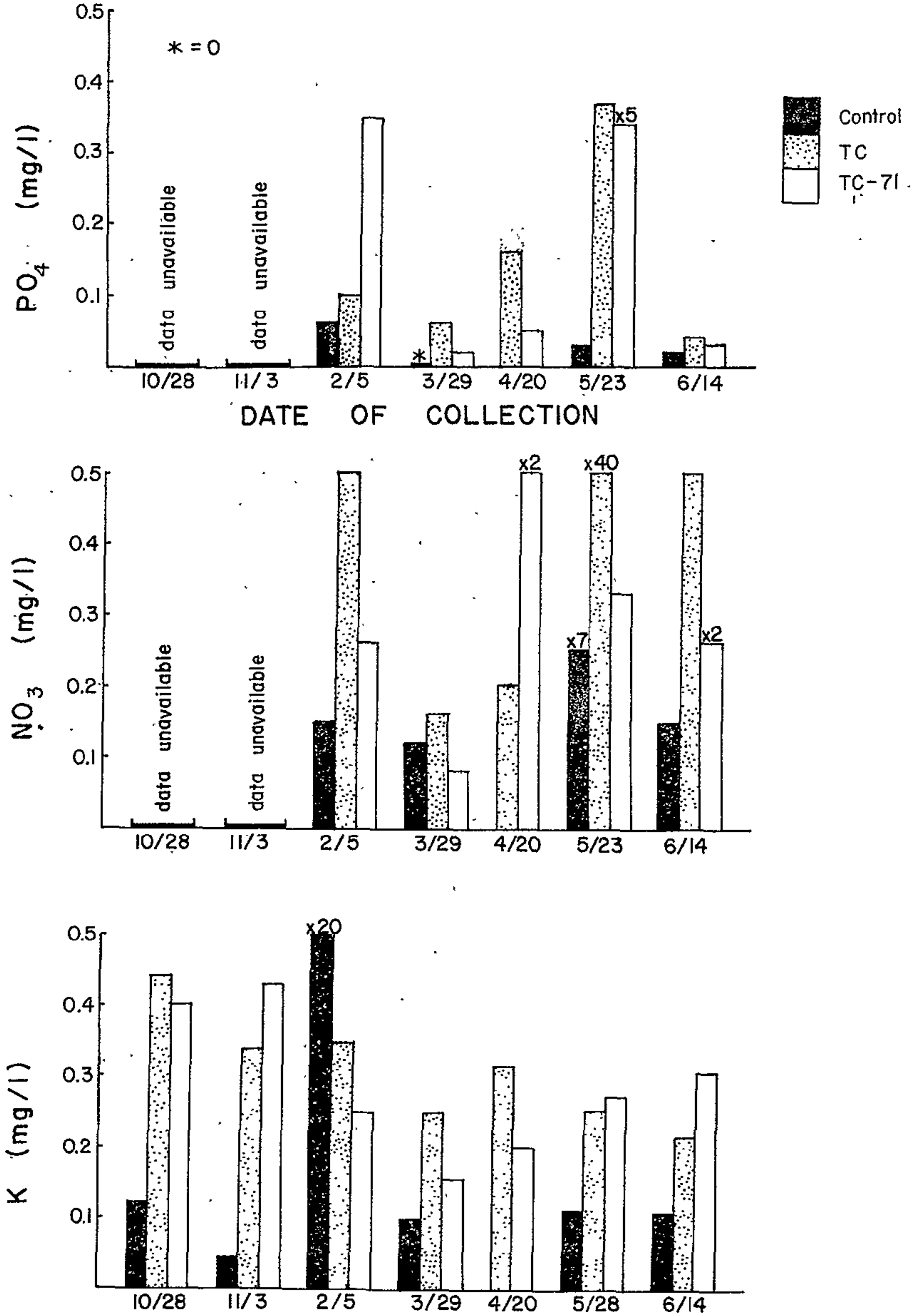


Figure 77. Orthophosphate, nitrate, and potassium values.

limestone in the winter and lawns are limed in the summer; these activities would provide possible sources of urban calcium. High values of SO_4 for the small urban watershed are probably due to exposure of the Fayetteville Formation at an excavation near the sampling site (Fig. 78).

5.5.10.3 Microparameters

The values of sodium (Na), potassium (K), and calcium (Ca) showed a wide range. The control site values were lower than the urban site values for all three parameters. The small urban watershed values were many times larger than the control site values. The calcium values were consistent with the alkalinity values. An anomalous high value for K at the control site on February 5, 1976, cannot be explained (Figs. 77, 79).

Magnesium (Mg) values covered a wide range. The control site had the lowest values and the small urban site had the highest values (Fig. 79).

The iron (Fe) values had a wide range, with no correlation to flow or to individual sampling sites.

The ranges of values for manganese (Mn) and arsenic (As) were very broad. There was only a trace of both at the control site, although there were relatively high values at both urban sites; Mn was always present at the urban sites and As showed high concentrations during spring months.

5.5.10.4 Biological Parameters

Fecal coliform concentrations ranged from 20 to 300 mg/l in the control stream, from 440 to 4,075 mg/l in the small urban watershed, and from 2,950 to 57,500 mg/l in the total urban watershed. The urban sites'

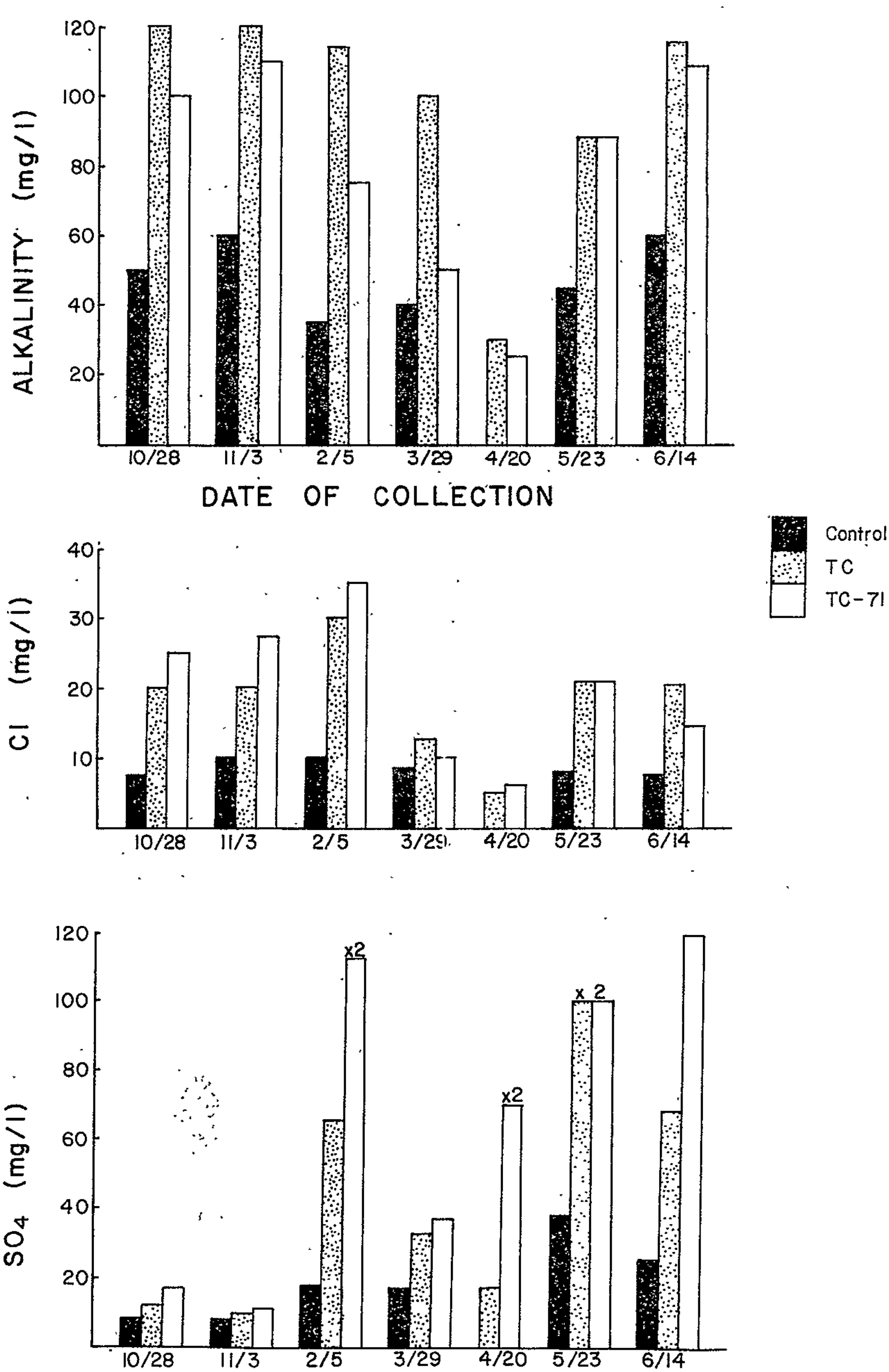


Figure 78. Total alkalinity, chloride, and sulfate values.

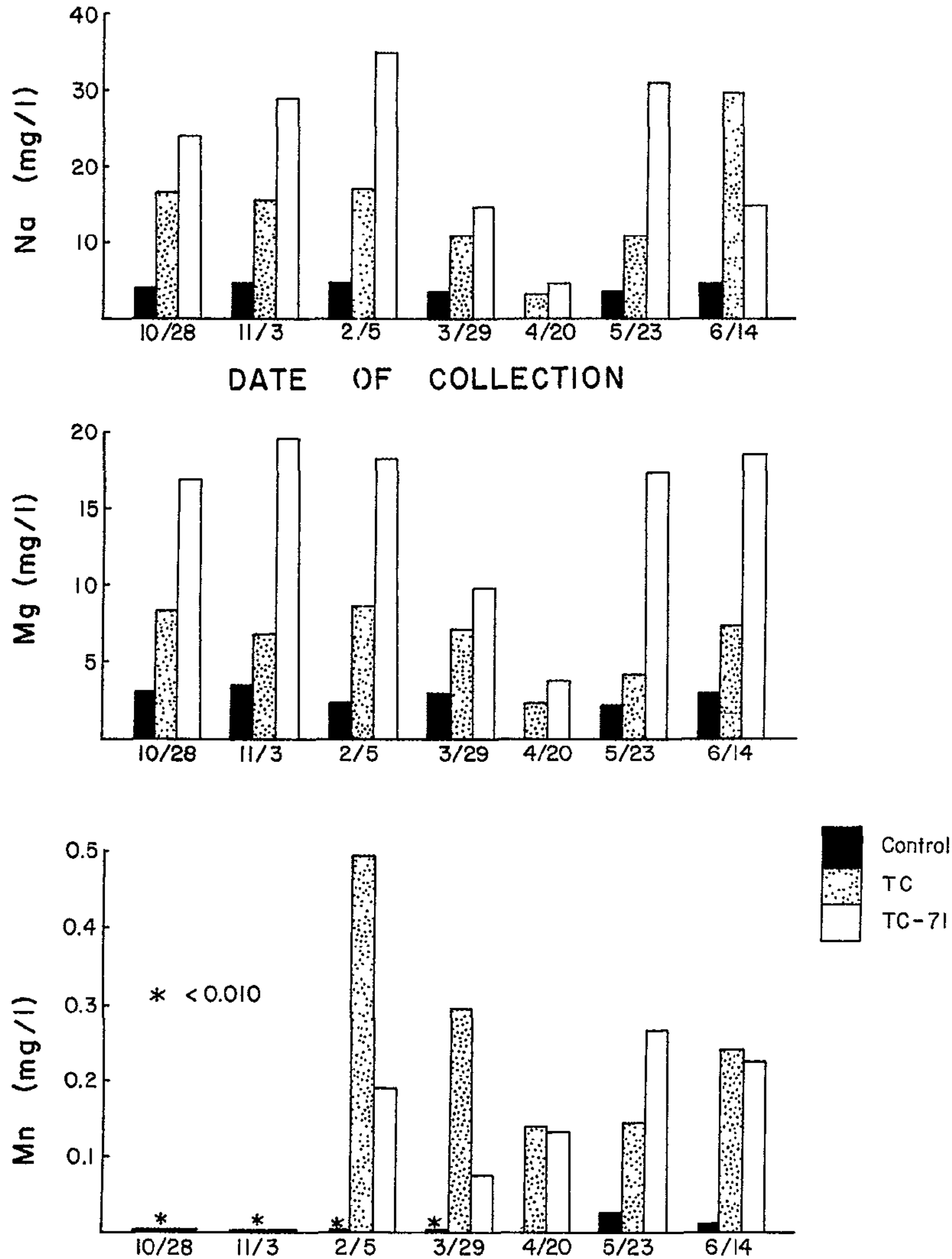


Figure 79. Sodium, magnesium, and manganese values.

levels were higher during all flow periods, and were highest during storm events. The control level was abnormally high during the highest flow periods, perhaps because of livestock in the control stream watershed. There is a direct correlation between fecal coliform and flow (Fig. 80).

5.5.11 Conclusions

Because the small urban watershed and the control watershed are approximately the same size and are similar geologically, their parameter values were compared to find possible indicators of contrasting land usage. The large urban area was used to show relative changes in a large urban area.

It was shown that the small urban area values for specific conductance, orthophosphate, total alkalinity, chloride, sulfate, sodium, potassium, magnesium, manganese, and fecal coliform were significantly higher than those of the control watershed. It must be concluded, therefore, that these would be indicators of urban land use change in this area. Urban activities consisting of construction, lawn and garden fertilization, industry, and human waste disposal are prime contributors to the introduction of the aforementioned materials into the natural water system.

An important factor of urbanization shown by this study is the extreme amount of fecal coliforms found in the urban stream. The Arkansas Department of Pollution Control and Ecology has determined a total coliform standard of 5000/100 ml for the White River Basin. This standard value is lower if the water is to be used for recreational purposes (ADPC&E bases this standard on total coliform, of which fecal coliform is only a part; see section 5.4.9.5). Yet, in this area, fecal coliform was found to be as much as 10 times the standard safe total coliform values during storm events, thereby indicating the drastic effect of urbanization on the

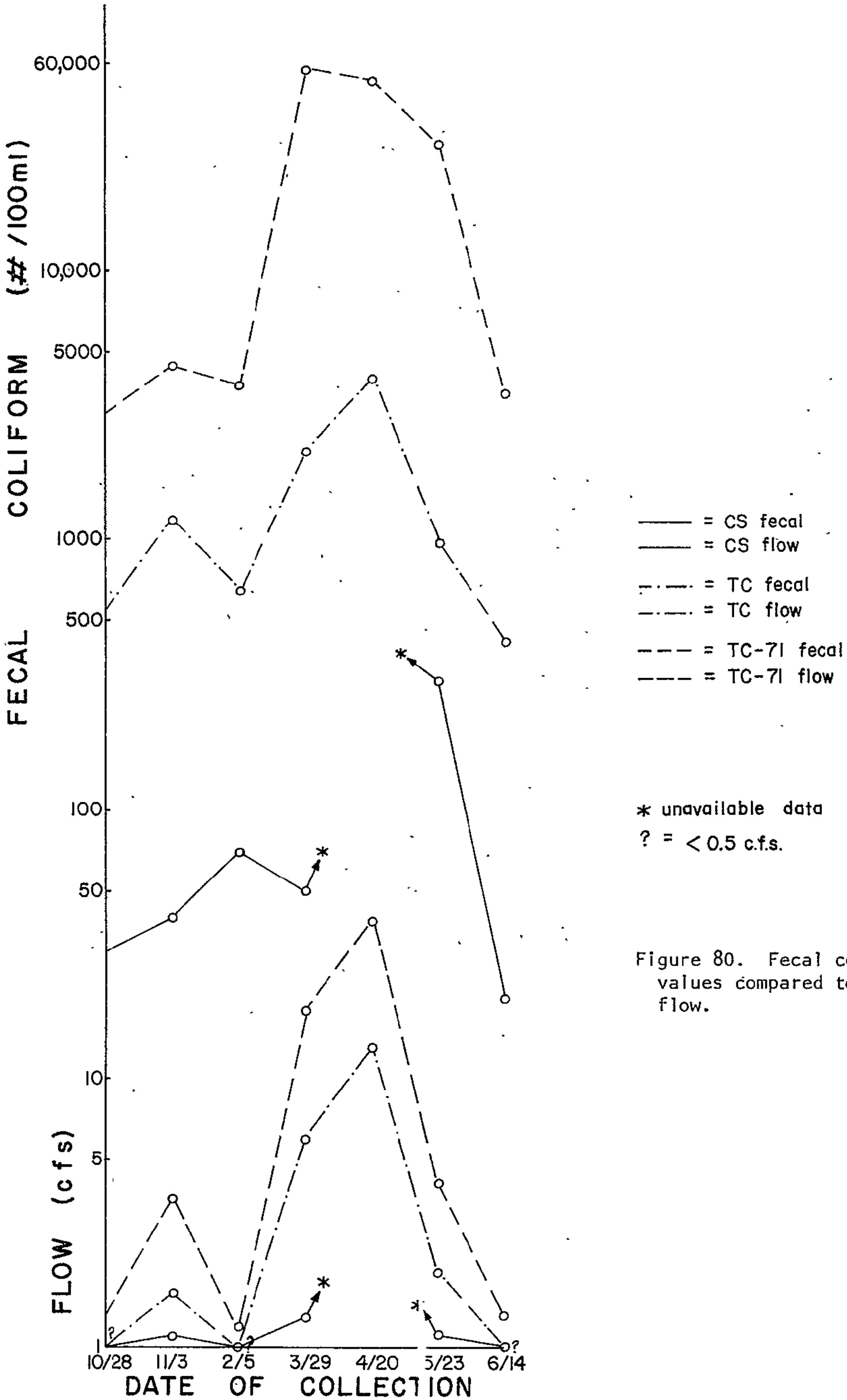


Figure 80. Fecal coliform values compared to streamflow.

fecal coliform content of natural waters.

Because most of the parameters studied were found to have higher values in the urban watersheds than in the control watershed, it is obvious that a water quality change due to a change in the land use by urbanization has occurred. These changes were seen at high flow even though most parameters show evidence of dilution caused by collection of samples as peak flow was diminishing. Although sampling prior to peak flow was impossible in most instances, all fecal coliform values show a continuous input into the water during storm events. This finding indicates that the fecal coliform of the peak flow was extremely concentrated. Fecal coliform is the best indicator for land use change due to urbanization in this area.

SECTION 6

IMPLEMENTATION AND COST EFFECTIVENESS

Though population growth may be healthy for the nation's economy, the attendant construction of new roads, homes, and shopping centers on a local level and the change of land usage from forest or other natural terrain can create trouble for streams and reservoirs that are expected to supply drinking water and provide recreation. As a stream moves toward a reservoir, for example, its collection of dissolved load, suspended solids, organic matter, and nutrients from nonpoint sources can cause problems that will remain even though advanced waste water treatment facilities are discharging clean water into the same stream. In fact, if greater attention is not given to land use as a component of most water quality management systems, the benefits of tertiary waste treatment may be offset by pollution from surface runoff.

During the conduct of this research program, two serious problems were encountered in the investigation of the effect of changing land use on water quality. First was the lack of historical water quality data that could be related to surface runoff, and second was the almost total absence of any program on the local, state, or federal level which might aid in understanding the complex interrelationships between land usage and environmental factors that influence nonpoint source pollution. Routine periodic stream sampling does not give satisfactory values of pollution loadings carried. For specific examples, nutrients, suspended sediments, and coliform counts may increase tremendously during storm events, but could be insignificant during low flow. Water quality monitoring should include a proportional sampling of storm events and, because there is no way a single sample can represent a particular storm event, sampling must be coordinated with hydrograph positioning.

The Federal Water Pollution Control Act, as amended in 1972, now requires that nonpoint sources of water pollution be considered in the development of water quality management proposals for both local and regional planning. Thus, planning agencies need an inexpensive and reasonably accurate method of estimating nonpoint source pollution loading. The potential impact of changing land use on water quality should be one of the concerns for any monitoring system. On the basis of the results of this research program, it is obvious that LANDSAT imagery change detection analysis provides a relatively inexpensive method for monitoring land use changes. If it is assumed that the level of nonpoint pollution is dictated by the manner in which the land is used and by the kinds of pollutants generated, then LANDSAT appears to provide at least half the information needed. The advantages of using LANDSAT data are measured not only in dollars saved, but more importantly in time saved.

In southwestern Arkansas, within the Cossatot River watershed, extensive clearcutting was the major land use change detected by comparing LANDSAT-1 and -2 imagery. The Cossatot is approximately 70 miles long, and its watershed is approximately 529 mi^2. The techniques used for change detection mapping are described in Section 5 of this report. If it is assumed that water quality conditions present in a stream are the result of the types and levels of land use on the watershed contributing the streamflow, then cost effectiveness of obtaining the land use data from various sources can be addressed. Cost comparison estimates have been made for land use analysis (scale 1:125,000) by conventional methods, U-2 photography, and LANDSAT imagery.

Cost comparison estimates can be made for land use analysis (scale 1:125,000) by means of conventional black and white photographs (1:20,000), U-2 color IR photographs (1:120,000), and LANDSAT imagery color composites (1:1,000,000). If all of the imagery sources were available, the single LANDSAT scene covering the Cossatot watershed would be by far the most economical data base ($15.00 for the LANDSAT composite in contrast to $450.00 for the large-scale photographs). However, the primary advantage of using LANDSAT imagery for clearcut change detection is in the saving of interpretation time. For the Cossatot watershed, trained interpreters can map and transfer the land use categories to a usable base map in approximately 20 hours. The same task with U-2 photographs would take approximately 35 hours, and the analysis and transfer would take about 100 hours with large-scale photographic interpretation. Not only can a LANDSAT land use map be obtained in a time effort at least five times as fast as normal, but LANDSAT also provides a built-in capability for quick, inexpensive updating as future imagery becomes available. Though the cost effectiveness of LANDSAT-derived land use data can be demonstrated, the future utility of such information in water quality monitoring for nonpoint source pollution has tremendous potential.

In Arkansas, during the 1975 water year, 123 gauging stations were monitored for water quality information. Depending on the parameters measured, the cost of station operation, collection, and water analysis ranged from about $3500 to $12,000 per station. Most of the water quality samples were collected during low flow steady-state conditions which unfortunately tell little about nonpoint source pollution. When the inadequacy of these data for nonpoint source pollution monitoring are fully realized, and when the full impact of EPA-208 nonpoint water quality planning requirements are recognized by local, state, and federal agencies, the true cost effectiveness of LANDSAT change detection mapping will become obvious.

The positioning of water quality monitoring stations to address the nonpoint source pollution problem should be determined ultimately by diversification of land use, geology, soils, topography, and other parameters. Inferences about water quality based primarily on such parameters as these may provide a suitable mechanism for predicting non-point pollutant sources, thus precluding a costly extensive monitoring network. Despite the lack of significant data relating surface runoff and storm-event water quality sampling, it appears that LANDSAT land use change detection mapping can provide an indication of overall water quality, and also a reliable mechanism for predicting areas that may eventually cause problems.

SECTION 7

SUMMARY

The hypothesis of this LANDSAT research proposal was that the quality of surface water at any given point within a watershed might be recognized as an excellent indicator of land use above that point. Conversely, the updating of LANDSAT-derived land use maps would provide a technique for defining, monitoring, and predicting changes in regional water quality. The overall objective of the research program was to compare gross water quality data with gross changes in land use.

Two obvious approaches were used in evaluating LANDSAT applicability for land use change detection. The first consisted of analyzing LANDSAT 1-2 imagery for changes in land use and then evaluating the areas on the basis of historical water quality. The second method provided for an evaluation of all historical water quality records, and location of anomalous changes or trends according to sample site to determine whether any land use change has occurred.

Water quality information for select Arkansas streams has been collected and published annually by federal and state agencies since 1944. States having large urban populations generally have monitoring programs that are more comprehensive and predate those of Arkansas. The apparent abundance of readily available water quality information that might be correlated with a multitude of environmental parameters appeared to provide an adequate data base for comparing variation in water quality with LANDSAT-derived land use changes.

Comparison between LANDSAT-1 and LANDSAT-2 imagery of Arkansas provided evidence of significant land use changes; however, water quality

records were not available in areas of maximum change. Sparse water quality records for Arkansas did not reveal favorable sites where land use change may have taken place; however, seven stations on Arkansas streams had enough historical data to allow investigation of the effect of different land uses on water quality. Data for these seven stations provide sufficient evidence to suggest the impact of surrounding land use on water quality, and to emphasize the importance of sampling in conjunction with hydrograph analysis.

In two areas (Buffalo River and DeGray Reservoir) where extensive water quality monitoring was being conducted during the LANDSAT investigation, land use changes were not significant. However, storm hydrographic water quality data for the Caddo River (DeGray Reservoir study) emphasized the fundamental importance of sampling streams during time of maximum surface runoff.

On the basis of the preliminary data analysis, it became evident that water quality samples collected during storm events would be indicative of surface runoff and land use. To confirm this assumption, two water quality sampling programs were conducted during periods of both low flow and storm events. These programs provided conclusive evidence as to the extremely variable nature of the rate and quality of land runoff. Among the more important variables that control runoff water quality are rainfall intensity and duration, antecedent conditions, and the type of land use.

Processing of all Arkansas water quality data published since 1944 revealed that only 7 percent of more than 200 stations have been in operation since 1964, and those having sufficient historical records provided data on parameters that have little relevance in identifying nonpoint source pollution. In the past, many of the water quality data that have been collected were not utilized to full potential and as a consequence, gaps in data gathering apparently have not been realized. It became obvious during the conduct of this investigation that past and present water quality monitoring programs have been hindered by the lack of a true realization of data needs, and lack of recognition of the potential for obtaining proper data. A few monthly samples taken without regard for rainfall, positioning on the stream hydrograph, and more importantly the parameters indicative of surface runoff tell very little about the water quality of a stream.

Land use now is recognized as the dominant overall influence affecting the quality of surface waters for much of the United States. Land and water no longer are considered to be independent components of the landscape. Though point source pollution has received considerable public attention in the past two decades, more complex diffuse or nonpoint pollution has been essentially ignored. With the exception of specific inputs such as irrigation return flows, surface mine drainage, and subsurface flow, most of the total contribution of nonpoint pollutants results from surface runoff. If greater attention is not given to land use as a component of any water quality management system, the benefits of tertiary and advanced waste treatment may be offset by pollution from surface runoff.

Nonpoint sources of pollution can be enormously great in number, yet rarely are cited as pollution sources to streams and rivers. The expense of monitoring all nonpoint sources in all river basins can be lessened by monitoring land use changes with LANDSAT imagery. What is urgently needed is initiation of water quality monitoring programs in which specific considerations are given to the hydrograph. The design of a monitoring network based on point sources alone can provide only partial information. Stormwater quality analyses should be undertaken on those stream segments where land usage indicates a significant impact. The consideration of storm runoff is essential for determining critical conditions.

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APPENDIX

MULTIVARIABLE ANALYSIS FOR THE RED RIVER, CADDO RIVER, ST. FRANCIS RIVER AND WHITE RIVER STATIONS.

UNCLASSIFIED

STERSTER DATA ANALYSIS

REGRESSION WITH ITEM DELETION

CADOGLEN DATA ANALYSIS

PROBLEM NO. 1

VARIABLES DATA

OBSERVATIONS DATE

GRAND TOTAL MATRIX

DELETED DATA VALUE IS 0

VARIABLE CODE DATA	SAMPLE SIZE	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
FLOW	5	4287.79688	4778.73828	1.04123	-0.47240
TOTRES	5	224.34999	119.57339	1.26276	-0.08433
TOTHARD	5	66.11996	33.76492	0.46154	-1.28437
PH	5	7.07399	0.58213	0.44845	-1.21396
TURB	5	85.20000	103.78197	1.46649	0.20329
SC	5	113.20000	48.48401	0.66537	-0.86818
BOD	5	1.69600	0.74262	0.20951	-1.22978
TOTNO3	5	0.25400	0.12402	0.05121	-1.46596
TOTCOL	5	5934.19922	12337.69141	1.49846	0.24795
FE	5	1239.00000	699.64624	0.84048	-0.42654
DO	5	9.60000	3.08788	-0.08287	-1.46223

UNCLASSIFIED

CADDOGLEN DATA CORRELATION

REGRESSION WITH ITEM DELETION

CADDOGLEN DATA ANALYSIS

PROBLEM NO. 1

VARIABLES DATA

OBSERVATIONS DATF

GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
DO	TURB	16	-0.08110	10.23860	-0.01572	0.05163
DO	SCOND	16	-0.73528	12.73960	-0.03544	0.00873

UNCLASSIFIED

CADDOGLEN DATA CORRELATION

REGRESSION WITH ITEM DELETION

CADDOGLEN DATA ANALYSIS

PROBLEM NO. 1

VARIABLES DATA

OBSERVATIONS DATE

GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
SS	DS	10	-0.14570	20.39182	-0.11602	0.27853
SS	CAL	10	0.08963	9.94804	0.31573	1.24043
SS	PH	10	0.18606	-60.49986	10.27777	19.18906
SS	TURB	10	0.46714	9.10049	0.75334	0.50413
SS	SCOND	10	-0.10066	16.93759	-0.04390	0.15343
SS	DO	10	-0.16094	29.68976	-1.63533	3.54556
DS	SS	10	-0.14570	61.87018	-0.18298	0.43926
DS	CAL	16	0.54479	27.92378	2.64125	1.08656
DS	PH	16	0.55306	-259.68945	43.79912	17.63399
DS	TURB	16	-0.15676	58.08310	-0.38060	0.64088
DS	SCOND	16	0.56667	30.93614	0.34219	0.13298
DS	DO	16	-0.51380	121.26775	-6.43648	2.87232
CAL	SS	10	0.08963	10.90650	0.02544	0.09996
CAL	DS	16	0.54479	4.32054	0.11237	0.04623
CAL	PH	16	0.75414	-78.16588	12.31878	2.86700
CAL	TURB	16	-0.52499	12.08843	-0.76292	0.11392
CAL	SCOND	16	0.87689	2.62627	0.10922	0.01600
CAL	DO	16	-0.55289	25.10663	-1.42861	0.57543
PH	SS	10	0.18606	7.15452	0.00337	0.00629
PH	DS	16	0.55306	6.81560	0.00698	0.00281
PH	CAL	16	0.75414	6.71658	0.04617	0.01074
PH	TURB	16	-0.30872	7.25960	-0.00946	0.00779
PH	SCOND	16	0.77594	6.77396	0.00592	0.00129
PH	DO	16	-0.71286	8.35078	-0.11276	0.02965
TURB	SS	10	0.46714	1.92950	0.28967	0.19384
TURB	DS	16	-0.15676	9.24895	-0.06456	0.10872
TURB	CAL	16	-0.52499	16.75607	-1.04831	0.45421
TURB	PH	16	-0.30872	78.20334	-10.06986	8.29159
TURB	SCOND	16	-0.38375	12.61075	-0.09544	0.06136
TURB	DO	16	-0.08110	9.88440	-0.41841	1.37441
SCOND	SS	10	-0.10066	81.41536	-0.23077	0.80647
SCOND	DS	16	0.56667	20.57056	0.93840	0.36467
SCOND	CAL	16	0.87689	-1.60767	7.04021	1.03142
SCOND	PH	16	0.77594	-660.25269	101.76108	22.11008
SCOND	TURB	16	-0.38375	81.76077	-1.54293	0.99231
SCOND	DO	16	-0.73528	227.88547	-15.25351	3.75774
DO	SS	10	-0.16094	10.11383	-0.01584	0.03434
DO	DS	16	-0.51380	12.44425	-0.04101	0.01830
DO	CAL	16	-0.55289	12.41946	-0.21397	0.08619
DO	PH	16	-0.71286	42.62524	-4.50655	1.18491

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CADOGLEN DATA ANALYSIS

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GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
FLOW	TOTRES	5	-0.23351	6381.98438	-9.33239	22.43584
FLOW	TOTHARD	5	-0.72766	11097.18750	-102.98541	56.04958
FLOW	PH	5	-0.05465	7461.25781	-448.60962	4732.39063
FLOW	TURB	5	-0.14862	4870.82813	-6.84312	26.28941
FLOW	SC	5	-0.61509	11150.52344	-60.62480	44.86774
FLOW	BOD	5	-0.13345	5744.28906	-858.78296	3682.01733
FLOW	TOTNO3	5	0.53519	-950.30078	20622.45703	18792.92969
FLOW	TOTCOL	5	-0.24051	4840.59766	-0.09316	0.21706
FLOW	FE	5	-0.20421	6015.93359	-1.39479	3.86033
FLOW	DO	5	-0.15811	6636.80078	-244.68803	882.25708
TOTRES	FLOW	5	-0.23351	249.45354	-0.00584	0.01405
TOTRES	TOTHARD	5	-0.29730	294.01343	-1.05284	1.95215
TOTRES	PH	5	-0.25823	599.61133	-53.04097	114.56879
TOTRES	TURB	5	0.95734	130.42395	1.10301	0.19222
TOTRES	SC	5	-0.35427	323.30469	-0.87372	1.33154
TOTRES	BOD	5	-0.14035	262.72827	-22.59926	92.04262
TOTRES	TOTNO3	5	0.58099	82.11577	560.17480	453.07837
TOTRES	TOTCOL	5	0.96840	168.70471	0.00939	0.00140
TOTRES	FE	5	0.96079	20.94998	0.16421	0.02736
TOTRES	DO	5	-0.84474	538.47603	-32.71107	11.96513
TOTHARD	FLOW	5	-0.72766	88.16519	-0.00514	0.00280
TOTHARD	TOTRES	5	-0.29730	84.95845	-0.08395	0.15566
TOTHARD	PH	5	0.50641	-141.66422	29.37297	28.87596
TOTHARD	TURB	5	-0.47915	79.40164	-0.15589	0.16487
TOTHARD	SC	5	0.97658	-10.86774	0.68010	0.08651
TOTHARD	BOD	5	-0.26259	86.36935	-11.93951	25.32944
TOTHARD	TOTNO3	5	-0.92411	130.02615	-251.59947	60.06793
TOTHARD	TOTCOL	5	-0.39657	72.56038	-0.00109	0.00145
TOTHARD	FE	5	-0.29169	83.56157	-0.01408	0.02665
TOTHARD	DO	5	0.37037	27.24173	4.04982	5.86418
PH	FLOW	5	-0.05465	7.10254	-0.00001	0.00007
PH	TOTRES	5	-0.25823	7.35610	-0.00126	0.00272
PH	TOTHARD	5	0.50641	6.49670	0.00873	0.00858
PH	TURB	5	-0.48913	7.30775	-0.00274	0.00282
PH	SC	5	0.67687	6.15402	0.00813	0.00510
PH	BOD	5	-0.31998	7.49941	-0.25083	0.42879
PH	TOTNO3	5	-0.62879	7.82369	-2.95156	2.10730
PH	TOTCOL	5	-0.43846	7.19676	-0.00002	0.00002
PH	FE	5	-0.04900	7.12451	-0.00004	0.00048
PH	DO	5	0.09930	6.89428	0.01872	0.10831

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GRAND TOTAL MATRIX

DELETED DATA VALUE IS 0

VARIABLE CODE DATA	SAMPLE SIZE	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
SS	10	13.50000	11.04788	0.97765	-0.61488
DS	16	55.93750	13.39885	-0.16092	-0.75176
CAL	16	10.60625	2.76368	0.47039	-0.05690
PH	16	7.20624	0.16919	-0.01490	-0.86285
TURB	16	5.63750	5.51855	2.47207	5.83547
SCOND	16	73.06250	22.18849	1.25195	0.74106
DO	16	10.14999	1.06958	0.02332	-1.04034

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GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
TOTCOL	TOTRES	7	0.06281	2158.39258	0.77928	5.53789
TOTCOL	TOTHARD	7	-0.58255	5328.06641	-18.63242	11.62592
TOTCOL	PH	7	0.19056	-11950.76953	1888.19897	4350.20703
TOTCOL	TURB	7	0.48673	1390.06177	7.02765	5.64055
TOTCOL	SC	7	-0.56208	4874.73438	-4.81734	3.17007
TOTCOL	BOD	7	-0.18613	3710.18555	-555.19751	1310.67236
TOTCOL	TOTNO3	7	0.26506	2147.27612	604.87305	984.03174
TOTCOL	FF	7	0.72498	804.10986	0.85103	0.36158
TOTCOL	DO	7	-0.22098	5746.33984	-371.73633	733.70313
FF	FLOW	7	0.91510	157.65601	0.05122	0.01009
FF	TOTRES	7	0.38237	-360.54370	4.04159	4.35782
FF	TOTHARD	7	-0.72430	5004.99829	-19.73505	8.40147
FF	PH	7	-0.01628	3225.15186	-137.38806	3774.58325
FF	TURB	7	0.74542	525.89063	9.16861	3.66675
FF	SC	7	-0.72400	4609.81250	-5.28602	2.25232
FF	BOD	7	-0.30676	3951.17554	-931.96094	1057.22144
FF	TOTNO3	7	0.38725	1543.68481	752.81396	801.55298
FF	TOTCOL	7	0.72498	529.57227	0.61761	0.26240
FF	DO	7	-0.20510	4615.21094	-293.91284	627.25635
DO	FLOW	7	-0.11284	8.51542	-0.00000	0.00002
DO	TOTRES	7	-0.71750	11.64744	-0.00529	0.00230
DO	TOTHARD	7	-0.34566	4.28923	-0.00657	0.00798
DO	PH	7	-0.84510	46.82300	-4.97803	1.40832
DO	TURB	7	-0.10220	8.49949	-0.00088	0.00382
DO	SC	7	-0.39116	9.26528	-0.00199	0.00210
DO	BOD	7	0.12199	7.92785	0.21631	0.78708
DO	TOTNO3	7	0.01741	8.32342	0.02361	0.60658
DO	TOTCOL	7	-0.22098	8.69031	-0.00013	0.00026
DO	FE	7	-0.20510	8.65244	-0.00014	0.00031

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TURB	FLOW	7	0.69198	55.27707	0.00315	0.00147
TURB	TOTRES	7	0.47365	-75.59123	0.40703	0.33847
TURB	TOTHARD	7	-0.68263	396.32397	-1.51217	0.72394
TURB	PH	7	0.03234	6.99574	22.19609	306.75781
TURB	SC	7	-0.69430	369.32837	-0.41213	0.19105
TURB	BOD	7	-0.28323	290.83325	-59.51337	88.60820
TURB	TOTNO3	7	0.88379	63.63292	139.68227	33.07161
TURB	TOTCOL	7	0.48673	89.40555	0.03371	0.02706
TURB	FE	7	0.74542	47.47772	0.06060	0.02424
TURB	DO	7	-0.10220	277.90723	-11.90671	51.83148
SC	FLOW	7	-0.67679	666.00635	-0.00519	0.00252
SC	TOTRES	7	0.21205	271.16772	0.30698	0.63271
SC	TOTHARD	7	0.99011	-69.21997	3.69498	0.23410
SC	PH	7	0.42468	-3332.61060	491.00513	468.11060
SC	TURB	7	-0.69430	671.72437	-1.16966	0.54221
SC	BOD	7	0.51827	116.78589	180.37971	133.11287
SC	TOTNO3	7	-0.50634	573.79297	-134.81842	102.68277
SC	TOTCOL	7	-0.56208	636.32520	-0.06558	0.04316
SC	FE	7	-0.72400	677.35938	-0.09916	0.04225
SC	DO	7	-0.39116	1103.38643	-76.77609	80.78415
BOD	FLOW	7	-0.48184	2.33413	-0.00001	0.00001
BOD	TOTRES	7	0.18302	1.44319	0.00076	0.00183
BOD	TOTHARD	7	0.59793	0.99533	0.00641	0.00384
BOD	PH	7	-0.18646	6.70648	-0.61939	1.45956
BOD	TURB	7	-0.28323	2.16338	-0.00137	0.00208
BOD	SC	7	0.51827	1.22932	0.00149	0.00110
BOD	TOTNO3	7	-0.19605	2.04199	-0.14998	0.33549
BOD	TOTCOL	7	-0.18613	2.08362	-0.00006	0.00015
BOD	FE	7	-0.36676	2.23078	-0.00014	0.00016
BOD	DO	7	0.12199	1.34463	0.06879	0.25032
TOTNO3	FLOW	7	0.37800	0.39672	0.00001	0.00001
TOTNO3	TOTRES	7	0.33608	-0.31818	0.00183	0.00229
TOTNO3	TOTHARD	7	-0.51576	1.86380	-0.00723	0.00537
TOTNO3	PH	7	0.13484	-3.70317	0.58552	1.92417
TOTNO3	TURB	7	0.88379	-0.17568	0.00559	0.00132
TOTNO3	SC	7	-0.50634	1.70306	-0.00190	0.00145
TOTNO3	BOD	7	-0.19605	1.31452	-0.25627	0.57323
TOTNO3	TOTCOL	7	0.26506	0.51563	0.00012	0.00019
TOTNO3	FE	7	0.38725	0.39196	0.00020	0.00021
TOTNO3	DO	7	0.01741	0.71581	0.01283	0.32962
TOTCOL	FLOW	7	0.42168	1560.18555	0.02770	0.02664

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DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
FLOW	TOTRES	7	0.38001	-5656.74609	71.76785	78.12308
FLOW	TOTHARD	7	-0.69031	87549.87500	-336.06104	157.52161
FLOW	PH	7	-0.07473	126262.68750	-11271.10156	67261.87500
FLOW	TURB	7	0.69198	12000.97266	152.07455	70.95181
FLOW	SC	7	-0.67679	80022.06250	-88.28645	42.94829
FLOW	BOD	7	-0.48184	81129.37500	-21876.84766	17792.02734
FLOW	TOTNO3	7	0.37800	28353.40234	13179.55078	14381.06641
FLOW	TOTCOL	7	0.42168	22180.28906	6.41847	6.17223
FLOW	FE	7	0.91510	3789.08594	16.35031	3.22202
FLOW	DO	7	-0.11284	63261.82813	-2889.26245	11377.65625
TOTRES	FLOW	7	0.38001	545.63721	0.00201	0.00219
TOTRES	TOTHARD	7	0.22777	539.87915	0.58715	1.12251
TOTRES	PH	7	0.46509	-2246.68555	371.42505	316.17480
TOTRES	TURB	7	0.47365	526.00415	0.55118	0.45833
TOTRES	SC	7	0.21205	556.63354	0.14647	0.30189
TOTRES	BOD	7	0.18302	540.01196	43.99965	105.69731
TOTRES	TOTNO3	7	0.33608	573.56689	61.81096	77.46658
TOTRES	TOTCOL	7	0.06281	611.03955	0.00506	0.03597
TOTRES	FE	7	0.38237	546.17700	0.03617	0.03909
TOTRES	DO	7	-0.71750	1436.00244	-97.27779	42.23366
TOTHARD	FLOW	7	-0.69031	199.52342	-0.00142	0.00066
TOTHARD	TOTRES	7	0.22777	88.82539	0.08836	0.16893
TOTHARD	PH	7	0.32791	-641.28101	101.58882	130.89020
TOTHARD	TURB	7	-0.68263	199.02805	-0.30816	0.14753
TOTHARD	SC	7	0.99011	21.19826	0.26531	0.01681
TOTHARD	BOD	7	0.59793	37.01230	55.76428	33.43066
TOTHARD	TOTNO3	7	-0.51576	174.27966	-36.79822	27.33638
TOTHARD	TOTCOL	7	-0.58255	192.17578	-0.01821	0.01136
TOTHARD	FE	7	-0.72430	201.50262	-0.02658	0.01132
TOTHARD	DO	7	-0.34566	295.67090	-18.17976	22.07137
PH	FLOW	7	-0.07473	7.74940	-0.00000	0.00000
PH	TOTRES	7	0.46509	7.36635	0.00058	0.00050
PH	TOTHARD	7	0.32791	7.57758	0.00106	0.00136
PH	TURB	7	0.03234	7.72158	0.00005	0.00065
PH	SC	7	0.42468	7.55998	0.00037	0.00035
PH	BOD	7	-0.18646	7.83768	-0.05613	0.13226
PH	TOTNO3	7	0.13484	7.70444	0.03105	0.10205
PH	TOTCOL	7	0.19056	7.67913	0.00002	0.00004
PH	FE	7	-0.01628	7.73417	-0.00000	0.00005
PH	DO	7	-0.84510	8.92694	-0.14347	0.04059

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GRAND TOTAL MATRIX

DELETED DATA VALUE IS 0

VARIABLE CODE DATA	SAMPLE SIZE	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
FLOW	7	39157.14063	40282.47266	0.77838	-0.78965
TOTRES	7	624.42847	213.29691	-0.04923	-1.60429
TOTHARD	7	144.00000	82.74457	0.99879	-0.45030
PH	7	7.73000	0.26708	-0.95484	0.66039
TURB	-7	178.57143	183.29640	1.28840	0.44995
SC	7	462.85693	308.79248	0.87828	-0.74206
BOD	7	1.91857	0.88723	1.16016	0.45671
TOTNO3	7	0.82286	1.15974	1.16511	-0.33122
TOTCOL	7	2645.00000	2646.50439	0.40118	-1.56604
FF	7	2163.14282	2254.53711	0.66673	-1.11927
DO	7	8.34285	1.57324	0.50895	-1.04882

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GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
TURB	FLOW	5	-0.14862	99.03902	-0.00323	0.01240
TURB	TOTRES	5	0.95734	-101.25563	0.83091	0.14480
TURB	TOTHARD	5	-0.47915	182.57745	-1.47274	1.55761
TURB	PH	5	-0.46913	702.06665	-87.20207	89.77574
TURB	SC	5	-0.56144	221.24260	-1.20179	1.07268
TURB	BOD	5	0.06956	68.71307	9.72107	80.49026
TURB	TOTNO3	5	0.72658	-69.23926	608.02930	331.96655
TURB	TOTCOL	5	0.99463	35.55080	0.00837	0.00050
TURB	FE	5	0.89485	-79.26370	0.13274	0.03823
TURB	DO	5	-0.74774	326.45850	-25.13110	12.88441
SC	FLOW	5	-0.61509	139.95804	-0.00624	0.00462
SC	TOTRES	5	-0.35427	145.43457	-0.14365	0.21892
SC	TOTHARD	5	0.97658	20.48012	1.40230	0.17837
SC	PH	5	0.67687	-285.58887	56.37399	35.39612
SC	TURB	5	-0.56144	135.54710	-0.26229	0.22320
SC	BOD	5	-0.29576	145.94946	-19.30984	36.00769
SC	TOTNO3	5	-0.95313	207.64700	-372.62646	68.29012
SC	TOTCOL	5	-0.46037	124.40222	-0.00189	0.00199
SC	FE	5	-0.29447	138.82703	-0.02068	0.03819
SC	DO	5	0.36937	57.52301	5.79969	8.42412
BOD	FLOW	5	-0.13145	1.78492	-0.00002	0.00009
BOD	TOTRES	5	-0.14035	1.89160	-0.00087	0.00355
BOD	TOTHARD	5	-0.26259	2.07787	-0.00578	0.01225
BOD	PH	5	-0.31998	4.58359	-0.40820	0.69779
BOD	TURB	5	0.06956	1.65359	0.00050	0.00412
BOD	SC	5	-0.29576	2.20881	-0.00453	0.00845
BOD	TOTNO3	5	0.07186	1.58667	0.43043	3.44827
BOD	TOTCOL	5	0.07882	1.66784	0.00000	0.00003
BOD	FE	5	-0.06059	1.77568	-0.00006	0.00061
BOD	DO	5	0.50212	0.39821	0.13519	0.11464
TOTNO3	FLOW	5	0.53519	0.19445	0.00001	0.00001
TOTNO3	TOTRES	5	0.58099	0.11878	0.00060	0.00049
TOTNO3	TOTHARD	5	-0.92411	0.47842	-0.00339	0.00081
TOTNO3	PH	5	-0.62879	1.20160	-0.13396	0.09564
TOTNO3	TURB	5	0.72658	0.18003	0.00087	0.00047
TOTNO3	SC	5	-0.95313	0.52998	-0.00244	0.00045
TOTNO3	BOD	5	0.07188	0.23364	0.01200	0.09617
TOTNO3	TOTCOL	5	0.65292	0.21505	0.00001	0.00000
TOTNO3	FE	5	0.50730	0.14259	0.00009	0.00009
TOTNO3	DO	5	-0.62998	0.49689	-0.02530	0.01801
TOTCOL	FLOW	5	-0.24051	8596.66016	-0.62094	1.44684

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GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
TOTCOL	TOTRES	5	0.96840	-16487.98438	99.92062	14.85672
TOTCOL	TOTHARD	5	-0.39657	15515.42578	-144.90677	193.66541
TOTCOL	PH	5	-0.43846	71671.06250	-9292.75781	10997.37500
TOTCOL	TURB	5	0.99463	-4140.07031	118.24265	7.10253
TOTCOL	SC	5	-0.48037	19771.76563	-122.24001	128.85648
TOTCOL	BOD	5	0.07882	3713.22314	1309.53857	9562.14453
TOTCOL	TOTNO3	5	0.65292	-10564.41016	64955.23828	43504.76953
TOTCOL	FE	5	[illegible]	-14067.7[illegible]	16.14362	4.09665
TOTCOL	DO	5	-0.72607	33783.96484	-2901.01831	1586.22266
FE	FLOW	5	-0.20421	1367.19531	-0.02990	0.08275
FE	TOTRES	5	0.96079	-22.52930	5.62179	0.93664
FE	TOTHARD	5	-0.29169	1638.64404	-6.04423	11.44306
FE	PH	5	-0.04900	1655.60840	-58.89297	693.06372
FE	TURB	5	0.89486	725.01367	6.03270	1.73727
FE	SC	5	-0.29847	1726.56616	-4.30712	7.95166
FE	BOD	5	-0.06059	1335.81274	-57.08308	542.94360
FE	TOTNO3	5	0.50730	512.05396	2861.99561	2806.91675
FE	TOTCOL	5	0.91547	930.92773	0.05191	0.01317
FE	DO	5	-0.79140	2960.40405	-179.31299	79.96783
DO	FLOW	5	-0.15811	10.03806	-0.00010	0.00037
DO	TOTRES	5	-0.84474	14.49518	-0.02181	0.00798
DO	TOTHARD	5	0.37037	7.36047	0.03387	0.04905
DO	PH	5	0.09930	5.87387	0.52674	3.04737
DO	TURB	5	-0.74774	11.49551	-0.02225	0.01141
DO	SC	5	0.36937	6.93698	0.02352	0.03417
DO	BOD	5	0.56212	5.63586	2.33735	1.98550
DO	TOTNO3	5	-0.62998	13.58422	-15.68596	11.16410
DO	TOTCOL	5	-0.72607	10.67836	-0.00018	0.00010
DO	FE	5	-0.79140	13.92759	-0.00349	0.00156

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WHITFL01 DATA ANALYSIS

REGRESSION WITH ITEM DELETION

DATA ANALYSIS

PROBLEM NO. 1

VARIABLES DATA

OBSERVATIONS DATE

GRAND TOTAL MATRIX

DELETED DATA VALUE IS 0

VARIABLE CODE DATA	SAMPLE SIZE	MEAN	STANDARD DEVIATION	SKEWNESS	KURTOSIS
FLOW	8	52375.00000	28670.19141	0.73382	0.12904
TOTRES	8	157.37500	52.86354	0.80966	-0.06447
TOTHARD	8	100.00000	22.57684	-0.45865	-0.26160
PH	8	7.54949	0.30585	0.70628	-0.71004
TURB	8	23.02499	13.28218	-0.19093	-1.52995
SC	8	144.87500	38.96678	-0.74690	-0.48679
BOD	8	2.63375	1.24820	0.93505	0.27317
TOTNO3	8	0.27375	0.24699	0.91772	-0.88964
TOTCOL	8	458.62500	431.96362	1.08176	0.01245
FE	8	705.50000	497.54297	0.77007	-0.19503
DO	8	8.18000	1.92530	-0.19598	-0.91130

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WHITFLD1 DATA ANALYSIS

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GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
FLOW	TOTRES	8	-0.39702	86261.43750	-215.32306	203.21266
FLOW	TOTHARD	8	-0.65593	135670.93750	-832.95947	391.32397
FLOW	PH	8	-0.73345	578340.75000	-68753.75000	26013.18750
FLOW	TURB	8	0.29611	37658.02734	639.17383	841.70239
FLOW	SC	8	-0.70287	153152.62500	-517.14014	213.66180
FLOW	BOD	8	-0.30992	71159.12500	-7118.60156	8915.41797
FLOW	TOTNO3	8	0.42302	39041.14063	48708.19922	42594.27734
FLOW	TOTCOL	8	0.18033	46865.77734	11.96888	26.55195
FLOW	FE	8	-0.06350	54956.44531	-3.65903	23.47723
FLOW	DO	8	0.25272	21590.76563	3763.35547	5881.98436
TOTRES	FLOW	8	-0.39702	195.71620	-0.00073	0.00069
TOTRES	TOTHARD	8	0.50344	39.49390	1.17881	0.82593
TOTRES	PH	8	0.48481	-483.66724	83.79646	61.71538
TOTRES	TURB	8	0.55767	106.27040	2.21953	1.34873
TOTRES	SC	8	0.52265	19.19942	0.70905	0.47218
TOTRES	BOD	8	-0.26707	187.22125	-11.31077	16.66199
TOTRES	TOTNO3	8	0.59648	122.70822	126.63672	69.56761
TOTRES	TOTCOL	8	-0.21924	169.67987	-0.02683	0.04875
TOTRES	FE	8	0.51387	118.85625	0.05460	0.03721
TOTRES	DO	8	-0.34367	234.56416	-9.43633	10.52660
TOTHARD	FLOW	8	-0.65593	127.05287	-0.00052	0.00024
TOTHARD	TOTRES	8	0.50344	66.16280	0.21501	0.15065
TOTHARD	PH	8	0.90616	-411.71240	66.89059	12.74518
TOTHARD	TURB	8	-0.09147	103.57983	-0.15548	0.69103
TOTHARD	SC	8	0.96164	-8.57683	0.55716	0.06488
TOTHARD	BOD	8	-0.17155	108.18762	-3.10285	7.27472
TOTHARD	TOTNO3	8	0.14043	95.52147	16.35991	36.40923
TOTHARD	TOTCOL	8	-0.69554	116.67224	-0.03635	0.01533
TOTHARD	FE	8	-0.14964	104.79033	-0.00679	0.01832
TOTHARD	DO	8	-0.35639	134.18579	-4.17919	4.47292
PH	FLOW	8	-0.73345	8.05979	-0.00001	0.00000
PH	TOTRES	8	0.48481	7.20857	0.00280	0.00207
PH	TOTHARD	8	0.90616	6.42242	0.01228	0.00234
PH	TURB	8	-0.02040	7.66081	-0.00047	0.00940
PH	SC	8	0.81462	6.40398	0.00639	0.00186
PH	BOD	8	-0.12278	7.72938	-0.03008	0.09928
PH	TOTNO3	8	0.02739	7.64078	0.03364	0.50128
PH	TOTCOL	8	-0.45600	7.79807	-0.00032	0.00026
PH	FE	8	-0.31013	7.78449	-0.00019	0.00024
PH	DO	8	-0.05216	7.71777	-0.00829	0.06476

WHITFLD1 DATA ANALYSIS

REGRESSION WITH ITEM DELETION

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PROBLEM NO. 1

VARIABLES DATA

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GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
TURB	FLOW	8	0.29511	15.84010	0.00014	0.00018
TURB	TOTRES	8	0.55767	0.97430	0.14012	0.08514
TURB	TOTHARD	8	-0.09147	28.40614	-0.05381	0.23917
TURB	PH	8	-0.02040	29.80113	-0.88577	17.72548
TURB	SC	8	-0.19282	35.83301	-0.06572	0.13654
TURB	BOD	8	-0.48125	36.53790	-5.12096	3.80805
TURB	TOTNO3	8	0.67322	13.19416	35.91176	16.10306
TURB	TOTCOL	8	0.19960	20.21025	0.00614	0.01230
TURB	FF	8	0.36640	16.12436	0.00978	0.01014
TURB	DO	8	0.30462	5.83502	2.10147	2.68255
SC	FLOW	8	-0.70287	244.90842	-0.00096	0.00039
SC	TOTRES	8	0.52265	134.24500	0.38526	0.25655
SC	TOTHARD	8	0.96164	28.89972	1.65975	0.19329
SC	PH	8	0.81462	-599.09717	103.76732	30.16740
SC	TURB	8	-0.19282	207.89993	-0.56569	1.17523
SC	BOD	8	-0.05875	199.71431	-1.83395	12.72281
SC	TOTNO3	8	0.14685	188.58377	22.98166	63.19685
SC	TOTCOL	8	-0.69948	223.81364	-0.06310	0.02632
SC	FF	8	0.04235	192.53499	0.00332	0.03194
SC	DO	8	-0.54886	285.74268	-11.10854	6.90687
BOD	FLOW	8	-0.30992	3.34543	-0.00001	0.00002
BOD	TOTRES	8	-0.20707	3.63114	-0.00631	0.00929
BOD	TOTHARD	8	-0.17155	3.58717	-0.00948	0.02224
BOD	PH	8	-0.12278	6.47193	-0.50107	1.65351
BOD	TURB	8	-0.48125	3.68006	-0.04523	0.03363
BOD	SC	8	-0.05875	3.00546	-0.00188	0.01305
BOD	TOTNO3	8	-0.65576	3.53865	-3.28733	1.54507
BOD	TOTCOL	8	0.59210	1.85407	0.00171	0.00095
BOD	FF	8	0.00850	2.62370	0.00002	0.00102
BOD	DO	8	-0.37225	4.61288	-0.24134	0.24565
TOTNO3	FLOW	8	0.42302	0.08133	0.00000	0.00000
TOTNO3	TOTRES	8	0.59648	-0.16839	0.00281	0.00154
TOTNO3	TOTHARD	8	0.18043	0.07476	0.00199	0.00443
TOTNO3	PH	8	0.02739	0.10318	0.02230	0.33224
TOTNO3	TURB	8	0.67322	-0.01684	0.01262	0.00566
TOTNO3	SC	8	0.14685	0.09084	0.00094	0.00258
TOTNO3	BOD	8	-0.65576	0.61893	-0.13081	0.06148
TOTNO3	TOTCOL	8	-0.37070	0.37175	-0.00021	0.00022
TOTNO3	FF	8	0.30663	0.16549	0.00015	0.00019
TOTNO3	DO	8	-0.18333	0.46769	-0.02371	0.05190
TOTCOL	FLOW	8	0.18033	316.32300	0.00272	0.00605

WHITFLD1 DATA ANALYSIS

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DATA ANALYSIS

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GRAND TOTAL MATRIX

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SAMPLE SIZE	CORRELATION COEFFICIENT	INTERCEPT	REGRESSION COEFFICIENT	STANDARD ERROR
TOTCOL	TOTRES	8	-0.21924	740.55225	-1.79144	3.25476
TOTCOL	TOTHARD	8	-0.69554	1789.39344	-13.30773	5.61214
TOTCOL	PH	8	-0.45600	5385.43359	-644.02808	513.15283
TOTCOL	TURB	8	0.19960	309.16138	6.49136	13.00990
TOTCOL	SC	8	-0.69948	1969.68579	-7.75400	3.23425
TOTCOL	BOD	8	0.59210	-82.07056	204.90630	113.85417
TOTCOL	TOTNO3	8	-0.37070	634.67407	-643.10254	657.78223
TOTCOL	FF	8	0.07604	412.05273	0.06601	0.35341
TOTCOL	DO	8	0.22460	-71.04028	64.75130	87.69757
FF	FLOW	8	-0.06350	763.21509	-0.00110	0.00707
FF	TOTRES	8	0.51387	-55.63184	4.93642	3.29625
FF	TOTHARD	8	-0.14964	1035.26440	-3.29765	8.89558
FF	PH	8	-0.31013	4564.94922	-504.50391	631.38013
FF	TURB	8	0.35640	389.48022	13.72508	14.22927
FF	SC	8	0.04235	600.12231	0.54074	5.20800
FF	BOD	8	0.00850	696.55859	3.38849	162.72485
FF	TOTNO3	8	0.30663	537.77295	612.70166	776.47070
FF	TOTCOL	8	0.07604	665.33423	0.08758	0.46887
FF	DO	8	-0.44891	1654.45850	-116.00967	94.27284
DO	FLOW	8	0.22272	7.29113	0.00002	0.00003
DO	TOTRES	8	-0.34367	10.14981	-0.01252	0.01396
DO	TOTHARD	8	-0.35639	11.21923	-0.03039	0.03253
DO	PH	8	-0.05216	10.69182	-0.32834	2.56641
DO	TURB	8	0.30462	7.16332	0.04416	0.05636
DO	SC	8	-0.54886	13.46472	-0.02712	0.01686
DO	BOD	8	-0.37225	9.69512	-0.57418	0.58445
DO	TOTNO3	8	-0.18333	8.56805	-1.41755	3.10321
DO	TOTCOL	8	0.26860	7.59005	0.00129	0.00174
DO	FF	8	-0.44891	9.40554	-0.00174	0.00141