Water-Quality Assessment of the Trinity River Basin, Texas—Analysis of Available Information on Nutrients and Suspended Sediments, 1974–91

By PETER C. VAN METRE AND DAVID C. REUTTER

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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PLATE

[Plate is in pocket]

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
centimeter per year (cm/yr)	0.3937	inch per year
meter (m)	3.281	foot
cubic meter (m^3)	35.31	cubic foot
cubic meters per second (m^3/s)	35.31	cubic foot per second
million cubic meters per year (Mm^3/yr)	810.7	acre foot per year
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
kilogram per day (kg/d)	2.2046	pound per day
kilogram per hectare per year [(kg/ha)/yr]	0.8907	pound per acre per year
tonne	1.102	ton

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L). Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8(°C) + 32$$

Water-Quality Assessment of the Trinity River Basin, Texas—Analysis of Available Information on Nutrients and Suspended Sediment, 1974–91

By Peter C. Van Metre *and* David C. Reutter

Abstract

The U.S. Geological Survey is conducting an assessment of water quality in the Trinity River Basin as part of the National Water-Quality Assessment Program. During the planning phase of this study, existing information on nutrients and suspended sediment was compiled and analyzed. A total of about 5,700 water-quality samples were analyzed from local, State, and Federal agencies. Of these, about 4,200 were from streams and about 1,500 were from wells. Additionally, atmospheric deposition data for two locations were obtained and analyzed.

Spatial variations in nutrient concentrations in streams are related primarily to point sources and reservoirs. Median total nitrogen concentrations downstream from major point sources, downstream from reservoirs, and on tributaries were 6.0, 1.3, and 2.4 milligrams per liter, respectively. Median total phosphorus concentrations for the same three settings were 1.6, 0.1, and 0.2 milligrams per liter, respectively. The largest concentrations occurred at low flow downstream from Dallas, Texas, when streamflow was dominated by treated wastewater from point sources. The smallest concentrations occurred immediately downstream from reservoirs, which act as sinks for nutrients. Nutrient concentrations in agricultural areas were positively correlated to percent of drainage in agricultural land use and to discharge, indicating washoff of nutrients from nonpoint sources during storms.

As with concentrations, nutrient loads were related to the presence of point sources and reservoirs. Loads increased substantially in the Dallas-Fort Worth area with the addition of nutrients from point sources; loads decreased substantially as flow passed through Livingston Reservoir.

Concentrations of total nitrogen and total phosphorus did not change significantly, at the 95 percent confidence level, from 1974 to 1991 at most sites. The exception was a decrease in phosphorus concentrations at two sites downstream from major wastewater-treatment plants in the Dallas area. Concentrations of organic nitrogen and ammonia declined and concentrations of nitrite plus nitrate increased at sites below major wastewater-treatment plants. These changes are indicative of improvements in wastewater treatment that converts organic nitrogen and ammonia to nitrite and finally nitrate. Because nitrogen conversion reactions consume oxygen, the occurrence of these reactions at the treatment plants instead of in the streams resulted in reduced loading of biochemical oxygen demand to the streams.

The only nutrient measured in ground water was nitrate. Nitrate concentrations varied by aquifer with the largest median concentrations in the Queen City and Nacatoch aquifers. There was a significant rank correlation between nitrate concentrations and depth of well for all seven aquifer groups sampled, with largest concentrations present in shallow wells. The large concentrations could result from nonpoint sources of nitrate associated with agricultural and urban land use; however, attempts to correlate nitrogen fertilizer application rates and agricultural land use to concentrations of nitrate in ground water were inconclusive.

Only limited suspended-sediment data were available. Four sites had daily sediment-discharge records for three or more water years (October 1 to September 30) between 1974 and 1985. An additional three sites had periodic measurements of suspended-sediment concentrations. There are differences in concentrations and yields among sites; however, the limited amount of data precludes developing statistical or cause-and-effect relations with environmental factors such as land use, soil, and geology. Data are sufficient, and the relation is pronounced enough, to indicate trapping of suspended sediment by Livingston Reservoir.

INTRODUCTION

The Trinity River drains about 48,000 km^2 of north-central and east Texas (pl. 1). The headwaters are north and west of Dallas and Fort Worth, Texas, and the mouth of the river is at Trinity Bay, part of Galveston Bay, in the Gulf of Mexico. The population within the Trinity River Basin in 1990 was about 4.5 million, with about 3.5 million living in the greater Dallas and Fort Worth area. The large population has caused stresses on water quality in the Trinity River, including 13 documented fish kills in the river from Dallas to Livingston Reservoir between 1970 and 1985 (Davis, 1987).

The U.S. Geological Survey (USGS) is conducting an assessment of water quality in the Trinity River Basin as part of the National Water-Quality Assessment (NAWQA) Program. During the planning phase of this study, existing information on nutrients and suspended sediment was compiled and analyzed. This report presents the results of that analysis.

The National Water-Quality Assessment Program

The goals of the NAWQA program (Hirsch, Alley, and Wilber, 1988) are to:

1. Provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources,

2. Define long-term trends (or lack of trends) in water quality, and

3. Identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends.

The NAWQA program is being executed through 60 (proposed) separate investigations of river basins and aquifer systems of the Nation, referred to as study units. Each study-unit investigation will include assessments of surface-water and ground-water quality. Study units will undergo cycles of 3 years of intensive study, followed by 6 years of limited monitoring, with the cycle repeated decadally (Leahy, Rosenshein, and Knopman, 1990). The planning phase for the first cycle began in 1991 for 20 of the 60 study units and the Trinity River Basin is one of the 20.

In addition to the study-unit investigations, teams of scientists are conducting national-synthesis investigations to develop a regional and national scale understanding of water quality. The first national synthesis topics being investigated are pesticides and nutrients. These investigations mostly will rely on data collected by the study-unit investigations. This approach will provide results useful both in understanding and managing the water resources of the study unit and in answering regional and national questions about water quality.

Purpose and Scope

This report describes the occurrence of nutrients and suspended sediments in streams and nutrients in ground water in the Trinity River Basin, and relates that occurrence to environmental factors. This evaluation precedes the intensive sampling phase of the NAWQA study and is, in part, intended to help design that sampling effort.

The scope of this report includes the Trinity River Basin and small areas on each side of the Trinity River Basin near its mouth (pl. 1). Streams and aquifer systems were addressed; reservoirs were not. This effort was limited by the availability of water-quality and environmental data. Only existing water-quality data collected between October 1, 1973, and September 30, 1991 (water years 1974–91), were used. Additional limitations on the inclusion of data for particular analyses are described in a later section, "Assessment Approach." In an effort to expand the availability of data, water-quality data from agencies other than the USGS were also used.

Nutrients in Natural Waters

Living organisms require at least 30 to 40 elements for their growth and development. The most important of these elements are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, magnesium, boron, zinc, chlorine, molybdenum, cobalt, iodine, and fluorine (Smith, 1980). Essential nutrients that are in the shortest supply tend to control plant production rates and are said to be "limiting." Because phosphorus and nitrogen are commonly the limiting nutrients in aquatic systems, this report focuses on those elements. In sufficiently large concentrations, phosphorus and nitrogen can adversely affect water quality through (1) eutrophication (abundant accumulation of nutrients causing excessive plant growth), (2) toxicity to aquatic life, and (3) toxicity to warm-blooded animals that drink the water.

Chemical and biological processes that transfer nitrogen to and from the lithosphere, atmosphere, hydrosphere, and biosphere represent the nitrogen cycle. Nitrogen makes up 79 percent of the atmosphere as molecular nitrogen, N_2. Processes by which nitrogen gas (N_2) is changed in oxidation state and converted to chemical compounds containing nitrogen are referred to as "nitrogen fixation." Ammonia is the product of biological fixation; nitrate is the product of high-energy fixation by lightning. Biological fixation contributes roughly 90 percent of the fixed nitrogen contributed to the earth each year. Biological fixation is accomplished by blue-green algae, symbiotic bacteria living in association with plants, and free-living aerobic bacteria (Smith, 1980). In addition to fixation, nitrogen is also made available through the breakdown of organic matter containing nitrogen, a process referred to as "respiration."

Nitrogen in reduced forms is converted by bacteria into nitrite (NO_2) and nitrate (NO_3). This process is commonly termed "nitrification." Nitrification can be described by the following reactions:

$$NH_4^+ + 3/2O_2 \rightarrow NO_2^- + 2H^+ + H_2O\ , \qquad (1)$$

$$NO_2^- + 1/2O_2 \rightarrow NO_3^-\ . \qquad (2)$$

Phosphorus and nitrogen mainly are provided to plants in aquatic systems by phosphate (PO_4) and nitrate (NO_3) or ammonium (NH_4). The average proportions of the major elements in algal biomass are described by the Redfield formula (Morel, 1983):

$$\text{Protoplasm} = C_{106}H_{263}O_{110}N_{16}P_1\ . \qquad (3)$$

A more complete stoichiometric description of photosynthesis and respiration in natural waters is provided by the following reactions:

$$106CO_2 + 16NO_3^- + H_2PO_4^- + 122H_2O + 17H^+ = \text{Protoplasm} + 138O_2\ , \qquad (4)$$

$$106CO_2 + 16NH_4^+ + H_2PO_4^- + 106H_2O = \text{Protoplasm} + 106O_2 + 15H^+\ . \qquad (5)$$

Reactions moving from left to right in equations 4 and 5 represent photosynthesis; reactions moving from right to left represent respiration.

As indicated by equations 1, 2, 4, and 5, nitrification and respiration exert an oxygen demand on natural waters. This oxygen demand is sometimes reported as the nitrogen biochemical oxygen demand (NBOD) and can be environmentally significant, for example, in rivers receiving effluents containing ammonia and organic nitrogen. Rickert and others (1976) found that nitrification was the dominant control on dissolved oxygen (DO) in some reaches of the Willamette River in Oregon during the summers of

1973 and 1974. The nitrification was caused by ammonia loading from a pulp mill.

Nitrate in anoxic environments can be reduced by bacteria to nitrous oxides or nitrogen gas. This process is commonly referred to as "denitrification" and is described by the following reaction:

$$4NO_3^- + 5\text{"}CH_2O\text{"} + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O \ , \quad (6)$$

where "CH_2O" is a symbol for organic matter, which is the carbon source needed for this reaction to proceed.

Phosphorus is a common element in igneous rock and is also fairly abundant in sediments, but concentrations present in solution in natural water generally are no more than a few tenths of a milligram per liter (Hem, 1985). The most common phosphate species present at pHs found in natural waters are $H_2PO_4^-$ and HPO_4^{2-}. Sources of phosphorus in the Trinity River Basin include the breakdown and erosion of phosphorus-bearing minerals in soil, decaying vegetation, phosphate fertilizers, sewage effluent, and metabolic wastes from animals. The transport of phosphate in fertilizers to streams may be partly restricted because phosphates are not very mobile in soils and sediments. Soil erosion, however, could contribute suspended phosphate to streams.

Phosphorus is present in animal waste and is therefore present in sewage. During the 1950's and 1960's, the increased use of phosphate in household detergents tended to increase the output of phosphate by sewage-treatment plants. Public awareness of problems caused by phosphorus, particularly eutrophication of lakes, has led to various measures to limit the use of phosphate in detergents (Hem, 1985). To discourage excessive growth of aquatic plants in flowing water, the U.S. Environmental Protection Agency (1986) recommended that total phosphorus concentrations should not exceed 0.1 mg/L as P. Total phosphorus is a measure of the organic and inorganic forms of dissolved and suspended phosphorus.

Acknowledgments

We gratefully acknowledge Steve Twidwell, Texas Water Commission; Roger Quincy, Texas Water Development Board; Starr Birch, City of Arlington; Richard Talley, City of Fort Worth; and Robert McCarthy, Dallas Water Utilities, for providing water-quality data collected by their agencies in the Trinity River Basin. We also wish to thank Sam Brush with the North-Central Texas Council of Governments for providing data on wastewater-treatment plants and for his insights and information on historical changes in treatment practices in the basin.

DESCRIPTION OF STUDY UNIT

The Trinity River Basin NAWQA study unit is located in the south-central United States, in north-central and east Texas (pl. 1). It extends on a southeast diagonal for about 570 km, from immediately south of the Oklahoma-Texas State boundary to Trinity Bay, a part of Galveston Bay, in the Gulf of Mexico. The study-unit boundary is the surface-water drainage divide of the Trinity River except in the area near the coast where it includes parts of Chambers and Liberty Counties. The study unit includes about 48,000 km^2 or about 6.5 percent of the total area of the State of Texas, with parts or all of 38 Texas counties within its limits.

The Trinity River Basin study unit can be described as a modified sedimentary landform reflecting a depositional geologic history of successive climate and sea level changes altered by the subsequent uplift or subsidence of areas of the study unit. The topography varies according to the nature of the rocks exposed and the stage reached in the erosion cycle. The study unit is dissected by alternate bands of rolling, treeless prairies, smooth to slightly rolling prairies, rolling timbered hills, and a relatively flat coastal plain. The study unit slopes gradually from about 300 m above sea level at the headwaters in the northwest to sea level in the southeast. Land-surface elevation decreases at about 1.3 m/km over the length of the study unit.

Climate

The climate of the study unit is best described as modified marine, subtropical humid, with warm summers and a predominant onshore flow of tropical maritime air from the Gulf of Mexico. This onshore flow is modified by a west to east increase in moisture and by intermittent seasonal intrusions of continental air. This variation in climate is attributed to changes in land elevation and the proximity to the Gulf of Mexico and the southern Great Plains. Most of the study unit has a winter surplus and a summer deficit of precipitation. The most northwestern section of the study unit experiences little or no water surplus in any season, and the lower tip of the basin experiences no water deficit in any season.

Average annual precipitation ranges from about 70 cm in the northwestern part of the study unit to about 130 cm in the southeastern part. The percent of precipitation that runs off also increases from northwest to southeast. Average annual temperature ranges from about 18 °C in the northwest to 20 °C in the southeast.

Geology

The surface geology (fig. 1) is composed of deposits ranging in age from Pennsylvanian to Quaternary (Peckham and others, 1963). Sediments of the Pennsylvanian and Permian Periods of the Paleozoic Era crop out in the northwestern part of the study unit and dip to the northwest. These sediments underlie about 6 percent of the study unit and consist of marine and nearshore sand, shale, and limestone. Cretaceous formations underlie about 48 percent of the study unit. The formations crop out in the northern and middle parts of the study unit (fig. 1) and dip to the southeast toward the Gulf of Mexico. Cretaceous deposits are composed of nearshore sand, marine-shale, and limestone. Formations of the Tertiary and Quaternary Periods crop out in the middle and southern parts of the study unit and dip to the southeast (fig. 1). Tertiary formations underlie about 30 percent of the study unit; Quaternary formations underlie the remaining 16 percent of the study unit. Tertiary and Quaternary formations contain a mix of marine and continental deposits. The marine deposits consist of clay, shale, and marl, with minor amounts of sand. Continental and nearshore deposits consist primarily of sand, with lesser amounts of clay, shale, and lignite.

Population and Land Use

Texas is the seventh fastest growing state in the United States, and the third largest in total population behind California (30 million), and New York (18 million) with a 1990 population of almost 17 million (A.H. Belo Corp., 1991). The study unit contains two of the four most populous counties in the State, Dallas and Tarrant Counties, with a combined 1990 population of about 3 million, or about 19 percent of the State's total population. These two counties account for about 66 percent of the total population of 4.5 million in the study unit. Between 1980–90, Denton County had the largest percent increase of all counties in the State (91 percent), followed by Collin County (86 percent), and Rockwall County (76 percent). During the same period, the total population in Texas increased by about 19 percent; however, the population of the study unit increased by about 26 percent, indicating that the study unit continues to be one of the major growth areas in the State. Population density of the State is about 26 persons per square kilometer, but the density of population within the study unit is about 100 persons per square kilometer. Dallas and Tarrant Counties both have population densities of over 386 persons per square kilometer.

Land-use and land-cover data are available as Geographic Information and Retrieval System (GIRAS) files for the entire United States (U.S. Geological Survey, 1990). Land-use and land-cover information was interpreted from topographic maps and high altitude aerial photos. The final boundaries were compiled at a scale of 1:250,000 and digitized at that scale. Land use is mapped to the detail described as level 2 by Anderson and others (1976). One limitation of the level-2 classification scheme when attempting to relate land use to water quality is that cropland and pasture are grouped. The level-2 category "cropland and pasture" accounts for about 99

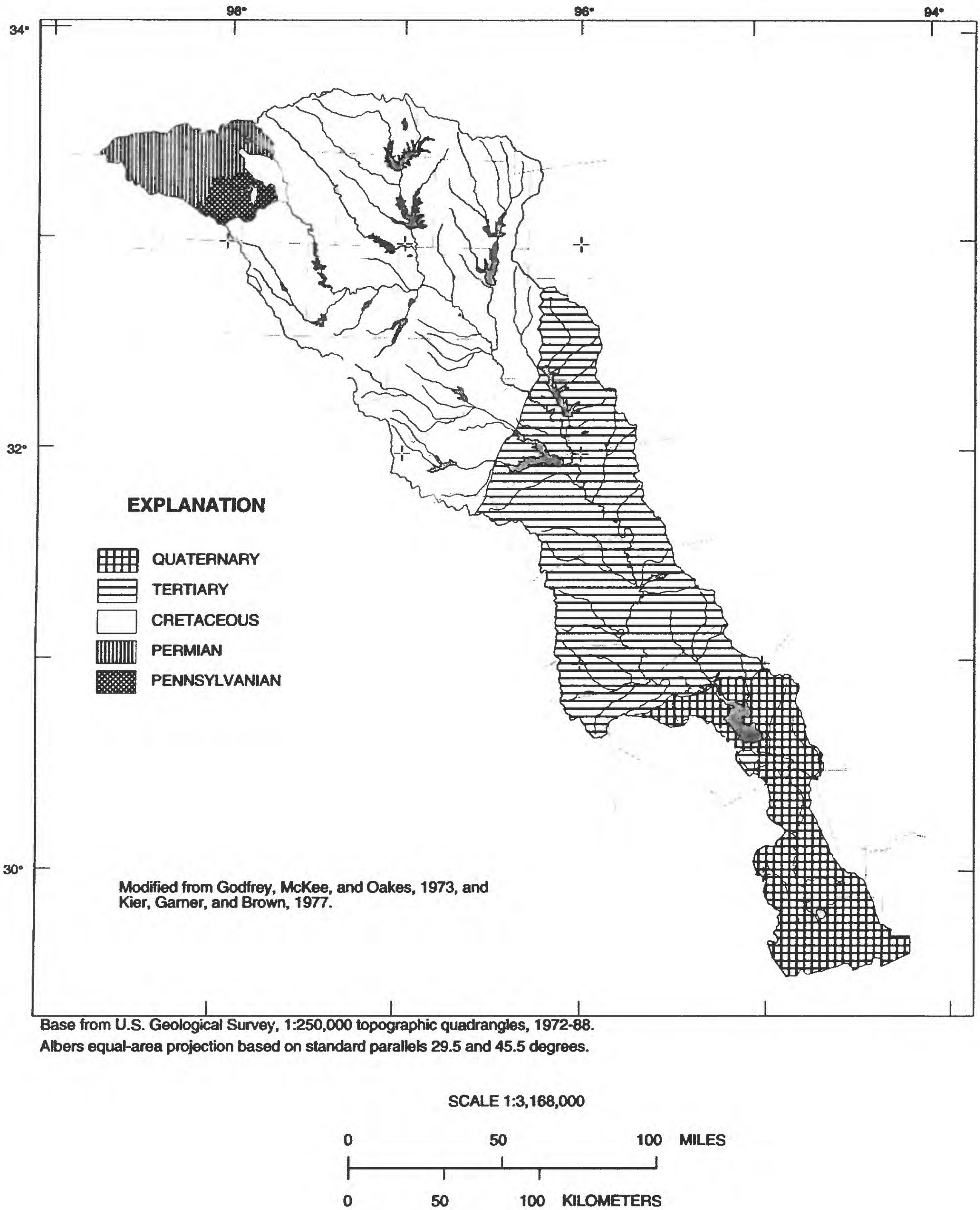

Figure 1. Surficial geology of the Trinity River Basin.

percent of all agricultural lands in the study unit. This classification precludes comparisons between pasture and the more intensively farmed and fertilized cropland and comparisons among crops. The distribution of land use within the study unit is shown on figure 2.

Historically, agriculture has been economically important in the study unit. The percentage of county area planted in a particular crop or crops in 1989 is shown on figure 3. The total major crop category (fig. 3A), includes corn, cotton, peanuts, sorghum, soybeans, rice, and wheat. Wheat, rice, and cotton are shown separately (figs. 3B, C, D) because of the significant differences in the geographic distribution and management practices of these crops. The major cotton producing area within the study unit is in the Blackland Prairie. Nitrogen and phosphorus fertilizer use in the study unit is generally distributed in patterns similar to agricultural land use (fig. 4).

Water Use, Diversions, Wastewater Treatment and Returns

Surface water is the main source of water supply for the study unit. The removal of water from the rivers and streams within the Trinity River Basin is reported in two different ways, withdrawals and consumptive use. Consumptive use is water which does not return to the system in its original form. Water-use data are provided by the Texas Water Development Board and aggregated as reported here by the USGS (Dee Lurry, U.S. Geological Survey, written commun., 1992). Total withdrawals for 1990 were estimated to be 3,800 Mm^3 and, of that amount, an estimated 520 Mm^3 was consumptive use (table 1). An estimated 96 percent of total withdrawals were from surface water with the remaining 4 percent coming from ground water.

The largest consumptive use in 1990 was for domestic water supply, the majority of which occurs in Dallas and Tarrant Counties due to their large populations (table 1). The largest category of withdrawals in 1990 was power generation with an estimated total of 2,500 Mm^3 (table 1); however, only 1.2 percent of that was estimated to be consumptive use. Farming and ranching activities are found in large areas of the basin. Irrigation withdrawals occur predominately in the rice-producing coastal area of the basin. Most of this water is supplied by surface water with some ground water pumped mainly from the Gulf Coast aquifer (Texas Department of Water Resources, 1984). Withdrawals for irrigation totaled 180 Mm^3 in 1990 with an estimated 84 Mm^3 for consumptive use. Livestock water use in the Trinity River Basin totaled 28 Mm^3 in 1990.

Transfers of water from the adjoining basins and from reservoirs below the Dallas-Fort Worth area are required to meet the needs of the Dallas-Fort Worth metropolitan area. In 1989, 111 Mm^3 of water was transferred into the Trinity River Basin from the Sabine, Neches, and Brazos River Basins (Texas Water Development Board, 1990). In 1989, 354 Mm^3 of water was exported from the Trinity River Basin which was equal to 5.4 percent of the mean annual discharge measured at site 08066500, the Trinity River at Romayor, Texas (pl. 1). The majority of the transfers were to the Houston area from Livingston Reservoir and the mainstem of the Trinity River downstream from Livingston Reservoir. Other exports were to adjacent and nearby basins (Texas Water Development Board, 1990).

In 1972, the Federal Water Pollution Act established higher standards for wastewater treatment. Included were lower levels for the biochemical oxygen demand (BOD) and ammonia in wastewater effluent. The BOD is the measured biochemical depletion of oxygen in a sample under controlled conditions (usually 5 days at 20 °C). It is considered a useful way of expressing stream-pollution loads. The treatment of wastewater is commonly described in terms of three main processes—primary, secondary, and tertiary treatment. In the major wastewater-treatment plants (WWTPs) in the Dallas-Fort Worth area primary treatment consists of using screens, aerated grit basins, and settlement ponds to remove solids. The secondary treatment process treats the primary treated water with activated sludge. Aerated basins are used to develop a large community of microorganisms which consume the organic contaminants in the wastewater. Clarifiers

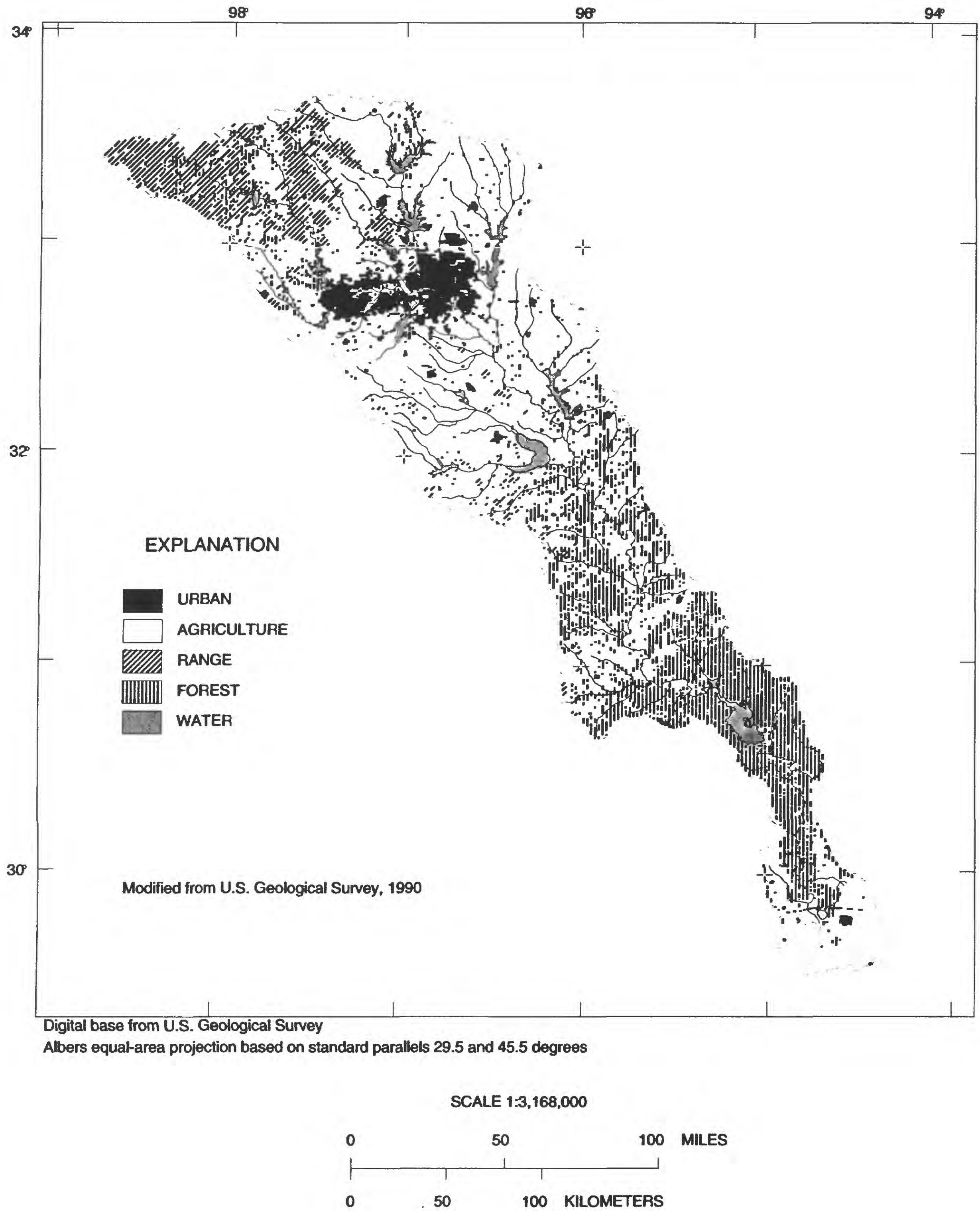

Figure 2. Land use in the Trinity River Basin.

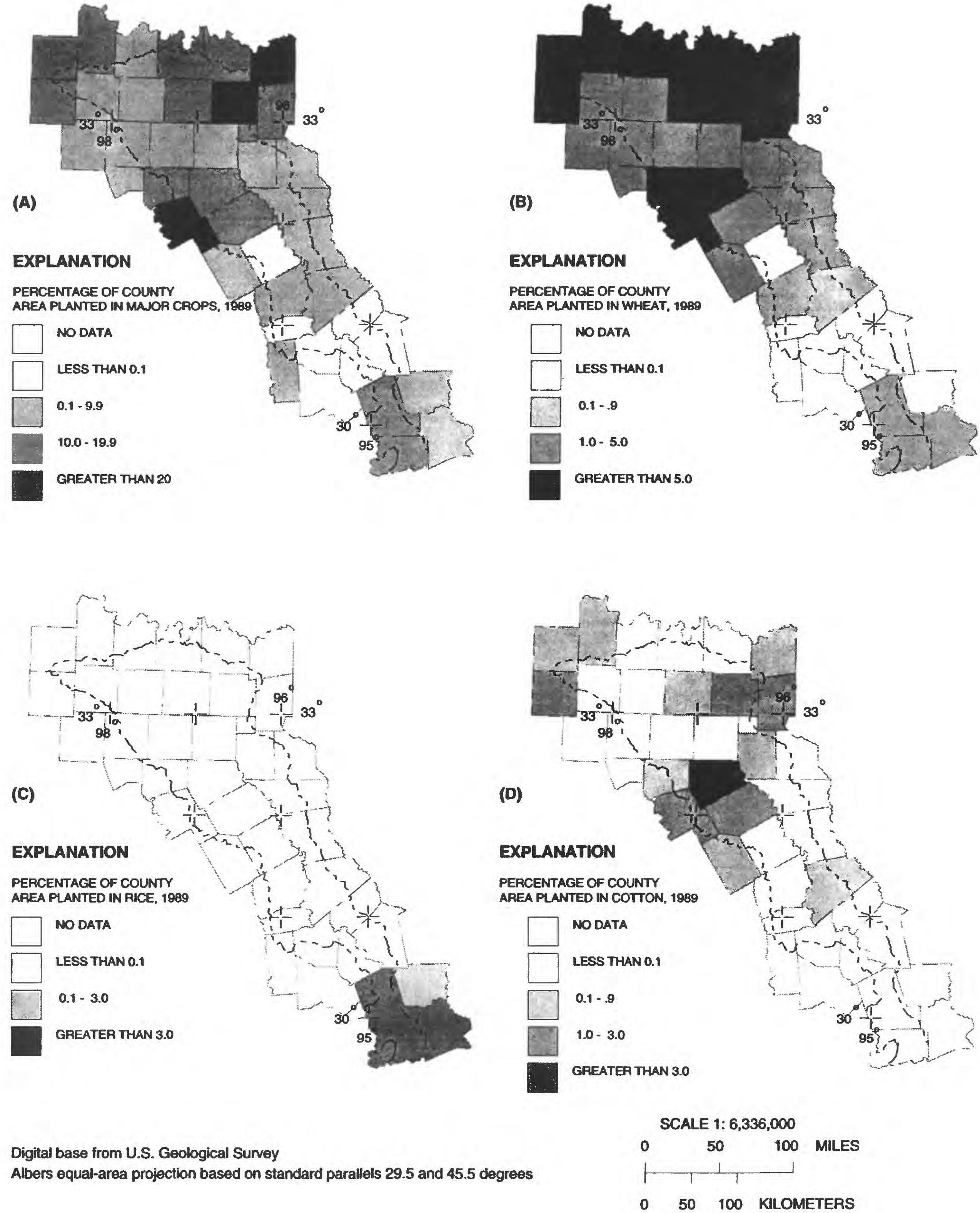

Figure 3. Distribution of (A) total major crops, (B) wheat, (C) rice, and (D) cotton production by county, 1989.

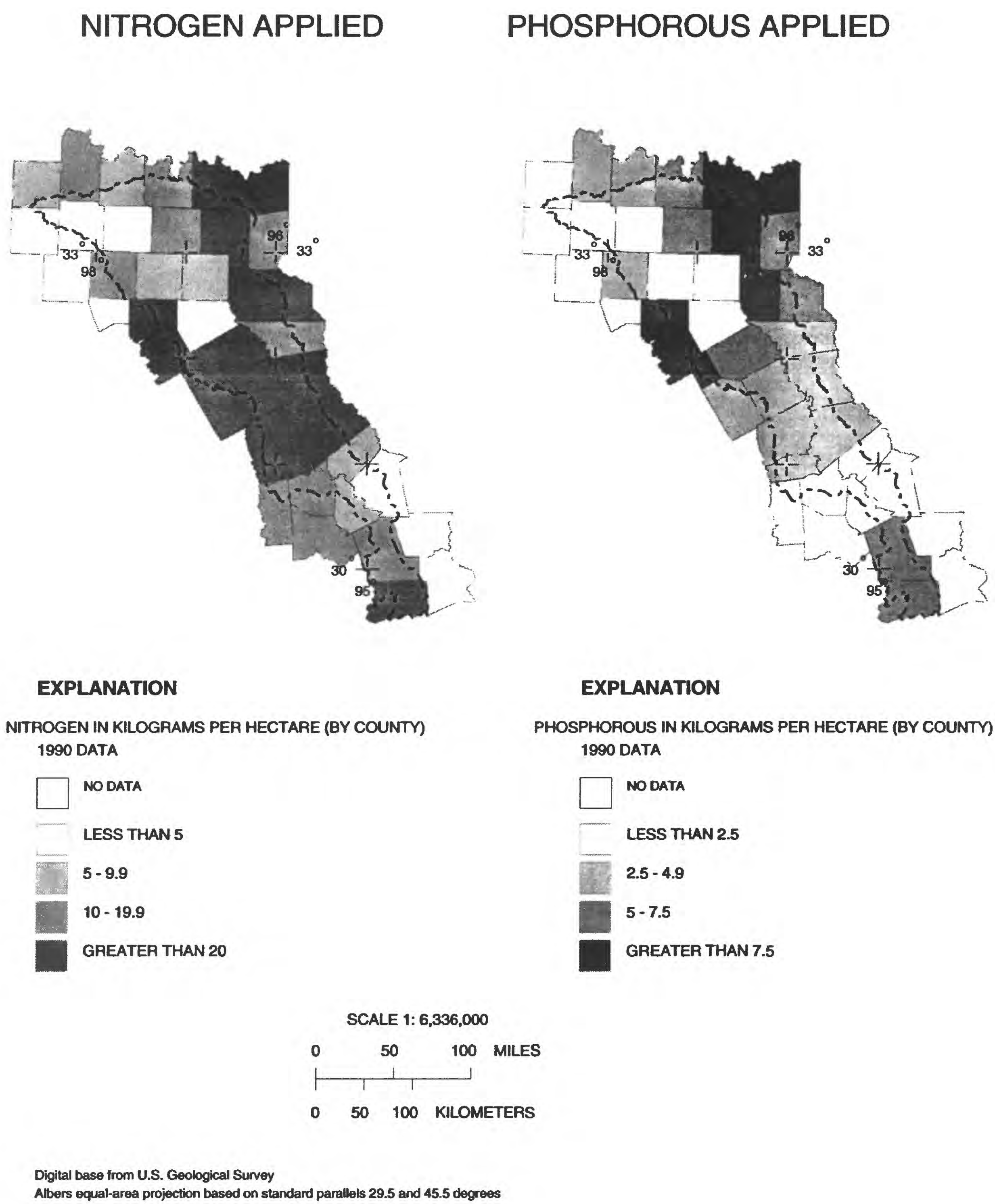

Figure 4. Nitrogen and phosphorus fertilizer use by county.

Table 1. Estimated withdrawals and consumptive water use for eight categories in the Trinity River Basin in 1990

[Water-use data provided by the Texas Water Development Board and aggregated by the U.S. Geological Survey (Dee Lurry, U.S. Geological Survey, written commun., 1992).]

Category	Withdrawals and deliveries from public supply (in million cubic meters per year)	Estimated consumptive use	
		Million cubic meters per year	Percent of supply
Commercial	52	26	5.0
Domestic	880	300	34
Industrial	100	43	43
Power	2,500	29	1.2
Mining	17	17	100
Livestock	28	28	100
Irrigation	180	84	47
Losses	12	12	100
Total	3,800	520	[1]14

[1] Average percent of total supply as consumptive use.

are then used to separate most of the microorganism population from the wastewater. Tertiary processes included filtration of the wastewater through sand filters or, in a few cases, carbon adsorption basins. The final product is disinfected with chlorine or sulfur dioxide, dechlorinated, then released into the natural waters.

Since 1972, regional WWTPs were constructed within the Dallas-Fort Worth area (pl. 1) to eliminate many of the community-owned WWTPs that provided only the primary treatment of wastewater (table 2). In 1970 the regional WWTPs treated and discharged about 390 Mm^3 (equal to 283 million gallons per day). The volume treated in 1990 by the seven largest WWTPs was approximately 760 Mm^3 (equal to 550 million gallons per day) and represents over 95 percent of the wastewater generated in the Dallas-Fort Worth metropolitan area (Brush and Promise, 1990). These facilities have both secondary and tertiary treatment processes. Bypasses from sewage-collection systems and sewage-treatment plants have historically contributed raw sewage containing nutrients to the Trinity River system. Total annual bypass volumes from major WWTPs ranged from 760,000 m^3 to 33 Mm^3 from 1978 to 1985 (Davis, 1987).

Several studies have documented improvements in water quality since the 1970's in the Trinity River below the Dallas-Fort Worth area. The improvements mainly were attributed to reductions in the loading of oxygen-demanding materials in sewage as a result of improved sewage treatment (Davis, 1987; Schertz, 1990).

Streams and Reservoirs

The western part of the basin is drained by the Clear Fork Trinity River and the West Fork Trinity River, which join in Fort Worth (pl. 1). The north-central part of the basin is drained by the Elm Fork Trinity River which joins the West Fork Trinity River in Dallas to form the Trinity River. The northeast part of the basin is drained by the East Fork Trinity River which joins the Trinity River about 32 km southeast of Dallas. Runoff increases from an average of 5.3 cm/yr in the west to 15 cm/yr in the east corresponding with the increase in

Table 2. Volumes of wastewater treated in 1990 by the seven largest wastewater-treatment plants in the Dallas-Fort Worth area, Texas

Time period	Average effluent discharges from the seven largest wastewater-treatment plants and total discharges form all plants (in million cubic meters per year)							
	Fort Worth Village Creek	Dallas Central	Dallas South-side	Trinity River Authority Central	City of Garland Duck Creek	North Texas Municipal Water District Mesquite	Trinity River Authority Ten Mile Creek	Total
1970–74	44	162	5.4	38	22	7.4	7.0	302
1975–79	69	187	8.3	70	22	7.3	8.9	402
1980–84	118	206	32	102	26	11	11	559
1985–89	153	206	56	122	29	14	16	672
1990–92	187	199	100	154	31	16	22	789

average annual precipitation from 71 cm to more than 100 cm.

The middle part of the Trinity River Basin is drained mostly by two tributaries, Cedar Creek from the east and Richland Creek from the west. Runoff from Richland Creek averaged 17 cm/yr from 1939 to 1989. Runoff from Cedar Creek averaged 21 cm/yr from 1963 to 1987.

Downstream from the mouth of Richland Creek the width of the basin narrows to about 70 km. Average runoff from Kickapoo Creek in the southeastern part of the basin was 25 cm/yr from 1965 to 1990 and average annual precipitation there was about 130 cm. Not only does runoff increase with increasing precipitation but the percent of precipitation running off also increases, from about 8 percent of precipitation in the northwest to about 20 percent in the southeast. There are several factors that could cause this. Rainfall exceeds soil infiltration capacities and evapotranspiration rates more frequently in wet areas than in dry areas, which results in increased runoff. Greater base flow from ground-water discharge to streams would also be expected in wetter areas where ground-water recharge is greater and ground-water levels tend to be closer to land surface.

The Trinity River discharges to Trinity Bay, a part of Galveston Bay, in the Gulf of Mexico. Total flow out of the Trinity River Basin can be approximated from flow measured at site 08066500, the Trinity River at Romayor, Texas. The drainage area at the Romayor gage is about 44,000 km^2 or about 96 percent of the Trinity River Basin. Average discharge at the Romayor gage from 1924 to 1991 was 208 m^3/s or 6,560 Mm^3/yr. Average runoff was 15 cm/yr, about 16 percent of the average precipitation in the drainage. The remainder of the precipitation either evaporates, is diverted out of the basin, or enters storage either in reservoirs or aquifers. The largest flows in the Trinity River generally occur during winter and spring and the smallest flows occur during summer and early fall.

Human activities have caused extensive changes in the stream network and streamflow in the basin. Agricultural and urban development have modified the landscape over most of the basin—converting grasslands and forests to ranches, farms, and cities. Numerous reservoirs have been built to retain runoff on all major tributaries and the mainstem of the Trinity River, and diversions move water within the basin and to and from adjacent river basins. Some of that water is used by the cities in the Dallas-Fort Worth metropolitan area, treated, and then returned to the Trinity River, thus adding solutes to the water and new pathways for water flow.

Human development has caused changes in the variability of streamflow in some streams in the study unit (Ulery and others, 1993). Two processes are responsible for the changes, discharge of effluents from WWTPs and construction of reservoirs. Under natural flow conditions streamflow is predominantly from two sources, baseflow from ground-water discharge to the stream and runoff from precipitation. The distribution of flows at a site is dependent on the amount of precipitation and the local physical characteristics, for example, soil infiltration rates. The effect of discharge of effluents has been to increase baseflow downstream from the Dallas-Fort Worth area. The effect of reservoirs has been to supplement baseflow and to reduce flood peaks in some reaches.

In addition to the reservoirs shown on plate 1, there are about 1,000 smaller reservoirs in the basin. Most of these are floodwater-retarding structures, constructed by the Soil Conservation Service (U.S. Department of Agriculture, 1979), with capacities generally between 0.5 and 1 Mm^3. Total conservation capacity in the basin, including the capacities of the floodwater-retarding structures, is estimated to be about 9,300 Mm^3. That is about 1.4 times greater than the mean annual flow at the Romayor gage.

Aquifers

The aquifers within the State have been classified as major and minor water-bearing formations based on their varying abilities for supplying ground water (Texas Board of Water Engineers, 1958). Based on that classification, there are three major aquifers in the Trinity River Basin, the Trinity Group, Carrizo-Wilcox, and Gulf Coast (fig. 5). Minor aquifers in the basin include the Woodbine, Nacatoch, Queen City, and Sparta. In addition, there are many other water-bearing formations which yield small or moderate quantities of water and are important locally. More detailed descriptions of ground water in the Trinity River Basin are found in Peckham and others (1963), Muller and Price (1979), Nordstrom (1982), and Texas Department of Water Resources (1984). Several reports have been written for the U.S. Geological Survey Gulf Coast Regional Aquifer-Systems Analysis study that includes the lower half of the Trinity River Basin. Hosman and Weiss (1991) described in detail the hydrogeologic framework for the Texas coastal uplands aquifer system. Pettijohn, Weiss, and Williamson (1988) presented maps of dissolved-solids concentrations in the gulf coast aquifer systems. Ryder (1988) described the hydrogeology and predevelopment flow in the Texas Gulf Coast aquifer systems.

Aquifers in the Trinity River study unit generally dip to the southeast. Recharge to the aquifers is primarily in the outcrop areas and discharge is to wells, adjacent beds, and the downdip saline zone. Major cones of depression have formed in the Trinity Group aquifer where declines of 30 to 76 m for extensive areas were reported during the period 1976–89 (Baker and others, 1990). Declines have also occurred in the Woodbine aquifer. Wells tapping zones under artesian conditions over a large area experienced declines of 7 m or more from 1976 to 1989 and declines in Grayson and Fannin Counties were as much as 45 m (Baker and others, 1990). Ground-water withdrawals have resulted in local and regional cones of depression in the Gulf Coast aquifer centering in the Houston area. As a result of this, upward vertical gradients have been reversed in those areas. Some water is also derived from the reduction in storage associated with the compaction of clays (Muller and Price, 1979).

ASSESSMENT APPROACH

The approach to this assessment followed four steps. They were:

1. Select constituents for analysis on the basis of the NAWQA study design, biochemical considerations, and data availability.

2. Select types and methods of analysis.

3. Compile and screen available data to develop data sets for analyses.

4. Analyze and interpret data.

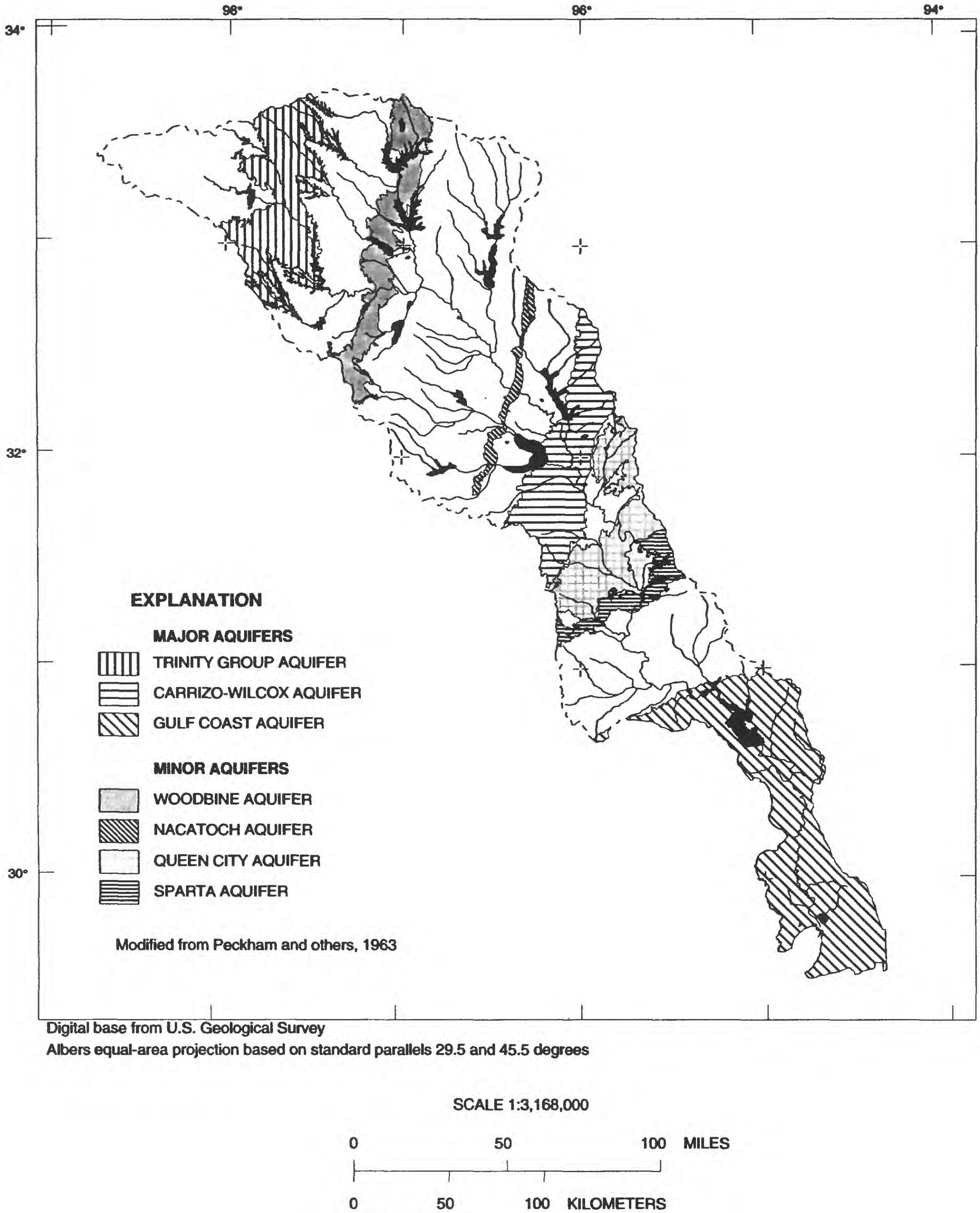

Figure 5. Major and minor aquifer outcrop areas in the Trinity River Basin.

Selection of Constituents for Analysis

Constituents evaluated included total nitrogen, ammonia plus organic nitrogen (commonly referred to as total Kjeldahl nitrogen (TKN)), nitrite plus nitrate (NO_2+NO_3), and total phosphorus. Additionally, trends were evaluated for the component parts of TKN and NO_2+NO_3: organic nitrogen, ammonia, nitrite, and nitrate. Concentrations are reported in milligrams per liter as N for the various nitrogen species and as P for total phosphorus. TKN and NO_2+NO_3 were chosen for analyses because the sum of TKN and NO_2+NO_3 approximately equals total nitrogen in natural waters and the relative proportions of each reflects differences in chemical behavior related to photosynthesis and oxygen demand.

Methods of Analysis

Spatial Distribution

The spatial distribution of constituents is presented using maps showing median and 90th percentile values in surface water. The time period used was water years 1982 to 1991 (October 1 to September 30), and data from other agencies were included. This time period was chosen as a compromise between using a long time period to maximize the likelihood of data and using a short time period to minimize the likelihood of possible temporal trends in the data. The sites used were those that had 12 or more samples collected during the time period. Sites with fewer than 12 samples were not used in order to avoid the potential for short-term variability and unknown variability due to flow conditions arising at some sites. Time period, number of analyses by constituent, and the number of sites for each type of analysis are listed in table 3.

Maps showing constituent concentrations were produced using different line symbols for reaches of the streams that vary based on differences in concentrations. This approach was chosen so that the reader can visualize spatial patterns in streams associated with features such as reservoirs and point sources. Stream reaches were broken at confluences of major tributaries, at reservoirs, and at major point sources. Generally, stream reaches are represented on maps using data from the sampling site in the reach with the largest number of samples. Actual concentrations at locations not sampled are not known.

Relations to Categorical Variables

The relation between concentrations in streams and one categorical variable, stream type, was evaluated. Three stream types were identified (1) reach downstream from a major point source or sources (below point source), (2) reach downstream from reservoirs with no major point sources between the reservoir and the site (below reservoir), and (3) tributary without major reservoirs or major point sources (tributary). Each sampling site was assigned to one of these three stream types. Sites were grouped by stream type and concentrations for groups were compared graphically and statistically. The data set used was stream samples from the USGS and other agencies from 1982 to 1991. Graphical comparisons are made using side-by-side modified boxplots. The modified boxplots show the 25th, 50th, and 75th percentiles as a rectangle or box and have whiskers on the lower and upper ends of the box extending to the 10th and 90th percentiles. Outliers and extreme values are not shown. Statistical comparisons between data grouped by stream type were made using the Kruskal-Wallis test. The test was used to determine the probability that each group of samples came from the same population.

Only one categorical variable was evaluated relative to nutrients in ground water. Nitrate concentrations in ground water were grouped by aquifer and compared using the same methods described above, side-by-side boxplots and the Kruskal-Wallis test.

Relations to Continuous Variables

Relations between concentrations in streams and three continuous variables were investigated: the percent of drainage in agricultural land use, streamflow, and time. These analyses required

Table 3. Sources of data, time periods, number of analyses, and number of sites used for analysis of nutrients in streams in the Trinity River Basin

[USGS, U.S. Geological Survey; TWC, Texas Water Commission; TRA, Trinity River Authority; ARL, city of Arlington; FW, city of Fort Worth; ---, indicates parameter not analyzed]

Type of analysis	Sources of data	Time period	Minimum number of samples per site	Number of analyses and number of sites (in parentheses)							
				Nitrogen	Phosphorus	Ammonia plus organic nitrogen	Nitrite plus nitrate	Ammonia	Organic nitrogen	Nitrite	Nitrate
Spatial distribution	USGS TWC TRA ARL FW	1982–91	12	1,043 (21)	2,197 (41)	1,881 (34)	1,208 (23)	---	---	---	---
Relations to point source and reservoirs	USGS TWC TRA ARL FW	1982–91	1	1,106 (34)	2,762 (66)	2,267 (68)	2,428 (74)	---	---	---	---
Relations to agricultural land use	USGS	1982–91	6	322 (14)	385 (14)	385 (14)	384 (14)	---	---	--	---
Relations to stream discharge	USGS	1982–91	19	760 (11)	807 (11)	830 (11)	827 (11)	---	---	---	---
Seasonal variation	USGS	1974–91	60	1,190 (8)	1,534 (8)	1,250 (8)	1,229 (8)	---	---	---	---
Temporal trends	USGS	1974–91	60	1,190 (8)	1,534 (8)	1,250 (8)	1,229 (8)	1,552 (8)	1,390 (8)	1,526 (8)	1,465 (8)
Loads	USGS	1974–90	114	1,095 (9)	1,120 (9)	1,200 (9)	1,125 (9)	---	---	---	---

digitized drainage areas, data for the related continuous variables including streamflow, and some knowledge of sampling and laboratory methods over time. Additionally, to evaluate relations to time, a minimum of 60 samples distributed over a minimum of 10 years was used (table 3).

Relations between concentrations and percent of drainage in agricultural land use were investigated by digitizing contributing drainage areas to each sampling site, then digitally overlaying those areas with GIRAS land-use data. Agricultural lands were then summed within each drainage area, divided by total area, and multiplied times 100 to calculate percent. The relation between concentrations and percent agricultural land use is displayed graphically using scatter plots of concentrations versus percent agricultural land use. Spearman's rank correlations were computed between the ranks of concentrations and percent agricultural land use to test whether concentrations generally increased or decreased with increasing agricultural land use. If such a relation exists, the two variables are said to possess a monotonic correlation (Helsel and Hirsch, 1992).

Relations to streamflow were evaluated graphically by plotting concentrations versus discharge. LOWESS, or LOcally WEighted Scatterplot Smoothing, curves are shown on these plots to emphasize the shape of the relationship between the variables. LOWESS involves fitting at least 2^n weighted least-square equations and, because of the weighting, is a robust method to compute a moving average (Helsel and Hirsch, 1992). Plots of concentrations versus discharge were grouped by stream type, as described above, to show variations in the relation to discharge for different hydrologic conditions. Relations to streamflow were evaluated statistically by computing rank correlations between concentrations and streamflow and evaluating the significance of the relation on the basis of p-values.

Seasonal variations of concentrations in streamflow were evaluated by plotting flow-adjusted residuals of concentrations by day of the year (Julian date) with LOWESS curves. Flow adjustment was accomplished by taking the difference between concentrations and the LOWESS curve of concentration versus discharge. The flow adjustment was made to remove some of the variance in concentrations caused by variations in streamflow. Seasonal variations and relations to time were evaluated for the 1974 to 1991 water years. The longer time period was used to include the occurrence of major changes in wastewater treatment in the 1970's (Brush and Promise, 1990).

Relations to time, or trends, were evaluated at selected stream sites using the seasonal Kendall test on the residuals of concentrations versus streamflow. The analyses were done using residuals to remove the variance in concentrations caused by variations in streamflow so that any "trend" signal present could be more easily detected. LOWESS curves were used to compute residuals because they describe the relation between concentrations and streamflow without assuming linearity or normality of residuals. The seasonal Kendall test accounts for seasonality by computing the Mann-Kendall test on each of the specified number of seasons separately and then combining the results (Helsel and Hirsch, 1992). The null hypothesis, that there was no relation between residuals and time, was evaluated at a confidence level of 95 percent. If a p-value of 0.05 or less was computed by the seasonal Kendall test, the null hypothesis was rejected and it was concluded that there was a trend.

Changes over time in the proportions of total nitrogen as TKN and as NO_2+NO_3 were also evaluated. Total nitrogen is approximately equal to the sum of TKN and NO_2+NO_3; therefore, as one constituent increases as a proportion of total nitrogen, the other will decrease. These changes are illustrated using side-by-side boxplots of proportion of total nitrogen as TKN and as nitrite-plus-nitrate at two sites for successive time periods (1974–76, 1977–81, 1982–86, and 1987–91).

Relations between nutrient concentrations and three continuous variables were evaluated in ground water. The variables were depth of well, nitrogen fertilizer application rate, and percent agricultural land use. The relation between nitrate concentrations and depth of well, by aquifer, was plotted with LOWESS curves and evaluated using rank correlations. The relation between nitrate concentrations and nitrogen fertilizer application rate, by county, was evaluated using rank correlations for wells less than 30 m deep. Wells were assigned fertilizer application rates based on what county they were located in. The relation between nitrate concentrations and percent agricultural land use was evaluated for wells less-than 30 m deep and wells less than 60 m deep. Percent agricultural land use was determined for each of these wells by digitally overlaying a 1-km radius circle around the well with the GIRAS land-use data and calculating the percent of area within that circle that was agricultural land use. The relation between nitrate concentrations and percent agricultural land use was plotted with LOWESS curves and evaluated using rank correlations.

Loads and Yields

Load is the mass of a constituent passing a location during a given time period, for example, kilograms of nitrogen per day passing a streamflow gaging station. Load is the product of concentration and discharge. Yield is the load per unit area and is calculated by dividing the load by the drainage area. Loads and yields of nitrogen, phosphorus, TKN, and NO_2+NO_3 were calculated for nine USGS streamflow gaging stations. Calculation of loads was accomplished using a program developed by the USGS (Tim Cohn, written commun., 1992) called the Minimum Variance Unbiased Estimator (MVUE). The MVUE estimates load by performing a regression analysis on the measured concentrations using linear and nonlinear functions of discharge and time. The MVUE accounts for both temporal trend and seasonality and includes estimates of the standard error of prediction. This program was used to estimate monthly and annual loads for each calendar year.

AVAILABLE DATA

Historical water-quality data were requested from State, local, and other Federal agencies that operate in the Trinity River Basin. Preferably, data were obtained in digital format; however, in a few cases, paper copies were obtained and entered into a data base by USGS personnel. Although a large number of analytical results were obtained, this was not intended to be an inventory of all existing water-quality data for the basin. Sources of data, time periods, number of samples, and number of sites used for each type of nutrient analysis in streams are summarized in table 3.

Data from the U.S. Environmental Protection Agency's Storage and Retrieval System (STORET) data base were helpful in determining what agencies had collected water-quality data in the basin. The agencies were contacted directly for their data. Available data, by agency, is briefly described below.

U.S. Geological Survey

The USGS collected a total of 2,324 nutrient samples from 42 stream-sampling locations in the Trinity River Basin from October 1, 1973, to September 30, 1991 (water years 1974–91). Each of those 2,324 samples had at least one analysis of the eight nutrient constituents used in the analysis of temporal trends. Seasonal variations, temporal trends, and loads were evaluated for the period 1974–91. Other analyses were for the period 1982–91. USGS stream-sampling locations for the period 1982–91 are shown on figure 6. Sampling at some sites began in the 1960's and continues to the present (1994).

Data from selected USGS sites were used to evaluate relations to time and to calculate loads. To accurately calculate the load of a constituent, the data set used must include samples collected at higher flows, when much of the load occurs. The distribution of samples over the discharge hydrograph is also relevant to the evaluation of relations to time. The distribution of samples as a function of flow for four sites used in the evaluation of relations to time and calculation of loads is shown on figure 7. Deciles of flow were determined using daily discharge data. Samples generally were evenly distributed over the range of flow at these sites and high flows were well represented.

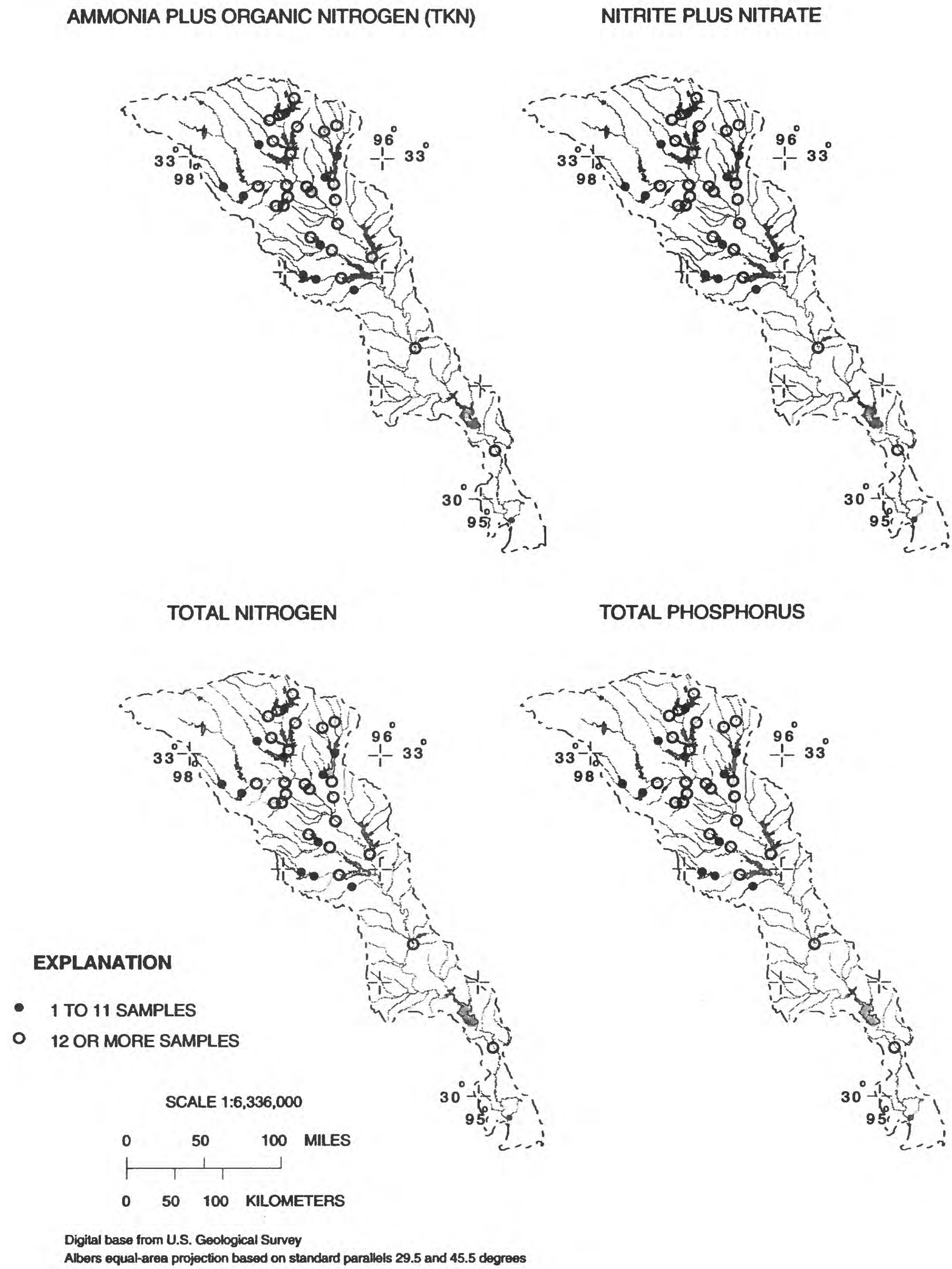

Figure 6. Locations and sampling frequency for U.S. Geological Survey nutrient samples from streams, 1982–91.

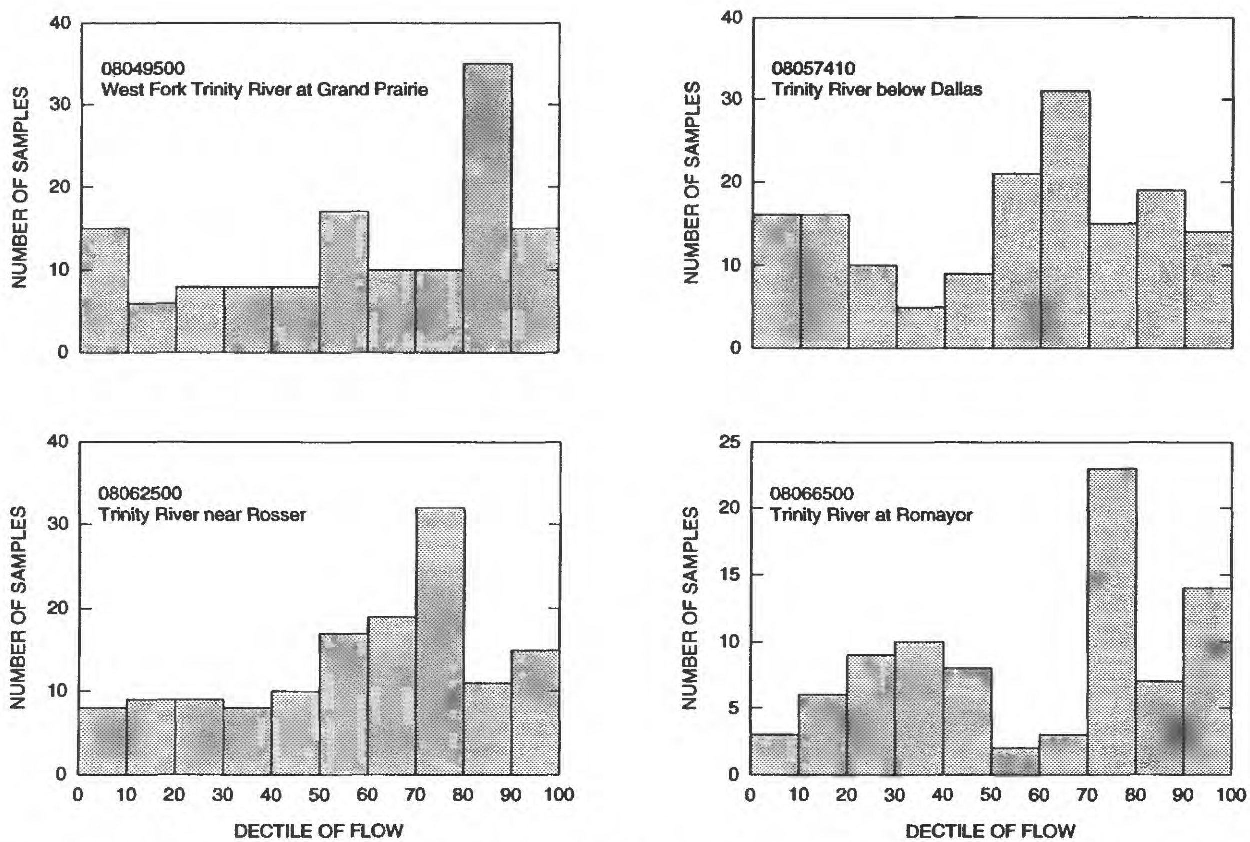

Figure 7. Distribution of samples collected by the U.S. Geological Survey by dectile of flow at four sites in the Trinity River Basin, 1982–91.

Texas Water Commission

The Texas Water Commission (TWC) provided samples from streams at more than 200 locations within the basin (fig. 8). The nutrients sampled at most sites included nitrite, nitrate, ammonia, TKN, total phosphate, orthophosphate, and total phosphorus. A total of 1,144 analyses, collected during the 1982–91 water years, were used for this analysis. Sampling results compared well at sites where sampling by the USGS and the TWC coincided. The TWC data were used for analyses of spatial distribution of nutrients and relations to point sources and reservoirs.

Trinity River Authority

A total of 418 analyses from 8 sites sampled by the Trinity River Authority (TRA) were included in the database obtained from the TWC and were used in this analysis (the TWC database contains data from several agencies in Texas). Nutrients commonly sampled included ammonia, nitrate, and TKN. These were used in the analyses of spatial distribution and relations to point sources and reservoirs.

City of Arlington

The city of Arlington provided data from 16 sampling locations within the basin; 5 in Lake Arlington and 11 on tributaries to Lake Arlington. The nutrients sampled included ammonia, nitrite, nitrate, TKN, total phosphate, and orthophosphate. Forty-two analyses from one site sampled by the city of Arlington were used in the analysis of spatial distribution and relations to point sources

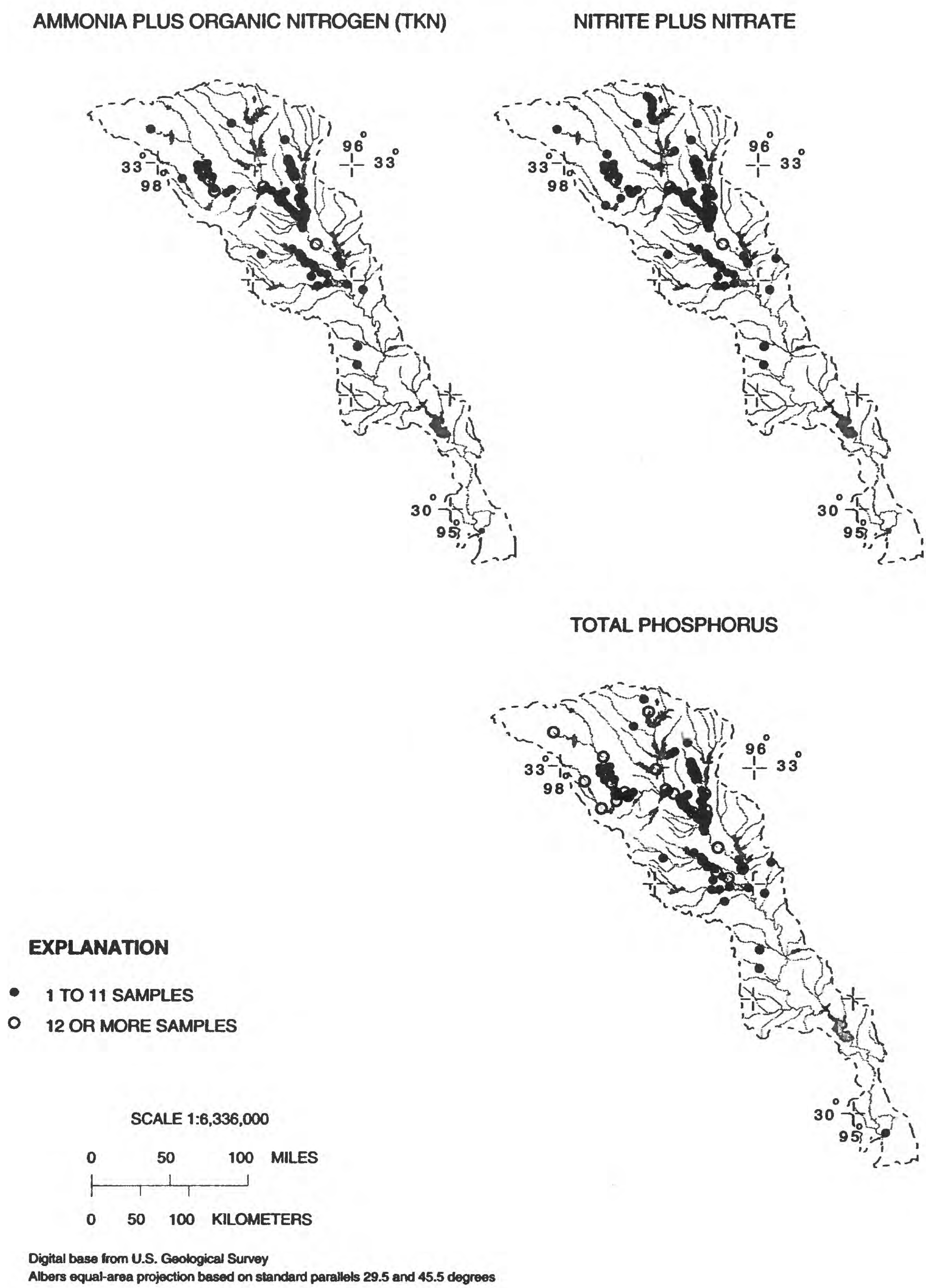

Figure 8. Locations and sampling frequency for the Texas Water Commission nutrient samples from streams in the Trinity River Basin, 1982–91.

and reservoirs. Samples from Lake Arlington were not within the scope of this report.

City of Fort Worth

The city of Fort Worth provided 182 analyses from 7 sampling locations in the greater Fort Worth area that were used in this analysis. The nutrients sampled included ammonia, nitrite, nitrate, TKN, total phosphate, and orthophosphate. These samples were used in the analysis of spatial distribution and relations to point sources and reservoirs.

Texas Water Development Board

The Texas Water Development Board is the only agency that provided ground-water quality data for nutrients to this study and the only nutrient measured was nitrate. Ground-water data used in this analysis were from seven major and minor aquifers in the basin, had an associated well depth, and were from water years 1974–91. A total of 1,482 nitrate analyses from 1,041 wells were available (fig. 9).

Sampling objectives for specific wells or analyses were generally not known; however, both routine monitoring and drinking water compliance sampling are performed by the State (Robert Blodgett, Texas Water Commission, oral commun., 1993). Additionally, the type of well was not known, and it may have been a domestic-supply well, monitoring well, or public-supply well. Sampling objectives, type of well, and well completion can affect the interpretation of results. If, for example, only monitoring wells near hazardous waste sites are included in the data set an obvious bias would result. On the basis of well locations and depths, and conversations with TWC (Blodgett, oral commun., 1993), it was assumed that these wells represent ambient water quality and were mostly domestic- and public-supply wells in the study unit.

National Atmospheric Deposition Program

Atmospheric-deposition data were obtained from the National Trends Network (NTN) Atmospheric Deposition Program. The data collected from two NTN stations, TX56 and TX38, were used in this report. Station TX56 is located in the northwestern part of the Trinity River Basin at the LBJ National Grasslands in Wise County, which is approximately 225 km from the geographic midpoint of the study unit (pl. 1). Station TX38 is located east of Palestine, Texas, approximately 80 km outside of the study unit and approximately 150 km from the geographic midpoint of the study unit. Concentrations and loads, estimated as the product of concentrations and precipitation, were available for ammonia and nitrate. Orthophosphate was also measured, but all samples were below the detection limit.

ANALYSIS OF AVAILABLE DATA FOR NUTRIENTS

Atmospheric Deposition

Precipitation is known to be an effective agent in cleansing the atmosphere of contaminants. This can result in precipitation having low pHs and containing large amounts of nutrients and toxic metals (Novotny and Chesters, 1981).

Concentrations of ammonium and nitrate in atmospheric deposition at the two NTN stations and the estimated average concentrations for the Trinity River Basin are listed in table 4. The estimated average concentrations were calculated as the average of the two NTN stations weighted by their distance to the geographic midpoint of the basin. Median concentrations of ammonium and nitrate from atmospheric deposition were both 0.2 mg/L as N. In comparison, the median concentrations of ammonia and nitrate from tributary stream-sampling sites in the Trinity River Basin were 0.1 and 0.3 mg/L, respectively. The comparatively large nutrient concentrations in

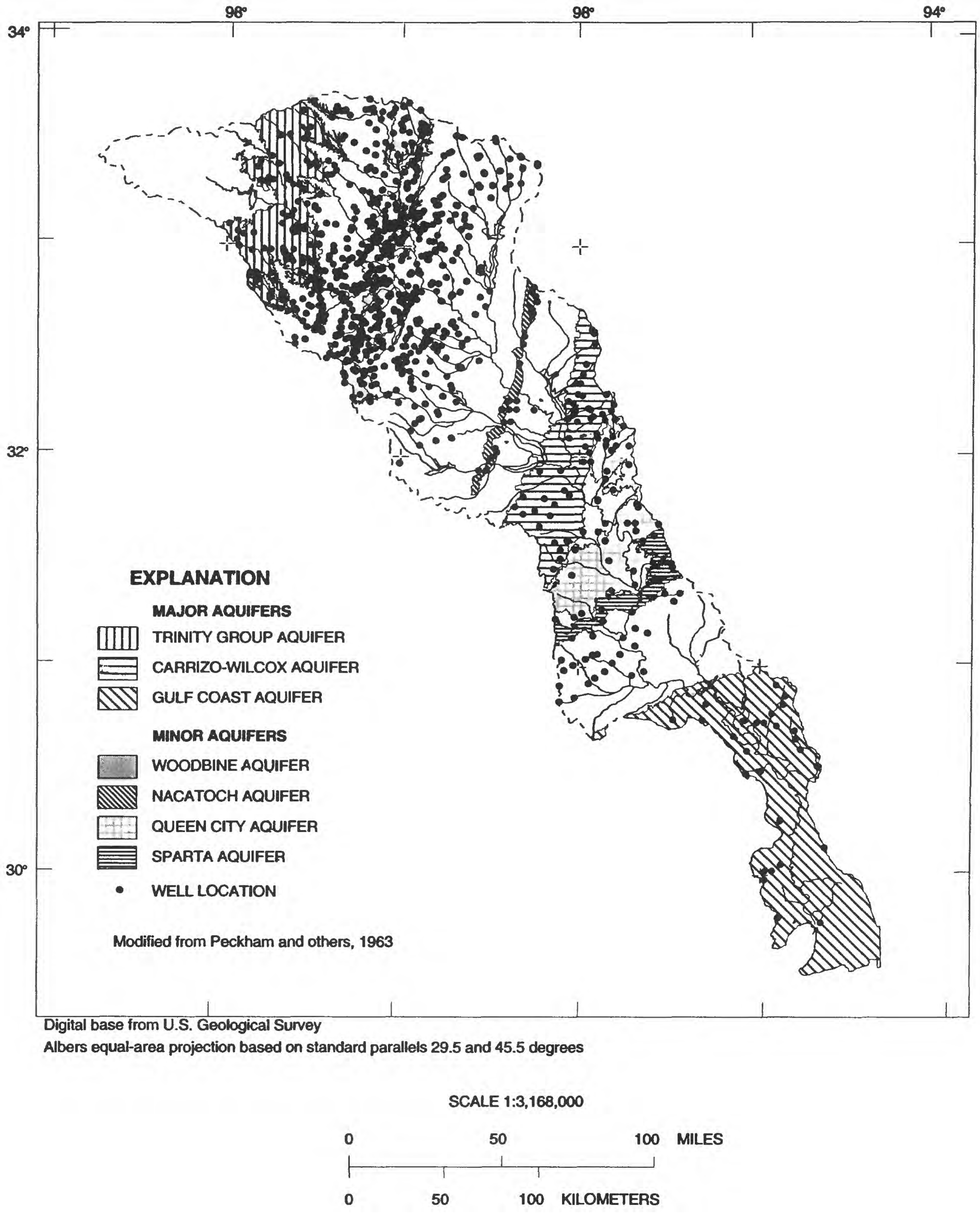

Figure 9. Locations of wells sampled by the Texas Water Development Board in the Trinity River Basin, 1974–91.

Table 4. Nutrient concentrations from atmospheric deposition recorded at National Trends Network stations in the vicinity of the study unit and the weighted-average concentration[1]

[NH_4, ammonium; NO_3, nitrate; Ppt., precipitation; mg/L, milligrams per liter; cm, centimeters; N, nitrogen; ---, no data]

Water year	National Trends Network stations						Basin weighted-average concentration	
	TX38			TX56				
	NH_4 (mg/L as N)	NO_3 (mg/L as N)	Ppt. (cm)	NH_4 (mg/L as N)	NO_3 (mg/L as N)	Ppt. (cm)	NH_4 (mg/L as N)	NO_3 (mg/L as N)
1982	0.19	0.19	105.72	---	---	---	---	---
1983	.20	.16	154.05	---	---	---	---	---
1984	.16	.20	87.12	0.22	0.23	64.07	0.19	0.21
1985	.08	.16	110.52	.27	.24	90.44	.15	.18
1986	.07	.13	141.11	.17	.17	103.19	.10	.14
1987	.14	.13	108.22	.19	.19	101.25	.17	.15
1988	.14	.18	76.07	.10	.16	80.38	.14	.17
1989	.26	.19	135.74	.32	.27	100.58	.31	.21
1990	.24	.16	105.40	.32	.21	111.76	.29	.17
1991	.18	.18	162.74	.23	.21	96.73	.23	.18
Median	.17	.17	109.4	.23	.21	98.6	.18	.18

[1] To calculate the weighted average for the Trinity River Basin, each monitoring site was spatially weighted by the inverse of the squared distance of the site to the geographic midpoint of the basin.

atmospheric deposition suggest that it could be a significant source of nutrients to streams.

Surface Water

Spatial Distribution

Median and 90th percentile concentrations of nitrogen, NO_2+NO_3,TKN, and phosphorus for stream reaches with sampling sites with 12 or more analyses during water years 1982–91 are shown on figures 10 through 13. Not all sites fitting this criteria were used to construct these figures. If two or more sites were nearby in a similar reach of a stream, the site with more samples generally was used to represent the reach.

The most obvious spatial patterns indicated on figures 10 through 13 are large concentrations in the West Fork Trinity River, East Fork Trinity River, and Trinity River below the Dallas-Fort Worth area. The large concentrations are caused primarily by point-source discharges of nutrients in sewage effluent from the major WWTPs. Other spatial patterns are indicated by small concentrations below reservoirs. The small concentrations downstream from reservoirs are caused by the trapping of sediments and associated nutrients in the reservoirs and by uptake of nutrients in the reservoirs by plants. With few exceptions, relatively small concentrations of nutrients also occur on tributaries upstream from reservoirs and point sources.

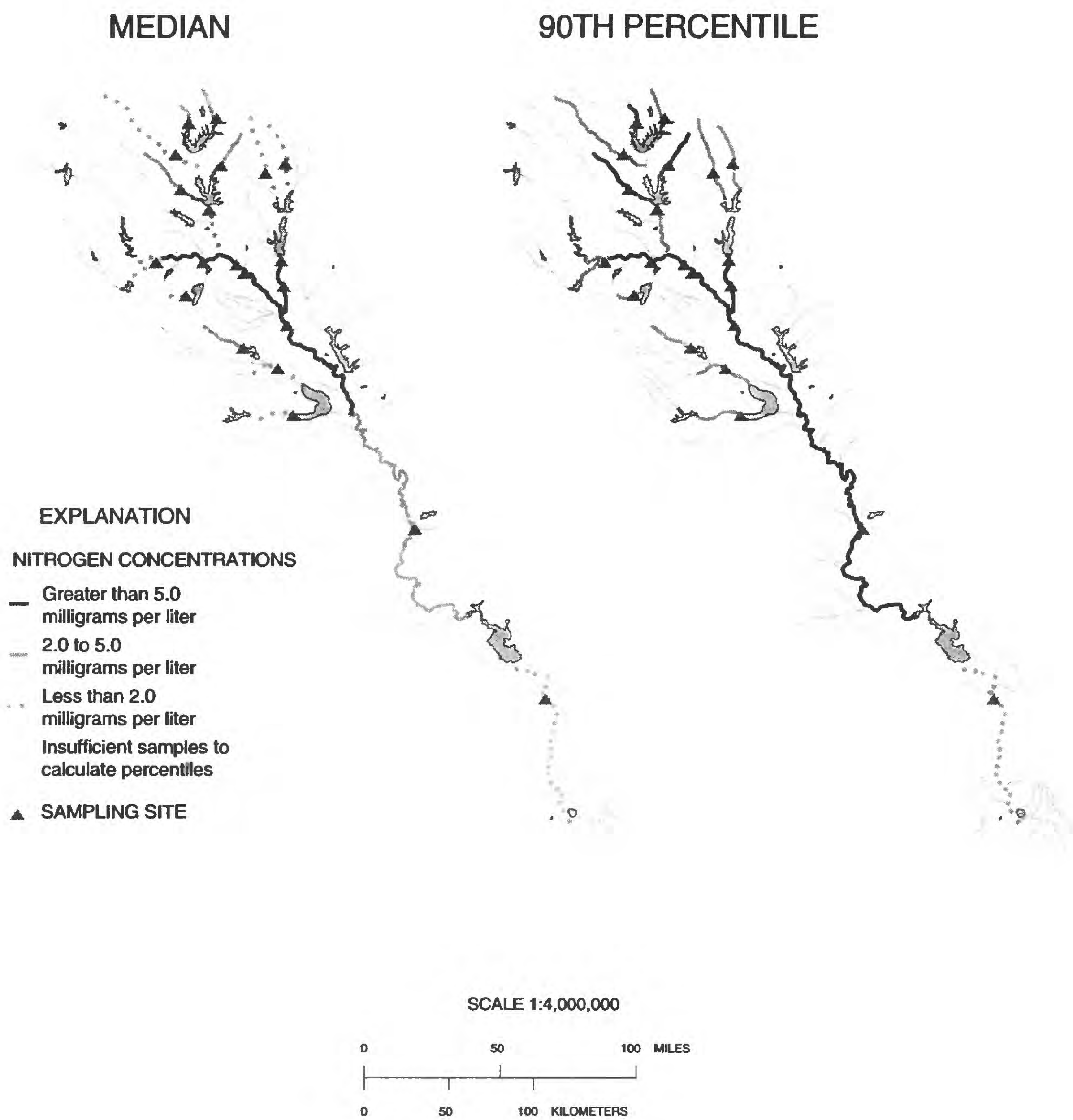

Figure 10. Median and 90th percentile nitrogen concentrations in Trinity River Basin streams, 1982–91.

It is evident from the figures showing spatial distribution that some parts of the study unit are lacking in nutrient data. There were few sites on tributaries in the middle and lower parts of the basin and there were no sites in the Cedar Creek drainage with 12 or more samples. There also were no large-scale synoptic sampling efforts over the basin designed to sample many streams during one season and flow condition, hence the use of statistical summaries.

Relations to Point Sources and Reservoirs

The spatial distribution of concentrations suggested three types of streams in the study unit

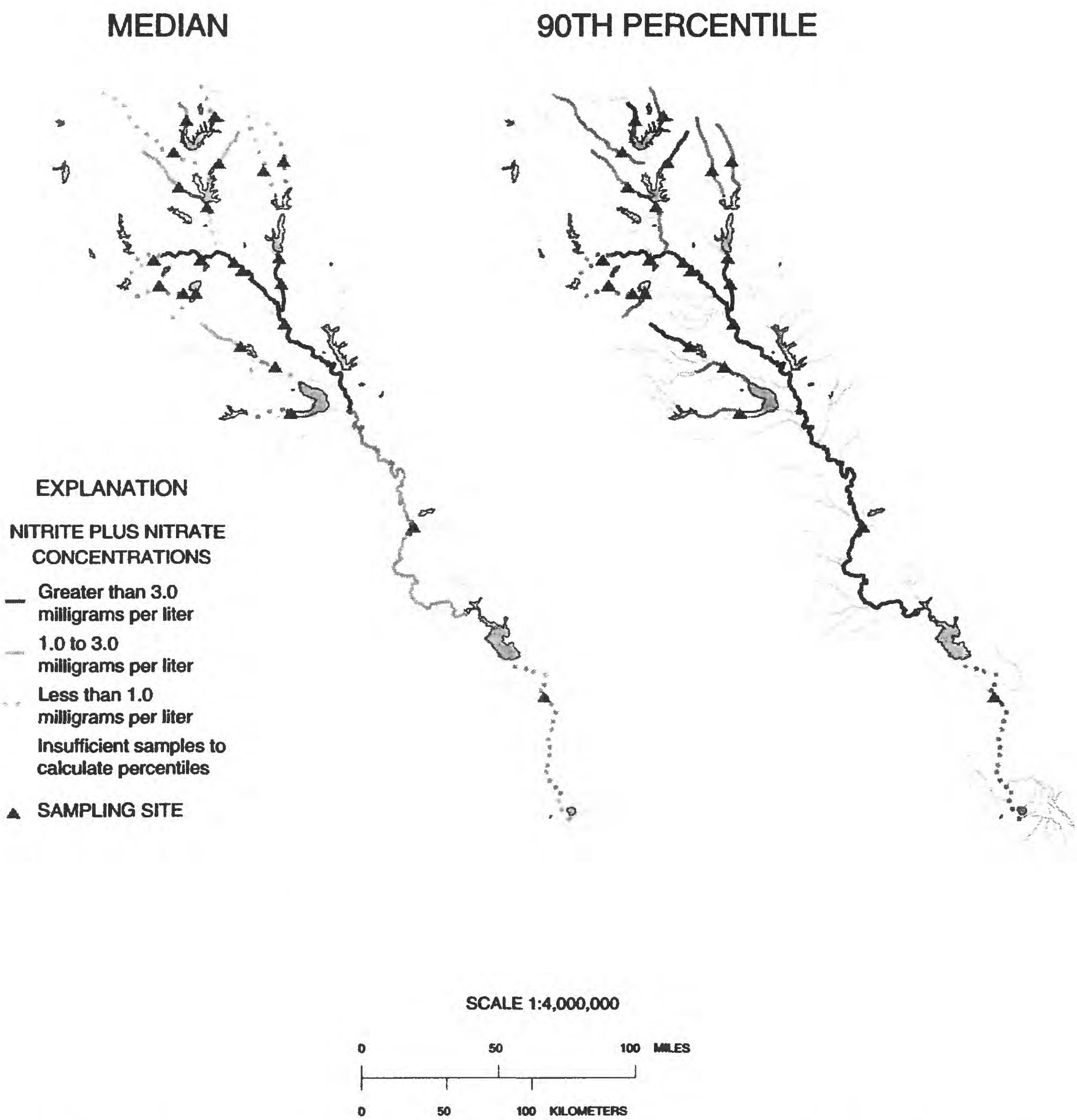

Figure 11. Median and 90th percentile nitrite-plus-nitrate nitrogen concentrations in Trinity River Basin streams, 1982–91.

with differing concentrations of nutrients (fig. 14). Each sampling site was assigned to one of three types: (1) reach downstream from a major point source or sources (below point source), (2) reach downstream from reservoirs with no point sources between the reservoir and the site (below reservoir), and (3) tributary without major reservoirs and point sources (tributary). As expected, concentrations are larger below the major point sources than for tributaries and below reservoirs (fig. 15, table 5). The differences in concentrations between the three stream types are statistically significant for all four constituents using the Kruskal-Wallis test, with p-values in each case less than 0.0001.

Differences in concentrations by stream type indicate the effects of two major environmental

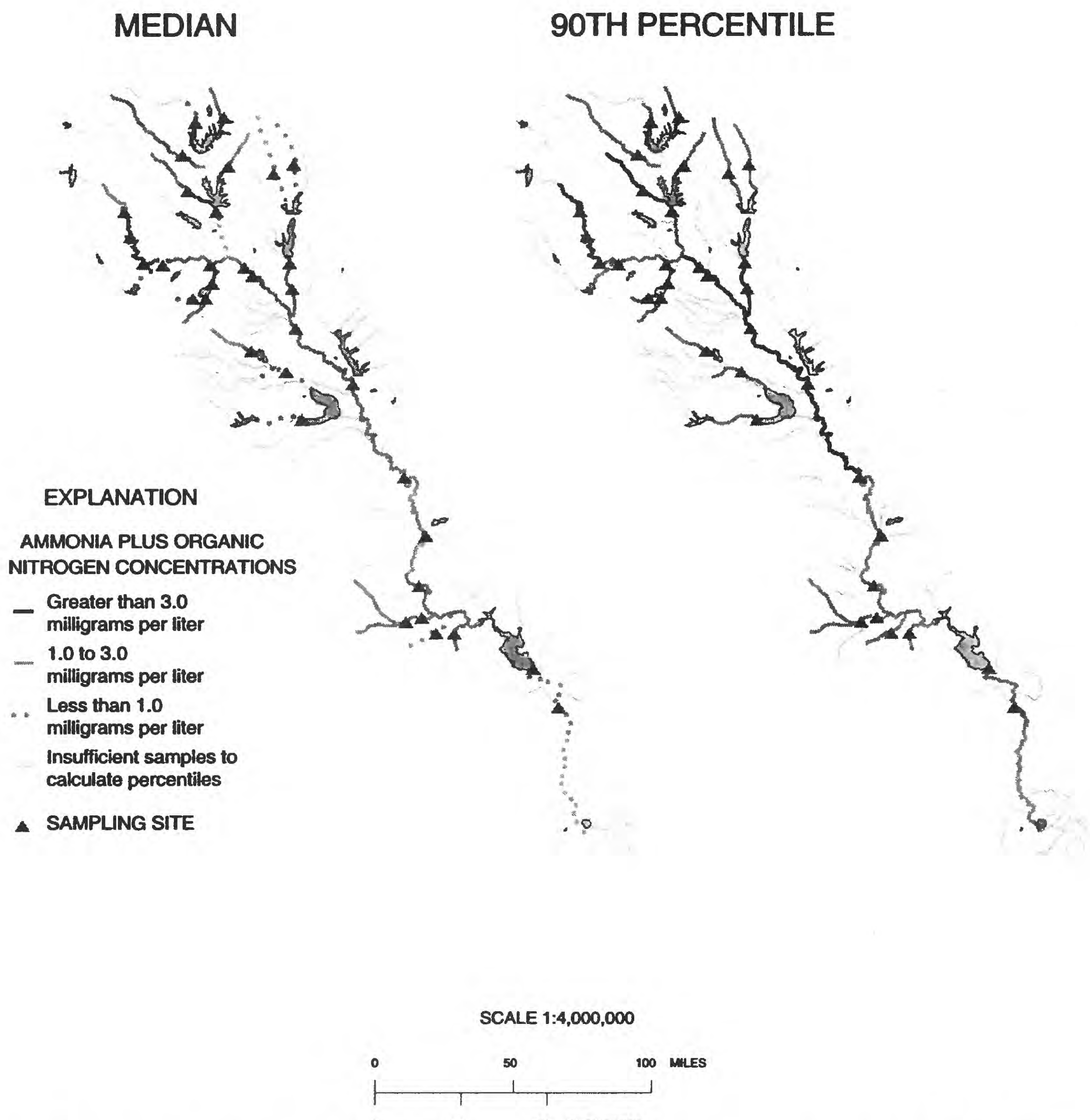

Figure 12. Median and 90th percentile ammonia plus organic nitrogen concentrations in Trinity River Basin streams, 1982–91.

factors in the Trinity River Basin, reservoirs and point sources. Reservoirs generally reduce nutrient concentrations, and discharge of sewage effluents from major WWTPs increases concentrations.

Relations to Agricultural Land Use

An important nonpoint source of nutrients to streams nationally is agricultural use of fertilizers. Contributing drainage areas were digitized and overlaid with GIRAS land-use data for 14 tributary sites sampled by the USGS. The percent of drainage area in agricultural land use was then calculated for comparison with nutrient concentrations. Only tributary sites were used because the effects of reservoirs and major point sources on downstream water quality overshadow the effects of nonpoint sources (land use) in the upstream drainage.

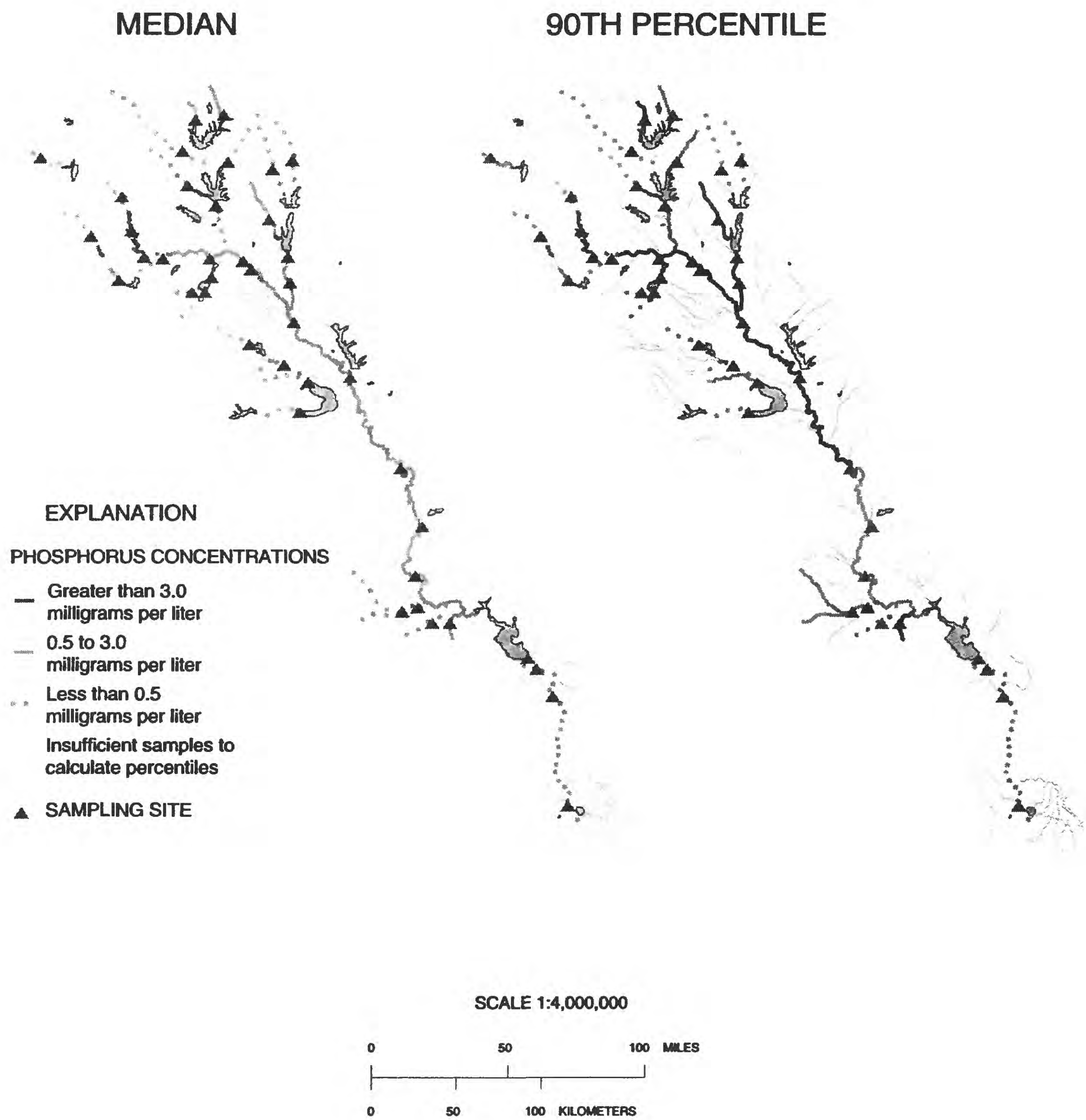

Figure 13. Median and 90th percentile phosphorus concentrations in Trinity River Basin streams, 1982–91.

There is a positive relation between percent agricultural land use and some constituent concentrations for tributary sites; however, there is a large amount of variability in concentrations (fig. 16). The lines shown on figure 16 are LOWESS curves. Statistically significant rank correlations, at a 95 percent confidence level, were computed between percent of drainage area classified as agricultural land use and nitrogen and NO_2+NO_3. Correlations to phosphorus and TKN were not statistically significant. The positive correlations are an indication that more nitrogen and NO_2+NO_3 are present in tributaries draining agricultural lands than in tributaries draining nonagricultural lands. Most of the nonagricultural land in the tributary drainages was either range or

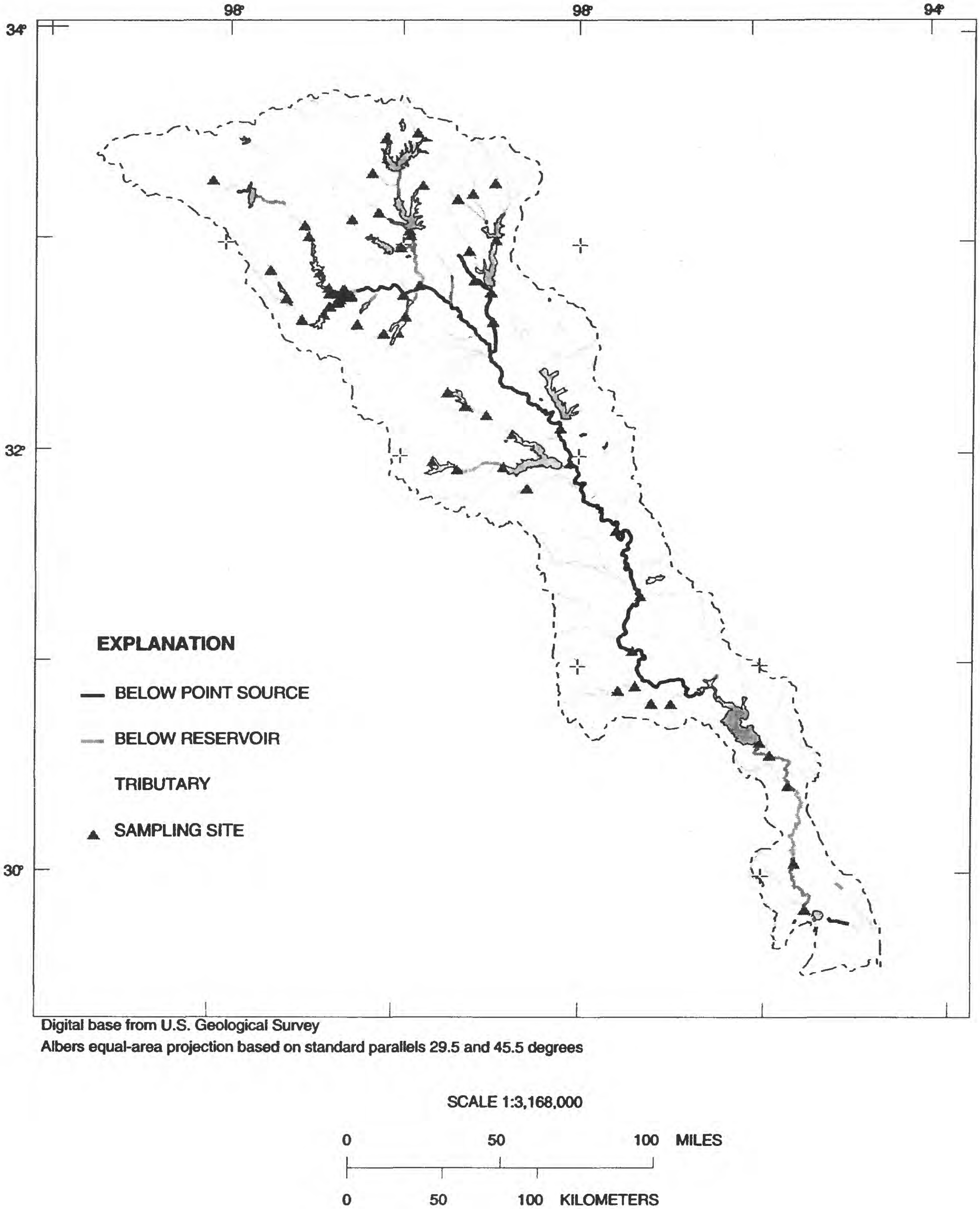

Figure 14. Delineation of stream type in the Trinity River Basin.

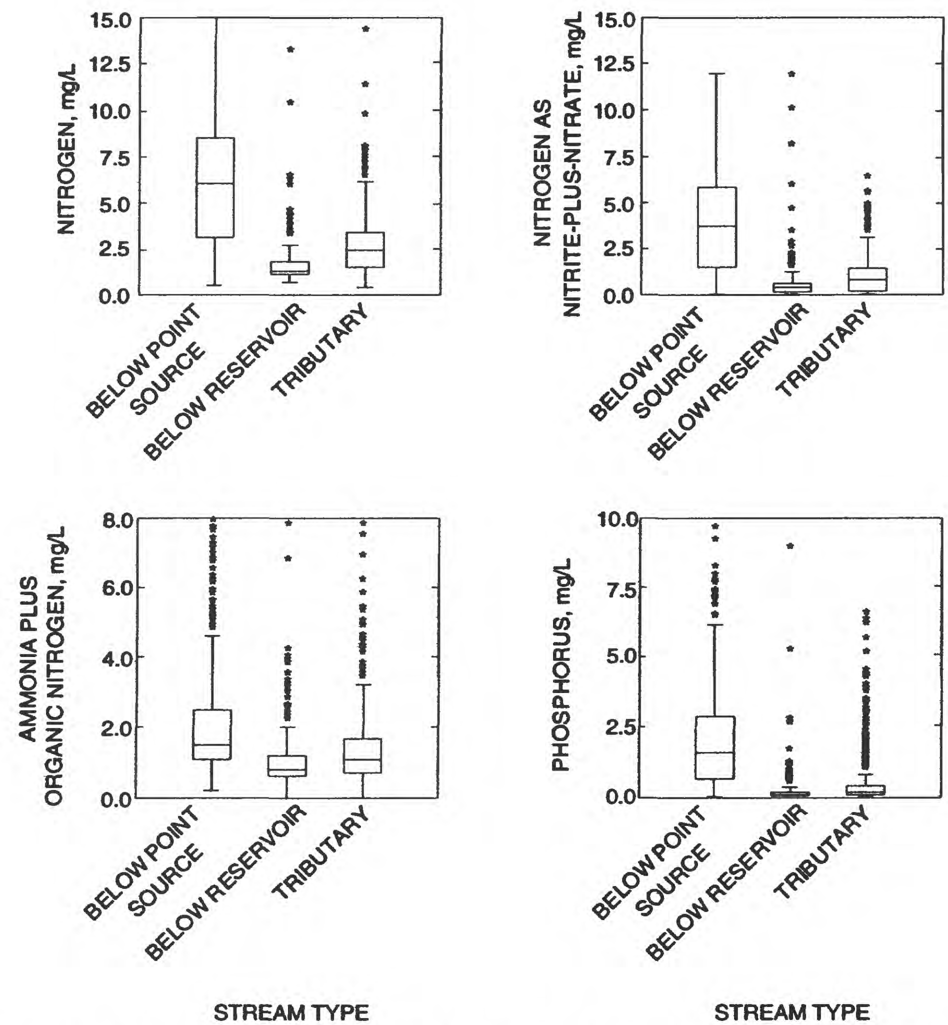

Figure 15. Concentrations of nutrients in streams grouped by stream type in the Trinity River Basin. (All concentrations of nitrogen expressed as N.)

Table 5. Median concentrations for all stream sites and for sites assigned to three groups based on stream type in the Trinity River Basin

[Number of samples shown in parentheses. TKN, Total Kjeldahl nitrogen; NO_2, nitrite; NO_3, nitrate]

Constituent	Median concentration in milligrams per liter and number of samples (in parentheses)			
	All sites	Point source	Reservoir	Tributary
Nitrogen	2.9 (1,106)	6.0 (564)	1.3 (229)	2.4 (313)
TKN	1.2 (2,267)	1.5 (981)	.8 (725)	1.1 (561)
NO_2+NO_3	.9 (1,497)	3.7 (620)	.4 (480)	.8 (397)
Phosphorus	.3 (2,762)	1.6 (1,244)	.1 (794)	.2 (724)

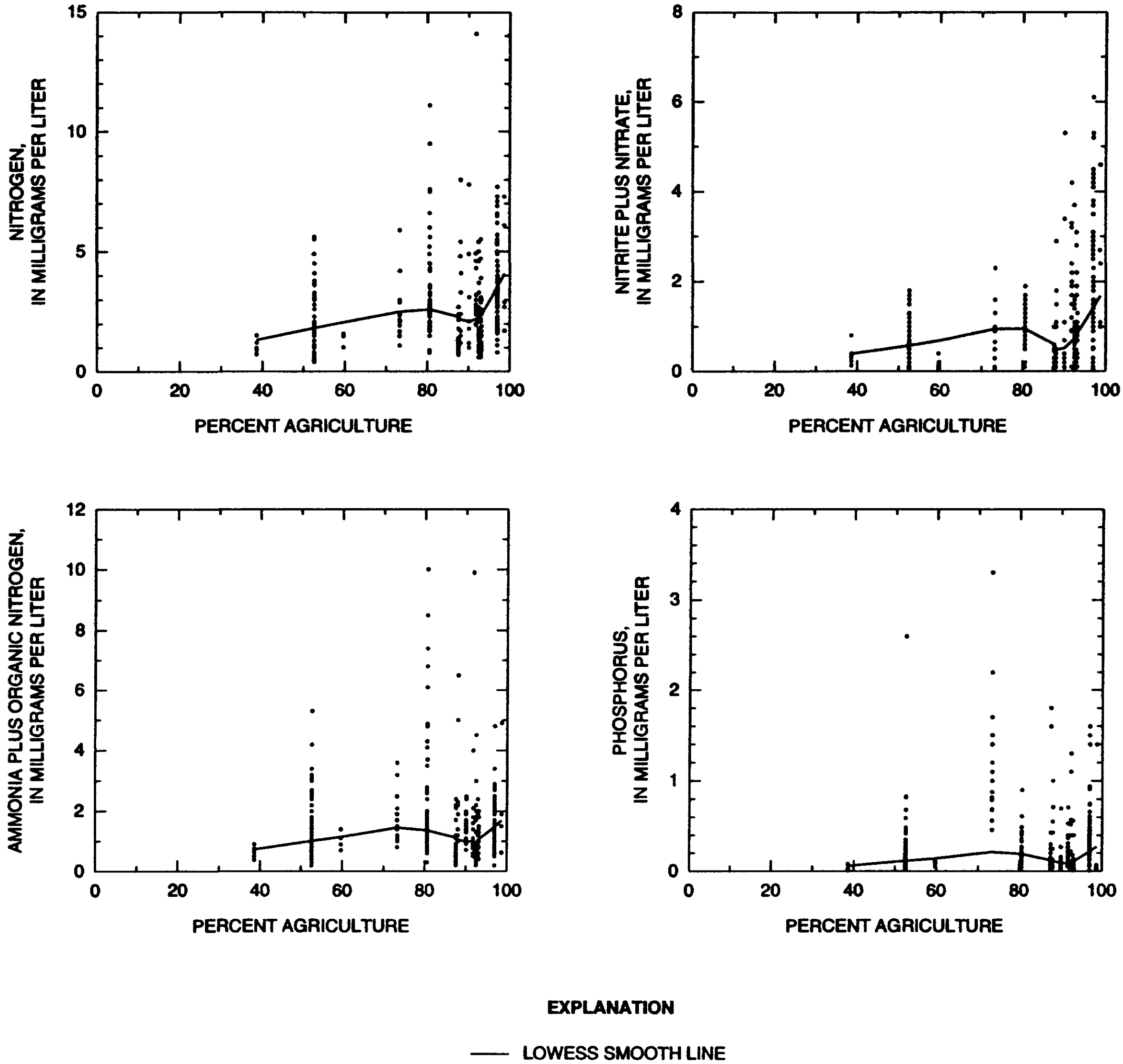

Figure 16. Relation between nutrient concentrations and percent of drainage in agricultural land use in the Trinity River Basin.

forest; none of the drainages had large areas of urban land use.

There are two known limitations with the land-use data used to determine percent agricultural land use for this analysis. The first is that the data were from the 1970's and land use changes have occurred in some parts of the study unit since then. The second is that the Anderson level-2 classification for agricultural land use combines cropland and pasture (Anderson, 1976). There are large differences in the use and timing of fertilizer application between different crops and between crops and pasture. Those differences cannot be evaluated using the available land-use data.

Relations to Streamflow

Two different physical phenomena can cause differences in concentrations in relation to streamflow at a site. One phenomenon is dilution. A solute may be delivered to the stream at a reasonably constant rate (due to a point source or ground-water discharge to the stream). Runoff will dilute the concentration of the solute as discharge

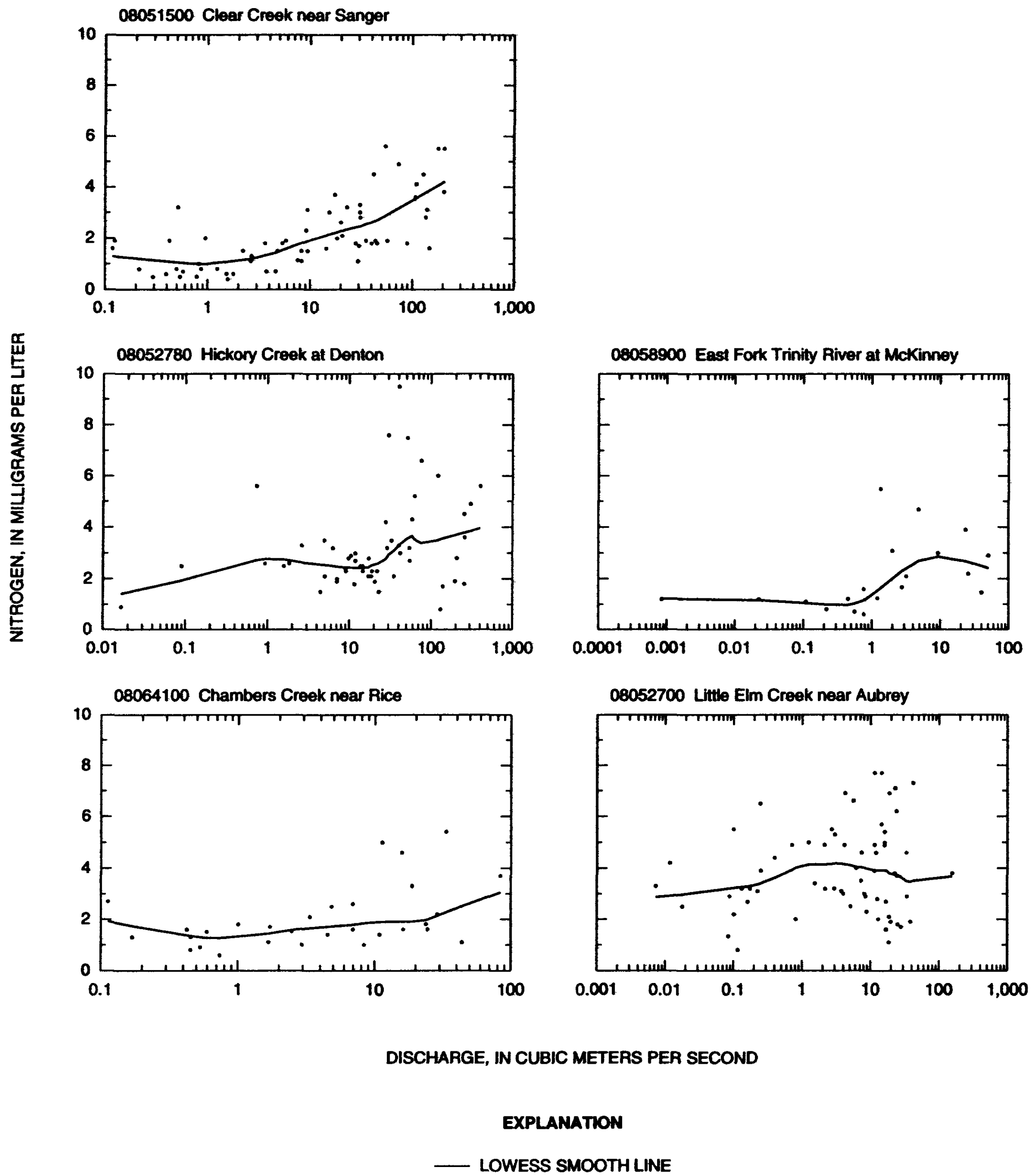

Figure 17. Relation between nitrogen concentrations and discharge for streams in agricultural areas.

increases. The result is a decrease in concentration with increasing flow. The other phenomenon is washoff. A solute, sediment, or a constituent attached to sediment can be delivered to the stream primarily from overland flow from paved areas or cultivated fields, or from streambank erosion. In this case, concentrations tend to increase with increasing flow. Both of these phenomena occur in the Trinity River Basin.

Twelve sites sampled by the USGS, representing all three stream types described above, were used to evaluate the relations between nutrient concentrations and streamflow. Rank

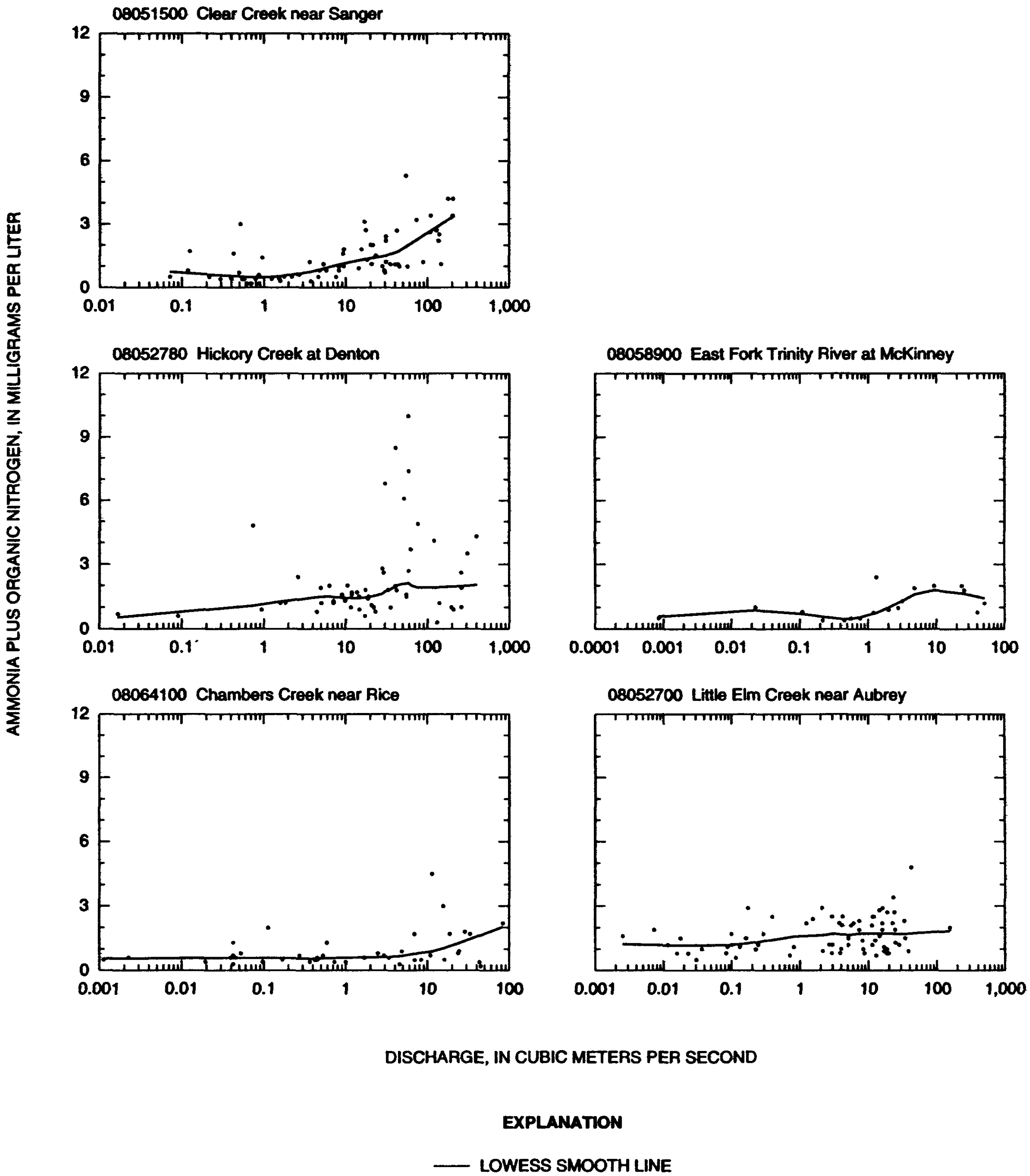

Figure 18. Relation between ammonia plus organic nitrogen concentrations and discharge for streams in agricultural areas.

correlations and p-values indicate the amount of monotonic correlation between the constituent concentration and discharge, and the significance of the relation (table 6). Increasing concentrations with increasing flow (washoff) occur at tributary sites in agricultural or mixed agricultural and range areas (figs. 17–20). This relation indicates natural and human nonpoint sources of nutrients are present in the tributary drainages.

Decreasing concentrations with increasing flow (dilution) occur at sites below the major point sources of wastewater in the Dallas-Fort Worth area (figs. 21–24). Concentrations at high flows in

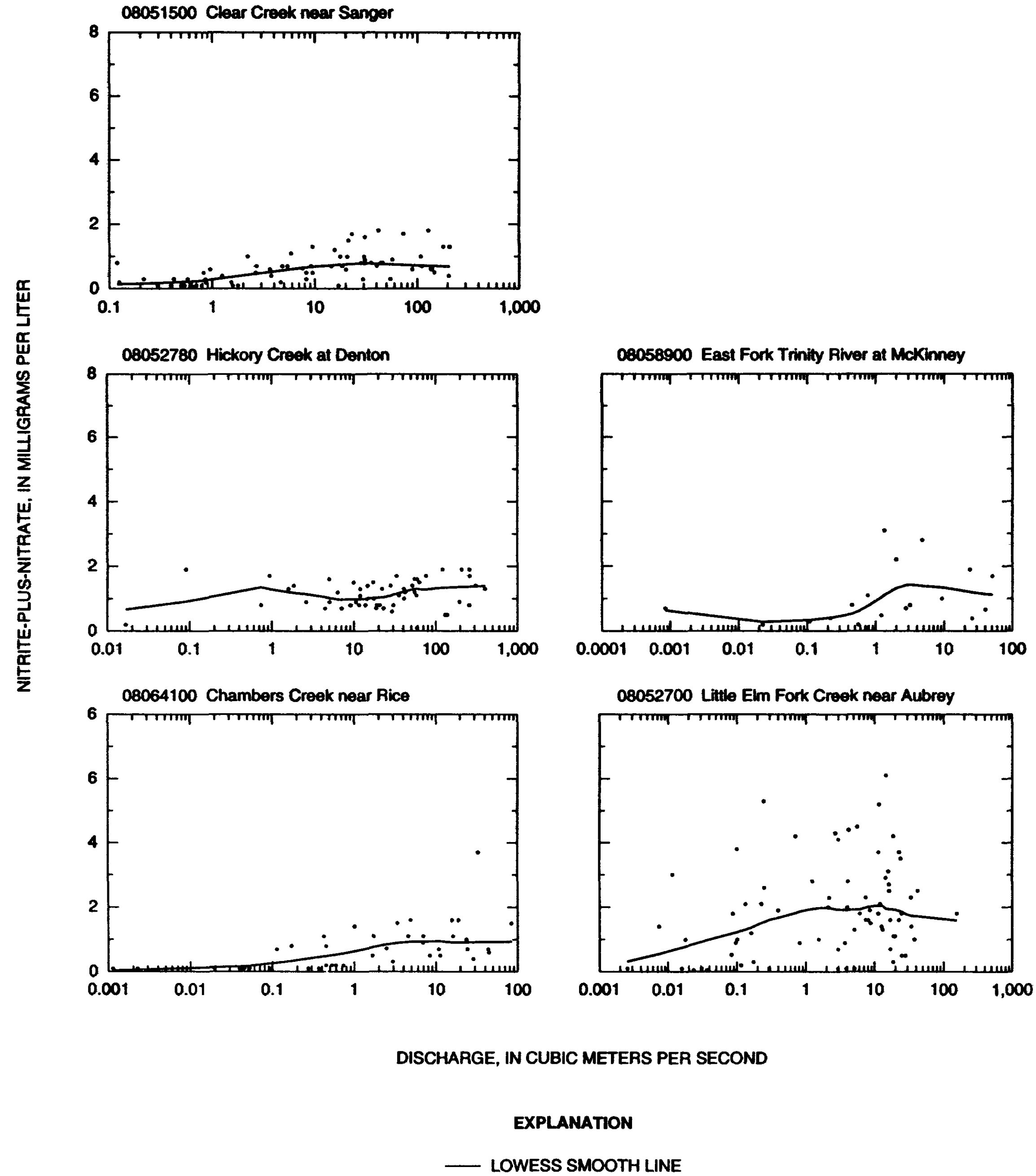

Figure 19. Relation between nitrite-plus-nitrate concentrations and discharge for streams in agricultural areas.

the tributary drainages are larger than concentrations at high flows at sites below major point sources (figs. 17–24). Plots on figures 21 through 24 are "stacked" in downstream order from upstream from the first major WWTP to downstream from Livingston Reservoir. The upper-left graph is the most upstream site and the lower-right graph is the most downstream (figs. 21–24). Increased concentrations and the change in relation to discharge caused by the addition of wastewater effluent are indicated by comparing site 08048543, West Fork Trinity River at Beach Street in Fort Worth (the most upstream site), with site 08049500, West Fork Trinity River

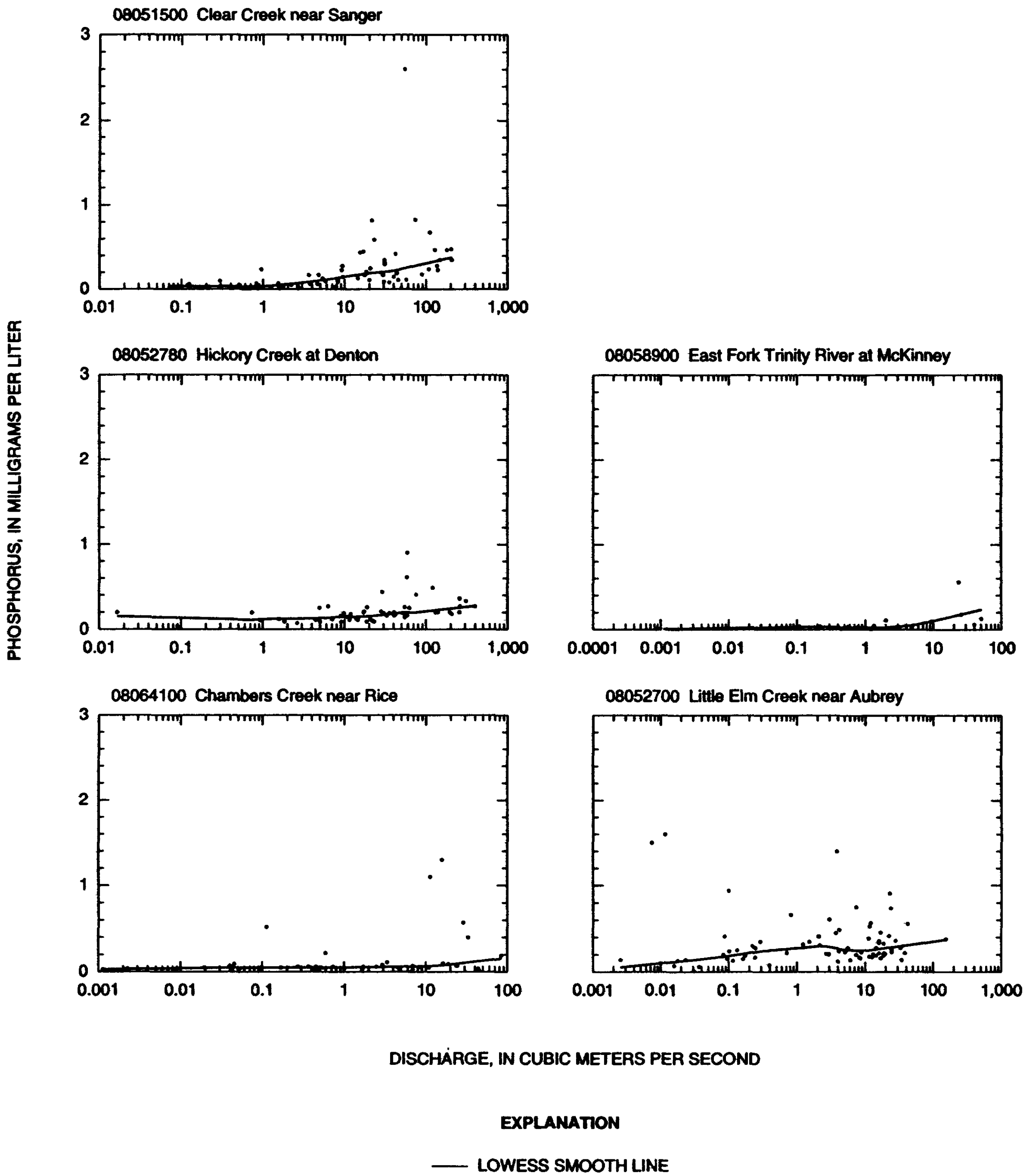

Figure 20. Relation between phosphorus concentrations and discharge for streams in agricultural areas.

at Grand Prairie. Livingston Reservoir is between site 08065350, Trinity River near Crockett, and site 08066500, Trinity River near Romayor. Constituent concentrations decline significantly between these two sites, and the relation to discharge changes.

Concentrations at sites 08048543 and 08066500 varied little with changes in discharge. Site 08048543 has about 93 percent of its drainage area regulated by Benbrook Lake on the Clear Fork Trinity River and Lake Worth on the West Fork Trinity River. Site 08066500 has about 96 percent

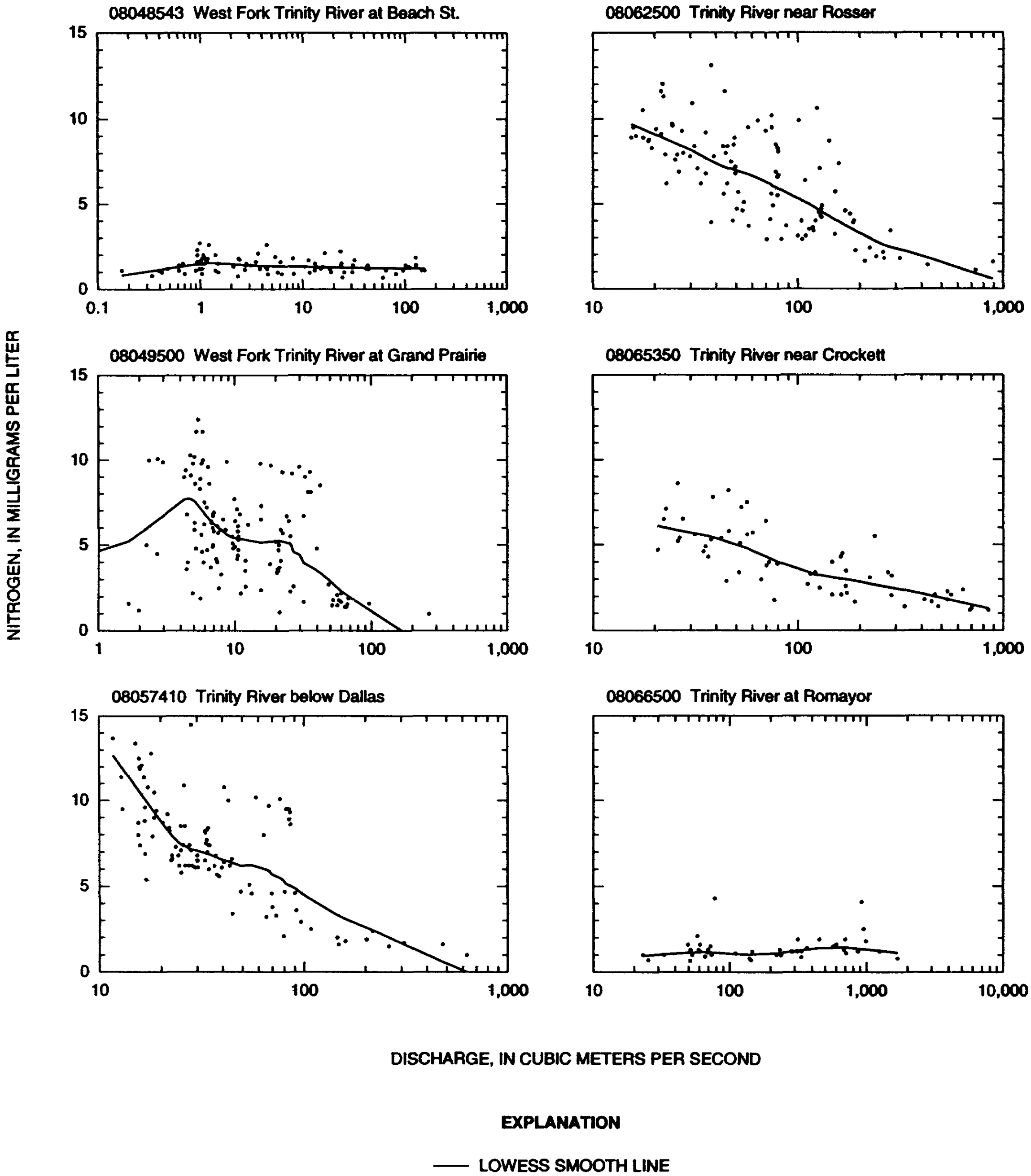

Figure 21. Relation between nitrogen concentrations and discharge for streams in and downstream from Dallas-Fort Worth.

of its drainage area regulated by Livingston Reservoir. Mixing of inflows in the reservoirs results in relatively little change in concentrations with changes in discharge downstream from the reservoirs. Some washoff from the adjacent urbanized areas of Fort Worth may contribute nutrients to site 08048543; however, it does not appear to be significant compared to the effects of the reservoirs.

The largest nutrient concentrations at sites subject to washoff often occur during the initial rise in streamflow. Larger concentrations during

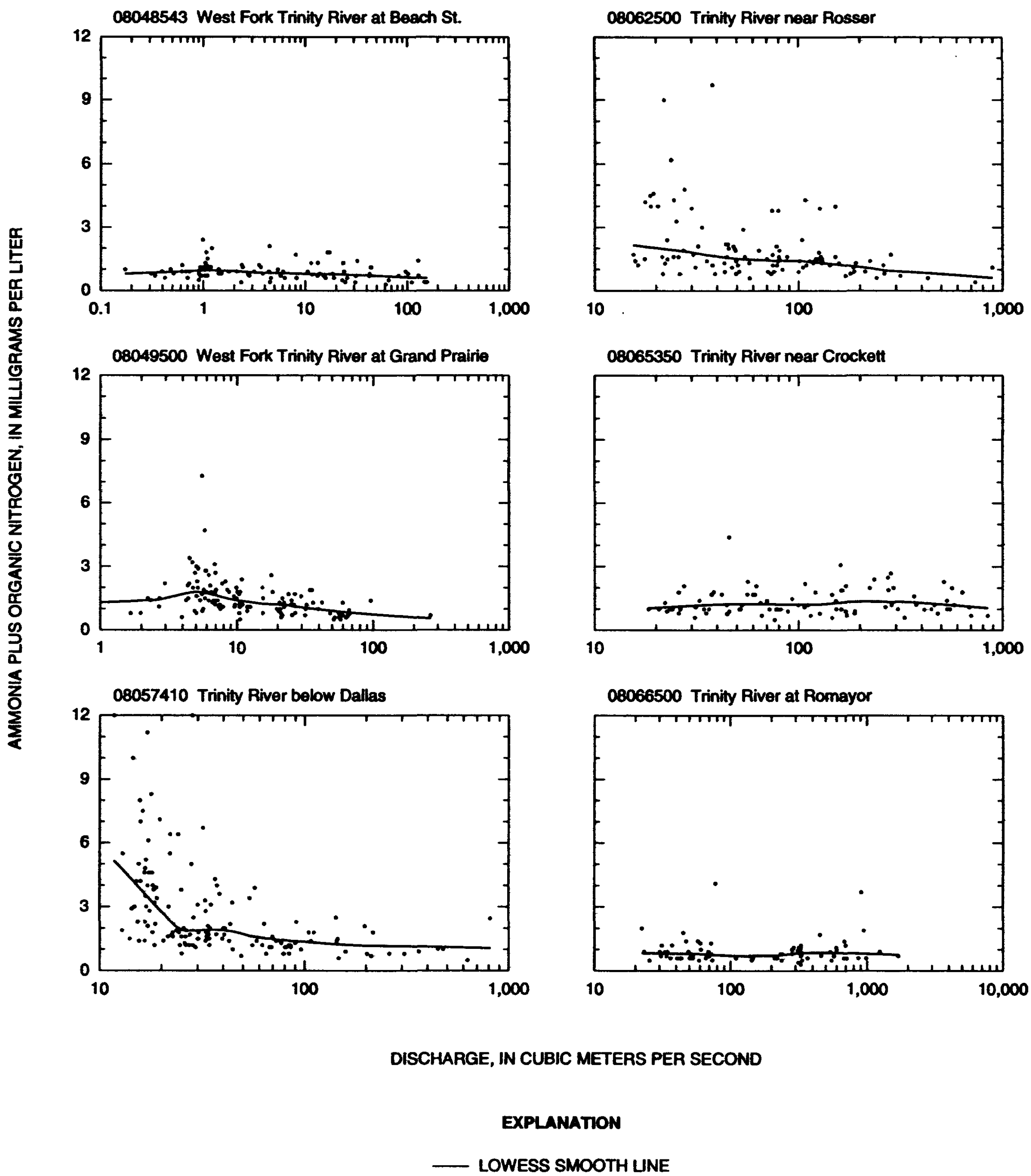

Figure 22. Relation between ammonia plus organic nitrogen concentrations and discharge for streams in and downstream from Dallas-Fort Worth.

the initial rise in streamflow are indicated by plots of discharge and concentrations for multiple samples for a single flow event at three tributary sites (fig. 25). The initial runoff from fields or developed areas can carry more sediment, nutrients, and other constituents that have accumulated during the preceding dry period. As rainfall continues less readily transported material is encountered and concentrations in washoff decrease.

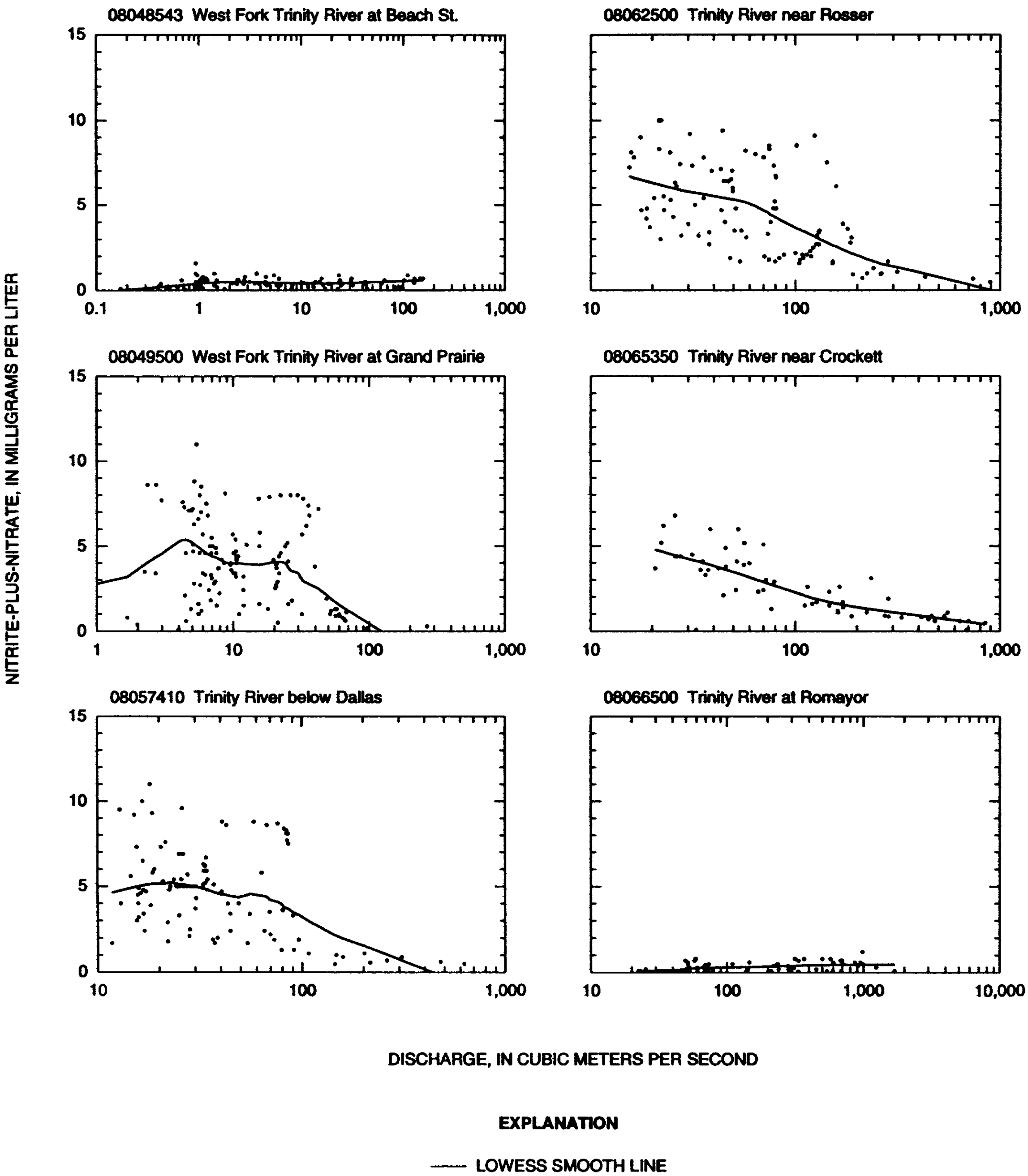

Figure 23. Relation between nitrite-plus-nitrate concentrations and discharge for streams in and downstream from Dallas-Fort Worth.

Seasonal Variations

Nutrient concentrations can vary seasonally because of seasonal changes in growth and decay of vegetation, changes in temperature and precipitation, seasonal applications of fertilizers containing nutrients, and other environmental factors. Seasonal variations in concentrations were evaluated at eight sites that each had 60 or more analyses collected from 1974 to 1991. Evaluations were made by plotting flow-adjusted residuals of concentrations by day of the year (Julian day) with LOWESS curves (figs. 26–29). Data from a longer time period was used for evaluation of seasonal

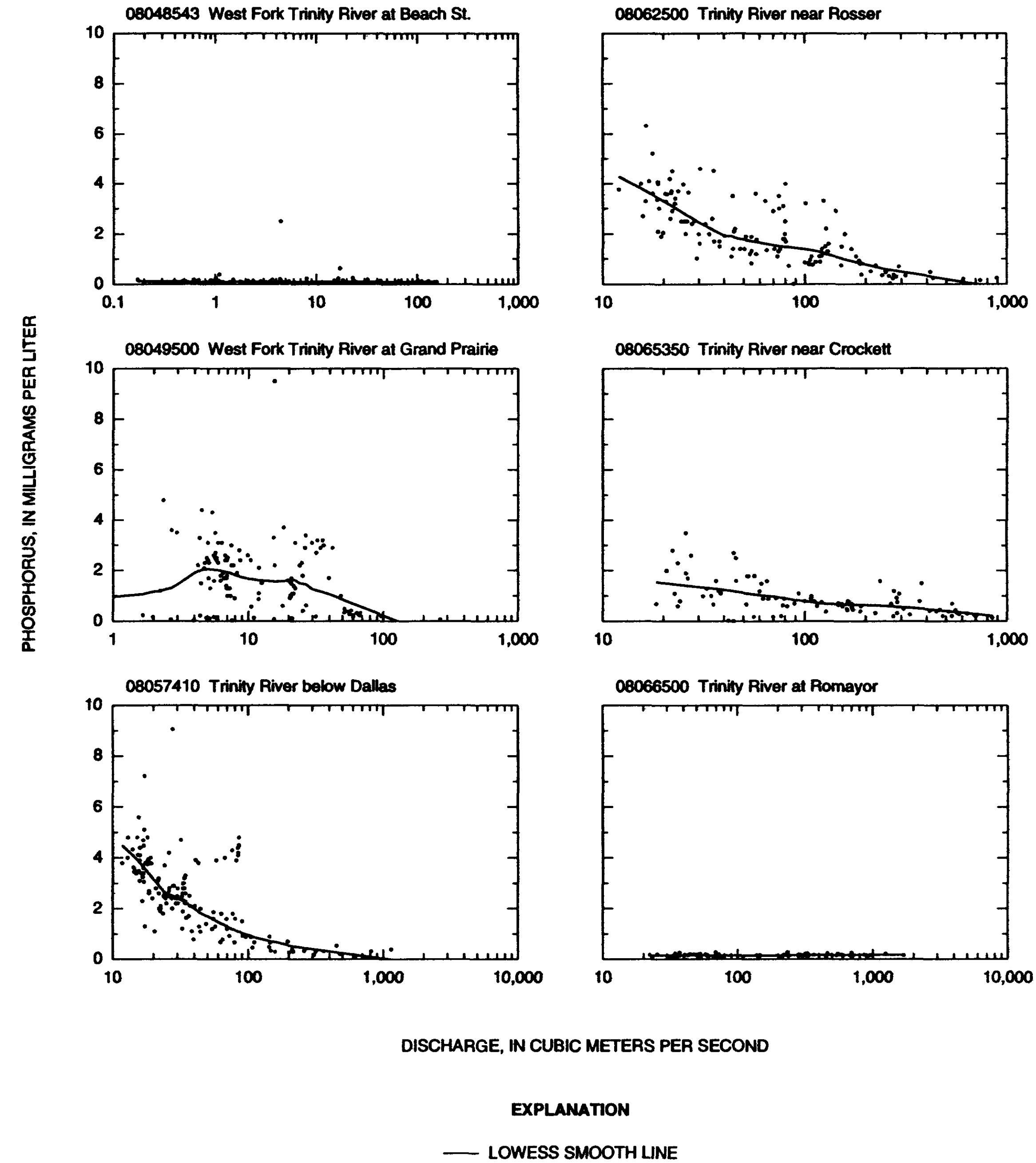

Figure 24. Relation between phosphorus concentrations and discharge for streams in and downstream from Dallas-Fort Worth.

variations, temporal trends, and loads to include major improvements in sewage treatment that occurred in the 1970's and early 1980's (Brush and Promise, 1990).

While there is considerable variability, the largest concentrations of nutrients generally occur during fall and winter and the smallest concentrations during spring and summer (figs. 26–29). This could reflect less utilization of nitrogen during fall and winter by plants. Exceptions for NO_2+NO_3 are at sites 08049500 and 08057410, where this pattern is reversed. At these two sites seasonal patterns of TKN and

Table 6. Rank correlations between discharge and nutrient concentrations in streams in the Trinity River Basin, 1982–91

[USGS, U.S. Geological Survey; TKN, Total Kjeldahl nitrogen; NO_2, nitrite; NO_3, nitrate]

USGS site	Constituent	Number of samples	Rank correlation (rho)	p-value	Significant at 95 percent level[1]	
		Tributary sites				
08051500 Clear Creek near Sanger	Nitrogen	64	0.69	0.00	yes	↑
	TKN	73	.69	.00	yes	↑
	NO_2+NO_3	72	.65	.00	yes	↑
	Phosphorus	73	.80	.00	yes	↑
08064100 Chambers Creek near Rice	Nitrogen	30	.45	.01	yes	↑
	TKN	44	.28	.06	no	•
	NO_2+NO_3	44	.72	.00	yes	↑
	Phosphorus	44	.39	.01	yes	↑
08052780 Hickory Creek at Denton	Nitrogen	55	.32	.02	yes	↑
	TKN	56	.33	.01	yes	↑
	NO_2+NO_3	56	.21	.13	no	•
	Phosphorus	56	.58	.00	yes	↑
08052700 Little Elm Creek near Aubrey	Nitrogen	64	.06	.65	no	•
	TKN	74	.29	.01	yes	↑
	NO_2+NO_3	74	.24	.04	yes	↑
	Phosphorus	74	.22	.06	no	•
08058900 East Fork Trinity River at McKinney	Nitrogen	19	.69	.00	yes	↑
	TKN	19	.62	.00	yes	↑
	NO_2+NO_3	19	.46	.05	yes	↑
	Phosphorus	19	.65	.00	yes	↑
		Sites below major point sources				
08049500 West Fork Trinity River at Grand Prairie	Nitrogen	118	-.53	.00	yes	↓
	TKN	119	-.58	.00	yes	↓
	NO_2+NO_3	119	-.40	.00	yes	↓
	Phosphorus	107	-.43	.00	yes	↓
08057410 Trinity River below Dallas	Nitrogen	105	-.60	.00	yes	↓
	TKN	105	-.65	.00	yes	↓
	NO_2+NO_3	106	-.30	.00	yes	↓
	Phosphorus	106	-.50	.00	yes	↓
08062500 Trinity River near Rosser	Nitrogen	104	-.71	.00	yes	↓
	TKN	104	-.42	.00	yes	↓
	NO_2+NO_3	104	-.62	.00	yes	↓
	Phosphorus	93	-.75	.00	yes	↓

Table 6. Rank correlations between discharge and nutrient concentrations in streams in the Trinity River Basin, 1982–91—Continued

USGS site	Constituent	Number of samples	Rank correlation (rho)	p-value	Significant at 95 percent level[1]	
Sites below major point sources—Continued						
08065350 Trinity River near Crockett	Nitrogen	62	-0.81	0.00	yes	↓
	TKN	63	-.16	.21	no	•
	NO_2+NO_3	63	-.83	.00	yes	↓
	Phosphorus	62	-.67	.00	yes	↓
Sites below major reservoirs						
08048543 West Fork Trinity River at Beach Street at Fort Worth	Nitrogen	88	-.16	.13	no	•
	KN	96	-.24	.02	yes	↓
	NO_2+NO_3	96	-.22	.03	yes	↓
	Phosphorus	95	-.07	.51	no	•
08066500 Trinity River near Romayor	Nitrogen	51	.20	.16	no	•
	TKN	77	-.07	.56	no	•
	NO_2+NO_3	74	.49	.00	yes	↓
	Phosphorus	78	.07	.55	no	•

[1] • = no change with discharge; ↑ = positive relation to discharge; ↓ = negative relation to discharge.

NO_2+NO_3 are opposite, with larger concentrations of TKN corresponding to smaller concentrations of NO_2+NO_3. Both sites are in the Dallas area and are dominated by wastewater effluents. TKN in wastewater is converted to NO_2 and NO_3 in the presence of dissolved oxygen. Dissolved oxygen concentrations at these sites also vary seasonally with larger concentrations during winter than summer (Brush and Promise, 1990, p. 206–207). More dissolved oxygen could lead to more rapid conversion of TKN to NO_2+NO_3 during winter and result in the observed seasonal patterns of TKN and NO_2+NO_3.

Phosphorus concentrations are larger at most sites during the fall and smaller during the spring (fig. 29). This pattern could indicate seasonal variations in the growth and decay of vegetation with smaller concentrations in spring resulting from more utilization of phosphorus by plants.

Temporal Trends

Trend analysis was performed on the same eight sites where seasonal variations were evaluated. Trends were evaluated for the period 1974–91 using the seasonal Kendall test on flow-adjusted residuals. The period varied slightly depending on available data (table 7). Trend results are presented in three ways: (1) graphically by plotting flow-adjusted residuals of nitrogen, TKN, NO_2+NO_3, and phosphorus versus time with LOWESS curves (figs. 30–33); (2) by symbols on table 7 indicating either no trend, increasing trend, or decreasing trend, at the 95 percent confidence level; and (3) numerically by multiplying the Kendall slope estimated for the trend (for statistically significant trends) times 15 years to show the expected change in median concentrations in milligrams per liter from about 1975 to about 1990 (table 7). In some cases, conclusions of trend analysis vary compared with other studies (Schertz, 1990) because of

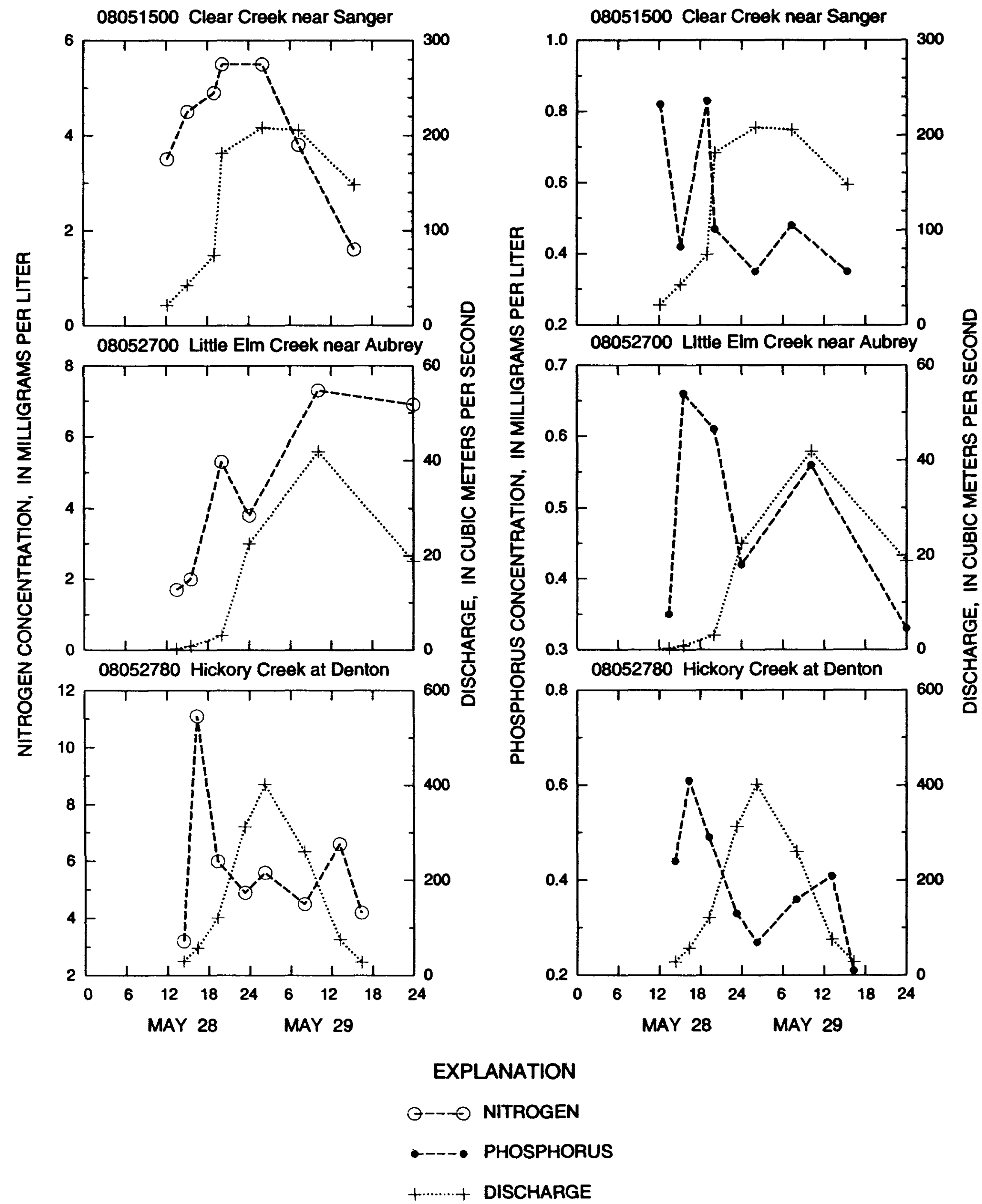

Figure 25. Nitrogen and phosphorus concentrations and discharge for three sites during a flow event on May 28–29, 1987.

differences in statistical methods, time periods selected, and confidence intervals used.

No trends were indicated at 08050500, Elm Fork Trinity River near Sanger. The Elm Fork site has one relatively small WWTP upstream, at the city of Gainsville, and is in an agricultural and range area. The gage was discontinued in 1985 prior to the flooding of the site by construction of Lake Ray Roberts.

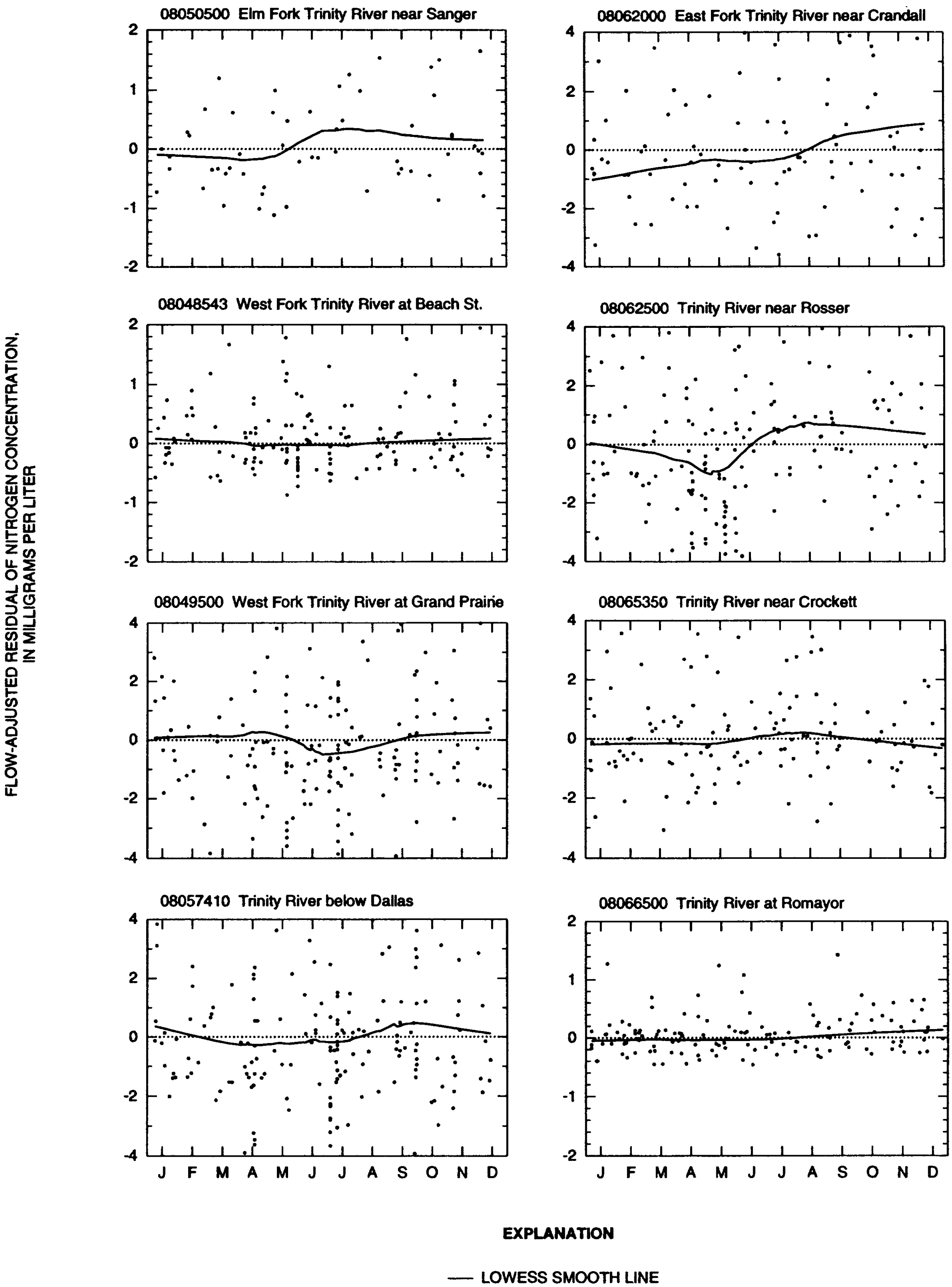

Figure 26. Seasonal variations in flow-adjusted residuals of nitrogen concentrations.

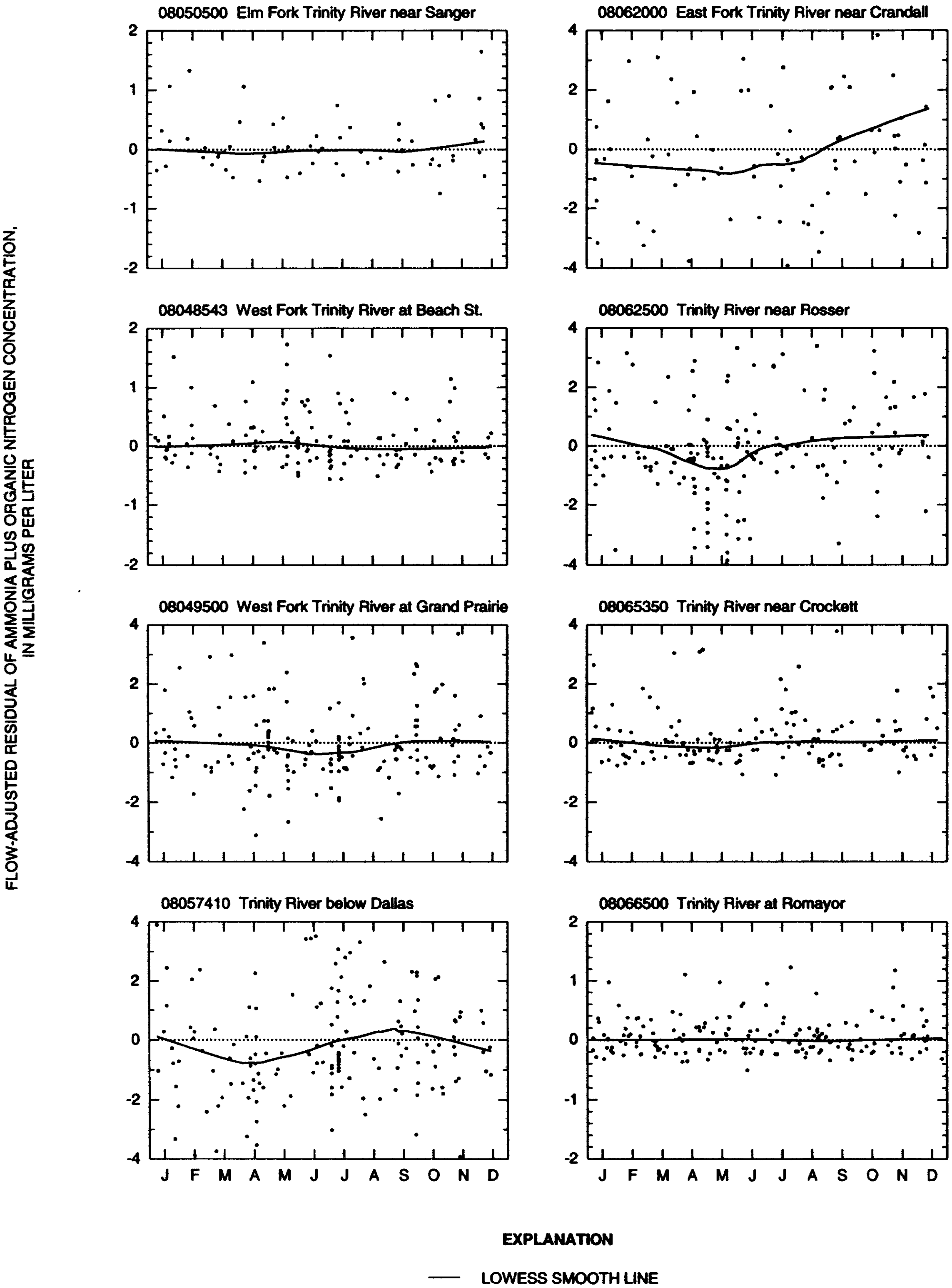

Figure 27. Seasonal variations in flow-adjusted residuals of ammonia plus organic nitrogen concentrations.

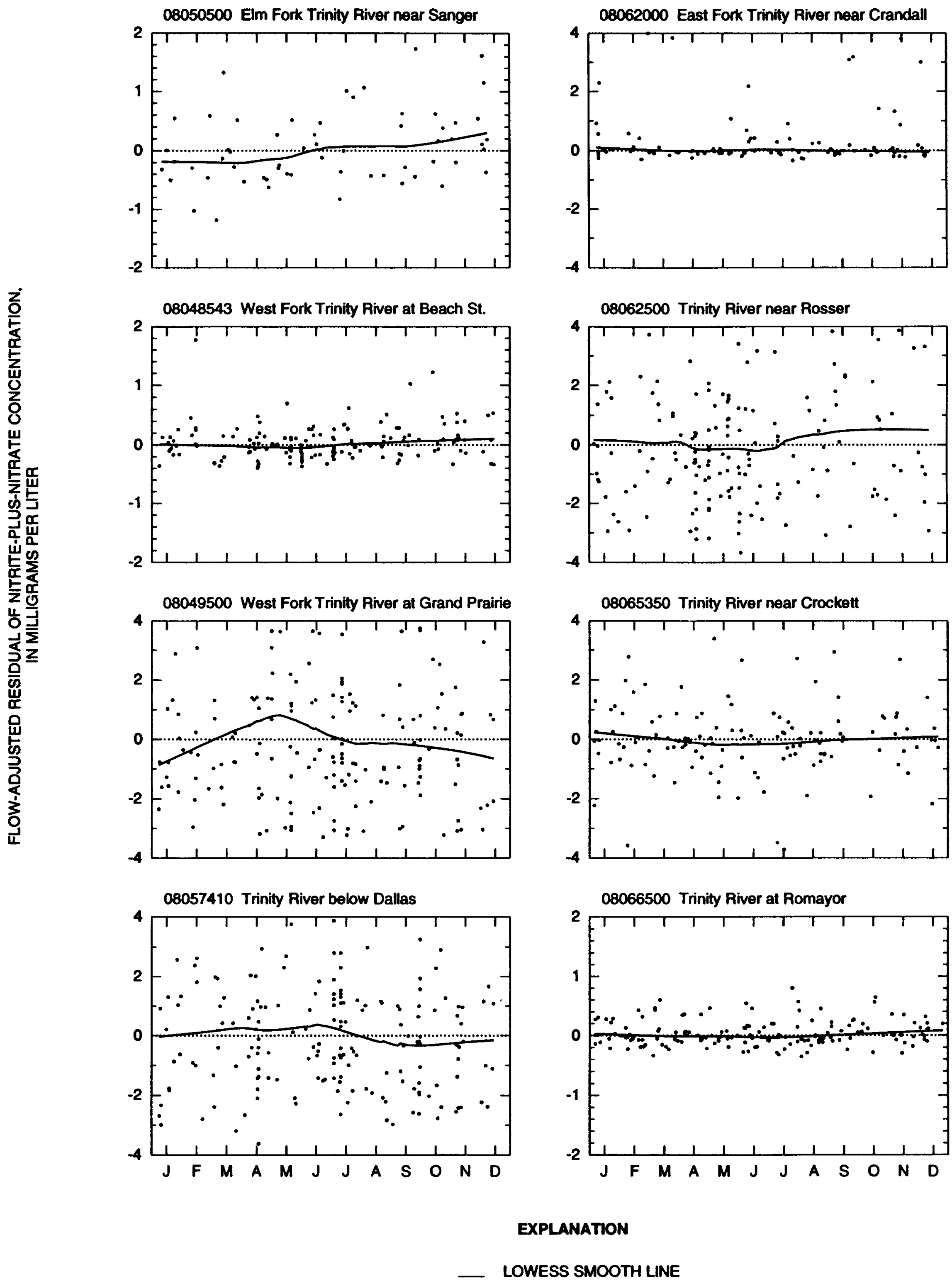

Figure 28. Seasonal variations in flow-adjusted residuals of nitrite-plus-nitrate concentrations.

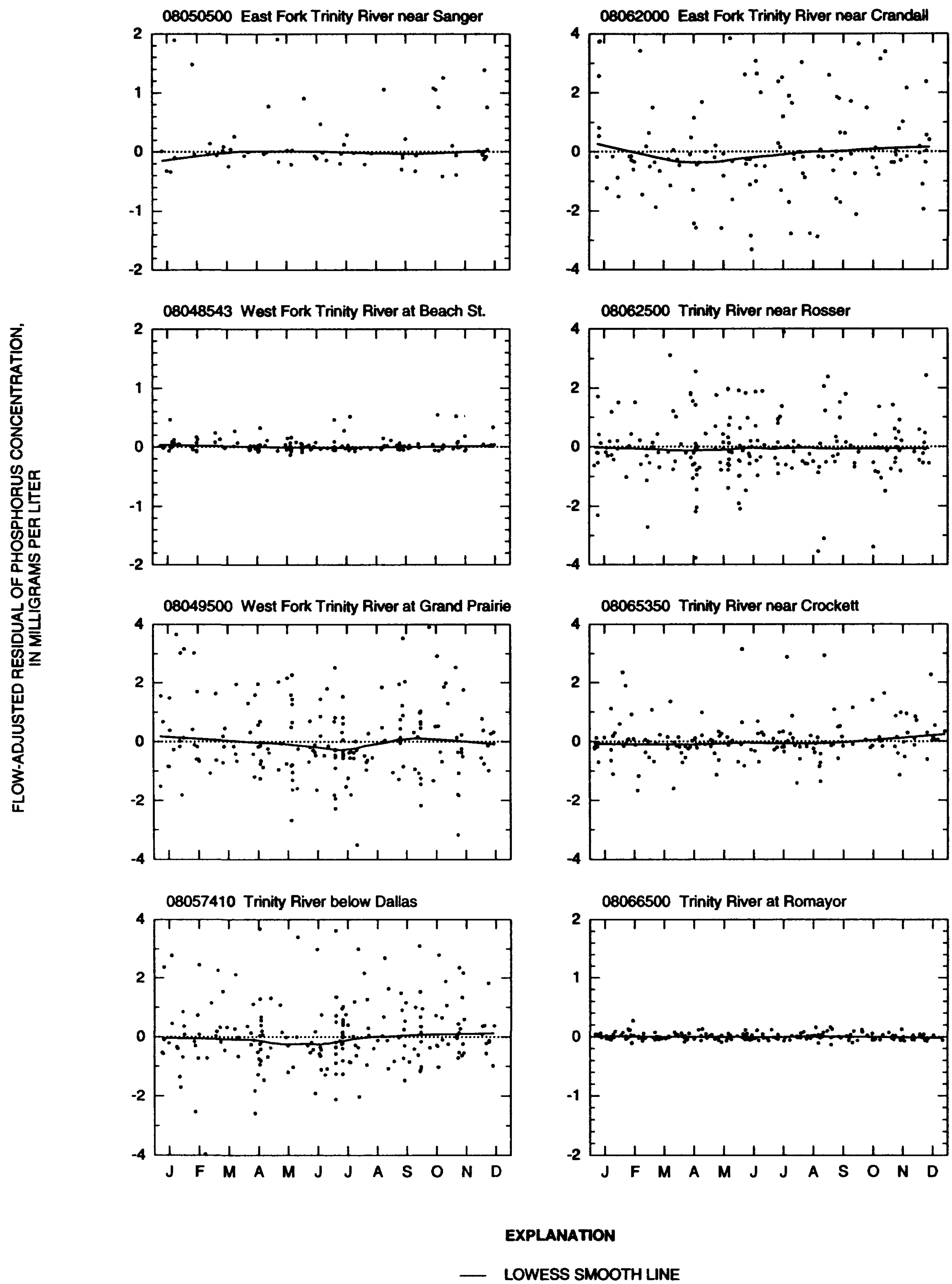

Figure 29. Seasonal variations in flow-adjusted residuals of phosphorus concentrations.

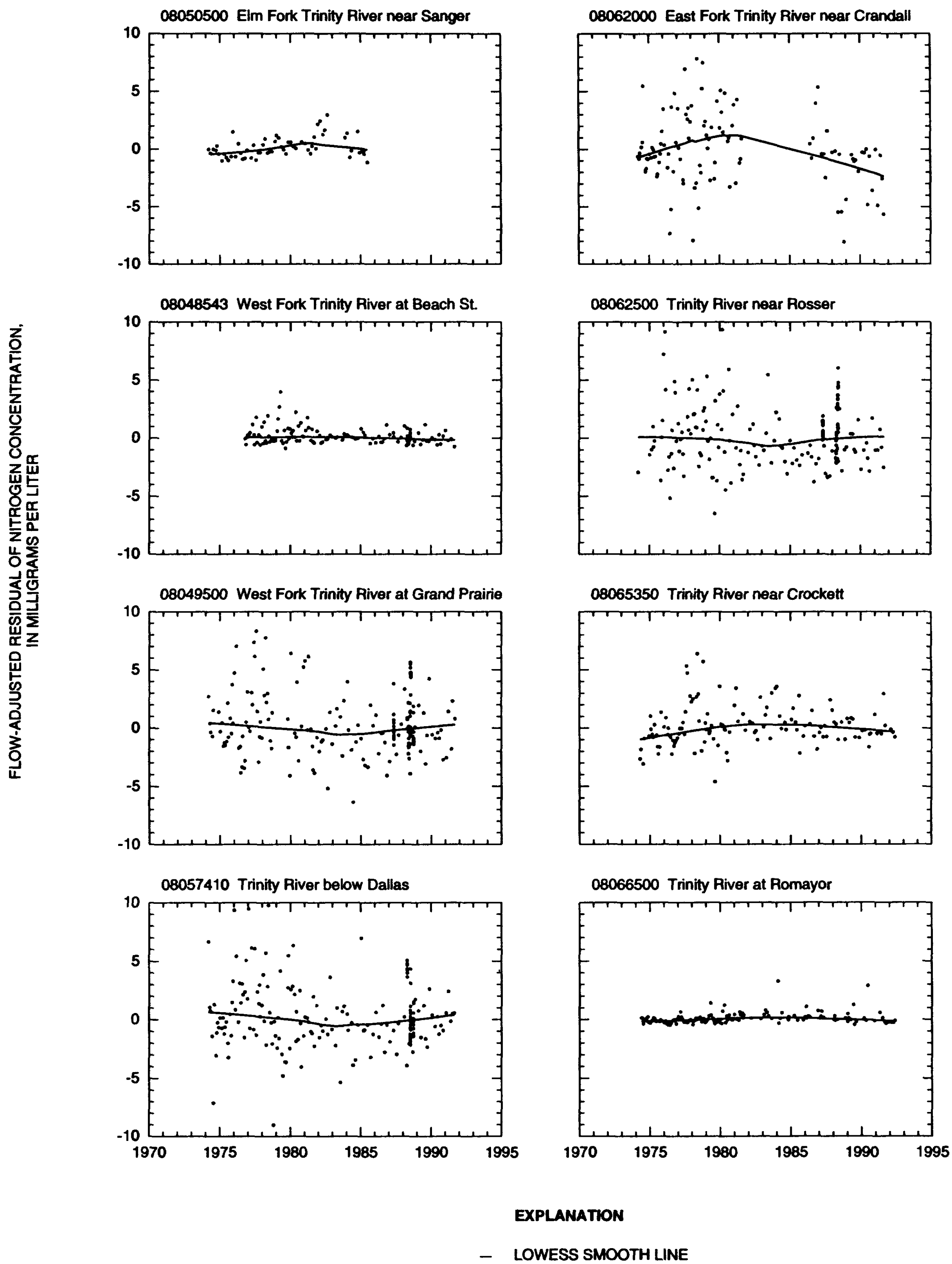

Figure 30. Temporal trends in flow-adjusted residuals of nitrogen concentrations.

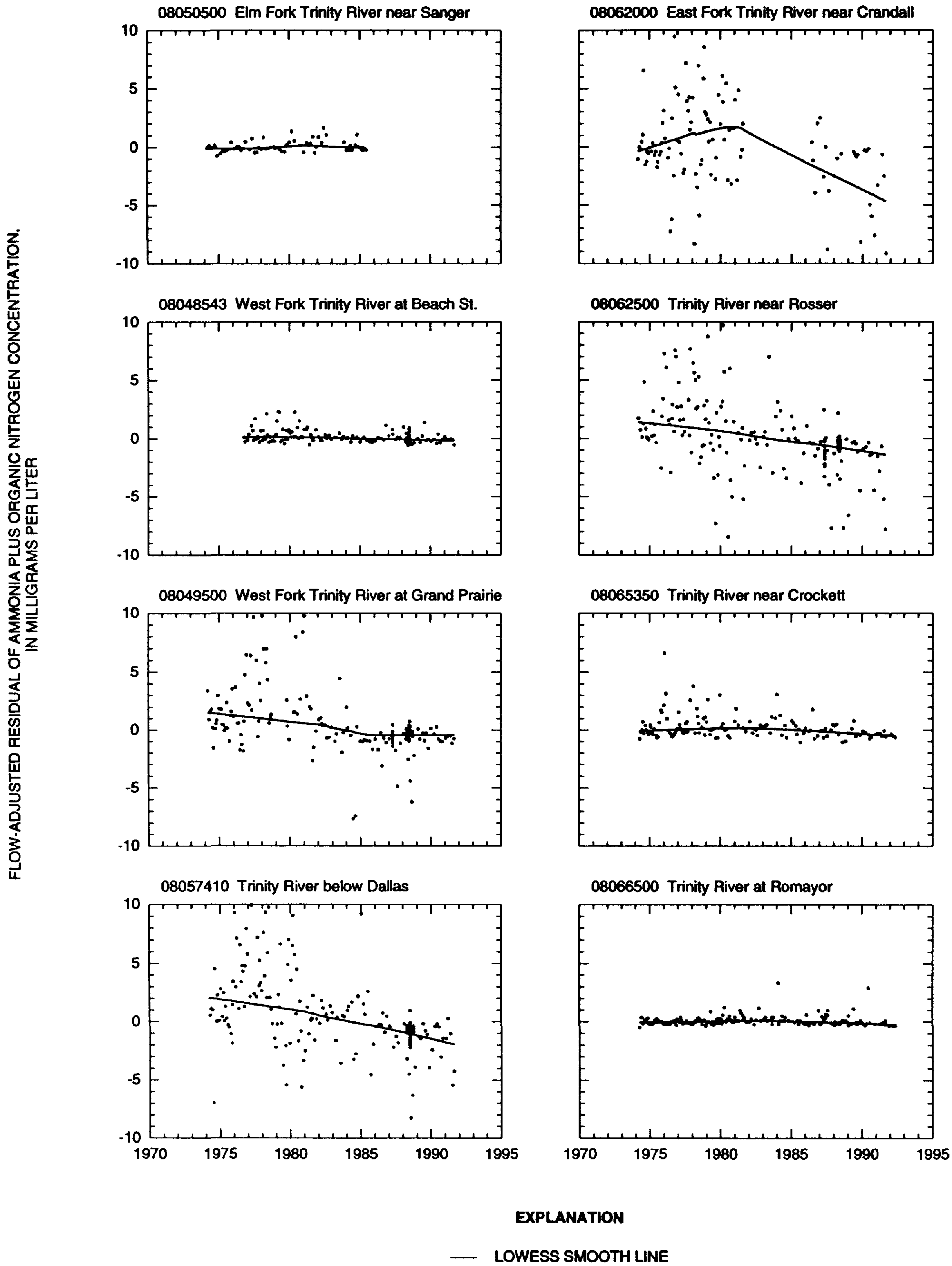

Figure 31. Temporal trends in flow-adjusted residuals of ammonia plus organic nitrogen concentrations.

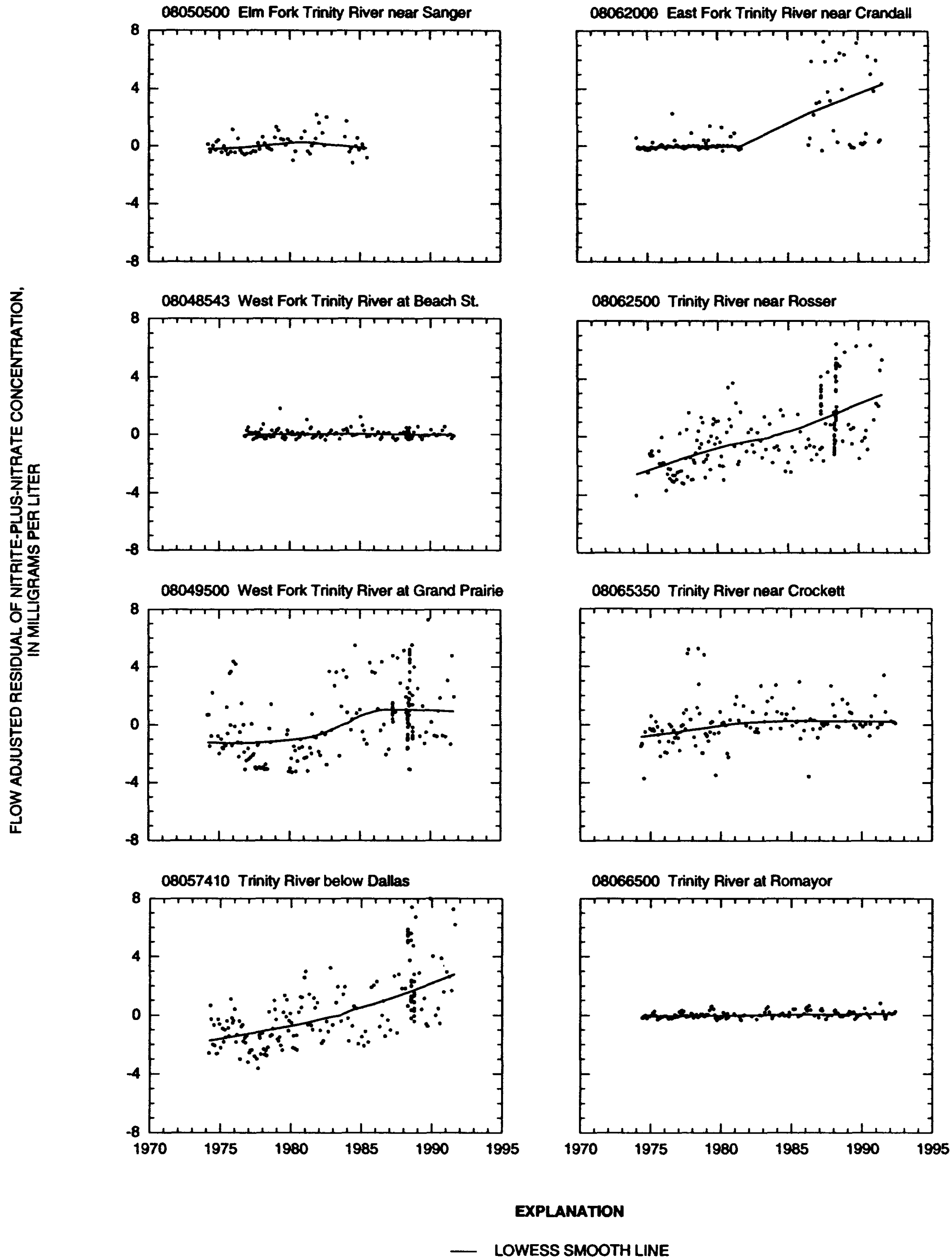

Figure 32. Temporal trends in flow-adjusted residuals of nitrite-plus-nitrate concentrations.

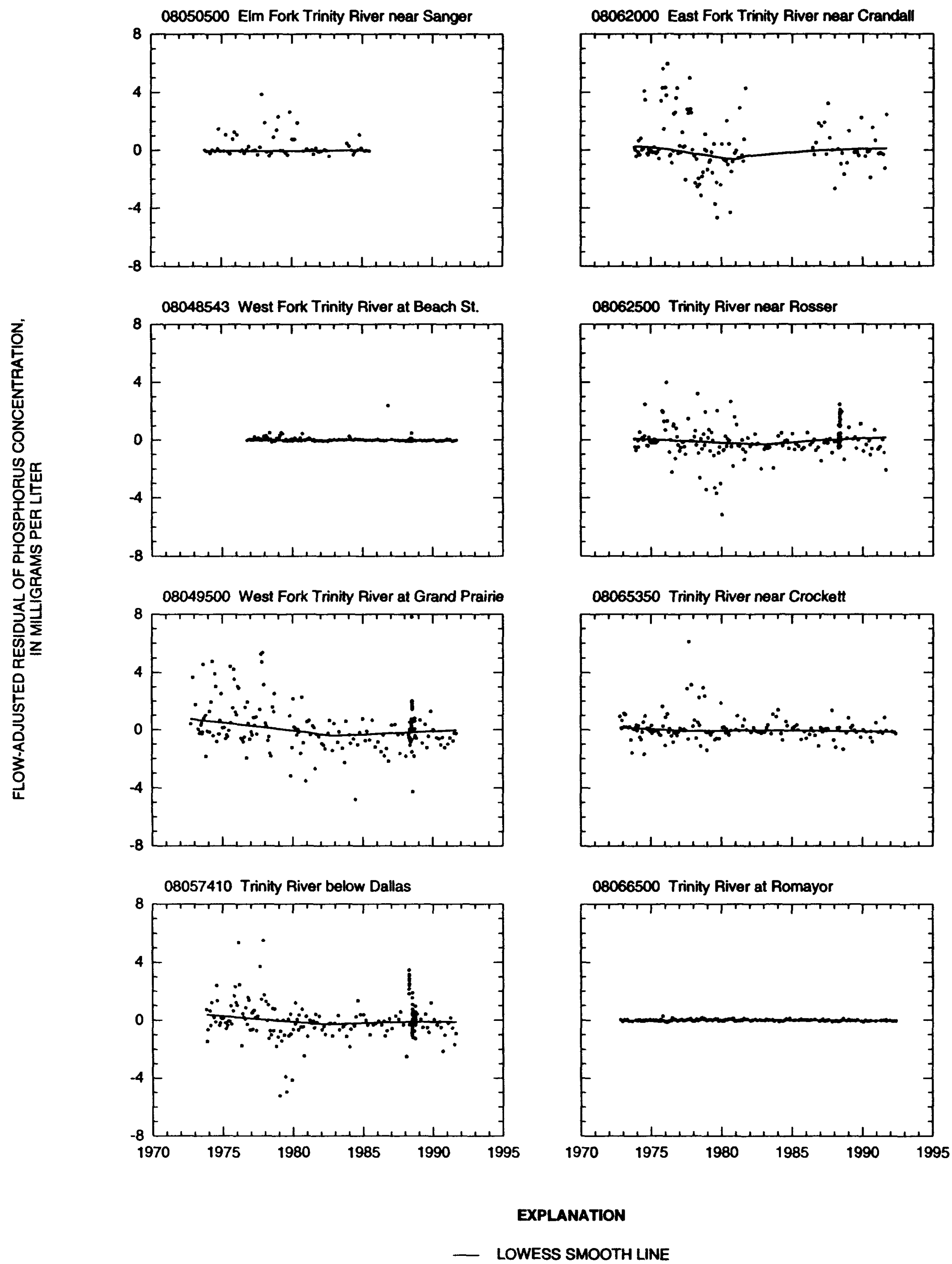

Figure 33. Temporal trends in flow-adjusted residuals of phosphorus concentrations.

Table 7. Trends in nutrient concentrations at selected sampling sites in the Trinity River Basin using the seasonal Kendall test

[Number shown is estimated change in concentration over 15 years, in milligrams per liter; USGS, U.S. Geological Survey; TKN, Total Kjeldahl nitrogen; NO_2, nitrite; NO_3, nitrate; ↓, decrease with time, •, no change in time, ↑, increase with time, at the 95 percent confidence level]

USGS site	Period(s) (year)	Nitrogen	Organic nitrogen	Ammonia	TKN	Nitrite	Nitrate	NO_2+NO_3	Phosphorus
West Fork Trinity River at Beach Street at Fort Worth 08048543	1977–91	↓ -0.42	↓ -0.39	↓ -0.16	↓ -0.51	•	↑ 0.13	•	↓ -0.092
West Fork Trinity River at Grand Prairie 08049500	1975–91	•	•	↓ -1.8	↓ -3.3	↓ -0.32	↑ 2.2	↑ 2.4	↓ -1.3
Trinity River below Dallas 08057410	1974–91	•	↓ -1.0	↓ -3.3	↓ -4.3	•	↑ 3.3	↑ 3.6	↓ -.51
East Fork Trinity River near Crandall 08062000	1971–81 1986–91	•	•	↓ -3.0	↓ -3.8	↑ .14	↑ 1.5	↑ 1.4	•
Trinity River near Rosser 08062500	1975–91	•	↓ -.50	↓ -2.2	↓ -3.7	•	↑ 3.0	↑ 3.4	•
Trinity River near Crockett 08065350	1974–91	•	•	↓ -.091	↓ -.71	•	↑ .56	↑ .86	•
Trinity River at Romayor 08066500	1974–91	•	•	•	•	↑ .003	•	↑ .12	•
Elm Fork Trinity River near Sanger 08050500	1974–85	•	•	•	•	•	•	•	•

Small increasing trends in nitrite and NO_2+NO_3 were indicated at 08066500, Trinity River at Romayor (table 7). The increasing trends could result from increases in nitrate and NO_2+NO_3 concentrations in the Trinity River above Livingston Reservoir being passed through the reservoir. The magnitude of change of these trends is small, estimated to be about 0.1 mg/L over 15 years for NO_2+NO_3. No trends were indicated at this site for nitrogen or phosphorus.

Decreasing trends in all constituents except nitrite and nitrate were indicated at 08048543, the West Fork Trinity River at Beach Street in Fort Worth. There was a small increasing trend in nitrate concentration. There are no large WWTPs upstream from the site and the causes of these trends are not known.

Similar patterns of trend were observed at each of the other five sites; decreases in ammonia and TKN and increases in nitrate and NO_2+NO_3. All five sites are downstream from major WWTPs in the Dallas-Fort Worth area. Changes in treatment practices since the mid-1970's have resulted in reduced BOD concentrations in effluents, primarily by converting ammonia and organic nitrogen to nitrate. Those changes have not significantly changed total nitrogen concentrations (table 7) but have significantly reduced TKN and increased NO_2+NO_3 concentrations. At 08057410, the Trinity River below Dallas, median TKN decreased about 4.3 mg/L over 15 years while median NO_2+NO_3 increased about 3.6 mg/L (table 7).

The conversion of TKN to NO_2+NO_3 over time is indicated by boxplots showing the percent of total nitrogen as TKN and as NO_2+NO_3 for successive periods at the Trinity River below Dallas and the Trinity River near Rosser (fig. 34). In the mid 1970's more than 75 percent of total nitrogen at these sites was TKN and less than 25 percent was NO_2+NO_3. By the late 1980's these proportions had reversed.

As indicated on table 7, there is a gap from 1982 to 1985 in the data for site 08062000. Helsel and Hirsch (1992; p. 349) recommend that if the gap in a sample record is more than about one-third the entire period of data collection a step trend procedure is probably best. Because the gap in record for site 08062000 was 4 years out of a period of 18 years, less than one-third of the record, a step trend procedure was not used. Pairwise slopes computed to estimate the Seasonal Kendall trend slope are calculated "across" the gap.

Statistically significant decreases in phosphorus occurred at the two sites downstream from major WWTPs in the Dallas area (08049500 and 08057410). The causes of the decreases in phosphorus concentrations are not known but could have resulted from reductions in the use of phosphate in detergents. There currently (1994) is not a phosphate ban in the Dallas-Fort Worth area (Samuel Brush, North-Central Texas Council of Governments, oral commun., 1993).

Loads and Yields

Loads of nitrogen, TKN, NO_2+NO_3, and phosphorus were calculated for nine sites in the study unit (table 8). Simplified diagrams of selected streams in the Trinity River Basin are used to illustrate the spatial changes that occur with nutrient loads (figs. 35–37). Streams were segmented at the locations of WWTP effluent discharge and at the midpoint between sites used to calculate loads. The thickness of stream segments on figures 35 to 37 was varied proportionally to mean loads for sites represented by the segments; the larger the load, the wider the line segment on these figures. Mean loads of nitrogen and phosphorus are presented graphically for calendar years 1974–89 because of the general lack of temporal trends in concentrations. Mean loads of TKN and NO_2+NO_3 are presented graphically for two time periods, 1974–79 and 1984–89, because of temporal trends in concentrations of these constituents during the 1970's and 1980's. There were significant decreases in TKN and increases in NO_2+NO_3 loads in streamflow downstream from the Dallas-Fort Worth metropolitan area from the late 1970's to the late 1980's (figs. 36, 37).

Average loads and average yields for 1984–87 for nine sites are shown versus distance upstream

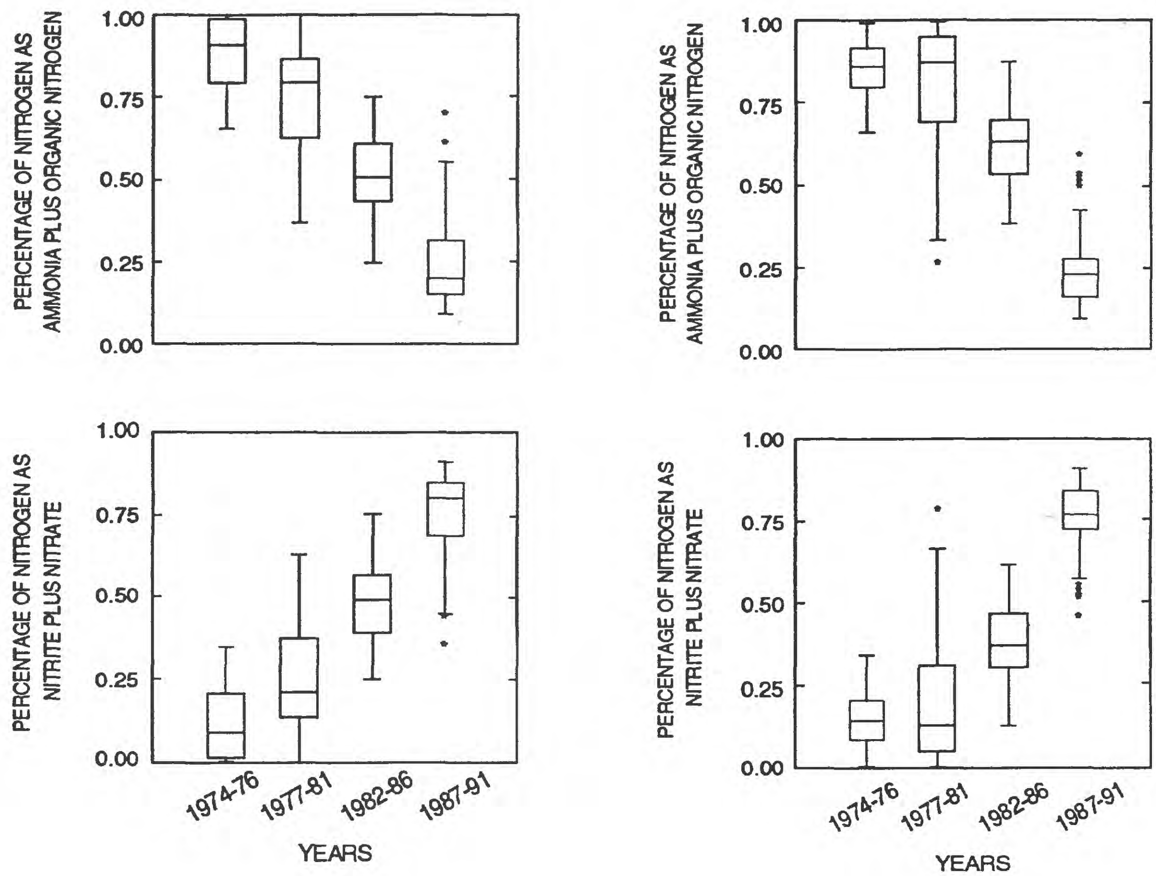

Figure 34. Change in percent of total nitrogen as ammonia plus organic nitrogen and nitrite plus nitrate for succesive periods at two sites downstream from Dallas.

from the mouth of the Trinity River on figures 38 through 41. Yield is the load at a site divided by the drainage area at the site. In natural streams, loads generally increase with increasing drainage area because of the positive relation between drainage area and discharge. Yields in natural streams remain relatively constant as drainage area increases. Small declines in yield with increasing drainage area can be caused by uptake of nutrients by plants, denitrification, and accumulation of sediments and their associated nutrients in channel deposits. In the Trinity River Basin, however, reservoirs and major point sources significantly change these relations.

The two most upstream sites shown on figures 38 to 41 are 08051500, Clear Creek near Sanger, and 08052700, Little Elm Creek near Aubrey (pl. 1). Both sites are tributaries above major point sources and reservoirs. Clear Creek drainage is largely pasture and range, and Little Elm Creek drainage is dominated by agriculture. Loads at these sites are small compared to downstream sites because their drainage areas are much smaller, however, yields of nitrogen from these drainages are similar in magnitude to yields for sites downstream from major WWTPs in Dallas (fig. 38). The 4-year average yield of nitrogen for Little Elm Creek was 6.7 (kg/ha)/yr compared with 2.8 (kg/ha)/yr at Clear Creek. More intensive farming in the Little Elm Creek drainage could cause the larger yield compared with Clear Creek; however, much of the difference can be explained by greater runoff in Little Elm Creek.

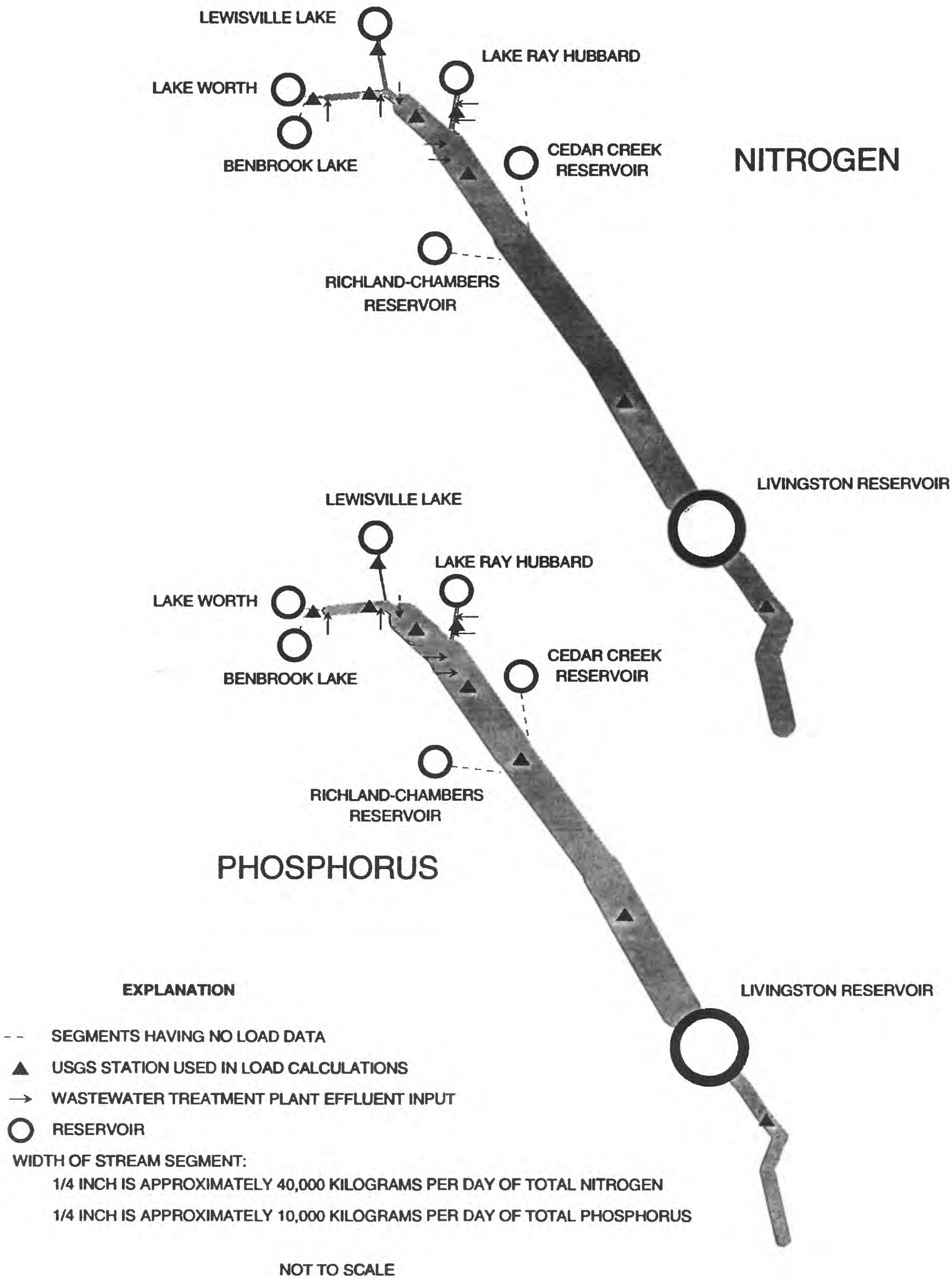

Figure 35. Mean loads of nitrogen and phosphorus in the Dallas-Fort Worth area and mainstem Trinity River, 1974–89.

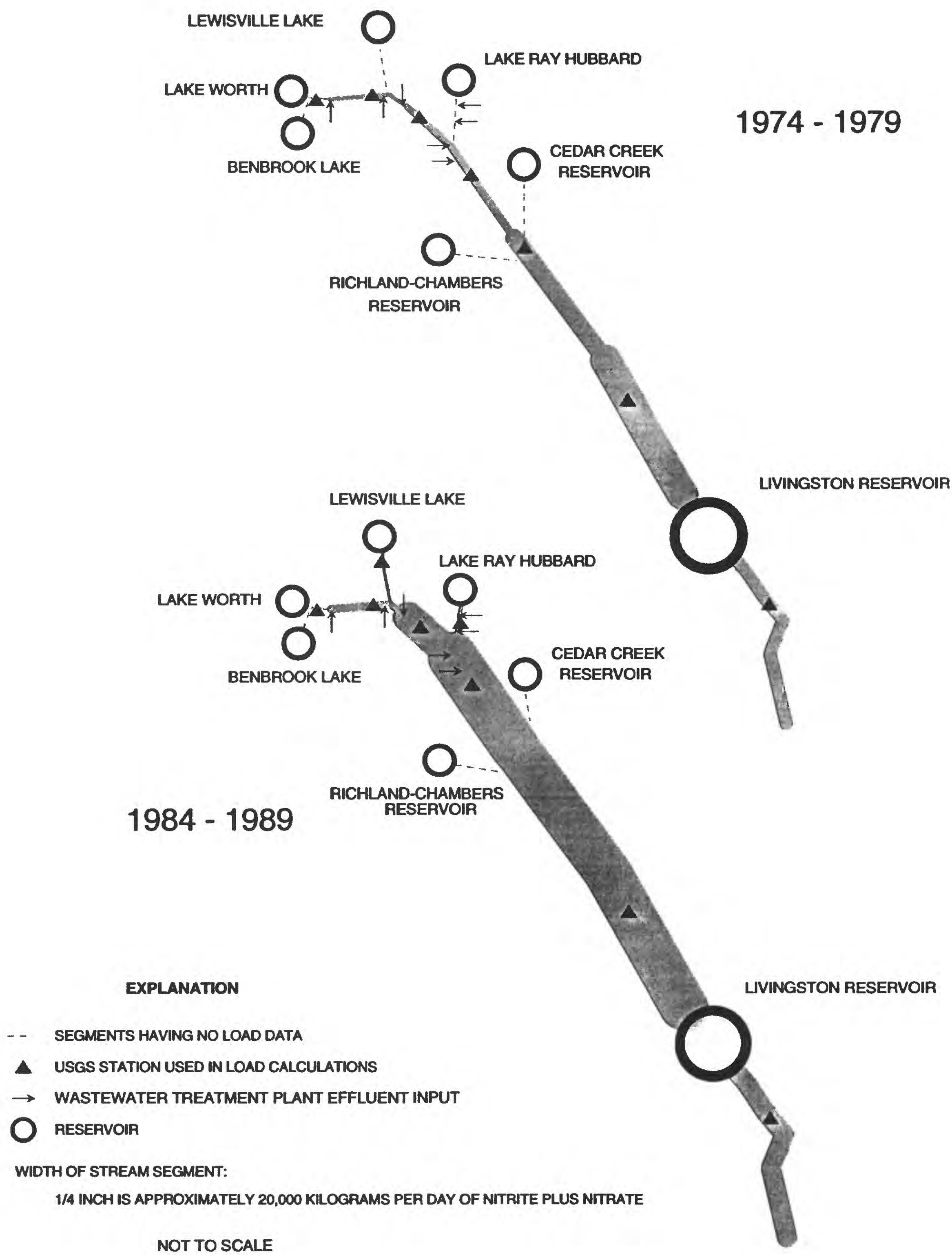

Figure 36. Mean loads of nitrite plus nitrate in the Dallas-Fort Worth area and mainstem Trinity River, 1974–79 and 1984–89.

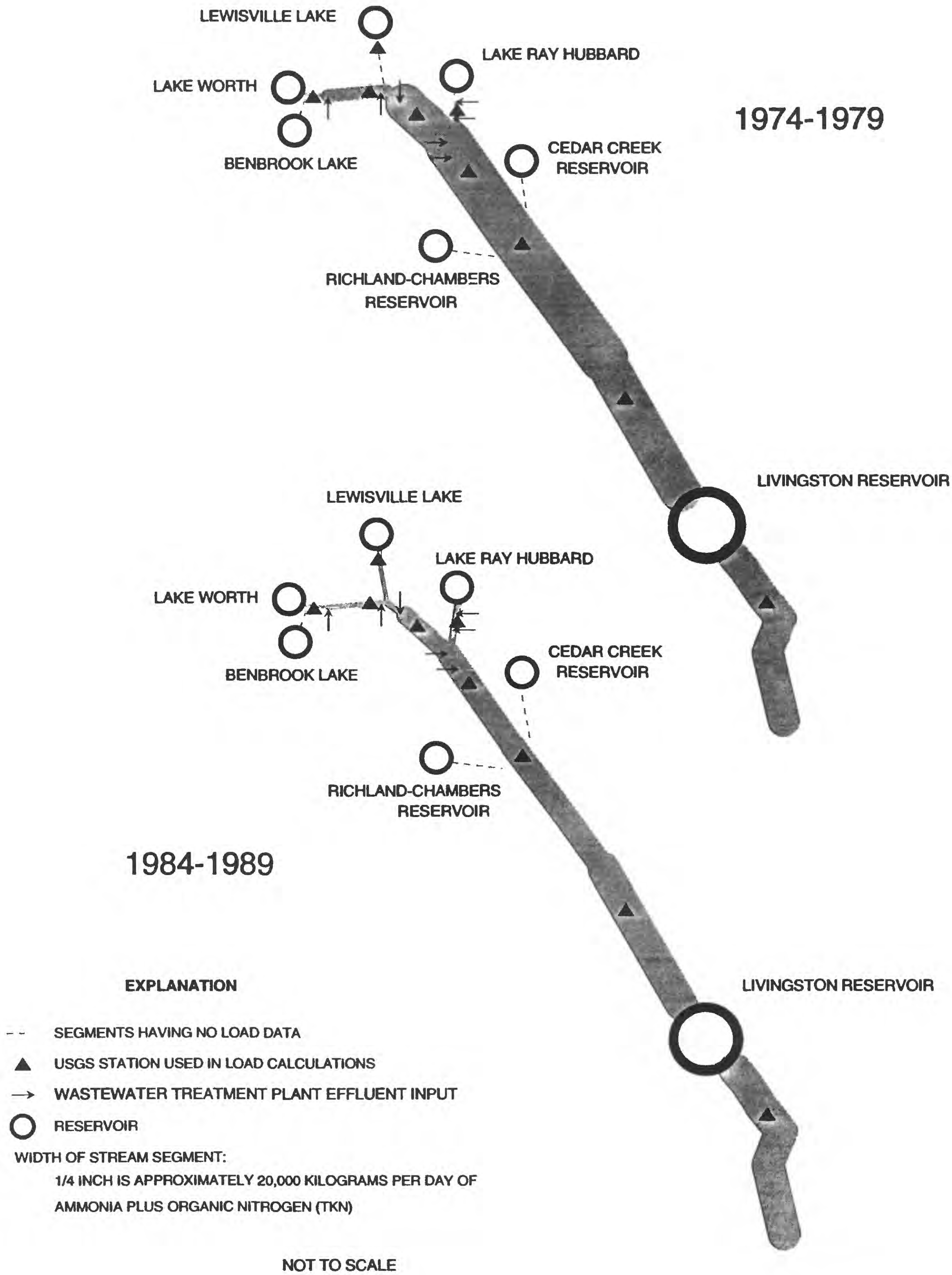

Figure 37. Mean loads of ammonia plus organic nitrogen in the Dallas-Fort Worth area and mainstem Trinity River, 1974–79 and 1984–89.

Table 8. Mean nutrient loads and mean daily discharge for nine sites in the Trinity River Basin

[USGS, U.S. Geological Survey; TKN, Total Kjeldahl nitrogen; NO_2, nitrite; NO_3, nitrate; kg/d, kilograms per day; m^3/s, cubic meters per second; ---, no data]

USGS site number	1974 to 1979			1984 to 1989			1974 to 1989		
	TKN (kg/d)	$NO_2 + NO_3$ (kg/d)	Mean daily discharge (m^3/s)	TKN (kg/d)	NO_2+NO_3 (kg/d)	Mean daily discharge (m^3/s)	Total nitrogen (kg/d)	Total phosphorus (kg/d)	Mean daily discharge (m^3/s)
08048543	[a]800	400	[a]8	800	500	13	[b]1,700	[b]100	[b]16
08049500	5,900	1,600	16	2,100	3,800	22	5,900	2,300	20
08053000	---	---	---	1,400	700	17	[c]2,700	[c]200	[c]21
08057410	19,900	3,200	52	8,900	15,600	64	23,700	8,100	61
08061750	---	---	---	2,700	1,400	16	[c]3,700	[c]600	[c]16
08062500	24,500	3,700	76	11,800	25,100	91	32,600	9,800	86
08062700	24,600	9,000	90	12,500	---	105	---	9,000	112
08065350	20,600	15,800	157	16,500	24,200	158	36,900	10,200	171
08066500	15,700	6,300	237	16,400	9,700	207	24,000	3,600	215

[a] 1977 to 1979.
[b] 1977 to 1989.
[c] 1981 to 1989.

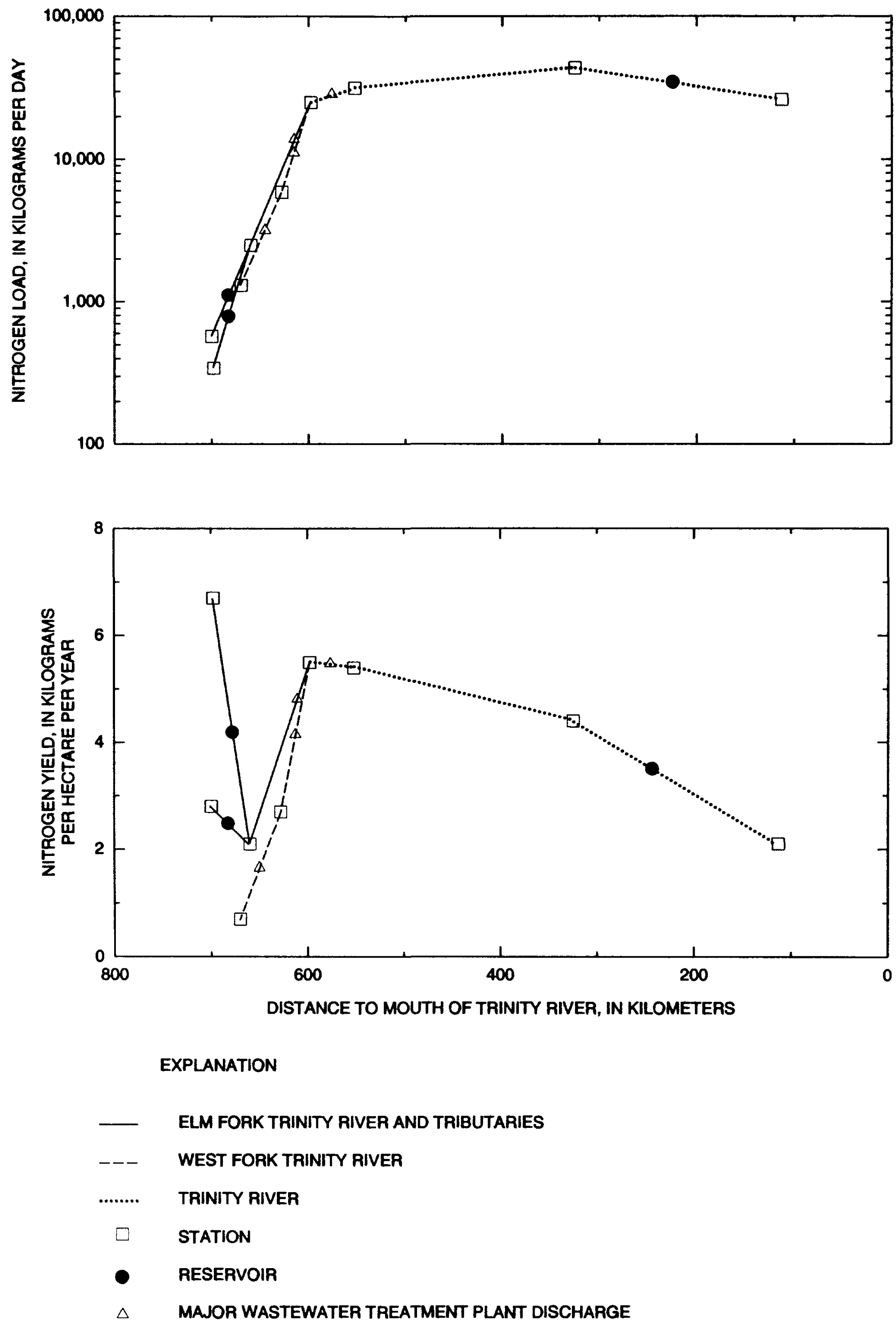

Figure 38. Plots showing average annual loads and yields for 1984–87 of nitrogen.

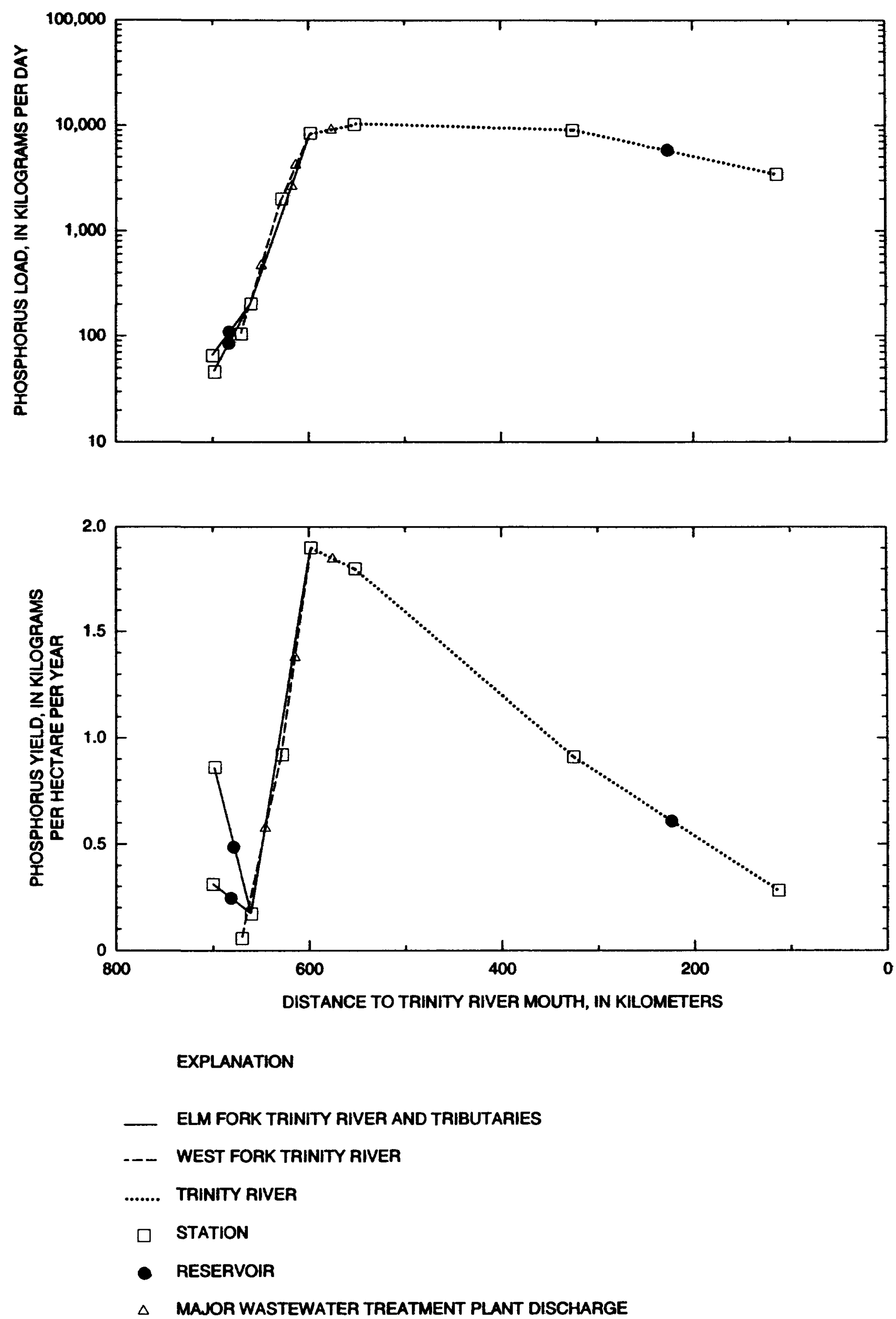

Figure 39. Plots showing average annual loads and yields for 1984–87 of phosphorus.

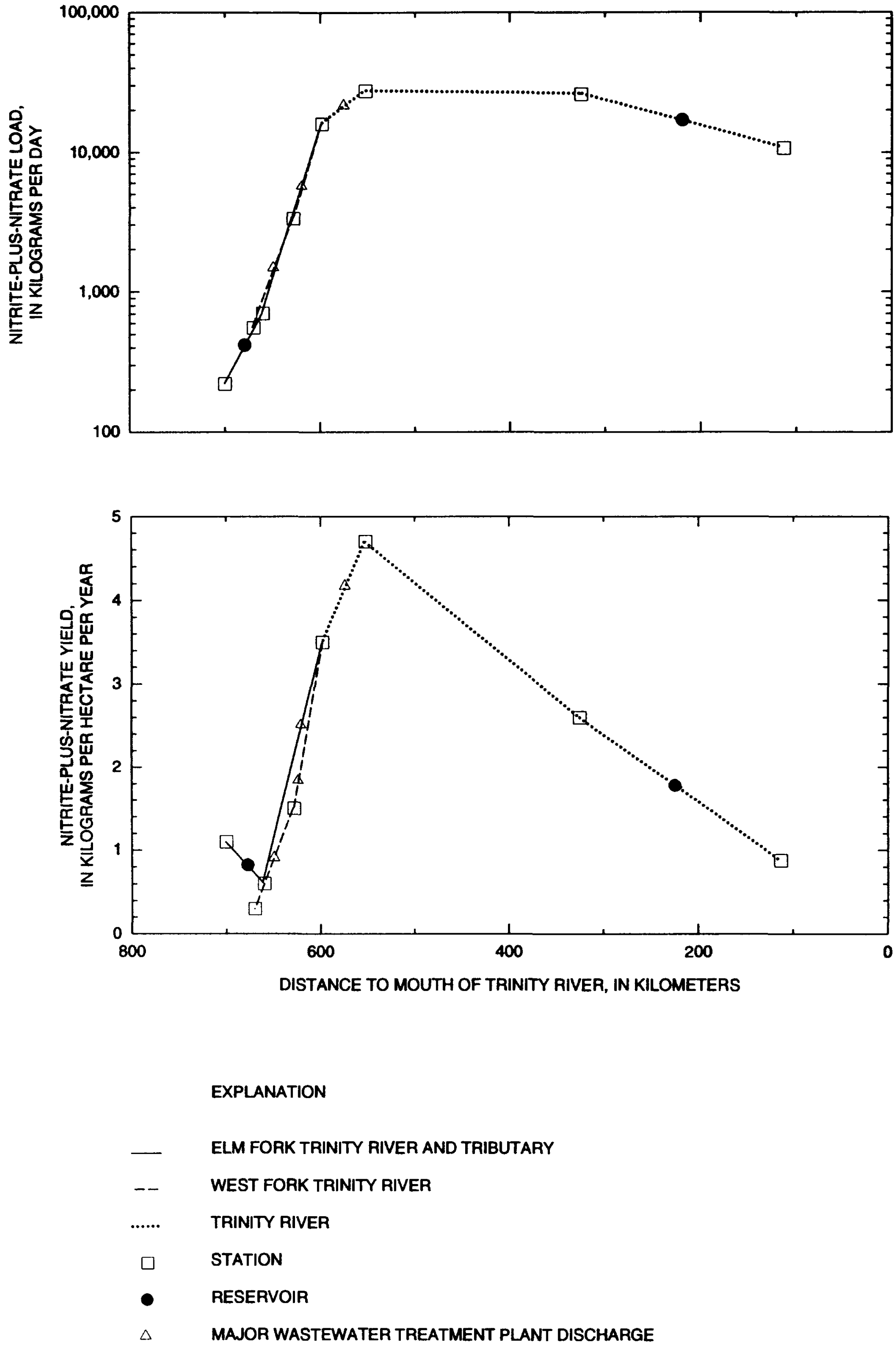

Figure 40. Plots showing average annual loads and yields for 1984–87 of nitrite plus nitrate.

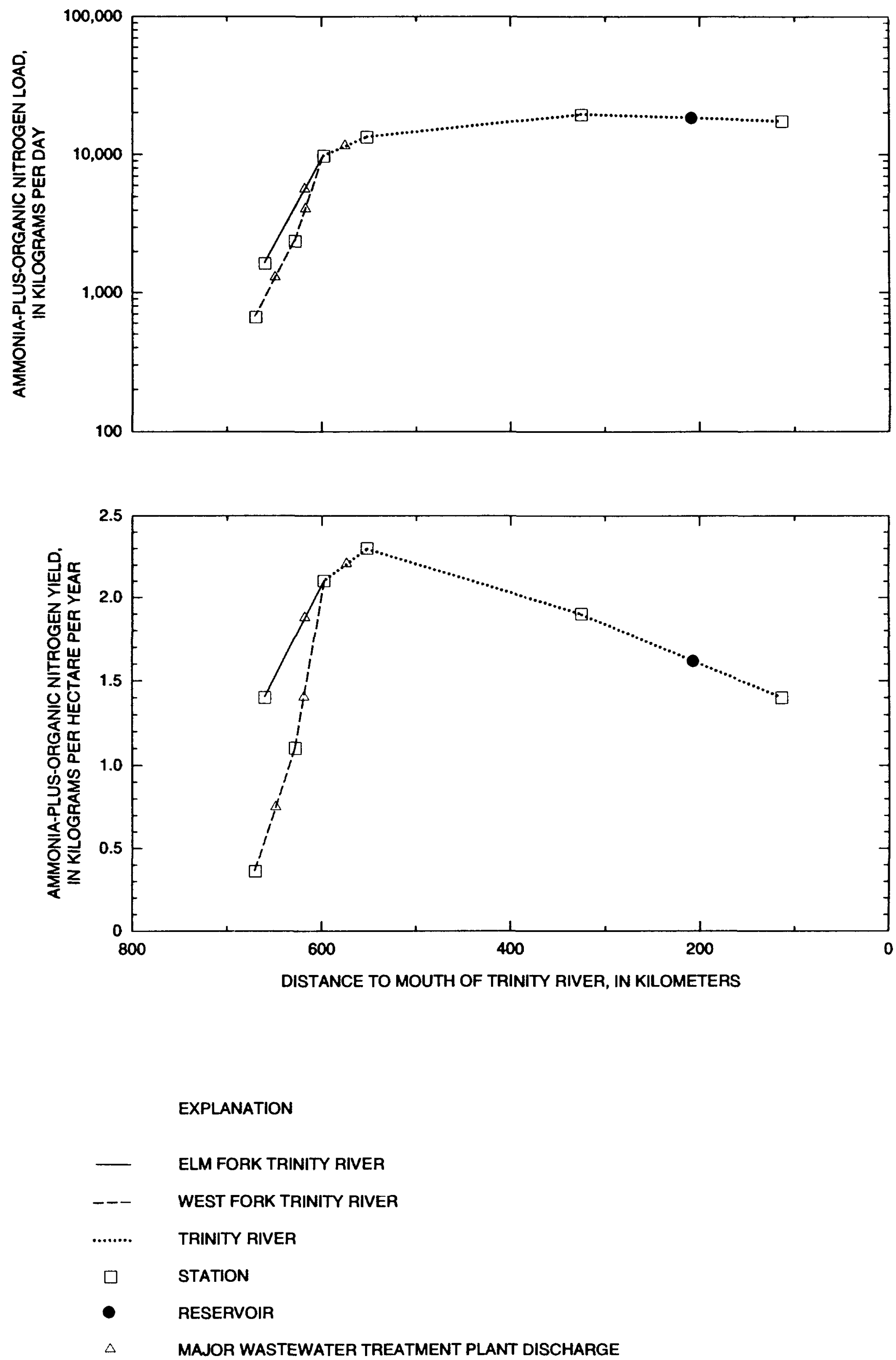

Figure 41. Plots showing average annual loads and yields for 1984–87 of ammonia plus organic nitrogen.

Flow from sites 08051500 and 08052700 passes through Lake Lewisville before reaching site 08053000, Elm Fork Trinity River near Lewisville (pl. 1). Load increases between these sites, however, the two tributary sites represent only 22 percent of the drainage area to site 08053000. The yield of nitrogen decreases from 2.8 and 6.7 (kg/ha)/yr at the tributary sites to 2.1 (kg/ha)/yr at site 08053000, downstream from Lake Lewisville. This decrease is caused by trapping and uptake of nutrients in the reservoir. No loads were calculated for sites on the West Fork or Clear Fork Trinity River upstream from site 08048543. Ninety-three percent of the drainage area to site 08048543 is captured by reservoirs and the 4-year average yield of nitrogen at the site was 0.7 (kg/ha)/yr, the smallest nitrogen yield calculated for any of these nine sites.

Similar downstream patterns of loads and yields occur for NO_2+NO_3, TKN, and phosphorous. Loads and yields are greatly increased by the addition of wastewater and are decreased by reservoirs. The magnitude of the increase in load caused by the WWTPs can be demonstrated by comparing loads for sites upstream and downstream from WWTP discharge. Site 08048543, the West Fork Trinity River at Beach Street, and site 08053000, the Elm Fork Trinity River near Lewisville, are both upstream from the major WWTPs. The combined drainage area of these two sites is 11,300 km^2. Site 08057410, the Trinity River below Dallas, is downstream from the confluence of the West Fork Trinity and Elm Fork Trinity Rivers and has a drainage area of 16,300 km^2. Discharges from three major WWTPs enter the river between the two upstream sites and site 08057410. For the period 1984–87, the combined mean loads for the two upstream gages were 3,800 kg/d of nitrogen and 310 kg/d of phosphorus, and the combined mean daily discharge was approximately 30 m^3/s. During this time the downstream site had mean loads of 25,000 kg/d of nitrogen and 8,400 kg/d of phosphorus and a mean daily discharge of 64 m^3/s. This is a 560 percent increase in nitrogen load and a 2,600 percent increase in phosphorus load, but only a 110 percent increase in discharge.

Loads continue to increase downstream from site 08057410; however, because drainage area is also increasing, the annual yield remains relatively constant between sites 08057410 and 08062500 and declines downstream at site 08065350. This decline could result from dilution of flow dominated by wastewater effluent at the more upstream sites by inflow from tributaries, some of which have reservoirs that could reduce nutrient loads.

Relations to Livingston Reservoir

Livingston Reservoir is a significant sink for nutrients traveling down the Trinity River (figs. 35–41). To examine the magnitude of this process, annual nutrient loads and yields for site 08065350, the Trinity River near Crockett, and site 08066500, the Trinity River at Romayor, were compared (fig. 42). The site near Crockett is located about 110 km upstream from Livingston Reservoir and the site at Romayor is located about 50 km downstream from the reservoir. From 1974 to 1989, the Trinity River near Crockett had mean monthly loads of 36,900 kg/d of nitrogen and 10,200 kg/d of phosphorus, whereas the Trinity River at Romayor had mean monthly loads of 24,000 kg/d of nitrogen and 3,600 kg/d of phosphorus. Although there was approximately a 30 percent increase in discharge between the two sites, there was a 35 percent decrease in nitrogen loads and a 65 percent decrease in phosphorus loads. Uptake of nutrients by plants, and settling of sediments and associated nutrients in Livingston Reservoir are two processes that contribute to the decrease in nutrient loads.

There was some indication of a decrease in phosphorus trapping in Livingston Reservoir with time (fig. 42). If in fact there was a decrease, as suggested by figure 42, then either loads into the reservoir were decreasing or loads out were increasing. There was no trend in phosphorus concentrations (table 7) or loads, based on a rank correlation between annual load and time, at the Trinity River at Romayor. Therefore, there is no evidence that loads out of the reservoir are increasing. There was a decrease in the phosphorus load at the Trinity River near Crockett during the time period. The rank correlation between annual

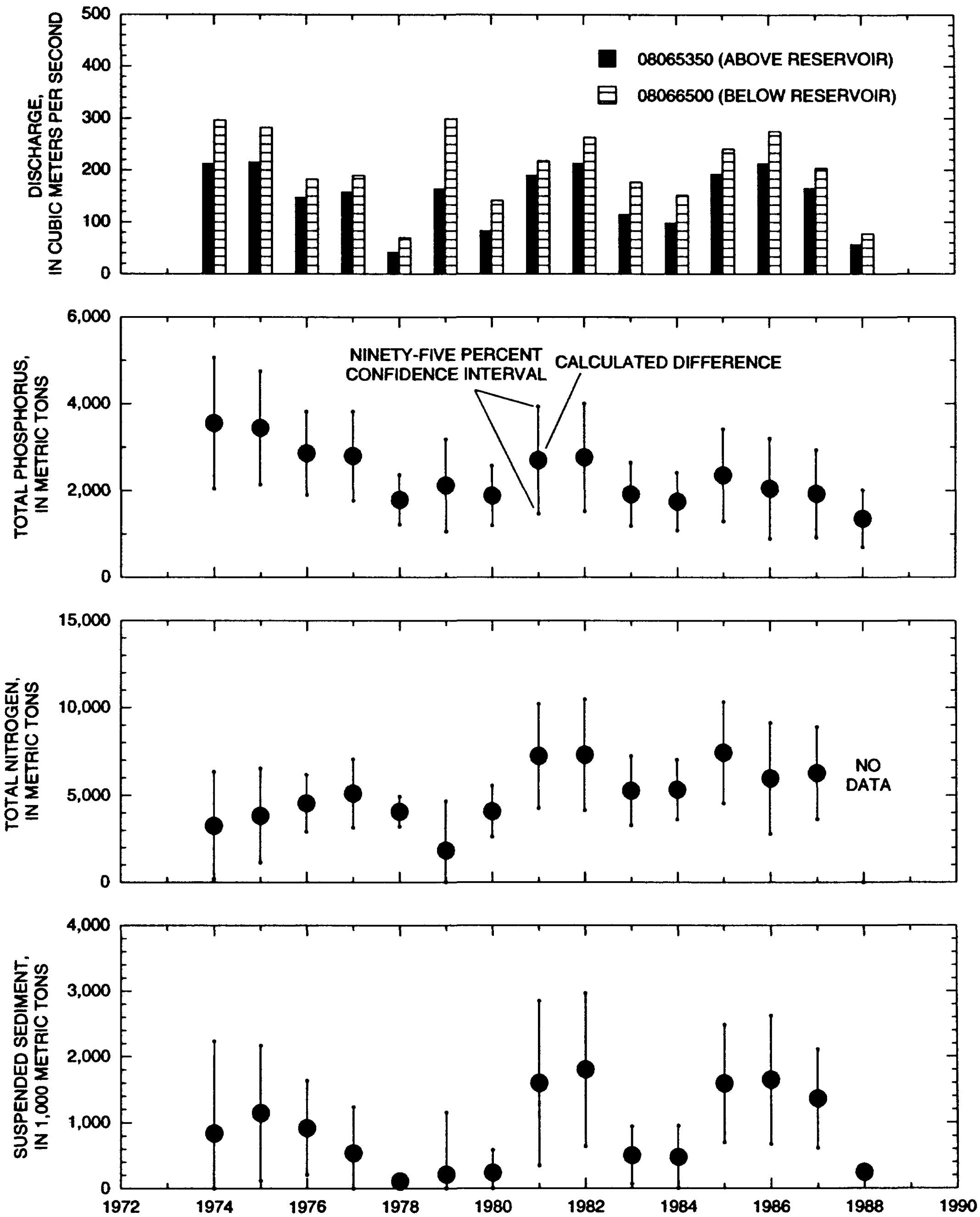

Figure 42. Discharge and differences in nitrogen, phosphorus, and sediment loads for sites above and below Livingston Reservoir, 1974–88. (Load differences were calculated by substracting the loads below Livingston Reservoir from the loads above Livingston Reservoir.)

Table 9. Loads of ammonium and nitrate from atmospheric deposition for two sites and the weighted average for the Trinity River Basin[1]

[NH_4, ammonium; NO_3, nitrate; kg/ha, kilogram per hectare; N, nitrogen; ---, no data]

Water year	National Trends Network stations				Basin weighted-average concentration	
	TX38		TX56			
	NH_4 (kg/ha as N)	NO_3 (kg/ha as N)	NH_4 (kg/ha as N)	NO_3 (kg/ha as N)	NH_4 (kg/ha as N)	NO_3 (kg/ha as N)
1982	2.01	2.01	---	---	---	---
1983	3.06	2.51	---	---	---	---
1984	1.41	1.73	1.26	1.51	1.36	1.67
1985	.92	1.76	2.15	2.15	1.11	1.88
1986	.96	1.84	1.51	1.71	1.12	1.80
1987	1.51	1.44	1.75	1.88	1.58	1.57
1988	1.04	1.33	.68	1.32	.93	1.33
1989	3.57	2.53	2.91	2.72	3.39	2.58
1990	2.62	1.64	3.15	2.37	2.77	1.85
1991	3.01	2.91	1.96	2.00	3.47	2.65
Median	1.75	1.81	1.85	1.93	1.47	1.83

[1] The weighted average for the Trinity River Basin was calculated by weighting site loads by the inverse of the squared distance of the site to the geographic midpoint of the basin.

phosphorus load and time was -0.58 with a p-value of 0.02. Additionally, time was a significant variable in the regression estimate of load at Crockett using the MVUE and the coefficient was negative. There was a small negative trend in phosphorus concentrations at this site but it was not statistically significant (table 7). The decrease in trapping by Livingston Reservoir is, therefore, attributed to a decrease in phosphorus load to Livingston Reservoir since the mid-1970's.

Comparison of Loads to Atmospheric Deposition

The precipitation that falls onto the study unit contains appreciable concentrations of ammonium and nitrate (table 4). Nutrient concentrations of this magnitude, times precipitation, result in a relatively large source of nitrogen to the Trinity River Basin. The mean annual loads for ammonium and nitrate reported at the two NTN stations (TX38 and TX56) of interest to the study unit are listed in table 9. Also listed are the spatially weighted averages of the loads estimated for the Trinity River Basin.

The atmospheric loads recorded at the NTN station at LBJ National Grasslands (TX56) were compared with the yields in streamflow calculated for site 08051500, Clear Creek near Sanger, located approximately 50 km from TX56 (pl. 1). For the water years 1984–88, the mean annual load of nitrate plus ammonium from atmospheric deposition was 3.5 kg/ha. In comparison, the mean annual yield at Clear Creek near Sanger for the same period was only 2.7 kg/ha of total nitrogen. In addition, the results of a 1988 survey by the Texas Agricultural Extension Service estimate that 18 kg/ha of total nitrogen is applied annually as

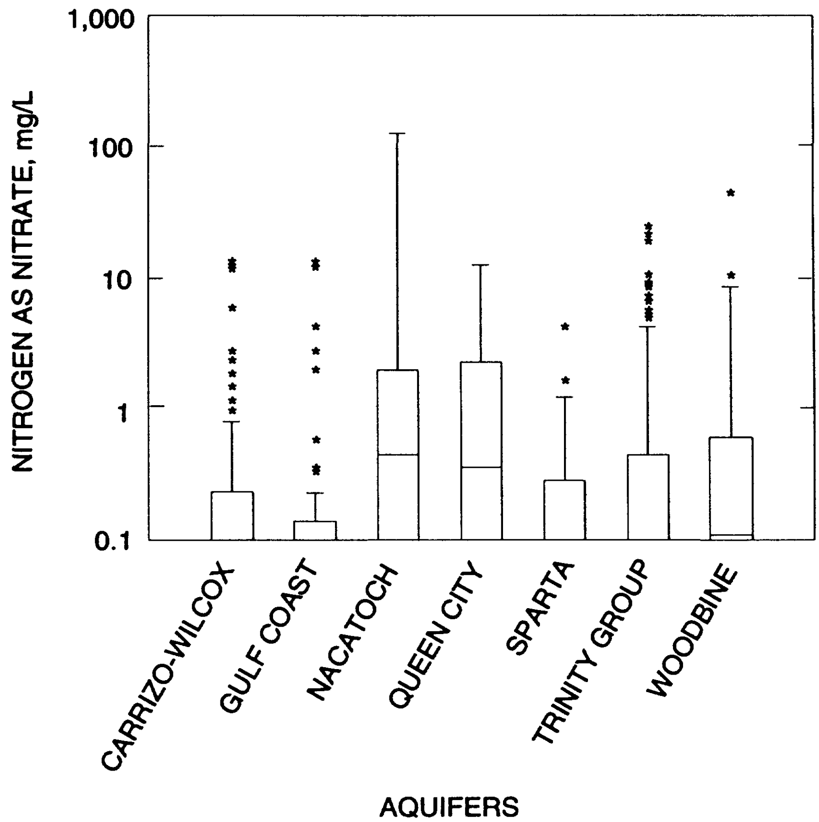

Figure 43. Nitrate concentrations for wells in seven major and minor aquifers in the Trinity River Basin, 1974–91.

fertilizer to Denton County, where Clear Creek near Sanger is located (Texas Agricultural Extension Service, written commun., 1992). These numbers suggest that only about 10 to 15 percent of the atmospheric and fertilizer load of nitrogen runs off. Other possible fates of the nitrogen include transport to ground water, uptake by plants, ammonium adsorption by soils, and denitrification (Novotny and Chesters, 1981).

Ground Water

A total of 1,482 measurements of nitrate from seven aquifers were available for this analysis. The median nitrate concentration of these measurements is 0.1 mg/L as N. The largest median concentrations by aquifer are in the Queen City and Nacatoch aquifers (fig. 43). The Kruskal-Wallis test of nitrate concentrations by aquifer had a p-value of 0.00001, indicating there are statistically significant differences in median concentrations by aquifer. A multiple-stage test using the Kruskal-Wallis test was performed to determine which aquifers were different (Helsel and Hirsch, 1992, p. 200). Nitrate concentrations fell into three groups by aquifer using this test and a 95 percent confidence interval. The largest median concentrations were in the Nacatoch and Queen City aquifers. Intermediate concentrations were in the Woodbine aquifer. The smallest concentrations were in the Trinity Group, Carrizo-Wilcox, Gulf Coast, and Sparta aquifers. The causes of these differences are not known; however, the Nacatoch and Queen City aquifers had relatively few samples and most of these

Table 10. Rank correlations for nitrate concentrations versus depth of well[1] by aquifer, 1974–91

Aquifer	Number of samples	Rank correlation, rho	p-value	Significant at 95 percent level
Trinity Group	649	-0.20	0.00	yes
Woodbine	347	-.11	.04	yes
Nacatoch	21	-.45	.04	yes
Carrizo-Wilcox	130	-.34	.001	yes
Queen City	32	-.39	.03	yes
Sparta	37	-.51	.001	yes
Gulf Coast	45	-.36	.02	yes
All wells	1,261	-.20	.000	yes

[1] Only wells less than 500 meters deep were used.

samples were from relatively shallow wells. These relations can be summarized by:

NCTC = QNCT > WDBN > TRIN = CZWX = GULF = SPRT,

where,

NCTC = Nacatoch

QNCT = Queen City

WDBN= Woodbine

TRIN = Trinity

CZWX= Carrizo-Wilcox

GULF = Gulf Coast

SPRT = Sparta

There is a significant rank correlation between nitrate concentration and depth of well for all seven aquifers with larger concentrations in shallow wells (fig. 44, table 10). The largest concentrations mostly occur in wells that are less than about 100 m deep. Less than 1 percent of samples exceeded the Environmental Protection Agency's maximum contaminant level (MCL) for nitrate of 10 mg/L; however, 5 of the 28 samples (18 percent) from wells less than 15 m deep exceeded the MCL. Ten of the 84 samples (12 percent) from wells less than 30 m deep exceeded the MCL. Larger concentrations in shallow wells could result from nonpoint sources of nitrate in water recharged through agricultural or residential areas.

The relation between nitrate concentrations in wells and agricultural land use was evaluated for wells less than 60 m deep. Land use was determined for wells by digitally overlaying 1-km radius circles around wells with the GIRAS land-use data. The percent of area within the circles classified as agricultural land use was than computed and assigned to the wells. There was not a significant rank correlation between percent agricultural land use and nitrate concentration for wells 0 to 60 m deep or for wells 0 to 30 m deep. For wells 0 to 60 m deep the correlation coefficient was -0.03, the p-value was 0.61, and the sample size was 250.

There are a number of limitations and assumptions to the analysis of relations to agricultural land use. These include: (1) the assumption that recharge to the wells occurs within 1 km of the well; (2) the assumption that water sampled from the well was recharged during a time period of similar land use to what is mapped by the GIRAS data (mid-1970's); (3) the limitation that other land uses such as urban are not accounted for; and (4) the limitation that a variety of land uses are

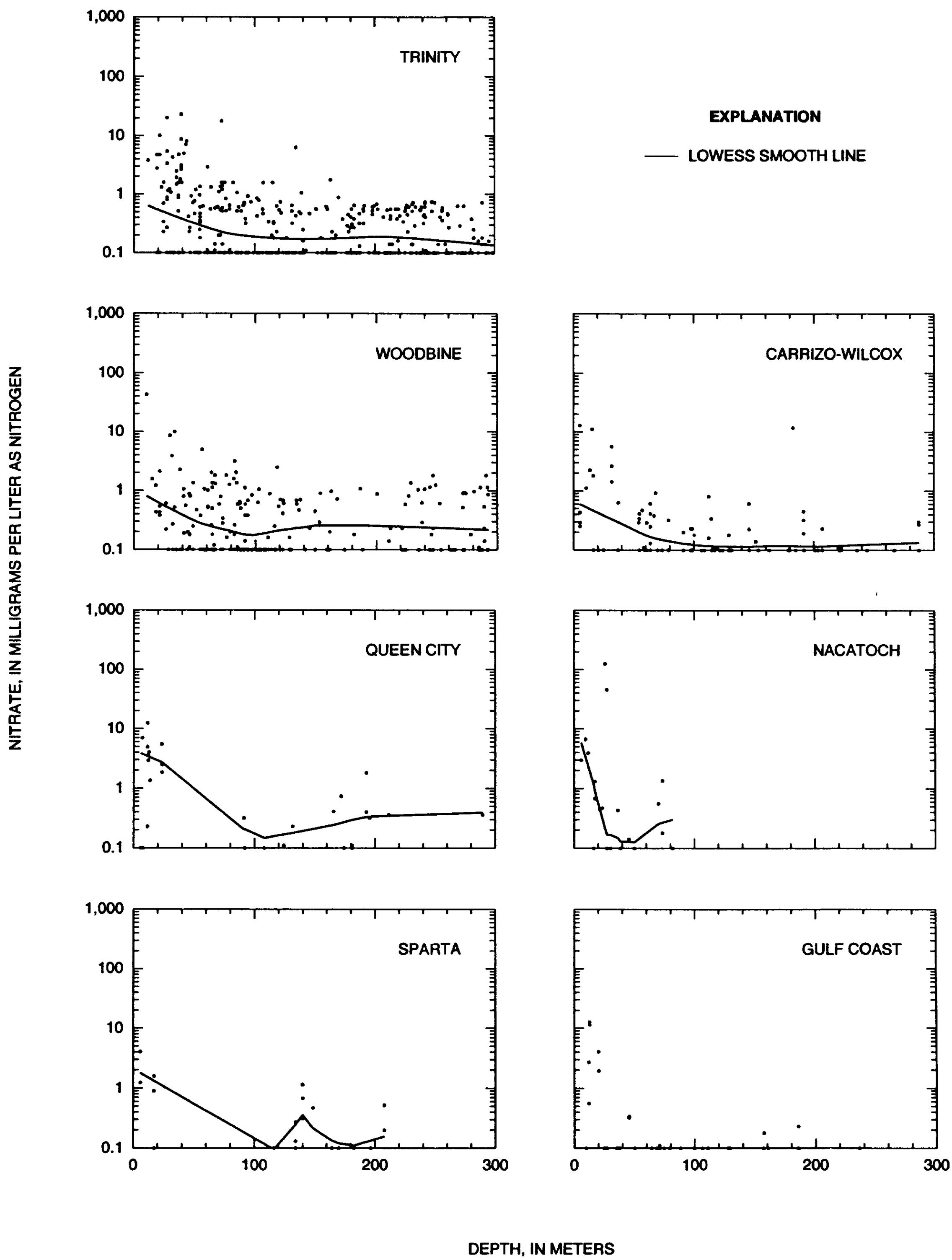

Figure 44. Relation between nitrate concentration and depth of well for seven aquifers, 1974–91.

Table 11. Summary of daily suspended-sediment data from selected U.S. Geological Survey sites

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; kg/ha, kilograms per hectare]

USGS site number	Site	Daily suspended-sediment concentrations (mg/L)			Daily suspended-sediment loads (tonnes)	Daily suspended-sediment yields (kg/ha)	Period of record used
		Median	Maximum	Minimum	Mean	Mean	
08044000	Big Sandy Creek near Bridgeport	68	1,150	3	70	1	10–73 to 7–76
08051500	Clear Creek near Sanger	36	2,920	1	317	4	10–73 to 8–76
08065000	Trinity River near Oakwood	105	1,920	15	2,586	1	10–75 to 6–80
08065800	Bedias Creek near Madisonville	35	915	10	68	1	10–83 to 7–85

included in the agricultural class in the GIRAS data.

The relation between nitrate concentrations and nitrogen fertilizer application data by county (Texas Agricultural Extension Service, written commun., 1992) was also evaluated. Wells were assigned nitrogen fertilizer application rates based on what county they were located in. Nitrate concentrations did not have statistically significant rank correlations to fertilizer application rates using all wells and using wells less than 30 m deep. For wells less than 30 m deep, the correlation coefficient was less than 0.01. Therefore, no relation to fertilizer application rates by county can be demonstrated.

These evaluations indicate that nitrate concentrations are larger in shallow zones of all seven aquifer groups. The zone of larger concentrations extends to a depth of about 100 m below land surface. Significant relations between nitrate concentrations and nitrogen fertilizer application rates and between nitrate concentrations and agricultural land use were not found using existing data.

ANALYSIS OF AVAILABLE DATA FOR SUSPENDED SEDIMENT

Suspended-sediment concentrations were monitored by the USGS at seven sites in the Trinity River Basin. Daily suspended-sediment concentrations were measured and loads were calculated at four USGS sites for periods from 3 to 6 years between water years 1974 and 1985. Three of these sites are on tributaries and one is on the mainstem of the Trinity River. In addition, three USGS sites on the Trinity River were sampled periodically, usually six times per year. Periodic data for two of these sites were used to calculate loads using the MVUE.

Minimum, median, and maximum suspended-sediment concentrations, loads, and yields were calculated for the daily suspended-sediment sites (table 11). The largest median concentration occurred at the Trinity River near Oakwood and the smallest occurred at Bedias Creek near Madisonville and at Clear Creek near Sanger. These differences could be related to land use, soil, geology, and other physical factors; however, no conclusions regarding relations to environmental factors were warranted because of the limited number of sites and because the periods of record differ between sites.

Livingston Reservoir is located between two sites, 08065350 and 08066500, for which periodic suspended-sediment data are available. The annual load of suspended sediment was smaller for the site below Livingston Reservoir (08066500) than for the site above the reservoir (08065350), even though mean discharge was approximately 30 percent greater at the downstream site during the study period (fig. 42). The differences in loads observed between these two sites can be attributed to trapping of sediment in Livingston Reservoir. Although no temporal trends are indicated by the annual load differences (fig. 42), there is a relation between annual load differences and discharge at these sites. The largest differences in the annual suspended-sediment loads take place during years of greatest discharge.

SUMMARY

A total of about 5,700 water-quality samples from the Trinity River Basin were analyzed. Of these, about 4,200 were from streams and about 1,500 were from wells. Additionally, atmospheric deposition data for two locations were obtained and analyzed.

Spatial variations in nutrient concentrations are related primarily to point sources and reservoirs. The smallest concentrations occurred immediately downstream from reservoirs, which act as sinks for nutrients. Nutrient concentrations in agricultural areas were positively correlated to percent of drainage in agricultural land use and to discharge, indicating washoff of nutrients from nonpoint sources during storms. Nutrient concentrations downstream from point sources were inversely related to discharge, indicating dilution at higher flows.

Total nitrogen and phosphorus concentrations did not change significantly, at the 95 percent confidence level, from 1974 to 1991 at most sites. The exception was a decrease in phosphorus concentrations at two sites in and downstream from major wastewater-treatment plants in the Dallas area. Concentrations of organic nitrogen and ammonia declined and concentrations of nitrite plus nitrate increased at sites below major wastewater-treatment plants. These changes are indicative of improvements in wastewater treatment that convert organic nitrogen and ammonia to nitrite and finally nitrate. Because nitrogen conversion reactions consume oxygen, this conversion at the treatment plants instead of in the streams resulted in reduced loading of biochemical oxygen demand to the streams.

As with concentrations, nutrient loads and yields were related to the occurrence of point sources and reservoirs. Loads calculated at sites above and below three major wastewater-treatment plants in the Dallas area showed a 560 percent increase in nitrogen load and a 2,600 percent increase in phosphorus load, but only a 110 percent increase in discharge below the plants. Nitrogen and phosphorus loads were 35 percent and 65 percent smaller, respectively, at the Trinity River at Romayor, downstream from Livingston Reservoir, than at the Trinity River near Crockett, upstream from Livingston Reservoir, even though flow was 30 percent greater at the downstream site.

The only nutrient measured in ground water was nitrate. Nitrate concentrations varied by aquifer with the largest median concentrations in the Queen City and Nacatoch aquifers. There was a significant rank correlation between nitrate concentrations and depth of well for all seven aquifer groups sampled with larger concentrations in shallow wells. The larger concentrations could result from nonpoint sources of nitrate in water recharged in agricultural and urban areas; however, concentrations of nitrate in ground water did not correlate to nitrogen fertilizer application rates or agricultural land use.

Only limited suspended-sediment data were available. Four sites had daily sediment-discharge records for three or more years between water years 1974–85. An additional three sites had periodic suspended-sediment concentrations measured. There are differences in concentrations and yields among sites; however, the limited amount of data precludes developing statistical or cause-effect relations with environmental factors such as land use, soils, and geology. Data are sufficient, and the relation is pronounced enough, to indicate trapping of suspended sediment by Livingston Reservoir.

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