

# **NUTRIENT LOADING TO LEWISVILLE LAKE, NORTH-CENTRAL TEXAS, 1984–87**

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## CONVERSION FACTORS AND ABBREVIATIONS

	Multiply	By	To obtain
	acre	0.4047	hectare
	acre-foot (acre-ft)	1,233	cubic meter
	cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft <sup>3</sup> /s)/mi <sup>2</sup> ]		0.01093	cubic meter per second per square kilometer
	foot (ft)	0.3048	meter
	foot per second (ft/s)	0.3048	meter per second
	mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)		0.04381	cubic meter per second
	pound per day (lb/d)	2.205	kilogram per day
pound per day per square mile [(lb/d)/mi <sup>2</sup> ]		0.0639	gram per square meter per year
	square mile (mi <sup>2</sup> )	2.590	square kilometer

### Abbreviations:

cells/mL, cells per milliliter  
 mg/L, milligram per liter

# Nutrient Loading to Lewisville Lake, North-Central Texas, 1984–87

By W. Scott Gain and Stanley Baldys III

## Abstract

Concentrations of nutrients in the streams of the 1,660-square-mile Lewisville Lake drainage basin have some association with the two types of physiographic regions in the basin—prairie regions and cross timbers regions. Total nitrogen and phosphorus concentrations generally are larger in streams draining the prairie regions than in streams draining the cross timbers regions, a characteristic that might be accounted for in part by the fact that prairie regions tend to have more nutrient-rich, less-permeable soils than cross timbers regions. Most of the variability in nutrient loads is associated with variability in discharge. During a low-flow synoptic survey, the largest contributor of total nitrogen and total phosphorus (at the downstream-most site) was Isle du Bois Creek (815 pounds per day of total nitrogen and 146 pounds per day of total phosphorus). During a high-flow synoptic survey, the largest contributor of total nitrogen and total phosphorus (at the downstream-most site) was Elm Fork Trinity River (4,620 pounds per day of total nitrogen and 210 pounds per day of total phosphorus).

On the basis of results of stormflow and periodic sampling, the total nitrite plus nitrate nitrogen that entered the reservoir on the average each day during 1986 was 5,640 pounds per day, and during 1987, 4,480 pounds per day. During the same period, about one and one-half as much nitrogen in the form of total ammonia plus organic nitrogen entered the reservoir (8,530 pounds per day in 1986 and 7,020 pounds per day in 1987); and about one-fourth as much total phosphorus entered the reservoir during the period (1,310 pounds per day in 1986 and 1,080 pounds per day in 1987).

Point sources accounted for small fractions (probably less than 10 percent) of the total nutrient load from Clear Creek, Little Elm Creek, Hickory Creek, and Elm Fork Trinity River.

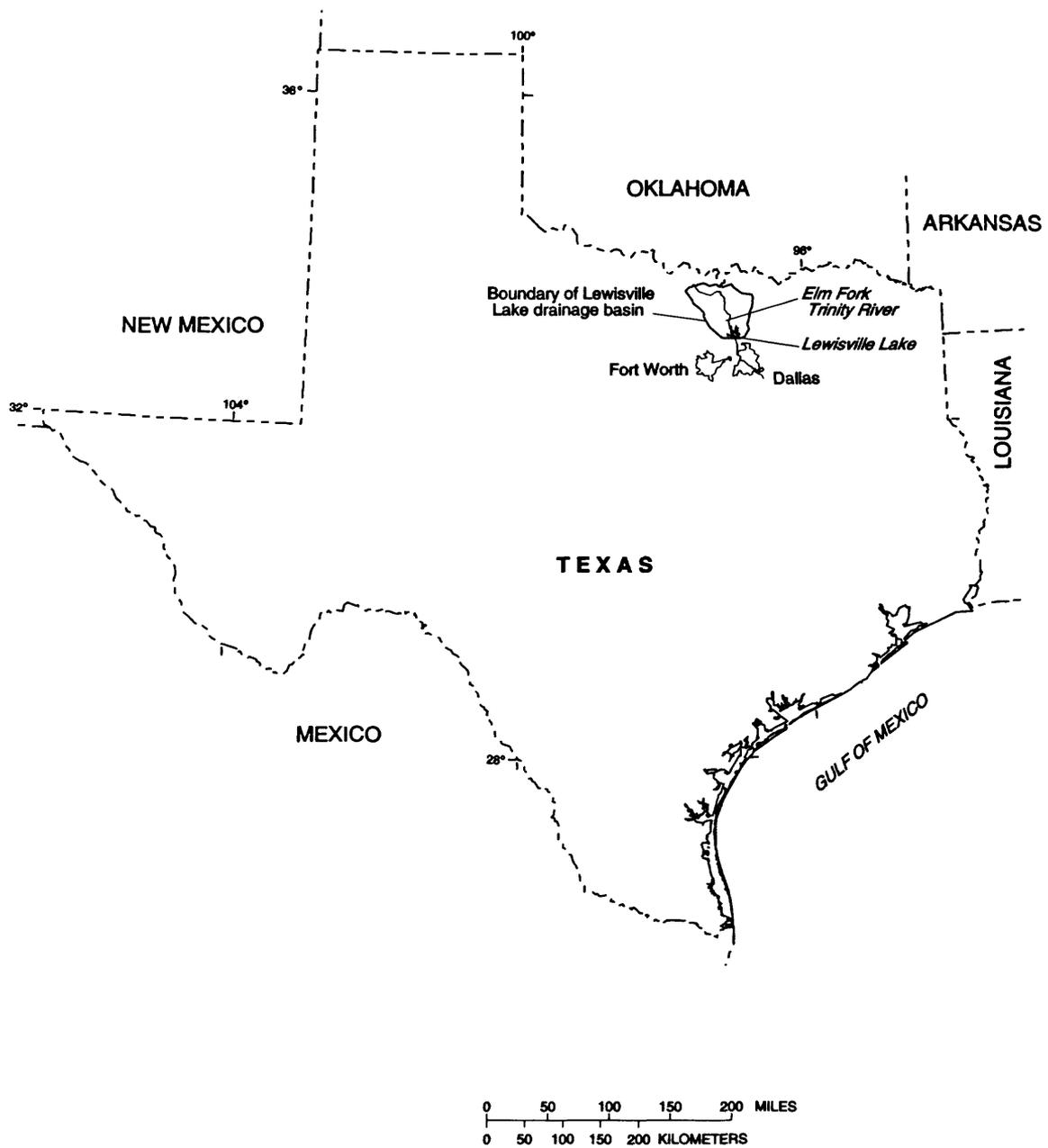
Most of the point-source load to Lewisville Lake could originate at a few sewage-treatment plants discharging to ungaged streams close to the reservoir.

The estimated long-term (1974–89 water years) average annual total nitrogen load (excluding loads from sewage-treatment plants in ungaged areas) is 11,800 pounds per day. The estimated long-term (1974–89 water years) average annual total phosphorus load (excluding loads from sewage-treatment plants in ungaged areas) is 1,100 pounds per day.

## INTRODUCTION

Lewisville Lake in north-central Texas, on Elm Fork Trinity River north of the Dallas/Fort Worth metropolitan area (fig. 1), has a conservation capacity of 457,600 acre-ft. The reservoir (pl. 1) is formed behind Lewisville Dam (constructed by the U.S. Army Corps of Engineers in 1954) and is used for water supply, flood control, and recreation. The reservoir is the principal source of water for several cities and communities in the area, including Dallas.

For many years before and after impoundment of Lewisville Lake, Dallas water utilities have documented recurring taste and odor problems in water pumped from Elm Fork Trinity River below the reservoir. The taste and odor problems in water from Lewisville Lake generally are attributed to the growth of algal blooms in the summer that contribute to excessive external nutrient (nitrogen and phosphorus) loading (Lee and others, 1977). Taste and odor could be imparted to the water by the exudates of algae or by the products of anoxic degradation of the algal mass by bacteria. Algal cell counts in Lewisville Lake have



**Figure 1.** Location of Lewisville Lake.

been documented for most of the 1980–90 water years by the U.S. Geological Survey (1981–91) in reservoir water-quality surveys. (A water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends.) In the summer, as many as 1.9 million cells/mL have been present in samples of water from one arm of the reservoir. Cell counts in the winter usually have been considerably less (several thousand cells per millimeter).

Effective management of water quality and nutrient loading in Lewisville Lake requires knowledge of the quantity and source of loads from the drainage basin. (Loads and loading refer to the constituent materials transported by, suspended in, or deposited by water and measured by weight, which are discharged in a given time.) Nutrient loads originate as localized and identifiable point sources or as diffuse nonpoint sources. Many point sources can be identified and controlled. Nonpoint sources can be more difficult to identify and control because they are diffuse and often are associated with broad-based land-use practices.

Point- and nonpoint-source nutrient loads to Lewisville Lake historically have been estimated only indirectly. Pillard and Dickson (1988) sampled streamflow and computed nutrient loads for a part of the drainage basin; however, no documented studies have measured loads directly or attempted to estimate loads for the whole drainage basin of Lewisville Lake on the basis of observed discharge and nutrient-concentration data. Point-source nutrient loads have been estimated (DelRegno and Atkinson, 1988) using discharge data from sewage-treatment plants, but these loads were based on assumed or estimated nutrient concentrations. Reliable nutrient-concentration data for point-source effluents have been and continue to be difficult to collect. The U.S. Environmental Protection Agency (1977) and DelRegno and Atkinson (1988) estimated nonpoint-source nutrient loads using regional estimates of nutrient yields that were based on land use.

The U.S. Geological Survey, in cooperation with the City of Dallas, made a study of external nitrogen and phosphorus loading to Lewisville Lake during 1984–87. The study objectives were (1) to identify principal nutrient-load sources and to quantify nutrient loading in the drainage basin, and (2) to evaluate the relative magnitude of point- and nonpoint-source nutrient loading in the drainage basin.

## Purpose and Scope

This report presents seasonal variations in loading and total annual loading of total nitrogen and phosphorus to Lewisville Lake from point and nonpoint sources.

## Description of the Study Area

The Lewisville Lake drainage basin (study area for this report) encompasses a 1,660-mi<sup>2</sup> area of rolling woodland, open prairie, rangeland, and farmland in north-central Texas and includes parts of Collin, Cooke, Denton, Grayson, Montague, and Wise Counties (pl. 1). Land use includes limited suburban development and various kinds of animal husbandry and agriculture—horse and cattle ranches; dairy and sod farms; and cotton and numerous seed and grain crops.

Most of the drainage basin is sparsely populated. Denton and Gainesville are the two largest cities, accounting for most of the population in the area but only a small part of the total area (about 20 mi<sup>2</sup> or 1.2 percent). Suburban development covers a relatively small part of the drainage basin, concentrated in areas on the eastern and western sides of the reservoir. In 1974, 2.8 percent of the drainage basin was commercial or residential. By 1986, commercial or residential areas had increased to 3.1 percent. One of the major changes in the drainage basin occurred in 1987 when Ray Roberts Lake on Elm Fork Trinity River (pl. 1) began filling with water. Also, between 1974 and 1986, about 21 percent of the drainage basin was converted from pasture to farmland (DelRegno and Atkinson, 1988).

Denton, Gainesville, and many small rural communities throughout the Lewisville Lake drainage basin operate sewage-treatment plants that discharge either directly into the reservoir or into streams flowing to the reservoir (pl. 1). The largest sewage-treatment plants are operated by Denton and The Colony; each plant routinely discharges from 3 to 10 Mgal/d. Each of the remaining 27 plants in the drainage basin are licensed to discharge less than 1 Mgal/d. Most discharge considerably less than 1 Mgal/d, and some operate only intermittently. Total effluent discharged directly to Lewisville Lake during 1986–87 was estimated to be 19.3 ft<sup>3</sup>/s. Effluent data from the sewage-treatment plants were compiled in 1991 from files of individual plants.

The Lewisville Lake drainage basin comprises four physiographic regions (pl. 1) that are associated

distinctly with topography, soils, vegetation, and agricultural land use (Austin, 1965). These regions are delineated by boundaries of the various geologic outcrops and formations that they commonly are associated with (University of Texas, Bureau of Economic Geology, 1967). From west to east (and geologically oldest to youngest) they are: (1) West Cross Timbers, (2) Grand Prairie, (3) East Cross Timbers, and (4) Texas Blackland Prairie.

Outcrops of sandstone underlying the West and East Cross Timbers regions tend to form low, rolling hills marked by deeply eroded, narrow stream channels with steep banks. Soils in these regions typically are well-drained, light-colored ultisols of loamy or sandy-loam texture, moderate to good permeability, and depths varying from a few inches on rock promontories to several feet in broad shallow valleys (Ford and Pauls, 1980). The natural vegetation in these regions is a scrubby woodland of post oak, blackjack oak, and mesquite. This woodland marks the western extent of the eastern forests of North America and is a transition to the more arid upland prairies of the west. In general, the soils in these regions are fertile, but their agricultural use is limited by the ruggedness of the terrain. Much of the land remains woodland or has been converted to fruit or nut orchards.

Limestone and calcareous shales underlying the Grand Prairie and Texas Blackland Prairie regions form nearly level grassland plains of dark, heavy soils and typically support few trees except along broad, shallow stream channels. The soils are mostly deep, well-mixed mollisols or vertisols of high base saturation and clay content. They are poorly drained and moderately to poorly permeable (Ford and Pauls, 1980). The soils of the Texas Blackland Prairie generally contain more clay, are less well drained, and are somewhat less permeable than those of the Grand Prairie region. Most of the land in these regions is used extensively for agriculture, and little or none of the natural prairie indigenous to the area remains.

Five principal stream drainage areas ranging from about 130 to about 380 mi<sup>2</sup> account for about 75 percent of the Lewisville Lake drainage basin (table 1). The largest is Elm Fork Trinity River drainage area, followed by Clear Creek, Isle du Bois Creek, Hickory Creek, and Little Elm Creek drainage areas. The remaining 25 percent of the drainage basin consists of the reservoir and the lands immediately adjacent to it, including numerous small streams with drainage areas of about 20 mi<sup>2</sup> or less. All five principal streams are

controlled to some extent by small flood-retention ponds, stock tanks, and reservoirs. The surface area of Lewisville Lake is about 23,000 acres, and its capacity is 457,600 acre-ft when filled to conservation pool level (U.S. Geological Survey, 1988). Mean hydraulic depth computed for Lewisville Lake is about 20 ft, and mean annual outflow during the 1955–87 water years was about 664 ft<sup>3</sup>/s. Computed mean hydraulic-residence time for Lewisville Lake is 0.97 year.

Ray Roberts Lake, another large water-supply reservoir built by the Corps of Engineers during this study, controls flow in Elm Fork Trinity River above Lewisville Lake. The reservoir began filling with water during July 1987. Ray Roberts Dam is about 25 mi upstream from Lewisville Dam. The drainage basin of Ray Roberts Lake is about 700 mi<sup>2</sup>, and the reservoir capacity at conservation pool level is about 800,000 acre-ft (U.S. Geological Survey, 1989).

## Sampling

Synoptic surveys of discharge and streamflow quality were made at 29 sites (pl. 1) in the Lewisville Lake drainage basin during 1984–85. Stormflow and periodic samples were collected during the 1986–87 water years at three streamflow-gaging stations on Clear Creek, Little Elm Creek, and Hickory Creek (pl. 1). Periodic samples also were collected during the 1986–87 water years at a station on Elm Fork Trinity River below the outflow at Ray Roberts Dam (pl. 1).

## Synoptic Surveys

The 29 synoptic-survey sites are on the headwaters and main stems of each of the principal tributaries as well as on some of the smaller streams in the areas adjacent to the reservoir (pl. 1). The sites are identified by a two-character alphanumeric symbol (table 1). The first character indicates drainage area, the second, downstream order. The drainage areas of 17 downstream-most sites constituted about 80 percent of the Lewisville Lake drainage basin (table 1). All 29 sites were sampled once in March 1984 during low flow and again in March 1985 when flows generally were higher. Two sites on Elm Fork Trinity River and two sites on Isle du Bois Creek were inundated when Ray Roberts Lake was filled (1989).

Each of the synoptic surveys was completed in 1 day. Instantaneous discharge, specific conductance, pH, temperature, and dissolved oxygen were determined in the field (Gain, 1989). Samples for nutrient

**Table 1.** Location, physiographic region, and drainage area of synoptic-survey sites in the Lewisville Lake drainage basin

[mi<sup>2</sup>, square miles; GP, Grand Prairie; ECT, East Cross Timbers; TBP, Texas Blackland Prairie]

Site number (pl. 1)	Location of site or streamflow-gaging station name (station number)	Physiographic region	Drainage area (mi <sup>2</sup> )
Hickory Creek drainage area:			
H1	North Hickory Creek at US 380	GP	39.4
H2	South Hickory Creek at US 380	GP	20.1
H3	Dry Fork Hickory Creek at US 380	GP	4.13
<sup>1</sup> H4	Hickory Creek at Denton, Tex. (08052780)	GP	129
<sup>1</sup> H5	Fincher Branch at unnumbered county road	ECT	5.62
Clear Creek drainage area:			
C1	Clear Creek at FM 455	GP	257
C2	Duck Creek at FM 455	GP	31.4
C3	Clear Creek near Sanger, Tex. (08051500)	GP	295
<sup>1</sup> C4	Clear Creek at FM 2164	GP	323
<sup>1</sup> C5	Milam Creek at FM 2164	GP	12.4
Elm Fork Trinity River drainage area:			
E1	Elm Fork Trinity River at FM 2071	GP	182
E2	Elm Fork Trinity River at FM 922	GP	265
E3	Spring Creek at unnumbered county road	GP	71.1
<sup>1</sup> E4	Elm Fork Trinity River near Sanger, Tex. (08050500)	GP	381
Isle du Bois Creek drainage area:			
I1	Jordan Creek at unnumbered county road	ECT	65.3
I2	Isle du Bois Creek at unnumbered county road	ECT	205
<sup>1</sup> I3	Isle du Bois Creek near Pilot Point, Tex. (08051000)	ECT	266
Little Elm Creek drainage area:			
L1	Little Elm Creek at FM 455	TBP	46.7
<sup>1</sup> L2	Little Elm Creek near Aubrey, Tex. (08052700)	ECT	75.5
<sup>1</sup> L3	Mustang Creek at FM 428	ECT	22.2
<sup>1</sup> L4	Pecan Creek near Aubrey, Tex. (08052730)	ECT	32.2
<sup>1</sup> L5	Running Branch at FM 2931	ECT	2.79
Other streams in Lewisville Lake drainage basin:			
<sup>1</sup> O1	Cooper Creek at unnumbered county road	ECT	6.66
<sup>1</sup> O2	Alyne Branch at FM 424	ECT	7.02
<sup>1</sup> O3	Pecan Creek at FM 288	ECT	12.3
<sup>1</sup> O4	Button Branch at unnumbered county road	TBP	14.8
<sup>1</sup> O5	Panther Creek at FM 423	TBP	20.3
<sup>1</sup> O6	Cottonwood Branch at FM 423	TBP	9.45
<sup>1</sup> O7	Stewart Creek at unnumbered county road	TBP	8.73

<sup>1</sup> Downstream-most sites.

analyses were collected using depth-integrating suspended-sediment samplers and standard U.S. Geological Survey methods such as equal-width increment or equal-depth increment (Guy and Norman, 1970; Rantz and others, 1982). Immediately after collection, all

nutrient samples were chilled and preserved with mercuric chloride. Analyses for determination of total nitrite plus nitrate nitrogen, total ammonia plus organic nitrogen, total nitrogen, total phosphorus, and total organic carbon concentrations were done by the U.S.

Geological Survey National Water Quality Laboratory in Arvada, Colorado, using standard analytical techniques (Skougstad and others, 1979).

### Stormflow and Periodic Sampling

Following the synoptic surveys, the principal streams were selected for additional and more detailed study of nutrient-loading rates to evaluate and refine estimates of loading to the reservoir during stormflow conditions. Two of the streams had existing streamflow-gaging stations operated by the U.S. Geological Survey—Clear Creek near Sanger, Tex. (08051500, pl. 1), and Little Elm Creek near Aubrey, Tex. (08052700, pl. 1). A third streamflow-gaging station was installed in July 1985 on Hickory Creek at Denton, Tex. (08052780, pl. 1).

Stations on the two remaining principal streams in the study area (Elm Fork Trinity River near Sanger, Tex., and Isle du Bois Creek near Pilot Point, Tex.) could not be sampled because of backwater from construction of Ray Roberts Lake. Therefore, a streamflow-gaging station was installed on Elm Fork Trinity River near Pilot Point, Tex. (08051130, pl. 1), immediately below Ray Roberts Dam to provide additional nutrient-load data.

Samples were collected at Clear Creek near Sanger, Little Elm Creek near Aubrey, and Hickory Creek at Denton for about three stormflow events in each wet season (January to June) during the 1986–87 water years. Samples were collected periodically during the 1986–87 water years at the stormflow sampling stations and also at Elm Fork Trinity River near Pilot Point.

An automatic, vacuum-type water sampler, actuated by a float switch, was installed at each of the three stations above Lewisville Dam. During storms, the samplers operated at regular intervals (1 to 6 hours depending on the site and season) and marked the time of each sample collection on an event recorder. After storms, selected samples were withdrawn from the samplers, treated with mercuric chloride, and chilled. Instantaneous discharges were determined for each sampling period using the stage recorded at the time of sample collection and the stage-discharge rating for the station. Some storm samples were collected manually with a depth-integrating suspended-sediment sampler. In addition to stormflow samples, periodic samples (about six per year) were collected at the three stations during various flow conditions. Periodic samples also were collected at Elm Fork Trinity River near Pilot Point.

All samples were analyzed for total nitrite plus nitrate nitrogen, total ammonia plus organic nitrogen, and total phosphorus concentrations. Periodic samples also were analyzed for specific conductance, pH, hardness, and dissolved calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, and silica.

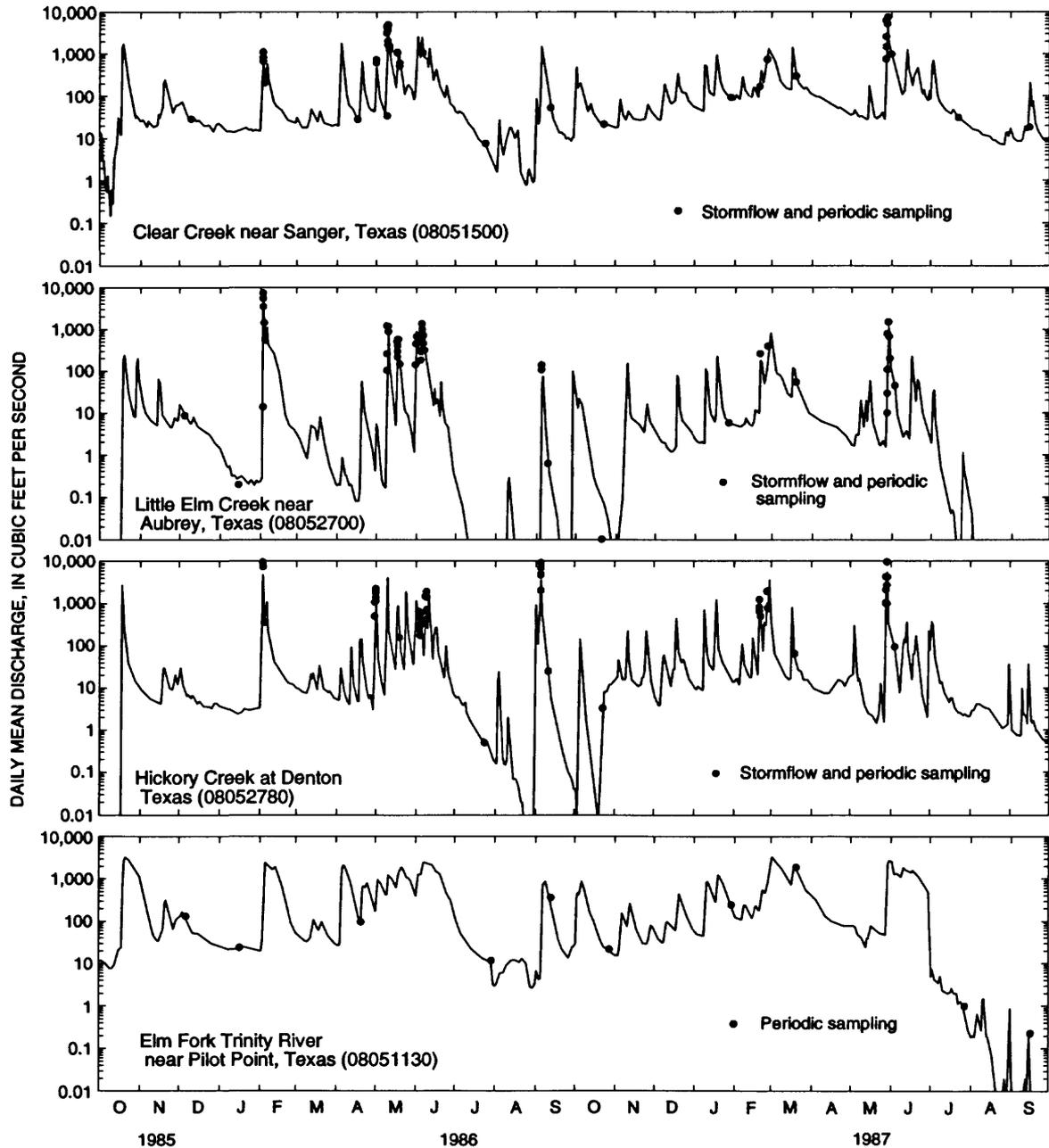
### Discharge Characteristics Associated with Stormflow and Periodic Sampling

Daily mean discharge for the period of record at three streamflow-gaging stations used for stormflow and periodic sampling and one station used only for periodic sampling is given in the following table:

Streamflow-gaging station	Station number (pl. 1)	Daily mean discharge (ft <sup>3</sup> /s)	Period of record <sup>1</sup>
Stormflow and periodic sampling			
Clear Creek near Sanger, Tex.	08051500	87.0	1950–87
Little Elm Creek near Aubrey, Tex.	08052700	46.4	1957–76, 1980–87
Hickory Creek at Denton, Tex.	08052780	94.4	1986–87
Periodic sampling			
Elm Fork Trinity River near Pilot Point, Tex.	08051130	<sup>2</sup> 284	1950–84, 1986–87

<sup>1</sup> U.S. Geological Survey, 1987–88.

<sup>2</sup> Sum of daily mean discharge at Elm Fork Trinity River near Sanger and Isle du Bois Creek near Pilot Point used for 1950–84.



**Figure 2.** Hydrographs showing daily mean discharge at streamflow-gaging stations used for stormflow and periodic sampling in the Lewisville Lake drainage basin, north-central Texas, 1986–87 water years.

Daily mean discharges ranged from 0.01 to 10,000 ft<sup>3</sup>/s during the 1986–87 water years at the stations used for stormflow and periodic sampling (fig. 2). Although stormflow peaks can arrive and pass within several hours, rises can last more than several days. During stormflows, the stage-discharge relation is channel controlled and streamflow velocities can range from 1 to 4 ft/s. Travel times from the stormflow sam-

pling stations to the reservoir at these velocities might be as short as several hours. During low flows, water in these streams moves through a series of pools and riffles where flow velocities range from less than 0.1 ft/s (in pools) to more than 2 ft/s (in riffles).

The 1986–87 water years generally were wetter than normal. Daily mean discharge for the 1986–87 water years at Clear Creek near Sanger was 152 ft<sup>3</sup>/s

(U.S. Geological Survey, 1987–88) or about 6 percent larger than the 1981–87 water-year daily mean discharge of 143 ft<sup>3</sup>/s (U.S. Geological Survey, 1988). The 1981–87 daily mean discharge was computed from records reflecting the effects of 51 floodwater-retarding structures in the Lewisville Lake drainage area that had been completed by 1980. The daily mean discharge for the 1986–87 water years at Little Elm Creek near Aubrey was 37.2 ft<sup>3</sup>/s (U.S. Geological Survey, 1987–88) or about 20 percent less than the 1957–76, 1980–87 water-year daily mean discharge of 46.4 ft<sup>3</sup>/s. There is no long-term record for Hickory Creek at Denton to compare with the daily mean discharge of 94.4 ft<sup>3</sup>/s for the 1986–87 water years. Daily mean discharge for the 1986–87 water years at Elm Fork Trinity River near Pilot Point was 401 ft<sup>3</sup>/s (U.S. Geological Survey, 1987–88) or about 45 percent larger than the sum of the 1950–84 water year average-annual discharges (277 ft<sup>3</sup>/s) for Elm Fork Trinity River near Sanger and Isle du Bois Creek near Pilot Point (U.S. Geological Survey, 1985). Daily mean discharge at the Lewisville Lake outflow station (Elm Fork Trinity River near Lewisville) for the 1986–87 water years was 950 ft<sup>3</sup>/s (U.S. Geological Survey, 1987–88) or about 43 percent larger than the average-annual discharge since the reservoir was impounded (664 ft<sup>3</sup>/s, 1955–87) (U.S. Geological Survey, 1988).

## NUTRIENT LOADING

### Nutrient Concentrations During Synoptic Surveys

The nutrient concentrations determined from the two synoptic surveys varied widely from site to site (pl. 2). The rank (or percentile) of each measured total nitrogen and total phosphorus concentration is indicated on plate 2.

Total nitrogen concentrations ranged from 0.50 to 8.0 mg/L in the low-flow (March 1984) synoptic survey and from 0.60 to 16 mg/L in the high-flow (March 1985) synoptic survey (pl. 2). The largest concentration in the high-flow survey was at Stewart Creek (O7). This stream also receives sewage effluent from The Colony sewage-treatment plant. Discharge for Stewart Creek during the high-flow survey was less than during the low-flow survey. Total nitrogen concentrations were generally smaller in the high-flow survey (median, 1.9 mg/L) than in the low-flow survey (median, 2.3 mg/L). A Wilcoxon signed-rank test

(Inman and Conover, 1983) on paired observations (high-flow/low-flow) indicated a 30-percent chance that this difference could have been random.

Data from the synoptic surveys indicate that total nitrogen concentrations could not be correlated with point-source inputs. Concentrations were largest in streams draining the Grand Prairie and Texas Blackland Prairie regions on the western and eastern sides of the reservoir (pl. 2). Because only some of the streams in these regions receive sewage effluent, nonpoint sources probably also contribute some nitrogen. The maximum total nitrogen concentration in the low-flow survey was in a stream (H2) in that part of the Hickory Creek drainage area not receiving sewage effluent. Total nitrogen concentrations were equal to or greater than the high-flow and low-flow survey medians on the eastern side of the reservoir in Panther Creek (O5) and Mustang Creek (L3), streams also not receiving sewage effluent. Large concentrations in Little Elm and Stewart Creeks probably represent a combination of point and nonpoint sources of nutrient loads.

The generally larger total nitrogen concentrations in streams of the prairie regions relative to concentrations in streams of the cross timbers regions indicate that total nitrogen concentrations might be more a function of soil type or agricultural land use than of sewage-effluent discharge. Because the Grand Prairie and Texas Blackland Prairie regions are farmed more intensively than the cross timbers regions and have more nutrient-rich, less-permeable soils, they might contribute more nitrogen from natural and/or agricultural processes to surface-water runoff.

Total phosphorus concentrations ranged from 0.02 to 0.63 mg/L during the low-flow survey and from 0.01 to 0.41 mg/L during the high-flow survey. Although the maximum concentration in the high-flow survey (0.41 mg/L) was smaller than in the low-flow survey (0.63 mg/L), the high-flow survey had a larger median total phosphorus concentration (0.12 mg/L). A Wilcoxon signed-rank test on paired observations did not indicate a statistically significant difference at the 95-percent confidence level between total phosphorus concentrations in the high- and low-flow surveys.

Physiographic region and sewage-effluent discharge appear to influence total phosphorus concentrations. Total phosphorus concentrations from streams draining the prairie regions were generally larger than those from streams draining the cross timbers regions. Within physiographic regions, the streams receiving sewage effluent had somewhat larger total phosphorus

concentrations than streams with no sewage-effluent discharge.

### **Nutrient Loads and Yields During Synoptic Surveys**

Nutrient loads (in pounds per day) were computed for each synoptic survey site (table 2) by multiplying measured (instantaneous) discharge (in cubic feet per second) by nutrient concentration (in milligrams per liter) by 5.39 (a units conversion factor). Loads at the downstream-most sites of individual drainage areas were summed to determine total loads from about 80 percent of the Lewisville Lake drainage basin.

Discharge tends to be more variable than concentration. Consequently, most of the variability in loads can be associated with discharge. During the low-flow survey, the largest contributors of total nitrogen (at the downstream-most sites) to Lewisville Lake were Isle du Bois Creek (815 lb/d, or 24 percent of total load) and Hickory Creek (621 lb/d, or 18 percent). The largest contributors of total phosphorus were Isle du Bois Creek (146 lb/d, or 50 percent) and Elm Fork Trinity River (59.5 lb/d, or 21 percent). During the high-flow survey, the largest contributors of total nitrogen and total phosphorus were Elm Fork Trinity River (4,620 lb/d, or 41 percent, and 210 lb/d, or 31 percent, respectively) and Clear Creek (2,460 lb/d, or 22 percent, and 175 lb/d, or 26 percent, respectively).

Storm-generated discharge typically produces changes in nutrient concentrations in streamflow. Nutrient concentrations are expected to decrease as discharge increases. Streams receiving sewage effluent have relatively larger nutrient concentrations in low flows than in high flows. A change in load relative to a change in discharge between the two surveys indicates the degree to which streams are influenced by sewage-effluent discharge. At the downstream-most sites, discharge in the high-flow survey was about 3.7 times that in the low-flow survey (table 2). Total nitrogen load was about 3.3 times larger and total phosphorus load about 2.3 times larger in the high-flow survey than in the low-flow survey.

Yields, or loads per unit area (table 2), allow direct comparisons between basins. Average nutrient yields for 1,329 mi<sup>2</sup> (80 percent) of the Lewisville Lake drainage basin included in the synoptic surveys were 2.5 and 8.4 (lb/d)/mi<sup>2</sup> of total nitrogen and 0.22 and 0.51 (lb/d)/mi<sup>2</sup> of total phosphorus in the low-flow

and high-flow surveys, respectively (table 2). High-flow yields were similar to those reported by Rast and Lee (1983) for rural/agricultural areas and those used by DeIRegno and Atkinson (1988)—about 8 (lb/d)/mi<sup>2</sup> for total nitrogen and 0.8 (lb/d)/mi<sup>2</sup> for total phosphorus. Some of the largest yields in both surveys were from the three streams receiving the largest amounts of sewage effluent, relative to their discharges—Elm Fork Trinity River, Little Elm Creek, and Stewart Creek. Clear Creek, with one of the largest drainage areas, was one of the large contributors of total load but had small yields. Hickory Creek, also one of the large contributors of total nitrogen load in the low-flow survey, had smaller total nitrogen yields than Clear Creek in the high-flow survey. The Denton sewage-treatment plant, downstream from a sampling site and near the reservoir, was not included in the synoptic surveys or subsequent stormflow and periodic sampling.

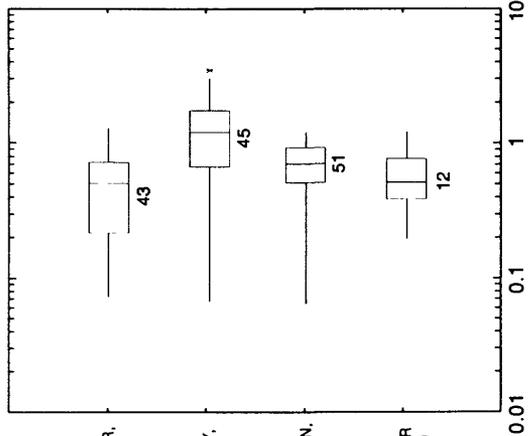
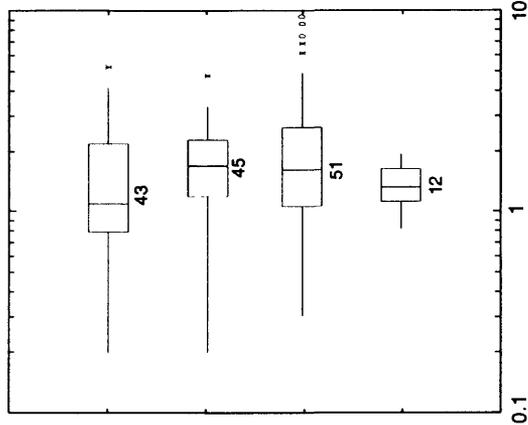
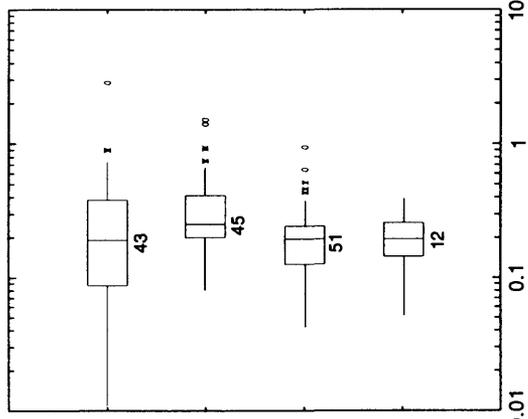
### **Nutrient and Major-Ion Concentrations During Stormflow and Periodic Sampling**

The range and distribution of nutrient data collected during the stormflow and periodic sampling are shown by boxplots (fig. 3). The nutrient data generally appear to be log-normally distributed and generally are skewed toward smaller concentrations, similar to nutrient data collected during the synoptic surveys.

A summary of water-quality data collected during the 1986–87 water years at the stations used for stormflow and periodic sampling is shown in table 3. Nutrient concentrations were determined for the stormflow and periodic samples. Major-ion concentrations were determined for the periodic samples to help identify sources of point and nonpoint loading.

Large mean total nitrite plus nitrate nitrogen concentrations and mean total phosphorus concentrations in samples collected at Little Elm Creek near Aubrey during the stormflow and periodic sampling are consistent with the synoptic survey results and might be related to sewage-effluent loading of the streams. Mean total ammonia plus organic nitrogen concentrations were largest in Hickory Creek.

Calcium generally was the dominant cation (mean concentrations range from 51 to 69 mg/L, table 3), and alkalinity expressed as calcium carbonate was the dominant anion (mean concentrations range from 120 to 169 mg/L, table 3). These characteristics are consistent with the large pH and divalent cation content of the prairie soils. Trilinear diagrams (fig. 4) show the



CLEAR CREEK NEAR SANGER, TEXAS (08051500)  
 LITTLE ELM CREEK NEAR AUBREY, TEXAS (08052700)  
 HICKORY CREEK AT DENTON, TEXAS (08052780)  
 ELM FORK TRINITY RIVER NEAR PILOT POINT, TEXAS (08051130)

TOTAL NITRITE PLUS NITRATE NITROGEN, IN MILLIGRAMS PER LITER

TOTAL AMMONIA PLUS ORGANIC NITROGEN, IN MILLIGRAMS PER LITER

TOTAL PHOSPHORUS, IN MILLIGRAMS PER LITER

EXPLANATION

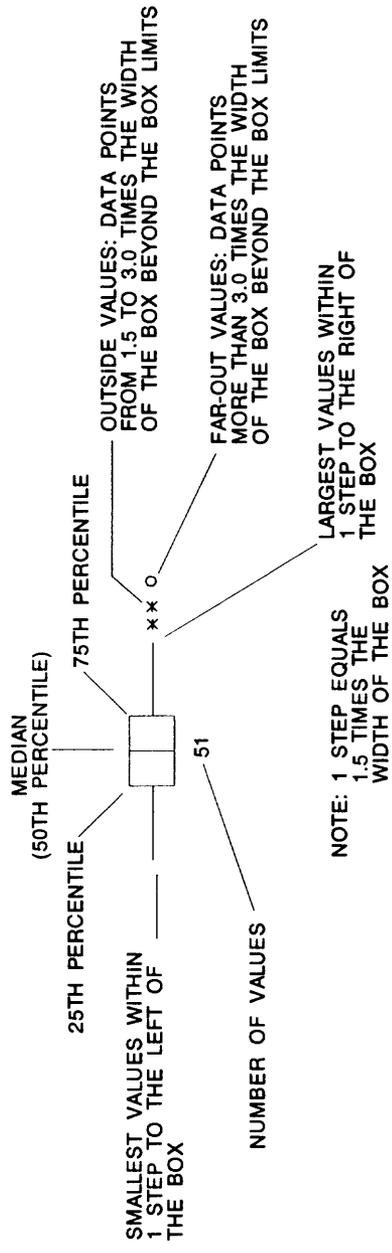
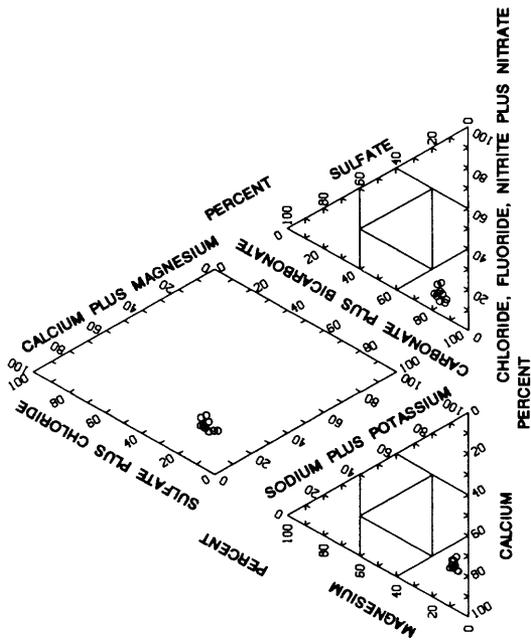
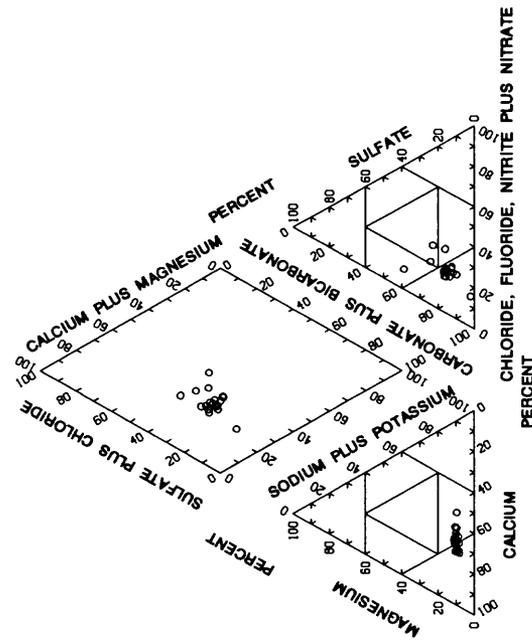


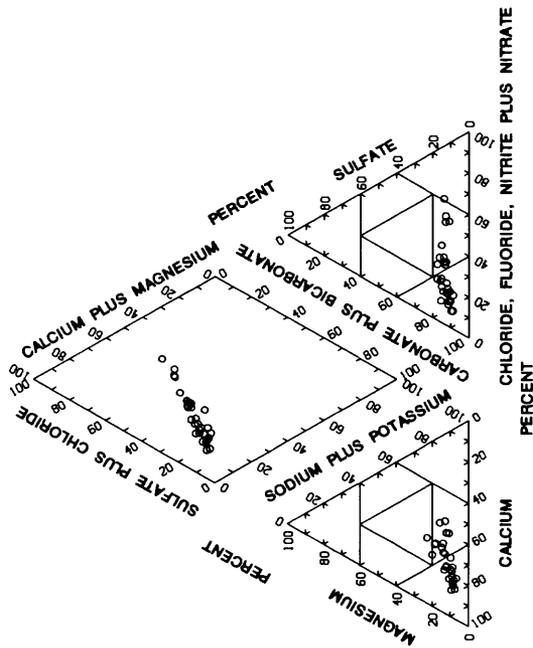
Figure 3. Range and distribution of nutrient concentrations in water at streamflow-gaging stations used for stormflow and periodic sampling in the Lewisville Lake drainage basin, north-central Texas, 1986-87 water years.



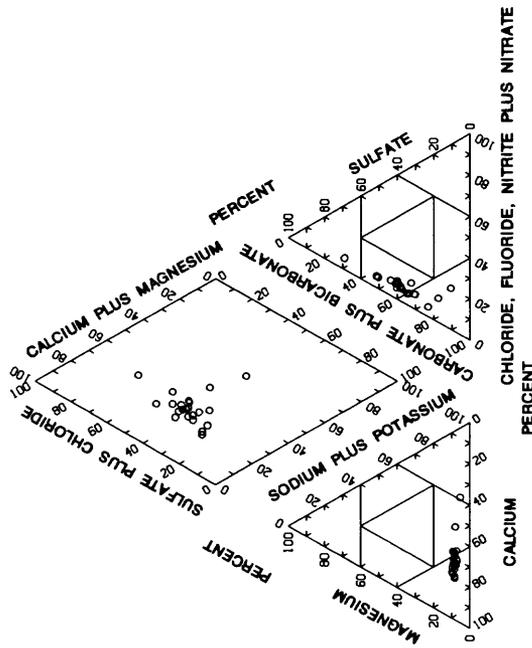
HICKORY CREEK AT DENTON, TEXAS (08052780)



ELM FORK TRINITY RIVER NEAR PILOT POINT, TEXAS (08051130)



CLEAR CREEK NEAR SANGER, TEXAS (08051500)



LITTLE ELM CREEK NEAR AUBREY, TEXAS (08052700)

Figure 4. Trilinear diagrams showing relation of major ions in water at streamflow-gaging stations used for periodic sampling in the Lewisville Lake drainage basin, north-central Texas, 1986–87 water years.

**Table 2. Discharge and daily mean nutrient loads and yields during low-flow (March 1984) and high-flow (March 1985) synoptic surveys in the Lewisville Lake drainage basin**

[ft<sup>3</sup>/s, cubic feet per second; lb/d, pounds per day; (lb/d)/mi<sup>2</sup>, pounds per day per square mile; <, less than]

Drainage area	Site	Instantaneous discharge <sup>1</sup> (ft <sup>3</sup> /s)				Daily mean total nitrogen				Daily mean total phosphorus						
		Low flow		High flow		Load <sup>2</sup> (lb/d)		Yield <sup>2</sup> [(lb/d)/mi <sup>2</sup> ]		Low flow		High flow		Yield <sup>2</sup> [(lb/d)/mi <sup>2</sup> ]		
Hickory Creek	H1	6.60	7.60	121	131	3.1	3.3	10.7	6.14	0.27	0.16					
	H2	8.10	3.90	349	84.1	17	4.2	10.0	2.73	.50	.14					
	H3	.300	1.10	4.04	12.5	.98	3.0	.323	.711	.08	.17					
	<sup>3</sup> H4	24.0	33.0	621	462	4.8	3.6	23.3	19.6	.18	.15					
	<sup>3</sup> H5	.100	.500	.323	1.62	.06	.29	.022	.108	<.01	.02					
Clear Creek	C1	47.0	180	127	1,160	.49	4.5	5.07	67.9	.02	.26					
	C2	4.20	14.0	36.2	136	1.2	4.3	.906	4.53	.03	.14					
	C3	63.0	296	204	2,390	.69	8.1	10.2	144	.03	.49					
	<sup>3</sup> C4	68.0	325	293	2,450	.91	7.5	25.7	175	.08	.54					
	<sup>3</sup> C5	2.20	1.70	19.0	9.16	1.5	.74	1.07	.367	.09	.03					
Elm Fork Trinity River	E1	58.4	277	535	3,430	2.9	19	78.7	269	.43	1.5					
	E2	66.0	360	747	3,690	2.8	14	99.6	310	.38	1.2					
	E3	5.70	24.0	64.5	466	.91	6.6	3.07	12.9	.04	.18					
	<sup>3</sup> E4	69.0	390	558	4,620	1.5	12	59.5	210	.16	.55					
Isle du Bois Creek	I1	6.10	22.0	92.9	130	1.4	2.0	2.30	15.4	.04	.24					
	I2	50.6	46.0	900	322	4.4	1.6	21.8	39.7	.11	.19					
	<sup>3</sup> I3	54.0	101	815	817	3.1	3.1	146	70.8	.55	.27					
Little Elm Creek	L1	9.40	84.9	289	1,650	6.2	35	22.8	151	.49	3.2					
	<sup>3</sup> L2	14.0	72.5	332	1,910	4.4	25	6.04	160	.08	2.1					
	<sup>3</sup> L3	2.80	1.30	64.9	16.1	2.9	.73	.906	1.12	.04	.05					
	<sup>3</sup> L4	2.70	6.20	36.4	40.1	1.1	1.2	1.02	5.35	.03	.17					
	<sup>3</sup> L5	1.20	1.30	7.76	7.71	2.8	2.8	.323	.701	.12	.25					
Cooper Creek	<sup>3</sup> O1	.700	1.00	4.15	8.08	.62	1.2	.189	.054	.03	.01					
Alyne Branch	<sup>3</sup> O2	.100	.400	.808	1.72	.12	.25	.194	.216	.03	.03					
Pecan Creek	<sup>3</sup> O3	1.70	1.90	7.33	11.3	.60	.92	1.74	1.02	.14	.08					

Footnotes at end of table.

**Table 2. Discharge and daily mean nutrient loads and yields during low-flow (March 1984) and high-flow (March 1985) synoptic surveys in the Lewisville Lake drainage basin—Continued**

Drainage area	Site	Instantaneous discharge <sup>1</sup> (ft <sup>3</sup> /s)		Daily mean total nitrogen				Daily mean total phosphorus			
		Low flow	High flow	Load <sup>2</sup> (lb/d)		Yield <sup>2</sup> [(lb/d)/mi <sup>2</sup> ]		Load <sup>2</sup> (lb/d)		Yield <sup>2</sup> [(lb/d)/mi <sup>2</sup> ]	
				Low flow	High flow	Low flow	High flow	Low flow	High flow	Low flow	High flow
Button Branch	<sup>3</sup> O4	2.20	5.70	80.6	67.6	5.4	4.6	7.47	8.91	0.50	0.60
Panther Creek	<sup>3</sup> O5	8.70	9.80	108	121	5.3	6.0	2.34	2.64	.12	.13
Cottonwood Branch	<sup>3</sup> O6	3.00	1.60	93.8	53.5	9.9	5.7	5.50	1.38	.58	.15
Stewart Creek	<sup>3</sup> O7	7.60	6.70	324	578	37	66	9.83	14.8	1.1	1.7
Total of discharges and loads and average yields for 17 downstream-most sites		262	960	3,370	11,200	2.5	8.4	290	672	.22	.51

<sup>1</sup> High flows were an average 3.7 times larger than low flows at downstream-most sites.

<sup>2</sup> Assumes constant flow rate for the entire day.

<sup>3</sup> The 17 downstream-most sites drain 80 percent (1,329 mi<sup>2</sup>) of the Lewisville Lake drainage basin (1,660 mi<sup>2</sup>).

**Table 3.** Mean water-quality data for stormflow and periodic sampling at streamflow-gaging stations in the Lewisville Lake drainage basin, 1986–87 water years

[ft<sup>3</sup>/s, cubic feet per second;  $\mu$ S/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; CaCO<sub>3</sub>, calcium carbonate; Ca, calcium]

Discharge or water-quality property or constituent	Stormflow and periodic sampling			Periodic sampling
	Clear Creek near Sanger (08051500)	Little Elm Creek near Aubrey (08052700)	Hickory Creek at Denton (08052780)	Elm Fork Trinity River near Pilot Point (08051130)
Instantaneous discharge (ft <sup>3</sup> /s)	1,239	619	2,123	546
Specific conductance ( $\mu$ S/cm)	496	411	376	451
pH (standard units)	7.9	7.8	--	7.8
Nitrogen, nitrite plus nitrate, total (mg/L as N)	.78	2.0	1.1	.95
Nitrogen, ammonia plus organic, total (mg/L as N)	1.6	1.8	2.3	1.3
Phosphorus, total (mg/L as P)	.29	.37	.19	.20
Hardness, total (mg/L as CaCO <sub>3</sub> )	210	140	160	160
Alkalinity (mg/L as CaCO <sub>3</sub> )	169	120	139	142
Calcium, dissolved (mg/L as Ca)	69	51	59	55
Magnesium, dissolved (mg/L)	8.3	4.4	4.1	5.3
Sodium, dissolved (mg/L)	34	32	20	32
Potassium, dissolved (mg/L)	3	5	3	4
Sulfate, dissolved (mg/L)	36	81	30	37
Chloride, dissolved (mg/L)	54	12	14	34
Fluoride, dissolved (mg/L)	.2	.4	.2	.2
Silica, dissolved (mg/L)	10	7	11	8.7

relation of major ions in the water from each stream. Linear patterns in the arrangement of data in trilinear diagrams indicate mixing of dissimilar waters (Hem, 1985). The linear arrangement of the data for Clear Creek near Sanger (fig. 4) indicates the mixing of two dissimilar waters—one dominated by calcium carbonate and the other by sodium and chloride ions. This is attributed to Clear Creek draining from the West Cross Timbers and Grand Prairie physiographic regions. Drier soils of the West Cross Timbers region could contain more sodium chloride than the prairie soils. As waters from the two regions mix, the major-ion ratios vary relative to the proportion of water from each of the regions.

A linear pattern, to a lesser degree than that of the Clear Creek near Sanger data, also can be seen in the data for Little Elm Creek near Aubrey (fig. 4), indi-

cating a mixture of calcium carbonate- and sulfate-dominated water. Sulfate concentrations in Little Elm Creek generally are largest in low flows.

The data for Hickory Creek at Denton and Elm Fork Trinity River near Pilot Point indicate a calcium carbonate-dominated water (fig. 4). One sewage-treatment plant discharges above the sampling point on Hickory Creek (pl. 1).

### Daily Mean Nutrient Loading

Daily mean nutrient loads for total nitrite plus nitrate nitrogen, total ammonia plus organic nitrogen, and total phosphorus were computed for each of four streamflow-gaging stations (on Clear Creek, Little Elm Creek, Hickory Creek, and Elm Fork Trinity River) (pl. 1), and for ungaged streams (collectively), in the

Lewisville Lake drainage basin for water years 1986–87 (table 4). Daily mean loads for each constituent at each station were computed by summing estimates of daily loads to obtain annual loads and then dividing by 365. Daily mean discharge data are available for each station but not daily mean nutrient concentrations; therefore daily loads could not be computed directly by multiplying discharge times concentration. Estimates of daily loads were obtained from nutrient-load transport equations developed for each constituent at each station by regressing log-transformed daily nutrient loads computed from water-sample data on log-transformed daily mean discharge. As applied, the transport equations for each constituent at each station (curves and equations shown in fig. 5) are of the form

$$L = B_2 Q^{B_1}, \quad (1)$$

where  $L$  = nutrient load, in pounds per day,

$Q$  = discharge, in cubic feet per second, and

$B_1$ ,  $B_2$  = regression coefficients.

Daily mean nutrient loads for each constituent at each station for each of the 2 water years thus were computed from the equation

$$L = \frac{\sum_{i=1}^{365} (B_2 Q_i^{B_1})}{365}. \quad (2)$$

Estimates of daily mean concentration for each constituent at each station (table 4) were computed by dividing computed daily mean loads by corresponding daily mean discharges.

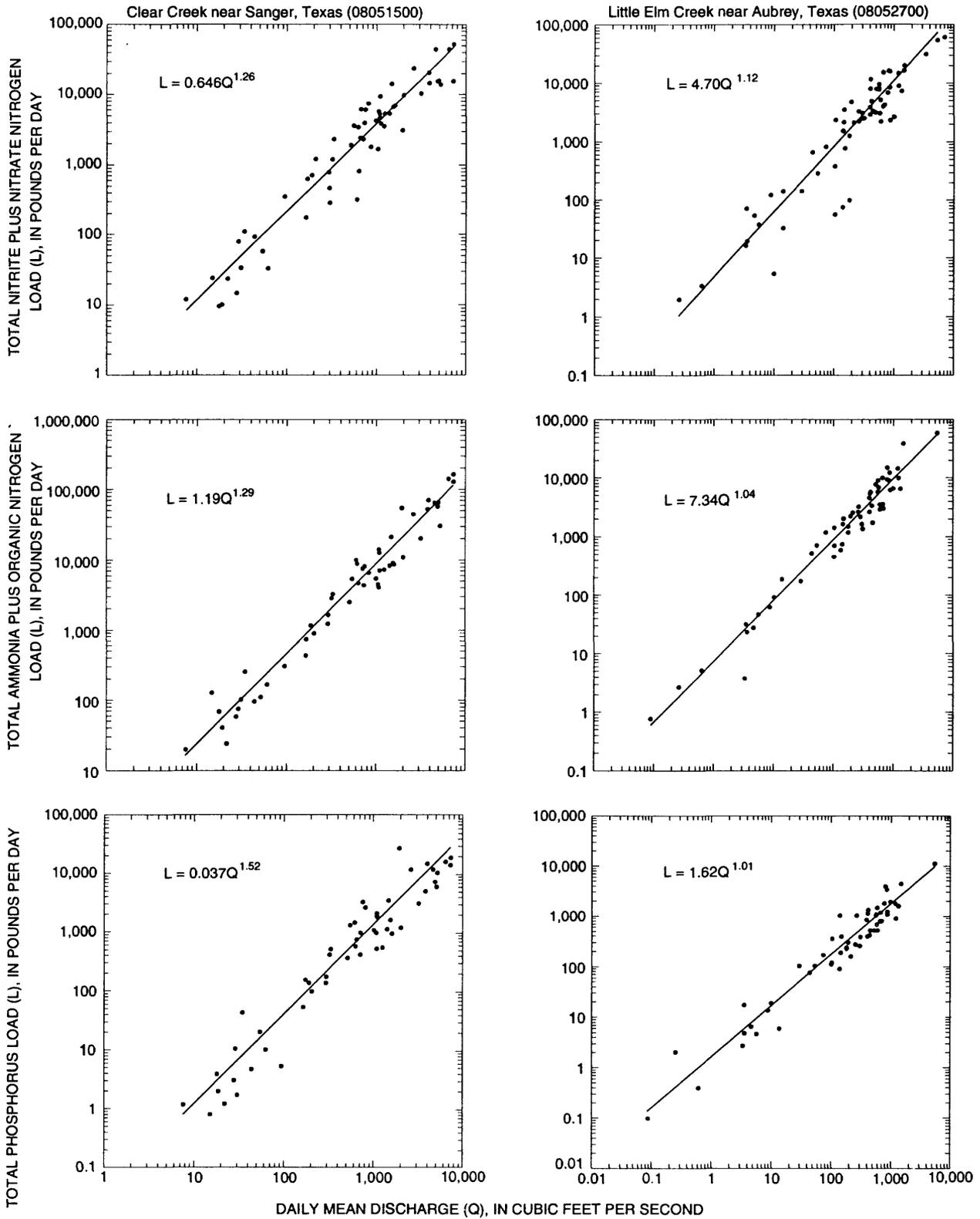
Ungaged streams in the lake basin drain about 434 mi<sup>2</sup>. On the basis of similarities in streamflow quality to waters at three gaging stations noted in analyses of synoptic samples, the ungaged area was divided into three subareas. A 243-mi<sup>2</sup> subarea was assumed similar in runoff and streamflow-quality characteristics to the Clear Creek drainage area; 33 mi<sup>2</sup> was assumed similar to the Little Elm Creek drainage area; and 158 mi<sup>2</sup> was assumed similar to the Hickory Creek drainage area. Daily mean nutrient loads in streams draining each of the three ungaged subareas were computed as the product of the ungaged subarea and the daily mean discharge per unit area (unit runoff) of the similar gaged area and the daily mean nutrient concentration at the gaging station of the similar gaged area. The daily mean nutrient load for the entire 434-mi<sup>2</sup> ungaged area

then was computed as the sum of the daily mean loads of the three subareas. The daily mean concentration for each constituent from the ungaged area was computed by dividing the daily mean load by the daily mean discharge from the ungaged area, the discharge having been obtained by summing the products of the ungaged subareas and the respective daily mean unit-runoff values.

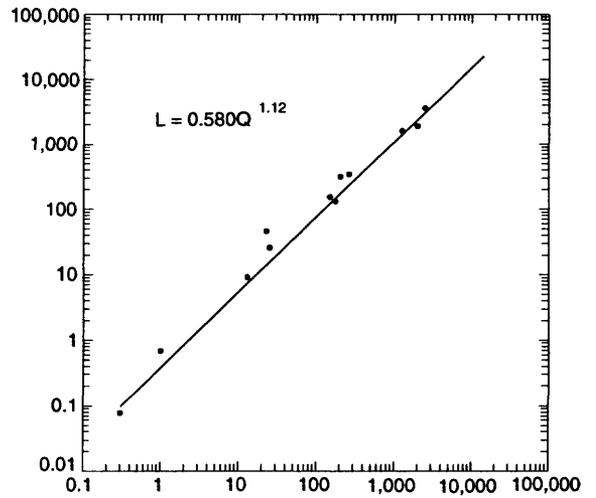
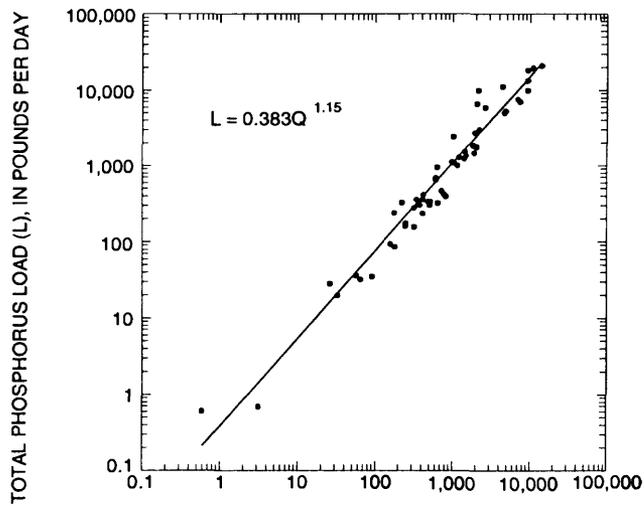
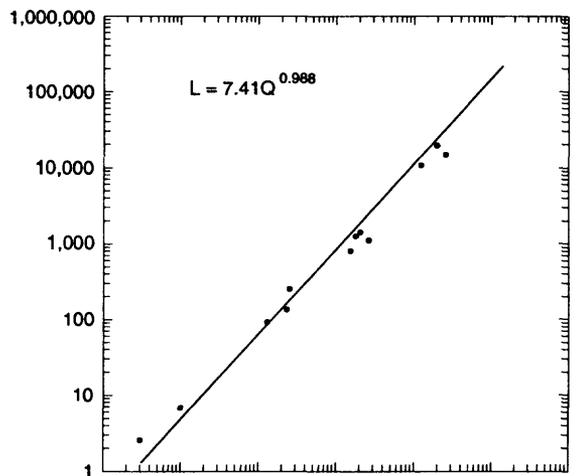
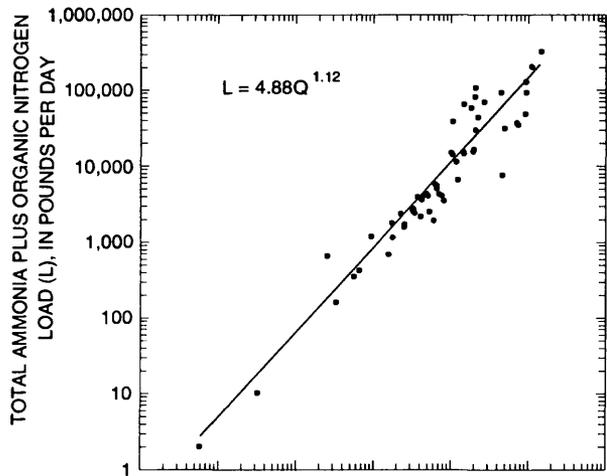
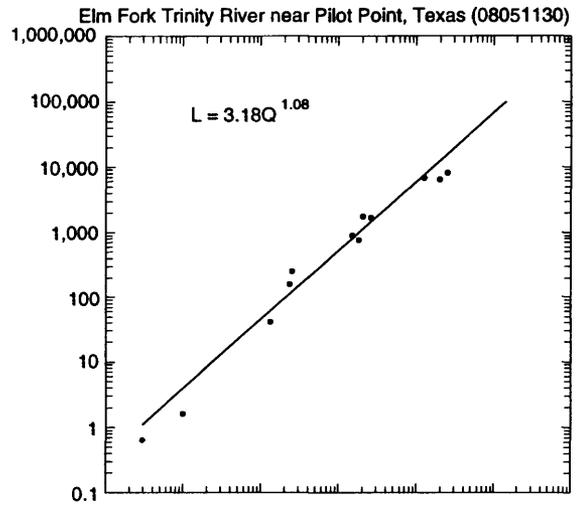
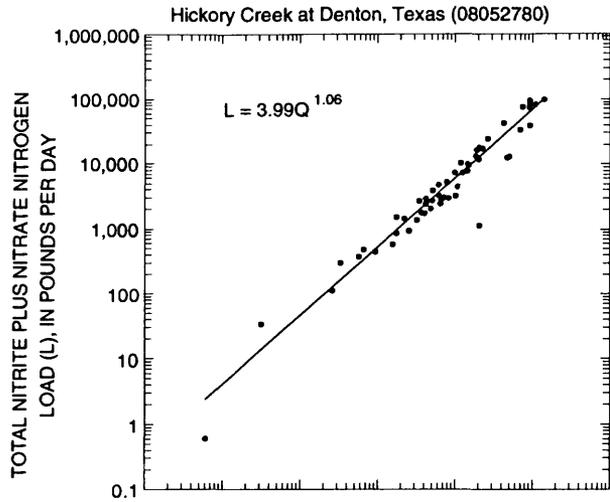
Nutrient-load transport equations used to compute daily nutrient loads are derived from instantaneous discharge observations; therefore, computations could result in some systematic error (bias) when discharge is not constant throughout the day. The size of this error depends on the range of variation in discharge during the day and the extent of slope (nonlinearity) of the transport curves. The magnitude of this error was assessed for several days of rapidly changing stage on Clear Creek by comparing loads computed by subdividing days into sections of similar discharge to loads computed from daily mean discharge. Total phosphorus loads computed from daily mean discharge could be 5 to 15 percent less than those computed by subdividing the day into sections of similar discharge. The total phosphorus loading to Lewisville Lake from Clear Creek might be underestimated because most of the total phosphorus load is associated with high flows, and high flows are associated with changing flow conditions.

The small nutrient loads contributed directly from precipitation on the 36-mi<sup>2</sup> lake surface were computed from precipitation records for Lewisville Lake from the U.S. Army Corps of Engineers and volume-weighted mean nutrient concentrations in precipitation collected at the National Atmospheric Deposition Program site at the Lyndon Baines Johnson National Grasslands in Alvord, Tex. (north-central Wise County), for 1986–87 (National Atmospheric Deposition Program, 1987a,b and 1988a,b).

For the water years 1986 and 1987, daily mean discharge to the reservoir (table 4) was 1,010 ft<sup>3</sup>/s and 870 ft<sup>3</sup>/s, respectively. The total nitrite plus nitrate nitrogen that entered the reservoir on the average each day during 1986 was 5,640 lb/d and during 1987 was 4,480 lb/d. During the same period, about one and one-half as much nitrogen in the form of total ammonia plus organic nitrogen entered the reservoir (8,530 lb/d in 1986 and 7,020 lb/d in 1987); and about one-fourth as much total phosphorus entered the reservoir during the period (1,310 lb/d in 1986 and 1,080 lb/d in 1987).



**Figure 5.** Nutrient-load transport curves for streamflow-gaging stations used for stormflow and periodic sampling in the Lewisville Lake drainage basin, north-central Texas, 1986–87 water years.



DAILY MEAN DISCHARGE (Q), IN CUBIC FEET PER SECOND

**Table 4.** Daily mean discharge and nutrient concentrations, loads, and yields for streamflow-gaging stations and ungaged streams in the Lewisville Lake drainage basin, 1986–87 water years

[mi<sup>2</sup>, square miles; ft<sup>3</sup>/s, cubic feet per second; (ft<sup>3</sup>/s)/mi<sup>2</sup>, cubic feet per second per square mile; mg/L, milligrams per liter; lb/d, pounds per day; (lb/d)/mi<sup>2</sup>, pounds per day per square mile; --, not applicable; <, less than]

Streamflow-gaging station (number)	Drainage area (mi <sup>2</sup> )	Water year	Daily mean discharge		Daily mean total nitrite plus nitrate nitrogen			Daily mean total ammonia plus organic nitrogen			Daily mean total phosphorus		
			(ft <sup>3</sup> /s)	[(ft <sup>3</sup> /s)/mi <sup>2</sup> ]	Concentration (mg/L)	Load (lb/d)	Yield [(lb/d)/mi <sup>2</sup> ]	Concentration (mg/L)	Load (lb/d)	Yield [(lb/d)/mi <sup>2</sup> ]	Concentration (mg/L)	Load (lb/d)	Yield [(lb/d)/mi <sup>2</sup> ]
Clear Creek near Sanger, Tex. (08051500)	295	1986	146	0.49	0.65	511	1.7	1.5	1,150	3.9	0.22	174	0.59
		1987	158	.54	.62	526	1.8	1.4	1,180	4.0	.21	177	.60
Little Elm Creek near Aubrey, Tex. (08052700)	75.5	1986	49.6	.66	1.9	503	6.7	1.8	469	6.2	.32	85.5	1.1
		1987	24.8	.33	1.6	216	2.9	1.7	223	3.0	.32	42.3	.56
Hickory Creek at Denton, Tex. (08052780)	129	1986	107	.83	1.1	646	5.0	2.1	1,210	9.4	.20	117	.91
		1987	81.7	.63	1.1	482	3.7	2.0	883	6.8	.19	85.2	.66
Elm Fork Trinity River near Pilot Point, Tex. (08051130)	692	1986	437	.63	1.0	2,450	3.5	1.3	2,970	4.3	.26	609	.88
		1987	365	.53	1.0	2,030	2.9	1.3	2,490	3.6	.26	502	.73
Ungaged streams in Lewisville Lake drainage basin	434	1986	272	.63	.97	1,420	3.3	1.8	1,2650	6.1	.22	1,324	.75
		1987	242	.56	.86	1,130	2.6	1.7	1,2,170	5.0	.21	1,270	.62
Lewisville Lake (precipitation) <sup>2</sup>	36.0	1986	--	--	.18	107	3.0	.14	83.0	2.3	<.003	<1.80	<.05
		1987	--	--	.18	92.0	2.6	.14	72.0	2.0	<.003	<1.60	<.04
Total	1,660	1986	1,010	--	--	15,640	--	--	18,530	--	--	1,310	--
		1987	870	--	--	14,480	--	--	17,020	--	--	1,080	--

<sup>1</sup> Does not include loads from sewage-treatment plants.

<sup>2</sup> National Atmospheric Deposition Program, 1987a, b, 1988a, b.

## Point- and Nonpoint-Source Nutrient Loading

Loads in table 4 represent mostly nonpoint-source nutrient loads. Loads from ungaged sewage-treatment plants near the lake are excluded. Although sewage-effluent discharge to Hickory Creek was negligible during the sampling period and thus was negligible in water samples from the Hickory Creek station, nutrient concentrations in samples from stations on the other three creeks probably were influenced by point sources (effluent from sewage-treatment plants).

Nutrients downstream from a point source generally are most concentrated at low flows and most diluted at high flows. Assuming nutrient discharges from point sources generally are independent of flow conditions, nutrient loads downstream from point sources generally would be more affected by the point-source discharge at low-flow conditions than at high-flow conditions. Assuming nutrient concentrations derived from nonpoint sources generally are constant, nutrient load from nonpoint sources would be low during low flow and high during high flow. On the basis of these assumptions, point sources would affect the load more during low-flow conditions and less during high-flow conditions. These characteristics of low-flow and high-flow loads have been used to distinguish between point-source and nonpoint-source loads (Pillard and Dickson, 1988). To estimate the fraction of total nutrient load contributed by point sources in the gaged drainage areas, the cumulative percent of nutrient load contributed by a specific daily mean discharge during the 1986 water year was computed for each of the four streams (fig. 6). For example, about 38 percent of the total phosphorus load from Clear Creek is associated with daily mean discharges of as much as 1,000 ft<sup>3</sup>/s, and about 73 percent is associated with daily mean discharges of as much as 2,000 ft<sup>3</sup>/s. Daily mean discharges ranging from 0 to 1,000 ft<sup>3</sup>/s in Clear Creek accounted for only about 38 percent of the total phosphorus load from Clear Creek to Lewisville Lake but about 65 percent of the total discharge from Clear Creek to the reservoir. Daily mean discharges ranging from 1,000 to 2,000 ft<sup>3</sup>/s account for about 35 percent of the total phosphorus load but only about 22 percent of the discharge to the reservoir. Base flows (considered low-flow conditions) for the drainage areas studied, although variable during the year (fig. 2), typically were about 90 ft<sup>3</sup>/s for Clear Creek near Sanger, about 10 ft<sup>3</sup>/s for Little Elm Creek near Aubrey, and about 100 ft<sup>3</sup>/s for Elm Fork Trinity River near Pilot Point

(the three sampled streams in which point-source loading was not negligible), and about 20 ft<sup>3</sup>/s for Hickory Creek at Denton. About 15 percent of total discharge and about 3 percent of the total phosphorus load in Clear Creek are associated with base-flow conditions (fig. 6). In Little Elm Creek, about 7 percent of total discharge as well as about 7 percent of the total phosphorus load are associated with base-flow conditions. In Hickory Creek, about 8 percent of the total discharge and about 3 percent of the total phosphorus load are associated with base-flow conditions. In Elm Fork Trinity River, about 5 percent of total discharge and total phosphorus load are associated with base flow. Nitrite plus nitrate load and ammonia plus organic nitrogen load associated with base-flow conditions similarly are small fractions of the total load of those constituents for the 1986 water year. On the basis of the preceding analysis and the assumptions that most of the nutrient load under conditions of base flow or less is from point sources and most of the nutrient load under conditions greater than base flow is from nonpoint sources, a small fraction (probably less than 10 percent) of the total nutrient load is from point sources.

The effects of the sewage effluent discharged into the Elm Fork Trinity River from the sewage-treatment plant near Gainesville cannot be differentiated from the effects of nonpoint-source loading. Although loads to the Elm Fork Trinity River are increased somewhat by point-source inputs, the daily mean concentration of total phosphorus for the 1986 water year in Elm Fork Trinity River (0.26 mg/L) is only slightly larger than that in Clear Creek (0.22 mg/L) (table 4). Sewage-effluent discharges to Little Elm Creek appear to increase overall concentrations of total nitrite plus nitrate nitrogen and total phosphorus in the stream; however, the load contributed by Little Elm Creek and other small streams receiving sewage effluent is small enough that exclusion of their point-source loads from computations does not substantially change loading rates for the entire Lewisville Lake drainage basin.

Most of the point-source load to Lewisville Lake could originate at a few sewage-treatment plants in the ungaged drainage area discharging into or close to the reservoir. On the basis of data obtained from individual sewage-treatment plants, these plants discharged an average of about 19.3 ft<sup>3</sup>/s during the 1986–87 water years. Total nitrogen and total phosphorus concentrations in sewage effluent have been estimated to range between 3 and 24 mg/L and between 2 and 8 mg/L,

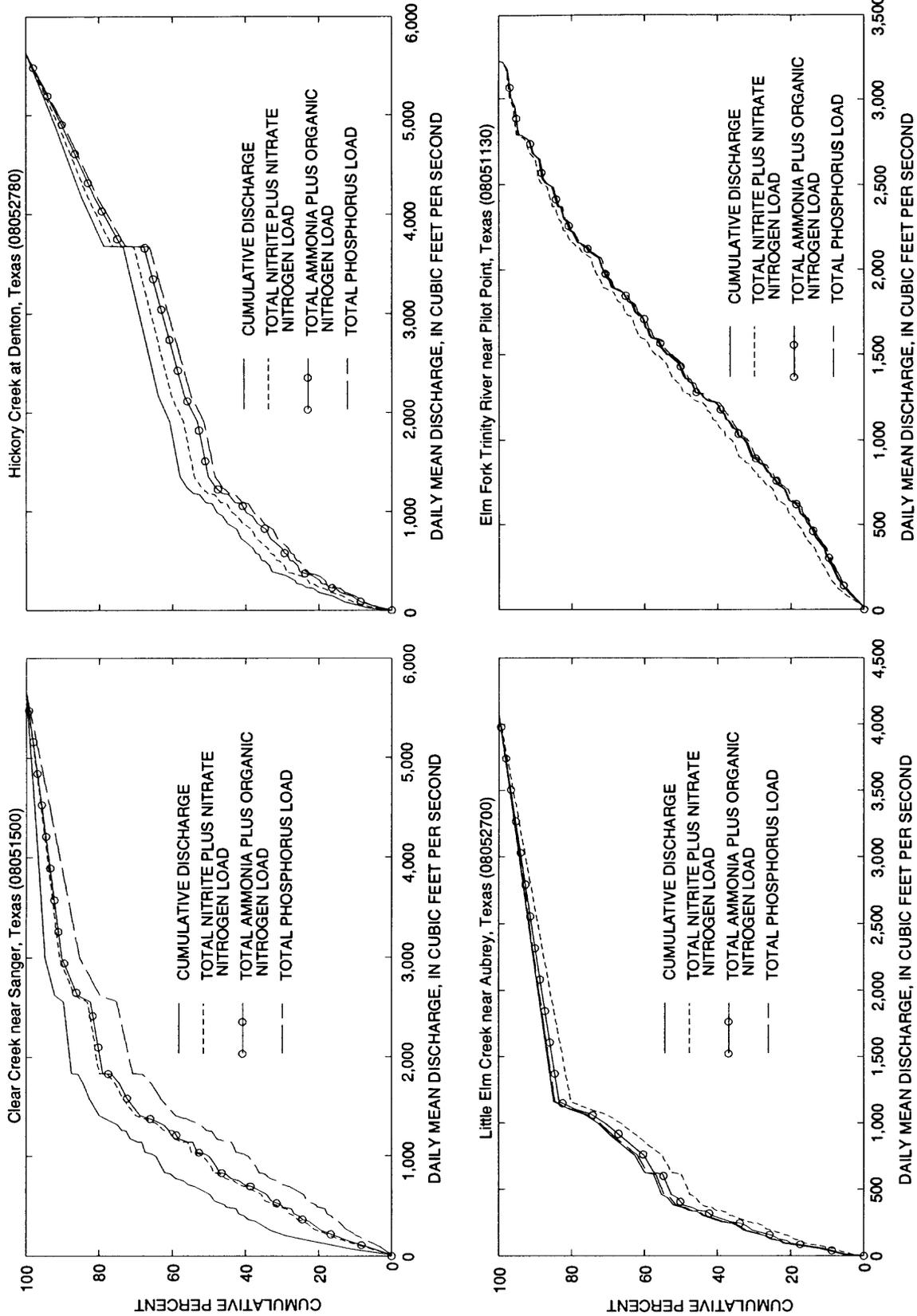


Figure 6. Cumulative percent of cumulative discharge and nutrient loads at various rates of daily mean discharge for streamflow-gaging stations in the Lewisville Lake drainage basin, north-central Texas, 1986 water year.

respectively (U.S. Environmental Protection Agency, 1977). On the basis of these ranges in concentration, the average point-source total nitrogen and total phosphorus loads during the 1986–87 water years from sewage-treatment plants in ungaged areas near the reservoir would range from about 310 to 2,500 lb/d and from about 210 to 830 lb/d, respectively. Because loads from the sewage-treatment plants were not gaged during this study, they were not included with the loads presented in table 4.

### Seasonal Nutrient Loading

Nutrient loading rates vary seasonally with discharge. Daily mean nutrient loads by month for the 1986–87 water years were computed for each of the four streamflow-gaging stations and estimated for the ungaged streams in the Lewisville Lake drainage basin (fig. 7). The maximum monthly daily mean nutrient loads were in June 1986. During that month, the daily mean total nitrite plus nitrate nitrogen load was about 17,000 lb/d—more than 3 times the average annual load for the 1986–87 water years (5,060 lb/d) (table 5). The daily mean total ammonia plus organic nitrogen load in June 1986 was about 26,000 lb/d, and daily mean total phosphorus load was about 4,200 lb/d. Minimum monthly mean loads were zero or near zero for all three nutrients in August of both water years.

Nutrient loading rates to Lewisville Lake are largest each year in three distinct seasons associated with high flow. The largest rates are usually in late spring (May–June), followed by late winter (February–March), and late summer–early fall (September–October). The distribution of monthly loads is expected to be similar to the distribution of monthly discharge.

### Annual Nutrient Loading

Average annual total nitrogen loading to Lewisville Lake from the sources accounted for in this report for the water years 1986–87 was about 12,800 lb/d (table 5); average annual total phosphorus was 1,200 lb/d. Nutrient loading for 1974–89 flow conditions can be estimated by multiplying the average annual nutrient loads for 1986–87 by the ratio of average discharge to Lewisville Lake for 1974–89 to average discharge to the lake for 1986–87. The 1974–89 average annual total nitrogen load thus computed, 11,800 lb/d, agrees well with the load of 11,400 lb/d estimated by DelRegno and Atkinson (1988) using satellite imaging/land-use classification (table 5). Similar

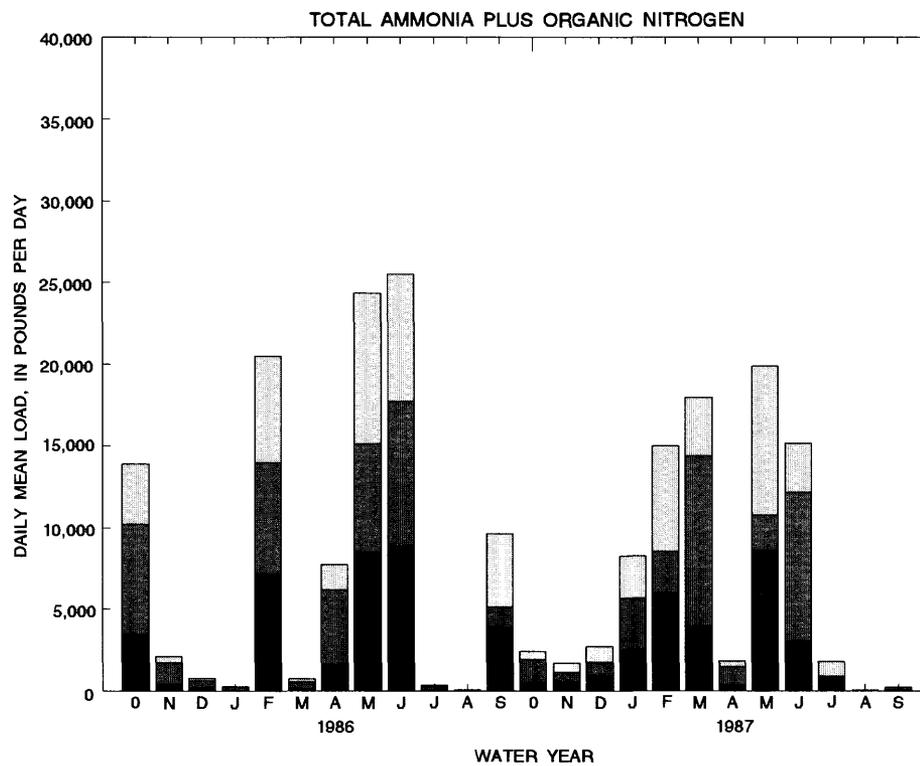
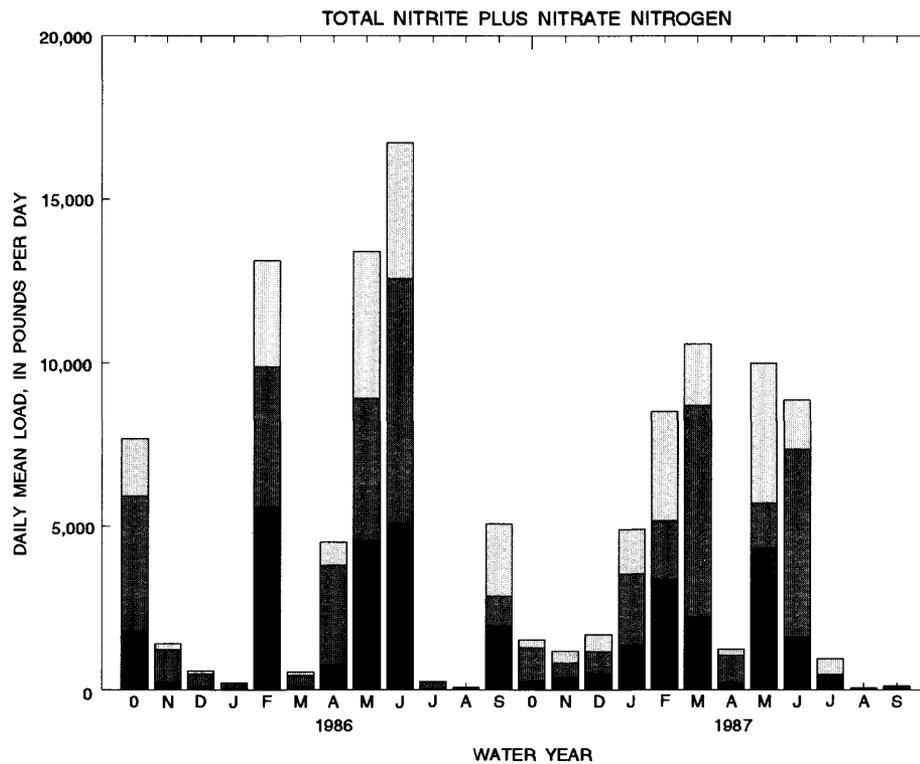
results were reported by Rast and Lee (1983) using land-use relative yields. The 1974–89 average annual total phosphorus load (1,100 lb/d) also agrees well with the 1,140 lb/d estimated by DelRegno and Atkinson. Total nitrogen and total phosphorus loads from this study are more than twice those estimated by the U.S. Environmental Protection Agency (1977) (table 5).

## SUMMARY

Lewisville Lake in north-central Texas, a major source of water for Dallas, could have contributed taste and odor problems to the city's water supply in recent years because of nutrient enrichment and eutrophication. This report presents seasonal variations in loading and total annual loading of total nitrogen and phosphorus to Lewisville Lake from point and nonpoint sources. The study, done in cooperation with the City of Dallas, included two periods of data collection and analysis: (1) synoptic sampling during 1984 (low flow) and 1985 (high flow) at 29 sites in the Lewisville Lake drainage basin; and (2) stormflow and periodic sampling at streamflow-gaging stations on four streams in the Lewisville Lake drainage basin during the 1986–87 water years.

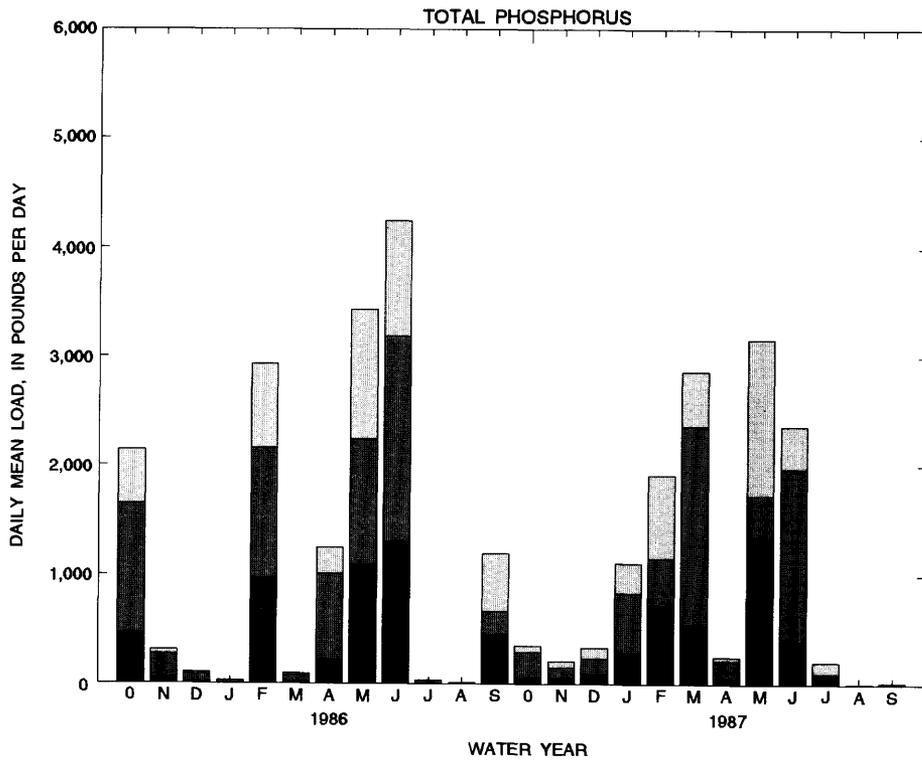
Concentrations of nutrients in the streams of the Lewisville Lake drainage basin have some association with the two types of physiographic regions in the basin—prairie regions and cross timbers regions. Total nitrogen and phosphorus concentrations generally are larger in streams draining the prairie regions than in streams draining the cross timbers regions, a characteristic that might be accounted for in part by the fact that prairie regions tend to have more nutrient-rich, less-permeable soils than cross timbers regions. Within physiographic regions, total nitrogen concentrations could not be correlated with point-source inputs (sewage-treatment plant effluent). However, total phosphorus concentrations were somewhat larger in streams that received sewage effluent than in those that did not.

Most of the variability in nutrient loads is associated with variability in discharge. During the low-flow synoptic survey, the largest contributor of total nitrogen and total phosphorus (at the downstream-most site) was Isle du Bois Creek (815 lb/d of total nitrogen, or 24 percent of a total of 3,370 lb/d; and 146 lb/d of total phosphorus, or 50 percent of a total of 290 lb/d). During the high-flow survey, the largest contributor of total nitrogen and total phosphorus (at the downstream-most



**Figure 7a.**

**Figure 7.** Monthly daily mean nutrient loads computed for streamflow-gaging stations and estimated for ungaged streams in the Lewisville Lake drainage basin, north-central Texas, 1986–87 water years.



**EXPLANATION**

- UNGAGED STREAMS
- ELM FORK TRINITY RIVER NEAR PILOT POINT, TEXAS (08051130)
- HICKORY CREEK AT DENTON, TEXAS (08052780)
- LITTLE ELM CREEK NEAR AUBREY, TEXAS (08052700)
- CLEAR CREEK NEAR SANGER, TEXAS (08051500)

**Figure 7b.**

**Table 5.** Estimates of average annual nutrient loads to Lewisville Lake[ft<sup>3</sup>/s, cubic feet per second; lb/d, pounds per day; --, not applicable]

Source of estimate	Average annual inflow (ft <sup>3</sup> /s)	Average annual load			
		Total nitrite plus nitrate nitrogen (lb/d)	Total ammonia plus organic nitrogen (lb/d)	Total nitrogen (lb/d)	Total phosphorus (lb/d)
1986–87 water years (this study) <sup>1</sup>	940	5,060	7,780	12,800	1,200
1974–89 (this study) <sup>1</sup>	<sup>2</sup> 865	4,660	7,160	11,800	1,100
DelRegno and Atkinson (1988)	--	--	--	11,400	1,140
U.S. Environmental Protection Agency (1977)	--	--	--	4,660	492
Point sources (sewage-treatment plants in ungaged area) <sup>3</sup> , 1986–87 water years	19.3	--	--	<sup>4</sup> 310–2,500	<sup>5</sup> 210–830

<sup>1</sup> Excluding sewage-treatment plants in ungaged areas.<sup>2</sup> Mean annual outflow, 1974–89, at U.S. Geological Survey streamflow-gaging station Elm Fork Trinity River near Lewisville (08053000) 688 ft<sup>3</sup>/s (U.S. Geological Survey, 1975–90) + 177 ft<sup>3</sup>/s computed from gross evaporation, 1940–65 (Texas Water Development Board, 1966) and assuming static lake volume.<sup>3</sup> Individual sewage-treatment plants (unpub. data, 1991).<sup>4</sup> Concentrations from 3 to 24 milligrams per liter estimated by the U.S. Environmental Protection Agency (1977).<sup>5</sup> Concentrations from 2 to 8 milligrams per liter estimated by the U.S. Environmental Protection Agency (1977).

site) was Elm Fork Trinity River (4,620 lb/d of total nitrogen, or 41 percent of a total of 11,200 lb/d; and 210 lb/d of total phosphorus, or 31 percent of a total of 672 lb/d).

Average nutrient yields (loads per unit area) for the 80 percent of the Lewisville Lake basin included in the synoptic surveys were 2.5 and 8.4 (lb/d)/mi<sup>2</sup> of total nitrogen and 0.22 and 0.51 (lb/d)/mi<sup>2</sup> of total phosphorus in the low-flow and the high-flow surveys, respectively. Some of the largest yields in both surveys were from the three streams receiving the largest amounts of sewage effluent—Elm Fork Trinity River, Little Elm Creek, and Stewart Creek.

On the basis of the results of stormflow and periodic sampling, the total nitrite plus nitrate nitrogen that entered the reservoir on the average each day during 1986 was 5,640 lb/d and during 1987 was 4,480 lb/d. During the same period, about one and one-half as much nitrogen in the form of total ammonia plus organic nitrogen entered the reservoir (8,530 lb/d in 1986 and 7,020 lb/d in 1987); and about one-fourth as much total phosphorus entered the reservoir during the period (1,310 lb/d in 1986 and 1,080 lb/d in 1987).

An analysis of time distributions of streamflow and nutrient loading during the 1986 water year was done to estimate the fraction of total nutrient load con-

tributed by point sources in the four gaged drainage areas. Point sources accounted for small fractions (probably less than 10 percent) of the total nutrient load from Clear Creek, Little Elm Creek, Hickory Creek, and Elm Fork Trinity River.

Most of the point-source load to Lewisville Lake could originate at a few sewage-treatment plants discharging to ungaged streams close to the reservoir. The average point-source total nitrogen and total phosphorus loads during the 1986–87 water years is estimated to range from about 310 to 2,500 lb/d and from about 210 to 830 lb/d, respectively.

Nutrient loading rates vary seasonally with discharge. Rates are largest each year in the three seasons of highest flows. The largest rates are usually in late spring (May–June), followed by late winter (February–March), followed by late summer-early fall (September–October).

The estimated long-term (1974–89 water years) average annual total nitrogen load (excluding loads from sewage-treatment plants in ungaged areas) is 11,800 lb/d. The estimated long-term (1974–89 water years) average annual total phosphorus load (excluding loads from sewage-treatment plants in ungaged areas) is 1,100 lb/d.

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