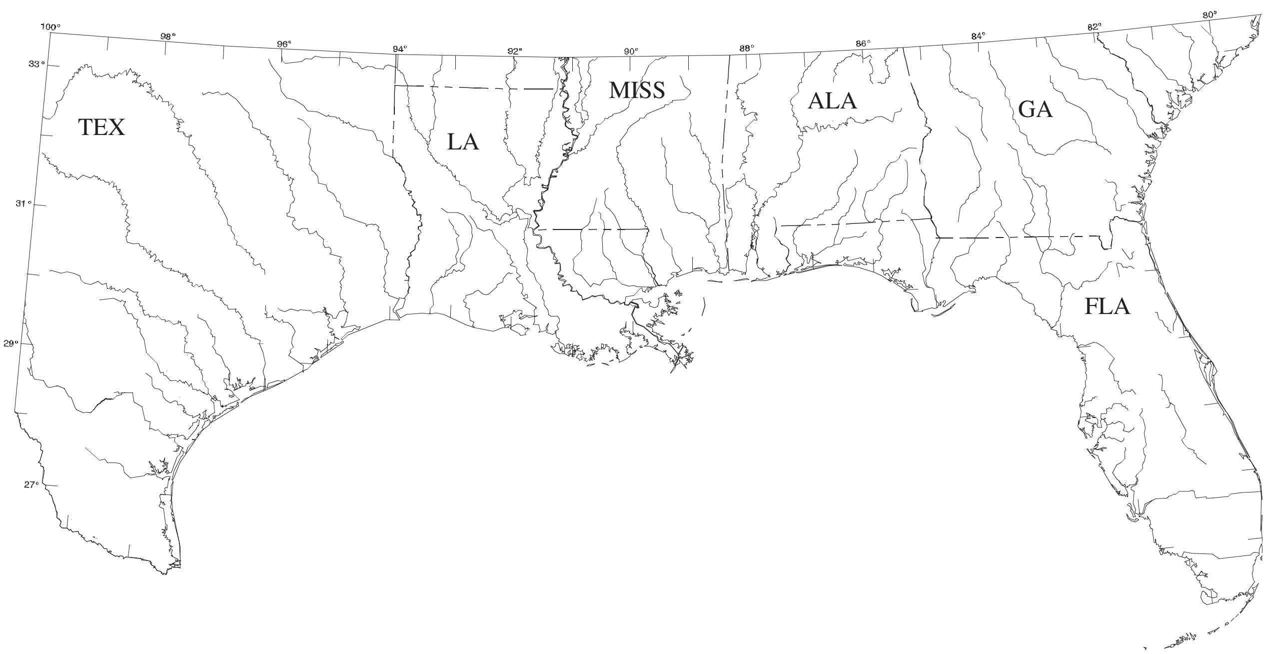
TRENDS IN NUTRIENT INFLOWS TO THE GULF OF MEXICO FROM STREAMS DRAINING THE CONTERMINOUS UNITED STATES, 1972–93

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96–4113



Prepared in cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY
GULF OF MEXICO PROGRAM,
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Austin, Texas
1996

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per square mile (acre-ft/mi^2)	4.761	cubic meter per hectare
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
ton	0.9072	megagram
ton per square mile (ton/mi^2)	0.35026	megagram per square kilometer
square mile (mi^2)	259.0	hectare
	2.590	square kilometer

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Trends in Nutrient Inflows to the Gulf of Mexico from Streams Draining the Conterminous United States, 1972–93

By David D. Dunn

Abstract

Trends are computed for nutrient inflows from 37 streams discharging into the Gulf of Mexico. The drainage areas of these streams represent about 86 percent of the drainage area to the Gulf from the conterminous United States. The period analyzed varies for each stream, but generally includes water years 1972–93. Stations included in this analysis primarily are part of the National Stream Quality Accounting Network operated by the U.S. Geological Survey.

Short-term trends for each station are indicated by LOWESS smooth lines superimposed on graphs of the relations between flow-adjusted residuals of concentration and time or load and time. Long-term trends were evaluated using Kendall's tau and the slope of the Kendall-Theil robust line. Long-term trends for each station are indicated by Kendall-Theil robust lines superimposed on the aforementioned graphs. Annual loads are estimated with regression analysis and corrected for log-transformation bias with the Minimum Variance Unbiased Estimator. Trends in annual streamflow are presented to aid in the interpretation of trends in nutrient inflows.

Statistically significant, long-term increases in flow-adjusted residual concentrations of total nitrogen were detected at 19 stations, decreases were detected at 7 stations, and no significant trends were detected at 11 stations. Long-term increases in total nitrogen load were detected at 3 stations, decreases were detected at 4 stations, and no significant trends were detected at 30 stations.

Long-term increases in flow-adjusted residual concentrations of total phosphorus were detected at 7 stations, decreases were detected at 11 stations, and no significant trends were detected at 19 stations. Long-term increases in total phosphorus load were detected at 3 stations, decreases were detected at 12 stations, and no significant trends were detected at 22 stations.

The median yields (mean annual load divided by drainage area) of total nitrogen and total phosphorus were significantly lower ($p \leq 0.05$) for the 13 streams in Texas than for the 24 streams east of the Sabine River (Texas-Louisiana boundary).

Statistically significant trends in annual streamflow were detected at only four stations. However, annual streamflow influences trends in load, even when the streamflow trends are not statistically significant.

INTRODUCTION

The Gulf of Mexico Program (GMP) was formed by the U.S. Environmental Protection Agency in 1990 to develop and implement a comprehensive strategy to protect and conserve the marine resources of the Gulf. Implementation of this program is coordinated through many committees; this study was done by the U.S. Geological Survey (USGS) in cooperation with the Nutrient Enrichment Committee of the GMP.

Freshwater inflows to the Gulf of Mexico contain nutrients, defined here as total nitrogen and total phosphorus. Total nitrogen and total phosphorus are the sums of the various species of each constituent, comprising dissolved and particulate phases. These nutrients naturally occur at some level in most streams. Nutrients, in combination with many other essential chemical elements, allow the development of living organisms. Most elements essential to plant production are found in relative abundance; nitrogen and phosphorus are not. Therefore, nitrogen and phosphorus usually "limit" plant productivity. Changes in plant productivity correspond to changes in nitrogen and phosphorus levels (Wetzel, 1983). While essential to maintaining a viable ecosystem, nitrogen and phosphorus at sufficiently high levels can have a detrimental effect. In sufficiently large concentrations, nitrogen and phosphorus in an aquatic environment can cause eutrophication (inordinate plant growth) and can be toxic to wildlife (Van Metre and Reutter, 1995).

Increased freshwater nutrient loads to the Gulf of Mexico can overstimulate phytoplankton production along the continental shelf and substantially decrease dissolved oxygen concentration. Decreased dissolved oxygen concentration can affect adversely fish and invertebrate populations and could cause a decrease in fishery productivity. Nutrient loads from the Mississippi River Basin have been identified as a factor contributing to seasonal hypoxic water conditions (oxygen concentrations less than 2 milligrams per liter [mg/L]) off the Louisiana coast (Turner and Rabalais, 1991).

Purpose and Scope

This report summarizes available data and presents temporal trends in nutrient inflows to the Gulf of Mexico from 37 streams. Presented are trends in flow-adjusted concentrations of total nitrogen and total phosphorus and trends in estimated annual loads of these constituents. Trends in annual streamflow are presented to aid in the interpretation of trends in nutrient inflows. The period analyzed is specific to each stream and depends upon the availability of data, but generally is from water year[1] 1972 to water year 1993, inclusive.

Short-term trends are represented graphically with best-fit curvilinear lines computed using the LOcally WEighted Scatterplot Smoothing (LOWESS) technique (Cleveland, 1979; Helsel and Hirsch, 1992). Long-term trends are computed using the Kendall-Theil robust trend line and are tested for statistical significance using the attained significance level (p-value) of Kendall's tau (Helsel and Hirsch, 1992). The p-value indicates the likelihood that, given the data available, the slope of the trend line is different from zero. Low p-values indicate strong evidence that the slope of the trend line is different than zero. Statistical significance is reported at three levels: strongly significant, $p \leq 0.05$; significant, $0.05 < p \leq 0.10$; and nonsignificant, $p > 0.10$. Annual loads are estimated using linear regression and are corrected for log-transformation bias with a Minimum Variance Unbiased Estimator (MVUE) (Cohn and others, 1989).

Streamflow, unless otherwise noted, refers to the water discharge that occurs in a natural channel. Annual values of streamflow and load presented in this report consist of daily values aggregated on an annual, water-year basis.

Previous Studies

The USGS, in cooperation with the Freshwater Inflows Committee of the GMP, summarized and analyzed trends and sources of trends in freshwater streamflow to the Gulf (Judd, 1995). C.R. Demas (U.S. Geological Survey, written commun., 1995), in cooperation with the Nutrient Enrichment Committee of the GMP, investigated the differences between wet and dry years in nutrient inflows from the Mississippi River. Smith and others (1982) analyzed trends in flow-adjusted concentrations of total phosphorus for 5- to 8-year periods in the late 1970s at 300 stations in the National Stream Quality Accounting Network (NASQAN), which were operated by the USGS. They report significant ($p \leq 0.1$) decreasing trends for 5 and significant increasing trends for 3 of the 37 streams included in the present study. Data for some of the streams, however, were collected at different streamflow-gaging stations than data used in the present study.

Schertz (1990) analyzes trends in water-quality data for Texas for water years 1969–86. Although the methodology used and the period analyzed differ from that of the analysis reported here, the results generally agree for sites common to both studies.

Smith and others (1993) summarize stream-water-quality trends in the 1980s. They divide the United States into six coastal segments and present trends in nitrate loads for 1980–88 and total phosphorus loads for 1982–88. They report decreases of about 3.5 percent per year for both constituents for the Gulf of Mexico segment during the periods analyzed.

Turner and Rabalais (1991) present changes in the water quality of the Mississippi River in the 20th century. They report substantial increases in both nitrogen and phosphorus loadings from the Mississippi River and attribute these to increased use of nitrogen- and phosphorus-based fertilizers.

[1]A water year is the 12-month period October 1–September 30. The water year is designated by the year in which it ends; thus, the water year ending September 30, 1993, is water year 1993.

USGS studies as part of the National Water-Quality Assessment (NAWQA) Program are ongoing in the Trinity River Basin; the Apalachicola-Chattahoochee Basin (Apalachicola and Chipola Rivers); and the Florida-Georgia Coastal Plain (Ochlockonee, Suwannee, Anclote, Hillsborough, Alafia, and Little Manatee Rivers) (Leahy and Wilbur, 1991), and might provide additional detailed information on freshwater inflows to the Gulf from streams in these basins.

Sources and Description of Data

Data used in this study were collected during water years 1972–93 at 37 streamflow-gaging stations near the Gulf coast that monitor streams draining into the Gulf. Most of these stations were operated by the USGS as part of NASQAN. The total drainage area upstream of the 37 stations (1.642 million mi^2) represents about 86 percent of the total drainage area from the United States to the Gulf (1.901 million mi^2). The remaining 14 percent represents primarily intervening drainage area between the stations and the coast, although this number does include the drainage areas of some streams that were excluded due to lack of data. Periodic samples for water-quality analysis were obtained at these stations about 3 to 10 times per year during the period analyzed. Stations selected are the closest to the Gulf for which sufficient data are available. A station was considered to have sufficient data if (1) analyses for total nitrogen and total phosphorus are available for at least 80 percent of the desired period (1972–93), (2) at least 50 analyses for both total nitrogen and total phosphorus are available over the period analyzed, and (3) no substantial gaps in data exist (generally, less than 6 consecutive years with no available data). Nutrient data were obtained from the water-quality data bases of local USGS offices responsible for operating the stations.

Daily mean streamflow data are available for the entire period analyzed at 31 of the 37 stations. For 5 of the remaining 6 stations, streamflow data were supplemented with data from adjacent stations on the same stream by directly substituting missing streamflow values. The differences between drainage areas for the five original stations and drainage areas for adjacent stations are less than 6.3 percent. Missing streamflow data for the sixth station was estimated by regression analysis using data from a station upstream. Streamflow data were obtained from the National Water Data Storage and Retrieval System (WATSTORE), local USGS offices, the International Boundary and Water Commission, and the U.S. Army Corps of Engineers.

Station locations are shown in figure 1. Station names, USGS station numbers, locations, and drainage areas are listed in table 1. The USGS station numbers are unique eight-digit numbers assigned by the USGS. Footnotes in table 1 indicate that streamflow data at a station were supplemented with data from a nearby station.

The periods of record and total number of analyses for total nitrogen and total phosphorus for each station are listed in table 2. The period of record used at a station corresponds to the longer of the two constituent periods.

Stations names are assigned three-letter abbreviations for identification on figures and tables.

METHODS OF ANALYSIS

Computation of Flow-Adjusted Nutrient Concentrations

Nutrient concentrations (and loads) are related to streamflow. The relation between nutrient concentrations and streamflow depends on flow conditions and the dominant sources of nutrients (Van Metre and Reutter, 1995). Under low-flow conditions at sites associated with nonpoint nutrient sources (such as fertilizers applied to irrigated cropland or urban landscapes, and decaying vegetative matter), nutrient concentrations in streamflow commonly are low; this is because low streamflow commonly comprises mostly ground water, which commonly has low nutrient concentrations relative to surface runoff. In contrast, under high-flow conditions at sites associated with nonpoint nutrient sources, nutrient concentrations in streamflow commonly are high relative to those under low-flow conditions; this is because high streamflow commonly comprises proportionately more surface runoff, which commonly contains higher nutrient concentrations than ground water.

The opposite relations between concentrations and streamflow can be observed immediately downstream from a point-source discharge such as a municipal wastewater-treatment plant outfall. Nutrient concentrations are high at low flows because the streamflow is dominated by the wastewater effluent, which commonly has much higher nutrient concentrations than ground water or surface runoff.

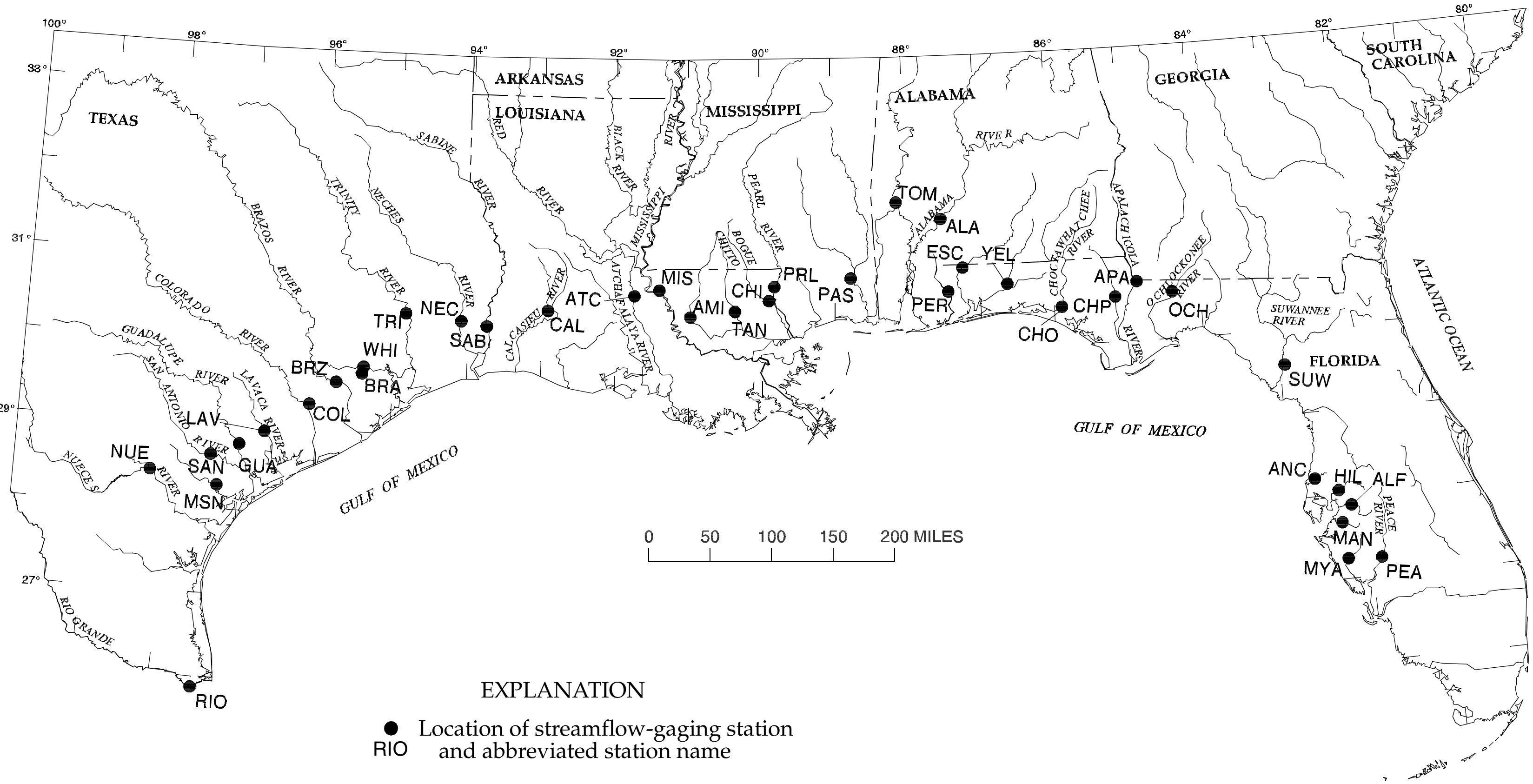

Figure 1. Locations of streamflow-gaging stations on the lower reaches of streams discharging into the Gulf of Mexico.

Table 1. Locations and drainage areas for selected streamflow-gaging stations on streams discharging to the Gulf of Mexico

[mi^2, square miles; L&D, lock and dam]

Abbreviated name	Station name	Station number	Latitude	Longitude	Drainage area (mi^2)
RIO	Rio Grande near Brownsville, Tex.	08475000	25°52'35"	97°27'15"	176,333
NUE	Nueces River near Three Rivers, Tex.	08210000	28°25'38"	98°10'40"	15,427
MSN	Mission River at Refugio, Tex.	08189500	28°17'30"	97°16'44"	690
SAN	San Antonio River at Goliad, Tex.	08188500	28°38'58"	97°23'04"	3,921
GUA	Guadalupe River at Victoria, Tex.	08176500	28°47'34"	97°00'46"	5,198
LAV	Lavaca River near Edna, Tex.	08164000	28°57'35"	96°41'10"	817
COL	Colorado River at Wharton, Tex.	08162000	29°18'32"	96°06'13"	42,240
BRZ	Brazos River at Richmond, Tex.	08114000	29°34'56"	95°45'27"	45,007
BRA	Brays Bayou at Houston, Tex.	08075000	29°41'49"	95°24'43"	95
WHI	Whiteoak Bayou at Houston, Tex.	08074500	29°46'30"	95°23'49"	86
TRI	Trinity River at Romayor, Tex.	08066500	30°25'30"	94°51'02"	17,186
NEC	Neches River at Evadale, Tex.	08041000	30°21'20"	94°05'35"	7,951
SAB	Sabine River near Ruliff, Tex.	08030500	30°18'13"	93°44'37"	9,329
CAL	Calcasieu River near Kinder, La.	08015500	30°30'10"	92°54'55"	1,700
ATC	Atchafalaya River at Melville, La.[1]	07381495	30°41'26"	91°44'10"	93,316
MIS	Mississippi River near St. Francisville, La.[2]	07373420	30°45'30"	91°23'45"	1,125,300
AMI	Amite River near Denham Springs, La.	07378510	30°26'30"	90°58'20"	1,290
TAN	Tangipahoa River at Robert, La.	07375500	30°30'23"	90°21'42"	646
CHI	Bogue Chitto near Bush, La.	02492000	30°37'45"	89°53'50"	1,213
PRL	Pearl River near Bogalusa, La.	02489500	30°47'35"	89°49'15"	6,573
PAS	Pascagoula River near Benndale, Miss.[3]	02479020	30°52'42"	88°46'20"	6,680
TOM	Tombigbee River below Coffeeville L&D, Ala.[4]	02469762	31°45'25"	88°07'30"	18,417
ALA	Alabama River at Claiborne, Ala.[5]	02429500	31°32'48"	87°30'45"	21,967
PER	Perdido River at Barrineau Park, Fla.	02376500	30°41'25"	87°26'25"	394
ESC	Escambia River near Century, Fla.	02375500	30°57'54"	87°14'03"	3,817
YEL	Yellow River at Milligan, Fla.	02368000	30°45'10"	86°37'45"	624
CHO	Choctawhatchee River near Bruce, Fla.[6]	02366500	30°27'03"	85°53'54"	4,384
CHP	Chipola River near Altha, Fla.	02359000	30°32'02"	85°09'55"	781
APA	Apalachicola River at Chattahoochee, Fla.	02358000	30°42'03"	84°51'33"	17,200
OCH	Ochlockonee River near Havana, Fla.	02329000	30°33'14"	84°23'03"	1,140
SUW	Suwannee River near Wilcox, Fla.	02323500	29°35'22"	82°56'12"	9,640
ANC	Anclote River near Elfers, Fla.	02310000	28°12'50"	82°40'00"	72
HIL	Hillsborough River near Temple Terrace, Fla.	02304000	28°03'15"	82°21'50"	630
ALF	Alafia River at Lithia, Fla.	02301500	27°52'19"	82°12'41"	335
MAN	Little Manatee River near Wimauma, Fla.	02300500	27°40'15"	82°21'10"	149
MYA	Myakka River near Sarasota, Fla.	02298830	27°14'25"	82°18'50"	229
PEA	Peace River at Arcadia, Fla.	02296750	27°13'19"	81°52'34"	1,367

[1]Atchafalaya River at Simmesport, La., 07381490, used for daily values of streamflow.
[2]Mississippi River at Tarbert Landing, Miss., 07295100, used for daily values of streamflow.
[3]Pascagoula River at Merrill, Miss., 02479000, used for daily values of streamflow.
[4]Tombigbee River at Coffeeville L&D, Ala., 02469761, used for daily values of streamflow.
[5]Alabama River at Claiborne L&D, Ala., 02428400, used for daily values of streamflow for 1976 through 1993.
[6]Daily values of streamflow from 4/83 through 5/84 estimated from regression ($R^2 = 0.95$) with upstream station Choctawhatchee River at Caryville, Fla., 02365500.

Table 2. Period of record and number of nutrient analyses available for selected streamflow-gaging stations on streams discharging to the Gulf of Mexico

Abbreviated name (table 1)	Total nitrogen			Total phosphorus		
	Period of record		Number of analyses	Period of record		Number of analyses
	Begin	End		Begin	End	
RIO	1974	1993	144	1974	1993	144
NUE	1974	1993	156	1972	1993	173
MSN	1974	1993	103	1972	1993	120
SAN	1974	1993	163	1972	1993	190
GUA	1973	1993	152	1973	1993	154
LAV	1974	1993	135	1972	1993	146
COL	1974	1993	153	1972	1993	168
BRZ	1974	1993	103	1972	1993	118
BRA	1974	1992	100	1972	1992	121
WHI	1974	1992	101	1972	1992	130
TRI	1974	1993	173	1972	1993	188
NEC	1974	1993	155	1972	1993	170
SAB	1974	1993	130	1972	1993	141
CAL	1978	1993	77	1974	1993	85
ATC	1978	1993	85	1978	1993	176
MIS	1974	1993	155	1974	1993	219
AMI	1973	1985	101	1973	1985	110
TAN	1976	1993	70	1974	1993	81
CHI	1974	1992	133	1974	1992	144
PRL	1973	1993	131	1973	1993	143
PAS	1973	1993	152	1973	1993	159
TOM	1974	1992	121	1972	1992	137
ALA	1973	1993	155	1972	1993	170
PER	1974	1993	83	1972	1993	106
ESC	1973	1993	138	1972	1993	147
YEL	1973	1993	120	1972	1993	143
CHO	1974	1993	119	1974	1993	128
CHP	1973	1993	116	1972	1993	139
APA	1974	1993	118	1972	1993	134
OCH	1973	1993	126	1972	1993	140
SUW	1973	1988	80	1972	1988	95
ANC	1973	1993	117	1972	1993	126
HIL	1973	1993	120	1972	1993	138
ALF	1973	1993	150	1972	1993	158
MAN	1973	1993	73	1972	1993	78
MYA	1974	1993	80	1972	1993	84
PEA	1973	1993	142	1972	1993	164

During periods of high streamflow, however, the wastewater effluent commonly is diluted by surface runoff and the nutrient concentrations in the stream decrease (Van Metre and Reutter, 1995).

The dominant effect that streamflow has on nutrient and other constituent concentrations requires that the effects of streamflow be removed prior to the evaluation of temporal trends in concentration. Otherwise, any trend detected could be due to a trend in streamflow, not from any change in the source of nutrients entering the stream. Nutrient concentrations were flow adjusted to remove the effects of streamflow before trend testing using the adjustment procedure described by Helsel and Hirsch (1992, p. 330–335): The technique involves LOWESS, or LOcally WEighted Scatterplot Smoothing (Cleveland, 1979; Helsel and Hirsch, 1992). The LOWESS procedure yields a curvilinear "smooth line" through an x-y scatterplot (graph of the relation between streamflow and concentration in this application). The smooth line is a moving average computed by fitting multiple-weighted least-squares equations to the data. LOWESS is insensitive to the presence of outliers and does not assume normally distributed data or a linear relation between discharge and concentration. LOWESS requires specification of a smoothness factor, f, which determines the width of the "discharge window" used to compute the moving average. The smoothness factor used to compute the LOWESS smooth line in this application is 0.25. Residuals (differences between LOWESS-fitted concentrations and measured concentrations) were computed. These residuals are referred to as flow-adjusted residuals of nutrient concentrations. It is the residual-time data pairs that are tested to indicate trends in flow-adjusted concentrations. A change in the flow-adjusted residuals over time will indicate a change in concentration over time that is independent of changes in streamflow.

Computation of Nutrient Loads

Annual loads of total nitrogen and total phosphorus were computed from the periodic nutrient analyses and the daily values of streamflow using the ESTIMATOR program (Cohn and others, 1992; Baier and others, 1993). ESTIMATOR does the computations for a multivariate linear regression and uses the MVUE bias correction factor (Cohn and others, 1989).

The ESTIMATOR regression procedure is a multivariate extension of standard univariate rating-curve approaches for estimating constituent loads in a stream from periodic samples and daily streamflow records. The typical univariate rating-curve method fits an exponential function to the observed data (daily loads computed from measured concentrations as a function of streamflow) graphically or through regression. The function usually takes the form

$$\log(\hat{L}_{RC}) = B_0 + B_1 \log(Q)\,, \qquad (1)$$

where
$\hat{L}_{RC}$ = estimated load;
B_0, B_1 = regression coefficients; and
Q = streamflow.

Relations of this form can have severe bias when the estimated load is transformed from log to linear units. The ESTIMATOR procedure corrects this bias by adjusting the regression function by a minimum variance unbiased estimator. The load estimate, using this correction, becomes

$$\hat{L}_{MVUE} = \hat{L}_{RC}\, g_m\left(\frac{m+1}{2m}[1-V]s^2\right)\,, \qquad (2)$$

where
$\hat{L}_{MVUE}$ = unbiased load estimate;
g_m = a Bessel function (Cohn and others, 1989);
V = estimated variance of $\hat{L}_{RC}$;
s^2 = estimated variance of the residuals following regression; and
m = degrees of freedom of the model.

The ESTIMATOR procedure performs a standard multivariate linear regression for daily load using several explanatory variables comprising streamflow, time, and seasonal indicators (sine and cosine transformations of time). The ESTIMATOR procedure then computes daily loads and applies the MVUE bias correction to the daily load estimates before summing them to monthly and annual values. The daily load estimates are very imprecise, but the errors are minimized by summing the daily load estimates to monthly and annual totals (T.A. Cohn, U.S. Geological Survey, written commun., 1995).

A common set of explanatory variables was chosen for each station included in the analysis. Not all explanatory variables were statistically significant for each station. However, statistically nonsignificant explanatory variables do not impair the accuracy of the model; regression coefficients for nonsignificant explanatory variables will be small and have little effect on predicted values. The explanatory variables used for each station in this analysis produced regression equations of the form

$$\log_e(\hat{L}_{RC}) = B_0 + B_1 \log_e\left(\frac{Q_d}{\overline{Q}}\right) + B_2(T - \overline{T}) - B_3 \sin(2\pi T) + B_4 \cos(2\pi T) \text{ , (3)}$$

where

B_0, B_1, B_2, B_3, B_4 = regression coefficients;
Q_d = daily mean streamflow (cubic feet per second);
T = time (decimal years);
$\overline{Q}$ = the centering value for streamflow calculated by the model; and
$\overline{T}$ = the centering value for time calculated by the model.

This method of estimating constituent loads by linear regression has one distinct limitation: While it accounts for seasonal variations in constituent concentrations and loads, it does not account for event-oriented variations. For example, constituent concentrations and loads typically are much higher at a given streamflow on the accession of a runoff hydrograph than on the peak or the recession. The method used here does not include any mechanism to account for the timing of a sample with respect to runoff conditions.

Detection of Trends

A short-term trend is defined in this report as the change (increase or decrease) with respect to time of the central tendency of subsets (moving windows) of the data. Short-term trends illustrate year-to-year fluctuations in the central tendency of flow-adjusted nutrient concentrations or loads. Because of the small number of data points and the arbitrary method of determining the width of the data subsets, no statistical significance can be assigned to the short-term trends and they must be evaluated graphically. Short-term trends are indicated by LOWESS smooth lines superimposed on graphs of the relations between flow-adjusted residuals and time or between load and time. The smoothness factor used to compute LOWESS smooth lines for evaluating short-term trends was 0.40.

A long-term trend is defined in the report as the change with respect to time of the central tendency (monotonic relation) of an entire set of data. Long-term trends were detected using Kendall's tau and the Kendall-Theil robust line. Kendall's tau is a nonparametric statistic that ranges from -1.0 to 1.0. The sign of tau indicates the direction of the trend; the magnitude of tau indicates the strength of the monotonic relation and, combined with the sample size, is used to calculate the statistical significance, or attained significance level (p-value), of the trend. The Kendall-Theil robust line is an estimate of the straight-line slope of the trend detected by Kendall's tau; it was computed to estimate the average annual change in residuals of flow-adjusted concentrations and annual loads. Nonparametric statistics such as Kendall's tau and the Kendall-Theil robust line are computed from the median and relative ranking of the data points. Consequently, the statistics are insensitive to the presence of outliers and do not require that the data fit a normal distribution. These features make the statistics ideal for analyzing environmental data, which commonly have large outliers and rarely fit a normal data distribution.

Trends presented in this report represent the tendency of the residuals of flow-adjusted concentrations or loads only for the period analyzed (generally 1972–93), and as such, represent only a sample of the overall data population (natural history). Trends identified in this report might be only short-term fluctuations relative to natural history, and the actual trend of the data could be oppositely directed over a longer period. The data presented here are the best available; but interpretations from these trend tests might not be definitive relative to trends throughout natural history.

An additional (parametric) trend test was applied to residuals of flow-adjusted concentrations and loads to support and verify the nonparametric test results. In this test, the regression coefficient for time (B_2 in equation 3) is tested for statistical significance. B_2 will be identical in regression equations for either concentration or load at a station. The test compensates for the effects of streamflow because streamflow is included in the regression equation (Helsel and Hirsch, 1992, p. 335). The sign and p-value for B_2 can be compared to the sign and p-value of Kendall's tau computed for residuals of flow-adjusted concentration and load.

LOWESS smooth lines, Kendall-Theil robust lines, and Kendall's tau also were computed for annual streamflow. Annual streamflow is graphed relative to time and the LOWESS smooth lines and Kendall-Theil robust lines superimposed.

TRENDS IN NUTRIENT INFLOWS

Trends in streamflow were analyzed to aid in interpreting trends in nutrient inflows, particularly trends in annual loads. Graphs of annual streamflow with the LOWESS smooth lines and the Kendall-Theil robust lines superimposed are shown for each station (figs. 6–42 at the back of this report). Annual streamflow is highly variable, and substantial short-term variations in streamflow are evident from the LOWESS smooth lines, which exhibit substantial peaks and valleys above and below the graphed long-term trend lines.

Statistically significant long-term trends in annual streamflow were detected for only four of the streams, all of which are in Texas: Rio Grande (RIO) and Nueces River (NUE), decreasing trends; Brays (BRA) and Whiteoak (WHI) Bayous in Houston, increasing trends. Results of analyses of trends in annual streamflow are listed in tables 3 and 4.

Extensive reservoir construction on the Rio Grande and surface-water withdrawals for irrigation upstream of the station probably have reduced streamflow at the station substantially (fig. 6). Judd and Slade (in press) identified long-term (1934–90) decreases in monthly mean streamflow from the Rio Grande and attributed these decreases in part to increased surface-water withdrawals. The total annual mean withdrawal to the United States from the Rio Grande Basin increased about 56 percent from 1940 to 1990 (Judd and Slade, in press). A sharp reduction in streamflow, starting in the late 1970s, also is evident from the LOWESS line. During the late 1970s, the Marte R. Gomez Reservoir was completed by the Republic of Mexico on the Rio San Juan, a tributary of the Rio Grande (G.B. Ozuna, U.S. Geological Survey, written commun., 1995). Withdrawals from this reservoir probably have contributed to the decrease in streamflow. Surface-water withdrawals from streams in the Nueces River Basin, which have increased eightfold since 1940 (Judd and Slade, in press), probably are responsible for decreased streamflow in the Nueces River (fig. 7).

Considerable urbanization has occurred in the watersheds of both Brays and Whiteoak Bayous. This urbanization has contributed to substantial increases in streamflow in these basins by increasing impervious cover and reducing infiltration and depression storage within the basins (Judd and Slade, in press).

Trends in Nutrient Concentrations

Results of analyses of trends in nutrient concentrations for all 37 stations are summarized in figures 2 and 3 and listed in tables 3 and 4. Graphs of the relation between nutrient concentration and daily mean streamflow for each station (figs. 6–42) illustrate the range in streamflow in which nutrient samples were taken. Graphs of time series of flow-adjusted residuals of nutrient concentrations with LOWESS smooth lines and Kendall-Theil robust lines superimposed show the presence (or nonpresence) of short-term and long-term trends (figs. 6–42).

Total Nitrogen

Strongly significant ($p \leq 0.05$) or significant ($0.05 < p \leq 0.10$) long-term increases in flow-adjusted residuals of total nitrogen concentration were detected at 19 stations, strongly significant or significant decreases were detected at 7 stations, and no significant long-term trends were detected at 11 stations (fig. 2, table 3). Twelve of the 16 stations above 29° latitude and east of the Mississippi River have long-term increasing trends. The remaining four stations in this region have no detectable trend. The San Antonio River (SAN) and Brays Bayou (BRA) in Texas have increasing trend slopes an order of magnitude greater than all other stations. Both of these stations are downstream of areas undergoing substantial urbanization. Increases in nitrogen concentrations in many streams have been linked to increases in urbanization and to increased application of nitrogen fertilizers in watersheds (Hem, 1989).

Total Phosphorus

Strongly significant or significant long-term increases in flow-adjusted residuals of total phosphorus concentration were detected at 7 stations, strongly significant or significant decreases were detected at 11 stations, and no significant long-term trends were detected at 19 stations (fig. 3, table 4). Two stations in Florida, the Alafia (ALF) and Peace (PEA) Rivers (fig. 1), have substantially larger decreasing trends than all other stations. These stations are downstream of areas of historically intensive phosphate mining. Decreases in phosphorus concentrations in those watersheds might be attributable to reductions in the level of phosphate mining activity and better environmental controls of phosphate-mining runoff. At other stations, increases in

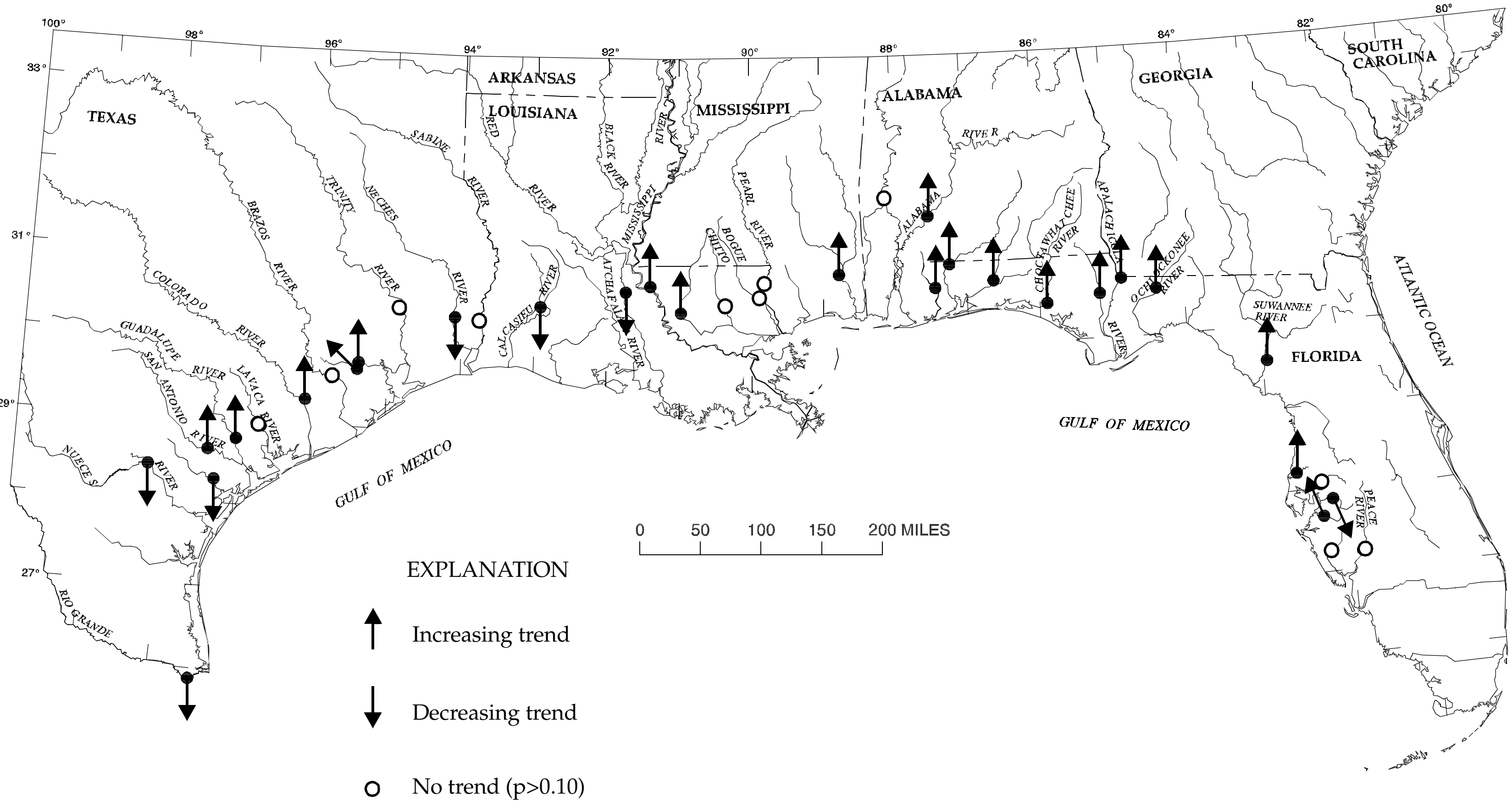

Figure 2. Trends in flow-adjusted residuals of total nitrogen concentration for streams discharging into the Gulf of Mexico, 1972–93.

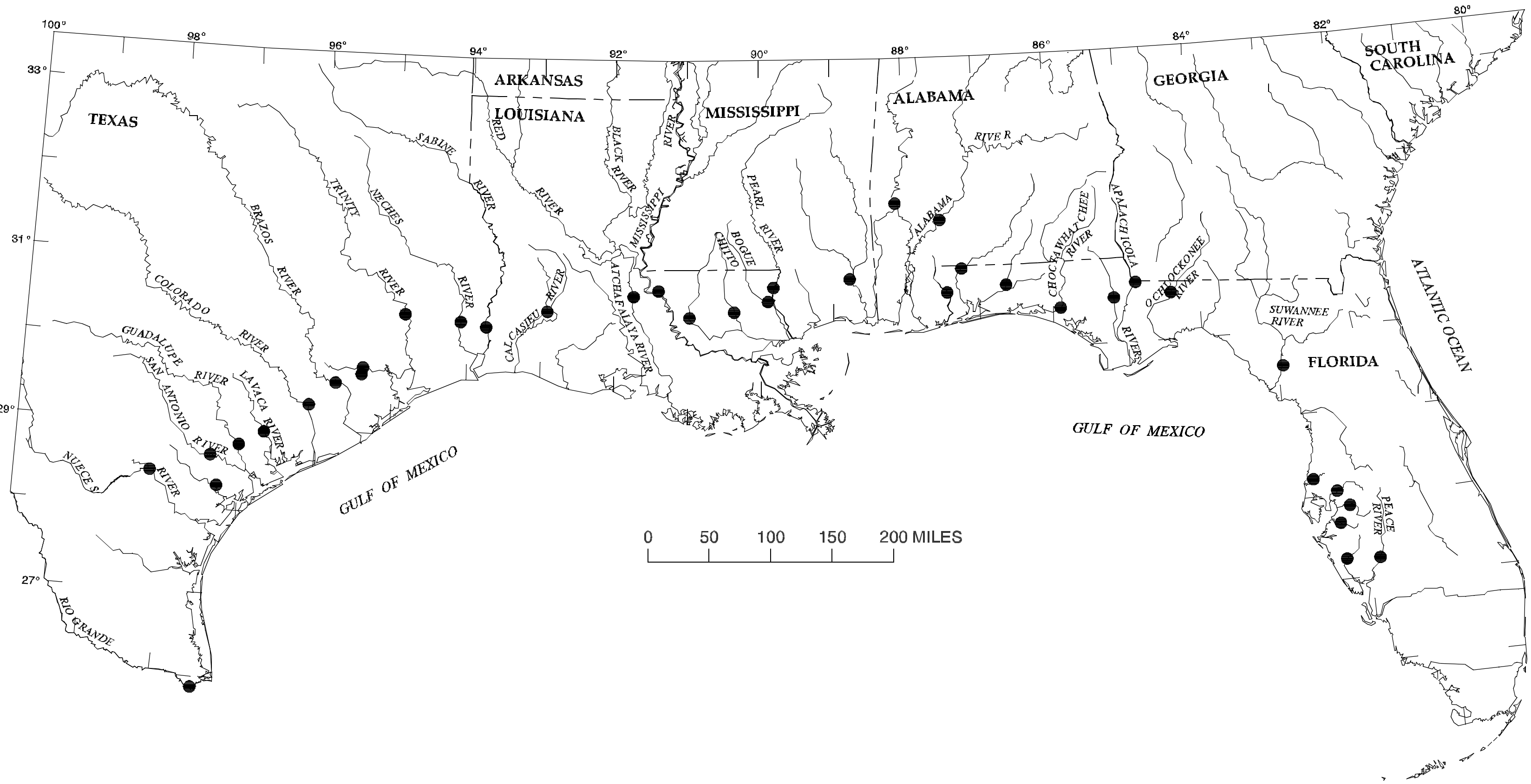

Figure 3. Trends in flow-adjusted residuals of total phosphorus concentration for streams discharging into the Gulf of Mexico, 1972–93.

Table 3. Trends in annual streamflow and total nitrogen inflows for selected streamflow-gaging stations on streams discharging to the Gulf of Mexico

[**bold print**, strongly significant (attained significance level [p-value] less than 0.05); --, nonsignificant trend (attained significance level [p-value] greater than 0.10); acre-ft, acre-feet; acre-ft/yr, acre-feet per year; (mg/L)/yr, milligrams per liter per year; ton/yr, tons per year; ton/mi^2, tons per square mile]

Abbreviated name (table 1)	Mean annual streamflow (acre-ft)	Trend in annual streamflow (acre-ft/yr)	Trend in total nitrogen concentration [(mg/L)/yr]	Trend in estimated annual total nitrogen load (ton/yr)	Estimated mean annual total nitrogen load (tons)	Standard deviation of estimated annual total nitrogen load (tons)	Estimated mean annual total nitrogen yield (ton/mi^2)
RIO	897,000	**-50,500**	**-0.018**	**-99.3**	1,450	1,570	0.008
NUE	507,000	**-21,300**	**-.089**	**-105**	1,360	1,280	.088
MSN	112,000	--	**-.013**	**-12.2**	230	169	.334
SAN	754,000	--	**.110**	--	4,270	2,250	1.09
GUA	1,720,000	--	**.019**	--	3,850	3,290	.741
LAV	318,000	--	--	--	564	421	.690
COL	2,090,000	--	**.024**	--	4,350	4,880	.103
BRZ	5,850,000	--	--	--	16,700	13,300	.371
BRA	173,000	**4,410**	**.133**	**51.8**	1,180	425	12.4
WHI	101,000	1,630	**.067**	**9.14**	498	122	5.79
TRI	6,430,000	--	--	--	11,100	5,910	.646
NEC	4,940,000	--	**-.008**	--	4,920	2,050	.619
SAB	6,470,000	--	--	--	5,920	2,210	.634
CAL	2,120,000	--	**-.020**	--	2,650	1,140	1.56
ATC	170,000,000	--	**-.046**	--	474,000	112,000	5.08
MIS	386,000,000	--	**.022**	--	1,280,000	353,000	1.14
AMI	1,830,000	--	**.032**	--	4,350	2,770	3.37
TAN	968,000	--	--	--	1,670	701	2.58
CHI	1,678,000	--	--	--	2,160	842	1.78
PRL	8,980,000	--	--	--	12,800	5,420	1.95
PAS	8,589,000	--	**.015**	--	9,380	3,400	1.40
TOM	23,400,000	--	--	--	27,500	11,400	1.49
ALA	25,300,000	--	**.009**	--	22,200	6,770	1.01
PER	596,000	--	**.009**	--	383	93.5	.973
ESC	4,890,000	--	**.014**	--	3,850	1,200	1.01
YEL	897,000	--	**.011**	--	692	263	1.11
CHO	5,330,000	--	**.011**	--	4,180	1,060	.955
CHP	1,100,000	--	**.030**	**39.8**	1,550	407	1.98
APA	16,600,000	--	**.009**	--	16,900	4,410	.984
OCH	853,000	--	**.018**	--	1,130	430	.991
SUW	8,050,000	--	**.030**	--	9,760	3,220	1.01
ANC	33,700	--	**.014**	--	62.6	43.8	.870
HIL	179,000	--	--	--	268	135	.426
ALF	191,000	--	**-.028**	**-24.6**	599	270	1.79
MAN	105,000	--	**.013**	--	255	135	1.71
MYA	157,000	--	--	--	307	110	1.34
PEA	552,000	--	--	--	1,580	700	1.16

Table 4. Trends in annual streamflow and total phosphorus inflows for selected streamflow-gaging stations on streams discharging to the Gulf of Mexico

[**bold print**, strongly significant (attained significance level [p-value] less than 0.05); --, nonsignificant trend (attained significance level [p-value] greater than 0.10); acre-ft, acre-feet; acre-ft/yr, acre-feet per year; (mg/L)/yr, milligrams per liter per year; ton/yr, tons per year; ton/mi^2, tons per square mile]

Abbreviated name (table 1)	Mean annual streamflow (acre-ft)	Trend in annual streamflow (acre-ft/yr)	Trend in total phosphorus concentration [(mg/L)/yr]	Trend in estimated annual total phosphorus load (ton/yr)	Estimated mean annual total phosphorus load (tons)	Standard deviation of estimated annual total phosphorus load (tons)	Estimated mean annual total phosphorus yield (ton/mi^2)
RIO	897,000	**-50,500**	**-0.003**	**-17.6**	211	248	0.001
NUE	507,000	**-21,300**	--	**-5.73**	128	80.5	.008
MSN	112,000	--	--	--	11.5	8.11	.017
SAN	754,000	--	--	-21.5	1,040	309	.265
GUA	1,720,000	--	--	--	326	275	.063
LAV	318,000	--	.001	--	67.4	52.1	.083
COL	2,090,000	--	**.003**	--	683	616	.016
BRZ	5,850,000	--	**-.004**	--	2,370	1,710	.053
BRA	173,000	**4,410**	--	**7.82**	452	68.8	4.76
WHI	101,000	1,630	**.061**	**5.04**	240	57.8	2.78
TRI	6,430,000	--	**-.001**	--	1,510	736	.088
NEC	4,940,000	--	--	--	368	145	.046
SAB	6,470,000	--	--	--	372	122	.034
CAL	2,120,000	--	--	--	165	52.4	.097
ATC	170,000,000	--	--	--	47,800	11,000	.512
MIS	386,000,000	--	--	--	110,000	23,500	.097
AMI	1,830,000	--	.003	--	396	209	.307
TAN	968,000	--	**.002**	6.22	184	92.2	.286
CHI	1,678,000	--	**-.001**	--	230	123	.190
PRL	8,980,000	--	--	--	1,520	713	.231
PAS	8,589,000	--	-.001	--	796	274	.119
TOM	23,400,000	--	**-.001**	**-108**	3,54	1,77	.192
ALA	25,300,000	--	--	**-60.7**	2,570	977	.117
PER	596,000	--	**-.001**	**-.843**	25.8	7.74	.066
ESC	4,890,000	--	--	--	299	123	.078
YEL	897,000	--	**-.001**	**-2.06**	48.0	31.6	.077
CHO	5,330,000	--	--	--	294	99.2	.067
CHP	1,100,000	--	--	--	52.8	15.3	.068
APA	16,600,000	--	--	**-39.6**	1,080	433	.063
OCH	853,000	--	--	-4.17	164	57.8	.143
SUW	8,050,000	--	--	--	2,050	547	.213
ANC	33,700	--	**.001**	--	2.85	1.69	.040
HIL	179,000	--	**-.008**	**-5.63**	112	69.2	.177
ALF	191,000	--	**-.148**	**-82.2**	1,260	656	3.78
MAN	105,000	--	--	--	115	57.0	.770
MYA	157,000	--	**.007**	--	97.0	44.2	.424
PEA	552,000	--	**-.102**	**-62.4**	1,070	523	.784

phosphorus concentrations could be linked to recent increases in urbanization because phosphorus concentrations commonly are enriched in wastewater effluent (Van Metre and Reutter, 1995). Decreases since 1972 within watersheds with stable populations might be attributed to a reduction in the use of phosphate in household detergents.

No relation appears to exist between trends in flow-adjusted residuals of total phosphorus and total nitrogen concentrations. Trends were detected for both constituents at 9 stations, but the trends at 3 of the 9 stations are in opposite directions.

Trends in Nutrient Loads

The means and standard deviations of the estimated annual loads and the estimated annual constituent yields (mean annual load divided by watershed area) are shown in tables 3 and 4. Results of analyses of trends in estimated annual nutrient loads are summarized in figures 4 and 5. Diagnostic statistics and coefficients from the regression analyses for nutrient loads are shown in tables 5 and 6. The variability of the estimated loads differs substantially between stations, but generally is quite large for all stations. The standard deviations of the annual load estimates range from 24 to 112 percent of the mean annual loads of nitrogen and from 15 to 117 percent of the mean annual loads of phosphorus. This variability is not unexpected; it simply reflects the natural temporal variability in hydrologic systems. Load is related to streamflow, and runoff from a watershed can vary greatly between years due to the natural variability in rainfall. Annual load estimates are shown in figures 6–42; the uncertainty associated with each individual estimate of annual load is depicted by an error bar, the length of which represents the 90-percent confidence interval for the load estimate.

The magnitude of the estimated loads differs substantially between stations. The Atchafalaya (ATC) and Mississippi (MIS) Rivers account for more than 85 percent of the annual nutrient loads to the Gulf from the streams analyzed. However, the loads from the smaller drainages are important: Despite nutrient loads several orders of magnitude smaller than the loads from the Atchafalaya and Mississippi Rivers, the nutrient inflows from the smaller streams can cause substantial localized effects on the receiving bays and estuaries. Many of these receiving bays and estuaries act as the primary breeding habitat for much of the Gulf's wildlife.

Generally, the model for total nitrogen load yielded better estimates than the model for total phosphorus load, with a larger R^2 and smaller standard deviation of the regression residuals. The performance of the regression model for total phosphorus can be explained in part by the association of phosphorus with sediment. Phosphorus will adsorb onto sediment particles, so the transport of phosphorus by a river is affected by the transport of sediment. Sediment transport is highly variable, typically displays strong hysteresis, and is affected more by antecedent conditions than are dissolved constituents. In a few cases, the load model for total phosphorus performed comparably with the nitrogen model.

Total Nitrogen

Strongly significant or significant long-term increases in estimated annual total nitrogen loads were detected at 3 stations, strongly significant or significant decreases were detected at 4 stations, and no significant long-term trends were detected at 30 stations (fig. 4, table 3). The test for statistical significance is a function of sample size—the greater the number of samples, the greater the likelihood of detecting a significant trend. The sample size for loads was 21 for most stations (1 per year), whereas the sample size for concentrations ranged from 70 to 163. Long-term trends in total nitrogen (concentration or load) detected using the regression coefficient, B_2 (table 5), from the load model agree with the results of Kendall's tau (table 3) for all but three stations (WHI, PER, OCH). In those instances of lack of agreement, strongly significant or significant trends are detected by Kendall's tau, but the p-value for B_2 is greater than 0.10, which indicates no trend. The sign of B_2, however, agrees in each instance with the direction of the trend detected by Kendall's tau.

Estimated mean annual loads of total nitrogen ranged from 62.6 tons (Anclote River [ANC]) to 1.28 million tons (Mississippi River [MIS]). Estimated mean annual yields ranged from 0.008 ton/mi^2 (Rio Grande [RIO]) to 12.4 ton/mi^2 (Brays Bayou [BRA]). Twenty-six of the stations had yields between 0.5 and 2.0 ton/mi^2, indicating relatively few extreme values. The Rio Grande, which has the second largest drainage area of the stations included in this analysis, has one of the smallest annual loads and an extremely small yield. Two factors contribute to this: The Rio Grande drainage is more arid and natural runoff is smaller than any

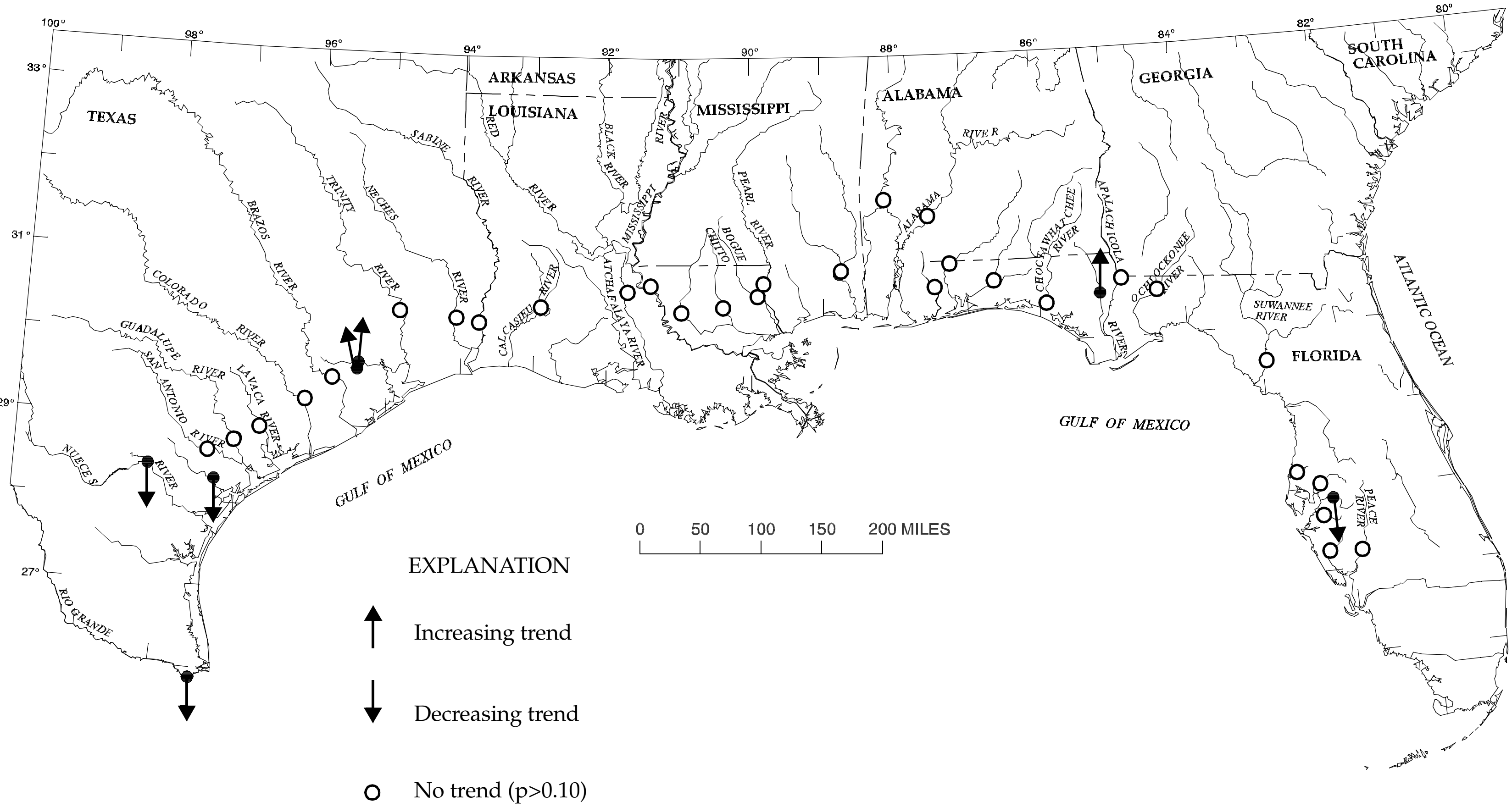

Figure 4. Trends in estimated annual loads of total nitrogen for streams discharging into the Gulf of Mexico, 1972–93.

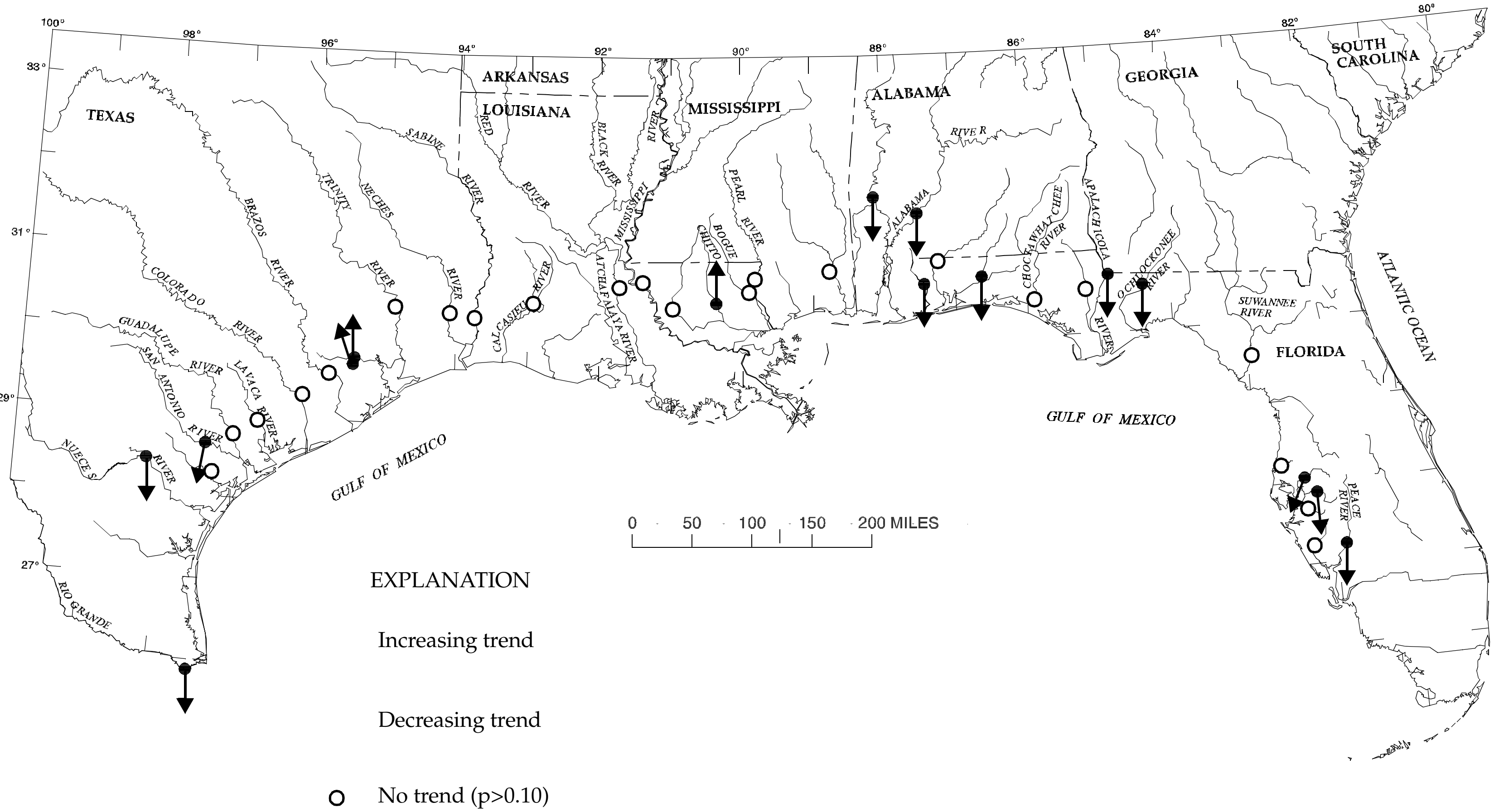

Figure 5. Trends in estimated annual loads of total phosphorus for streams discharging into the Gulf of Mexico, 1972–93.

Table 5. Parameter estimates for total nitrogen load model

[model: $\log_e$(LOAD) = $B_0 + B_1\log_e$(FLOW/CENTERED FLOW) + B_2(TIME – CENTERED TIME) + $B_3\sin(2\pi$[TIME]) + $B_4\cos(2\pi$[TIME]) where LOAD is estimated daily total nitrogen load in kilograms per day; FLOW is daily mean streamflow in cubic feet per second; CENTERED FLOW is a centering variable as calculated by the model; TIME is time in decimal years; CENTERED TIME is a centering variable as calculated by the model; p-value, attained significance level; R^2, coefficient of determination (variability explained by the model); s, standard deviation of the residuals from ordinary least squares fit, in log units]

Abbreviated name (table 1)	B_0 (p-value)	B_1 (p-value)	B_2 (p-value)	B_3 (p-value)	B_4 (p-value)	R^2	s
RIO	6.8665 (0.0000)	1.0076 (0.0000)	-0.0285 (0.0000)	0.0540 (0.2415)	0.0661 (0.1498)	95.2	0.3995
NUE	6.3074 (.0000)	.9641 (.0000)	-.0644 (.0000)	.1549 (.0021)	.1134 (.0293)	94.8	.4557
MSN	3.4034 (.0000)	1.1212 (.0000)	-.0229 (.0092)	.0119 (.8372)	-.1471 (.0212)	94.7	.4404
SAN	9.2761 (.0000)	.7489 (.0000)	.0160 (.0004)	.0260 (.4514)	.1486 (.0000)	79.5	.3193
GUA	8.5910 (.0000)	1.0708 (.0000)	.0211 (.0276)	.1633 (.0179)	-.0278 (.7059)	66.8	.6224
LAV	3.1845 (.0000)	1.0787 (.0000)	-.0128 (.1382)	.0193 (.7532)	-.0355 (.5592)	95.0	.4940
COL	8.8096 (.0000)	1.0769 (.0000)	.0202 (.0031)	.1344 (.0131)	.0984 (.0686)	84.7	.4619
BRZ	9.5685 (.0000)	1.2178 (.0000)	-.0125 (.2259)	.1252 (.1520)	.1607 (.0424)	85.6	.6125
BRA	8.5781 (.0000)	.6943 (.0000)	.0297 (.0000)	.0515 (.2807)	.0332 (.5069)	87.4	.3719
WHI	7.3877 (.0000)	.7380 (.0000)	.0032 (.6470)	.1096 (.0432)	-.0741 (.1322)	88.5	.4013
TRI	9.5273 (.0000)	1.0847 (.0000)	.0002 (.9695)	.1174 (.0061)	.0236 (.5369)	93.9	.3588
NEC	8.8998 (.0000)	.9622 (.0000)	-.0149 (.0117)	.0600 (.2487)	-.0392 (.4042)	80.5	.4144
SAB	8.9495 (.0000)	.9715 (.0000)	-.0074 (.2957)	.0094 (.8844)	.0074 (.8924)	84.1	.4540
CAL	8.0083 (.0000)	1.0501 (.0000)	-.0342 (.0030)	.0749 (.3614)	-.1242 (.0794)	89.8	.4345
ATC	13.6587 (.0000)	1.1322 (.0000)	-.0232 (.0008)	.0311 (.5591)	-.1507 (.0006)	86.8	.2740
MIS	14.6090 (.0000)	1.2091 (.0000)	.0071 (.0988)	.0476 (.2492)	-.1063 (.0022)	84.3	.3011
AMI	8.6338 (.0000)	1.3496 (.0000)	.0328 (.0133)	-.0053 (.9282)	-.1510 (.0078)	79.7	.5485
TAN	8.5487 (.0000)	1.2520 (.0000)	.0019 (.8840)	.0242 (.7924)	.0080 (.9212)	79.7	.4938
CHI	8.5651 (.0000)	1.1679 (.0000)	-.0106 (.1594)	.0727 (.2517)	-.0769 (.1841)	82.1	.4505
PRL	9.8593 (.0000)	1.0920 (.0000)	.0032 (.6136)	.0314 (.6230)	-.0789 (.1105)	88.2	.3846
PAS	9.7499 (.0000)	1.0310 (.0000)	.0213 (.0005)	-.0310 (.6190)	-.0991 (.0493)	87.6	.4144
TOM	10.3717 (.0000)	1.0661 (.0000)	-.0040 (.4326)	.0217 (.6574)	.0235 (.5747)	95.3	.3033
ALA	10.6869 (.0000)	1.0049 (.0000)	.0088 (.0733)	.0955 (.0476)	.0301 (.4667)	88.8	.3464
PER	6.8119 (.0000)	.9518 (.0000)	.0129 (.1879)	-.0625 (.3225)	-.1646 (.0130)	65.7	.4180
ESC	8.9074 (.0000)	1.0515 (.0000)	.0226 (.0000)	-.0015 (.9740)	-.1447 (.0004)	88.7	.3326
YEL	7.1940 (.0000)	1.1449 (.0000)	.0201 (.0037)	.0371 (.5023)	-.1604 (.0022)	83.4	.4020
CHO	9.1178 (.0000)	.9583 (.0000)	.0236 (.0000)	.0764 (.0508)	-.1392 (.0001)	86.2	.2703
CHP	8.2289 (.0000)	.9106 (.0000)	.0283 (.0000)	.0189 (.5869)	-.0679 (.0314)	82.7	.2430
APA	10.5825 (.0000)	1.0059 (.0000)	.0147 (.0012)	.1461 (.0002)	.0940 (.0044)	90.8	.2597
OCH	7.3359 (.0000)	.8550 (.0000)	.0025 (.6289)	-.0043 (.9276)	-.0001 (.9977)	92.2	.3294
SUW	10.0767 (.0000)	.9954 (.0000)	.0339 (.0000)	-.1031 (.0264)	-.0711 (.0569)	81.1	.2422
ANC	3.9148 (.0000)	1.2091 (.0000)	.0210 (.0021)	-.0507 (.3591)	-.0173 (.7631)	95.3	.4408
HIL	-6.2368 (.0000)	1.0021 (.0000)	.0033 (.6456)	-.0260 (.6542)	.0813 (.1790)	99.4	.4646
ALF	7.1926 (.0000)	1.1203 (.0000)	-.0241 (.0001)	.0339 (.4780)	.1449 (.0065)	86.9	.4353
MAN	5.7964 (.0000)	1.2400 (.0000)	.0272 (.0018)	-.0229 (.6960)	-.0900 (.1721)	93.7	.3817
MYA	-7.1695 (.0000)	.9802 (.0000)	-.0056 (.5106)	-.0608 (.2476)	-.1361 (.0204)	99.2	.3510
PEA	7.6743 (.0000)	1.0698 (.0000)	.0018 (.7650)	-.1071 (.0264)	.1441 (.0043)	90.9	.4165

Table 6. Parameter estimates for total phosphorus load model

[model: $\log_e(\text{LOAD}) = B_0 + B_1\log_e(\text{FLOW/CENTERED FLOW}) + B_2(\text{TIME} - \text{CENTERED TIME}) + B_3\sin(2\pi[\text{TIME}]) + B_4\cos(2\pi[\text{TIME}])$ where LOAD is estimated daily total phosphorus load in kilograms per day; FLOW is daily mean streamflow in cubic feet per second; CENTERED FLOW is a centering variable as calculated by the model; TIME is time in decimal years; CENTERED TIME is a centering variable as calculated by the model; p-value, attained significance level; R^2, coefficient of determination (variability explained by the model); s, standard deviation of the residuals from ordinary least squares fit, in log units]

Abbreviated name	B_0 (p-value)	B_1 (p-value)	B_2 (p-value)	B_3 (p-value)	B_4 (p-value)	R^2	s
RIO	4.4795 (0.0000)	1.0776 (0.0000)	-0.0418 (0.0004)	-0.0274 (0.7545)	-0.0529 (0.5431)	86.6	0.7591
NUE	3.9205 (.0000)	.9585 (.0000)	-.0012 (.9039)	.0056 (.9431)	-.2843 (.0005)	86.6	.7555
MSN	.0586 (.4261)	1.0934 (.0000)	-.0069 (.5832)	-.0038 (.9674)	-.2143 (.0400)	85.2	.7875
SAN	7.8531 (.0000)	.5153 (.0000)	-.0055 (.3603)	.0055 (.9148)	.0735 (.1568)	43.0	.5082
GUA	6.0244 (.0000)	1.1814 (.0000)	.0028 (.7420)	.0731 (.2455)	-.0362 (.5956)	74.4	.5773
LAV	1.5314 (.0000)	.9980 (.0000)	.0107 (.1635)	.0480 (.4106)	-.0904 (.1237)	93.6	.4937
COL	7.0203 (.0000)	.9587 (.0000)	.0123 (.0925)	.1780 (.0039)	.0440 (.4738)	74.4	.5580
BRZ	7.6908 (.0000)	1.1899 (.0000)	-.0237 (.0046)	.0609 (.4378)	.0913 (.2042)	85.3	.5975
BRA	7.3172 (.0000)	.5577 (.0000)	.0005 (.9679)	.0460 (.5937)	.1052 (.2577)	52.4	.7510
WHI	6.3240 (.0000)	.6909 (.0000)	.0076 (.5668)	.0297 (.7797)	-.0352 (.7276)	57.7	.9255
TRI	7.5494 (.0000)	1.0776 (.0000)	-.0112 (.0104)	-.1464 (.0004)	-.1468 (.0001)	93.4	.3595
NEC	6.2350 (.0000)	.9156 (.0000)	-.0032 (.6120)	.1474 (.0158)	-.0518 (.3437)	75.5	.5048
SAB	6.2395 (.0000)	.8191 (.0000)	.0096 (.1870)	.1060 (.1242)	.0523 (.3794)	76.6	.5217
CAL	5.4565 (.0000)	.8062 (.0000)	-.0223 (.1158)	.0842 (.4628)	.0035 (.9697)	72.8	.6194
ATC	11.2586 (.0000)	1.2385 (.0000)	-.0124 (.1542)	-.1254 (.0825)	-.0113 (.8373)	62.9	.5200
MIS	12.1960 (.0000)	1.0318 (.0000)	-.0061 (.3475)	-.0847 (.1933)	.0074 (.8831)	49.8	.5324
AMI	6.6398 (.0000)	1.2134 (.0000)	.0300 (.0243)	-.1379 (.0215)	-.1298 (.0331)	76.5	.5961
TAN	6.2760 (.0000)	1.3460 (.0000)	.0286 (.0033)	.0491 (.5047)	-.0703 (.2945)	84.6	.4330
CHI	6.1900 (.0000)	1.3867 (.0000)	-.0280 (.0006)	-.0860 (.2003)	-.1071 (.0891)	81.7	.5043
PRL	7.6160 (.0000)	1.1760 (.0000)	-.0086 (.2883)	.0415 (.6113)	-.0530 (.4093)	83.9	.5155
PAS	7.2978 (.0000)	.9766 (.0000)	-.0074 (.3025)	-.1142 (.1281)	-.0816 (.1792)	79.7	.5082
TOM	7.9322 (.0000)	1.3474 (.0000)	-.0191 (.0059)	-.1450 (.0463)	.1214 (.0549)	92.2	.4920
ALA	8.3624 (.0000)	1.2134 (.0000)	-.0093 (.0823)	.0228 (.6807)	.1177 (.0143)	88.7	.4168
PER	3.9506 (.0000)	.8720 (.0000)	-.0335 (.0019)	-.0628 (.4404)	-.1278 (.1237)	44.1	.6023
ESC	6.1220 (.0000)	1.2388 (.0000)	.0035 (.5911)	-.0967 (.1118)	-.1048 (.0476)	85.7	.4529
YEL	4.2165 (.0000)	1.2594 (.0000)	-.0412 (.0000)	-.1089 (.1248)	-.1311 (.0418)	77.9	.5459
CHO	6.2553 (.0000)	1.2536 (.0000)	-.0031 (.6969)	-.0015 (.9823)	-.0559 (.3583)	76.4	.4774
CHP	4.5844 (.0000)	1.2174 (.0000)	.0002 (.9803)	.1055 (.1384)	.0207 (.7401)	65.6	.5362
APA	7.7228 (.0000)	1.2718 (.0000)	-.0192 (.0009)	.0230 (.6627)	.0542 (.2216)	86.0	.3820
OCH	5.5273 (.0000)	.7020 (.0000)	-.0193 (.0023)	.0453 (.4456)	-.0023 (.9626)	83.5	.4285
SUW	8.4653 (.0000)	.9626 (.0000)	.0077 (.2167)	-.0389 (.4611)	.0592 (.1635)	71.1	.3075
ANC	1.2239 (.0000)	.9598 (.0000)	.0296 (.0000)	-.0719 (.1900)	-.1871 (.0011)	92.0	.4611
HIL	-6.7093 (.0000)	1.0157 (.0000)	-.0305 (.0000)	-.0794 (.0956)	-.2044 (.0000)	99.5	.4110
ALF	7.8348 (.0000)	.9962 (.0000)	-.0512 (.0000)	-.0492 (.4300)	.0008 (.9900)	75.4	.5980
MAN	4.8431 (.0000)	1.2665 (.0000)	-.0050 (.4777)	.0362 (.5184)	-.2206 (.0005)	93.0	.3916
MYA	-8.8296 (.0000)	1.0282 (.0000)	.0173 (.0491)	.0135 (.8263)	-.2286 (.0010)	98.9	.4285
PEA	7.5719 (.0000)	.7396 (.0000)	-.0548 (.0000)	.0521 (.2163)	.0410 (.3391)	84.3	.3965

of the other 36 streams. Additionally, the majority of the water draining from the Rio Grande Basin is diverted above this station and is not returned to the river. The Nueces River (NUE) presents a similar but less extreme situation.

Except for the two stations noted above, mean annual yield estimates are fairly uniform, varying by about an order of magnitude. The yields, however, do exhibit a significant spatial trend. The yields for the 24 basins east of the Sabine River (SAB) generally are larger than yields west of, and including, the Sabine River (basins in Texas). This observation was tested statistically using the Wilcoxon rank-sum test, a non-parametric test for comparing the medians of two sets of data (Helsel and Hirsch, 1992). The median of the yields east of the Sabine River (1.2 ton/mi^2) was significantly larger ($p < 0.01$) than the median yield of the basins in Texas (0.63 ton/mi^2).

This difference could be due to several factors: Nutrient yield is related to streamflow, and the median unit runoff (ratio of mean annual streamflow to basin drainage area) for basins east of the Sabine River (1,230 acre-ft/mi^2) is significantly larger ($p < 0.001$) than the unit runoff from basins in Texas (330 acre-ft/mi^2). This fact results from larger rainfall east of the Sabine, and partly from the extensive reservoir construction that has taken place in Texas. Judd and Slade (in press) present the total normal reservoir storage capacity of major reservoirs (those with greater than 5,000 acre-ft storage) for each basin draining to the Gulf, expressed as the ratio of normal reservoir storage to drainage area (normal-capacity ratio). As reservoir storage increases in a basin, total streamflow from that basin to the Gulf can be expected to decrease as more water is made available for consumptive use and to evaporation within the basin. The median normal-capacity ratio for basins east of the Sabine River (38.9 acre-ft/mi^2) is significantly smaller ($p < 0.05$) than the median for basins in Texas (80.4 acre-ft/mi^2).

Total Phosphorus

Strongly significant or significant long-term increases in estimated annual total phosphorus loads were detected at 3 stations, strongly significant or significant decreases were detected at 12 stations, and no significant long-term trends were detected at 22 stations (fig. 5, table 4). Long-term trends in total phosphorus (concentration or load) detected using the regression coefficient, B_2 (table 6), from the load model agree with the results of Kendall's tau for all but six stations (NUE, SAN, LAV, BRA, WHI, PAS). In those instances of lack of agreement, significant trends are detected by Kendall's tau, but the p-value for B_2 is greater than 0.10, which indicates no trend. The sign of B_2, however, agrees in each instance with the direction of the trend detected by Kendall's tau.

Estimated mean annual loads of total phosphorus ranged from 2.85 tons (Anclote River [ANC]) to 110,000 tons (Mississippi River [MIS]). Estimated mean annual yields ranged from 0.001 ton/mi^2 (Rio Grande [RIO]) to 4.76 ton/mi^2 (Brays Bayou [BRA]). As with the nitrogen yields, the median phosphorus yield of basins east of the Sabine River (0.160 ton/mi^2) is significantly greater ($p < 0.05$) than the median yield of basins in Texas (0.052 ton/mi^2).

The phosphorus concentrations (before flow adjustment), loads, and yields were substantially lower than the corresponding values for nitrogen, but were distributed very similarly. The one notable exception to this is the Alafia River (ALF), which has a larger phosphorus load and yield than nitrogen. Extensive phosphate mining occurs in the Alafia River Basin, which is a likely cause of the abnormally large loads of total phosphorus.

Factors Affecting Trends in Nutrient Inflows

Data Limitations

As with most analyses of this type, the accuracy of the analysis is limited by the quality and availability of data and by the ability of the analysis techniques to describe natural processes. The quality of the data depends greatly upon the methods used for sample collection, sample preservation, and laboratory analysis. The USGS uses standardized techniques for all these methods, but the techniques have changed over time to reflect technological improvements, as well as changing budgetary and policy considerations. These changes have been shown to bias reported values (Schertz and others, 1994). The bias caused by changes in collection, preservation, or analytical methods can affect the results of the trend tests for concentration and can change the computed loads. However, evaluating these effects is beyond the scope of this report.

In addition to statistical significance, long-term trends in flow-adjusted residuals of concentrations should be evaluated with regard to chemical significance. Several of the trends reported for total nitrogen and the majority of those for total phosphorus are below the minimum chemical reporting level (0.01 mg/L). The error in concentration for any individual analysis is generally ±2 to ±10 percent. At values near the detection limit, this error might even be greater (Hem, 1989, p. 163). This error is in addition to any errors in field sampling or sample preservation. Inferences regarding the chemical significance of the computed trends for any period shorter than that analyzed should be made considering errors in the collection, preservation, and laboratory analysis of individual samples.

Sample size substantially affects the ability to detect a trend. In this analysis, there are substantially more samples for nutrient concentrations (70 to 219) than for annual streamflow and load (16 to 22). The tests for trend in concentrations are, therefore, more likely to detect trends with statistical significance than are the tests for trend in streamflow or loads.

Influence of Streamflow on Loads

Load is highly dependent on streamflow—it is the product of concentration and discharge. Consequently, the LOWESS lines for annual nutrient loads follow the same patterns of peaks and valleys as the LOWESS lines for annual discharge. The effect streamflow has on the load estimates also is apparent from inspection of the plots of the Kendall-Theil lines in figures 6–42. Although only four stations have statistically significant trends in annual streamflow, the direction of the streamflow trends, even if nonsignificant, influences the direction of the annual load trends. For example, strongly significant increasing trends in nitrogen concentrations were detected for the San Antonio River (SAN) and the Alabama River (ALA). Decreasing trends in annual streamflow were computed, although these are nonsignificant. Nonsignificant decreasing trends in annual total nitrogen loads were computed for both of these stations. The decreasing trends in streamflow, while nonsignificant, affect the direction of the trends in load and the statistical significance of the trends.

In another example, a strongly significant increasing trend in total nitrogen concentration was detected for the Apalachicola River (APA). The trend in annual streamflow is decreasing, but is nonsignificant. The trend in annual load for total nitrogen is increasing, but is nonsignificant. In this case, the nonsignificant trend in streamflow does not change the direction of the load trend, but does reduce the ability to detect a significant trend in load.

As a final example, the trend for total phosphorus concentration for the Apalachicola River is nonsignificant and decreasing. The trend for annual streamflow also is nonsignificant and decreasing. The nonsignificant decreasing trends for streamflow and concentration, when combined, appear to have produced a strongly significant decreasing trend in load.

The preceding examples demonstrate that the direction of the streamflow data, even when it is not statistically significant, can have a large influence on the trend of the computed annual loads. Accordingly, any trend in computed loads must be interpreted concurrently with the trends in streamflow and concentration. Although the direction of the streamflow trend has a substantial influence on trends computed for load, the directions of trends in estimated annual nutrient loads agreed with the directions of trends in nutrient concentrations at stations where significant trends for both loads and concentrations were detected.

Mississippi River Diversion to Atchafalaya River

Loads and trends in loads estimated for the Atchafalaya (ATC) and Mississippi (MIS) Rivers are influenced substantially by a large diversion from the Mississippi River. Streamflow is diverted from the Mississippi River to the Atchafalaya River through the Old River Outflow Channel (outflow channel). The facility is operated such that 30 percent of the combined flow of the Atchafalaya and Mississippi Rivers is in the Atchafalaya. The outflow channel discharges to the Atchafalaya River below the confluence of the Red and Black Rivers; the confluence of the outflow channel with the Red River represents the head of the Atchafalaya River. The point of diversion from the Mississippi and the confluence of the outflow channel with the Red River are both upstream of the stations used in this analysis. Mississippi River streamflow and nutrient inflows measured below the diversion are reduced and Atchafalaya River streamflow and nutrient inflows measured below the outflow channel are increased by this diversion.

The relative contribution of nutrients from the outflow channel to the Atchafalaya River was estimated using the daily loads computed for the Mississippi River. The daily nutrient loads estimated for the Mississippi River were divided by the corresponding daily mean streamflow to obtain daily nutrient

Table 7. Mean annual streamflow and nutrient inflows for the Mississippi River, Atchafalaya River, Old River Outflow Channel, and Red River, 1978–93

[acre-ft, acre-feet; ton/mi^2, tons per square mile; --, not computed]

	Mean annual streamflow (acre-ft)	Annual total nitrogen inflows		Annual total phosphorus inflows	
		Load (tons)	Yield (ton/mi^2)	Load (tons)	Yield (ton/mi^2)
Mississippi River	396,000,000	1,340,000	[1]1.51	112,00	[1]0.127
Atchafalaya River	170,000,000	474,000	--	47,800	--
Old River Outflow Channel	108,500,000	364,000	--	30,700	--
Red River	61,500,000	110,000	[2]1.18	17,100	[2].183

[1]The yields for the Mississippi River are computed as the sum of the loads computed for the Mississippi River and the Old River Outflow Channel, divided by the drainage area above the Mississippi River station. The resulting figures represent the yields from the Mississippi River Basin without a diversion to the Atchafalaya River.

[2]The yields for the Red River are computed as the difference between the loads computed for the Atchafalaya River and the Old River Outflow Channel, divided by the drainage area above the Atchafalaya River station. The resulting figures represent the yields from the Red River Basin without the diversion from the Mississippi River.

concentrations for the Mississippi River. Daily loads in the outflow channel were computed by multiplying these concentrations by the daily mean discharges in the outflow channel and then summing the daily values to annual totals. The difference between the loads estimated for the Atchafalaya River and for the outflow channel represents the nutrient contributions from the Red River.

The Mississippi River station is near the outflow channel diversion, so concentrations in the Mississippi River can be considered representative of the concentrations in the outflow channel. This assumption could be tenuous due to the adsorption of nutrients, particularly phosphorus, onto sediment particles. The rates of sediment transport in the Mississippi River and the outflow channel are not proportional to the discharges in the respective channels, and the effects of this phenomenon on nutrient inflows is difficult to determine with the available data. The mean of the annual loads estimated for the outflow channel and the Red River, however, are fair representations of the long-term mean annual nutrient inflows to the Atchafalaya River from those two channels for the period analyzed.

The mean annual loads of total nitrogen and total phosphorus contributed from the Old River Outflow Channel represent about 70 percent of the total load of each constituent in the Atchafalaya River. The mean annual loads and yields of total nitrogen and total phosphorus, estimated for the Mississippi River, Atchafalaya River, Old River Outflow Channel, and Red River are shown in table 7. The period of record for the Atchafalaya River (1978–93) is several years shorter than the period of record for the Mississippi River and Old River Outflow Channel (1974–93). The mean annual streamflow and nutrient loads in table 7 for the Old River Outflow Channel and for the Mississippi River are for the same period as the Atchafalaya River (1978–93). The mean annual streamflow and nutrient loads for the Mississippi River in tables 3 and 4, however, are for the entire period of record for the Mississippi River (1974–93).

SUMMARY AND CONCLUSIONS

Trends in nutrient inflows (total nitrogen and total phosphorus) from 37 streams representing about 86 percent of the total drainage area from the United States to the Gulf of Mexico are presented. The period analyzed varies for each station, but generally is water years 1972–93. Most of the stations are part of NASQAN. Short-term trends for each station are indicated by LOWESS smooth lines superimposed on graphs of the relations between flow-adjusted residuals of concentrations and time, or load and time. Long-term trends were evaluated using Kendall's tau and the slope of the Kendall-Theil robust line. Long-term trends for each station are indicated by Kendall-Theil robust lines superimposed on the aforementioned graphs.

The relation between nutrient concentrations and streamflow, and trends in annual streamflow, are presented to aid in the interpretation of trends in nutrient loads. Statistically significant long-term trends in streamflow were detected at only four stations. However, the trends in streamflow, even where not statistically significant, have a substantial effect on the trends detected for annual nutrient loads.

Nutrient concentrations were flow adjusted to remove the effects of streamflow, and the flow-adjusted residuals of concentrations were tested for long-term trend. Strongly significant or significant long-term increases in flow-adjusted residuals of total nitrogen concentration were detected at 19 stations, strongly significant or significant decreases were detected at 7 stations, and no significant long-term trend was detected at 11 stations. Strongly significant or significant long-term increases in flow-adjusted residuals of total phosphorus concentration were detected at 7 stations, strongly significant or significant decreases were detected at 11 stations, and no significant long-term trend was detected at 19 stations.

Annual loads of total nitrogen and total phosphorus were estimated with regression. Load estimates from regression were corrected for log-transform bias using the Minimum Variance Unbiased Estimator (MVUE). Explanatory variables used in the regression are logarithm of daily mean streamflow; time, as expressed in decimal years; and sine and cosine of time, expressed in decimal years. Trends estimated using the nonparametric method (Kendall's tau) generally agreed with trends estimated using the sign and attained significance level (p-value) of the regression coefficient for time (as expressed in decimal years).

Strongly significant or significant long-term increases in estimated annual total nitrogen loads were detected at 3 stations, strongly significant or significant decreases were detected at 4 stations, and no significant long-term trend was detected at 30 stations. Strongly significant or significant long-term increases in estimated annual total phosphorus loads were detected at 3 stations, strongly significant or significant decreases were detected at 12 stations, and no long-term trend was detected at 22 stations.

Mean annual yields were computed from the estimated mean annual loads. The median of the annual yields for the 24 streams east of the Sabine River on the Texas-Louisiana boundary is significantly larger than the median for the 13 streams in Texas, for both total nitrogen and total phosphorus.

More than 85 percent of the nutrient loads to the Gulf of Mexico are from the Mississippi and Atchafalaya Rivers. About 70 percent of the mean annual nutrient loads from the Atchafalaya River are introduced from the Mississippi River through the Old River Outflow Channel.

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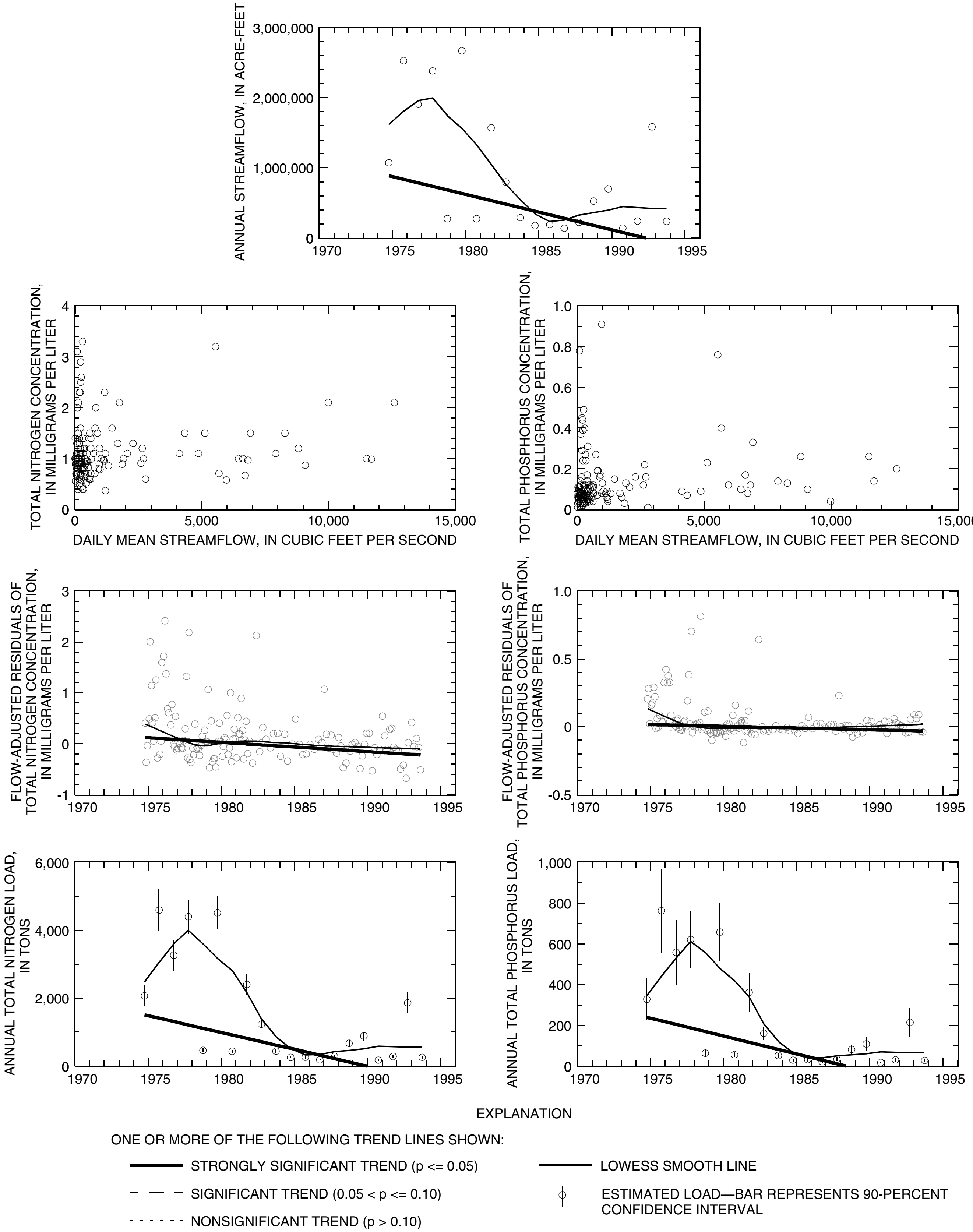


Figure 6. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Rio Grande, Tex. (RIO) (08475000).

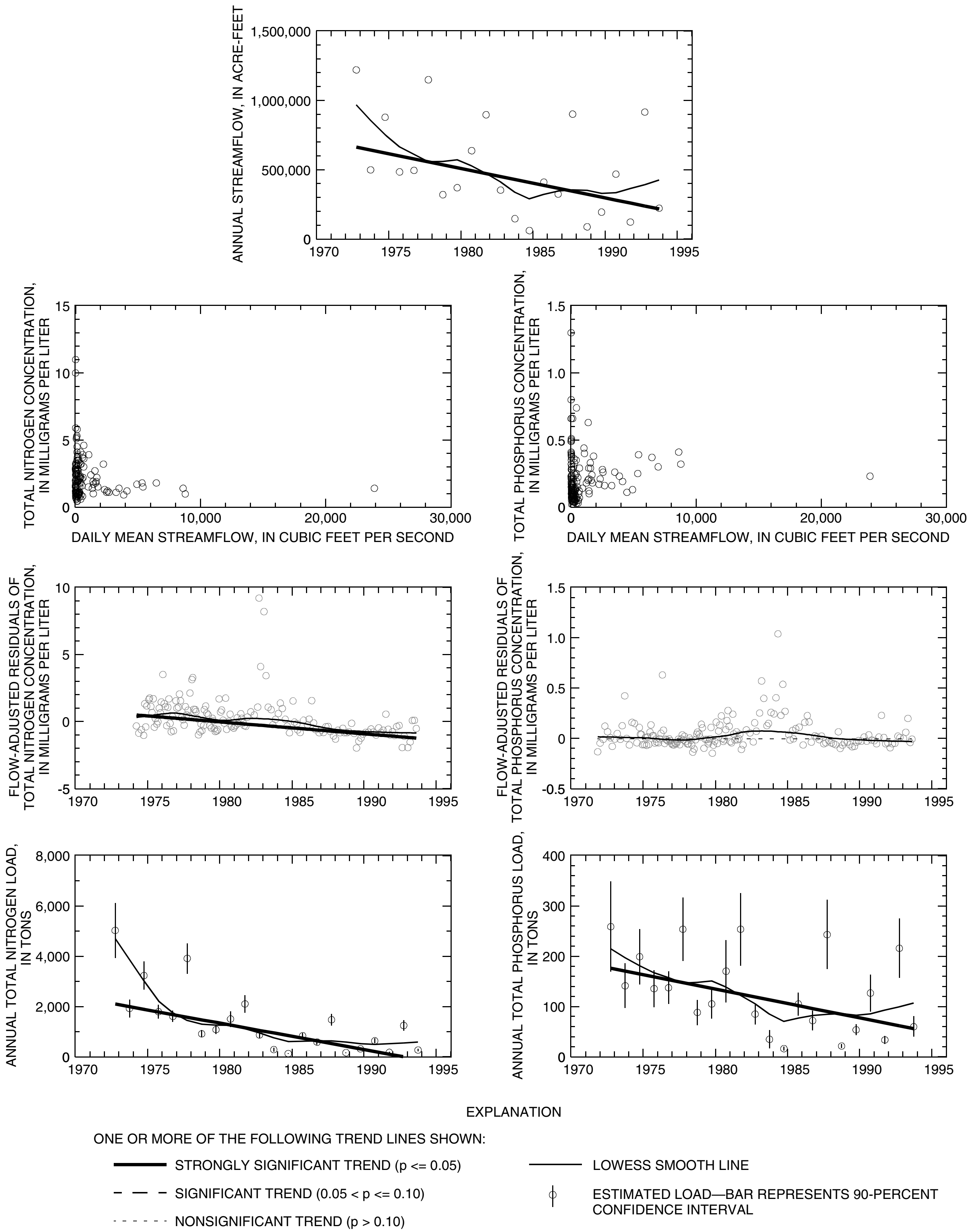


Figure 7. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Nueces River, Tex. (NUE) (08210000).

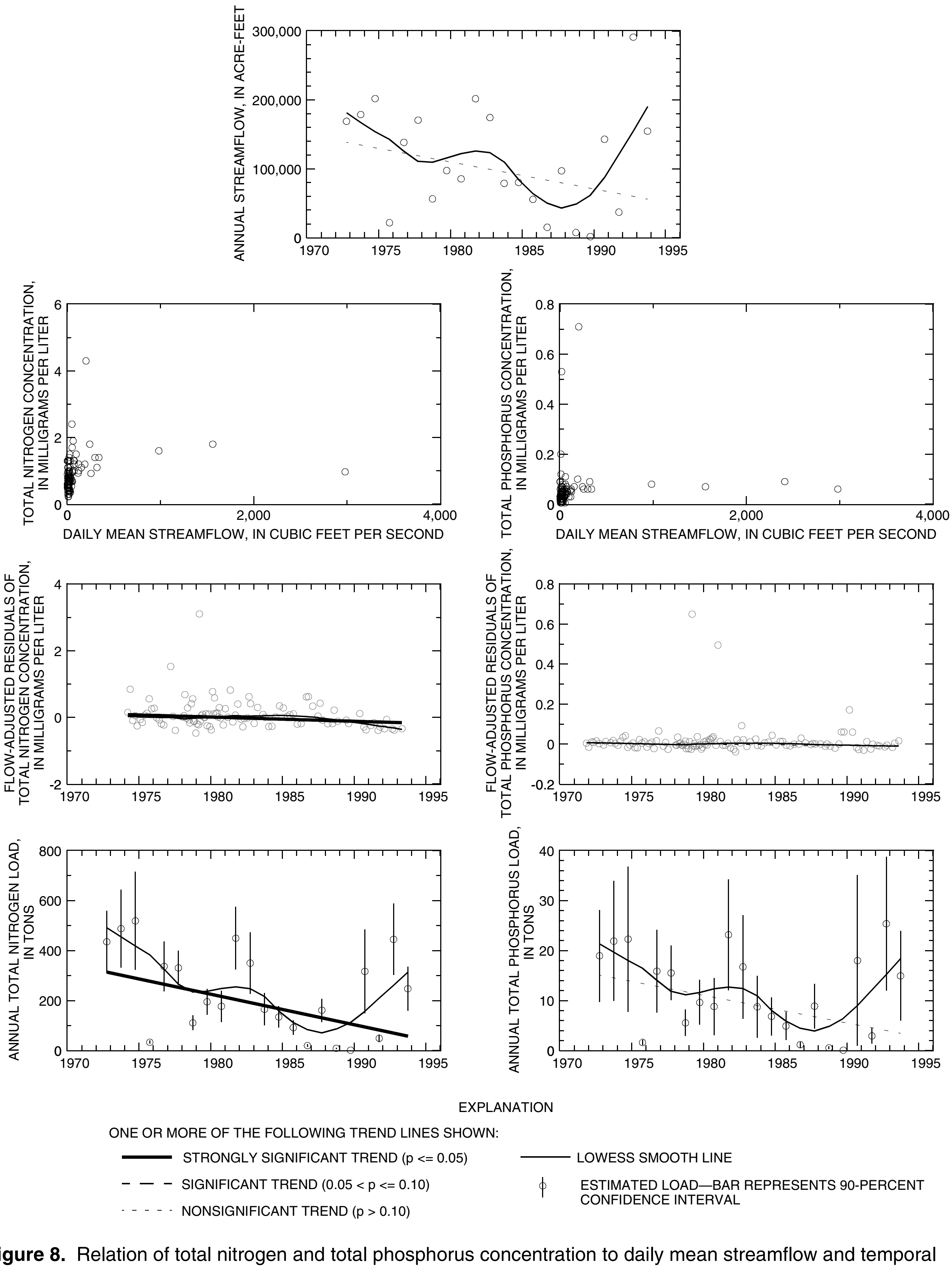


Figure 8. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Mission River, Tex. (MSN) (08189500).

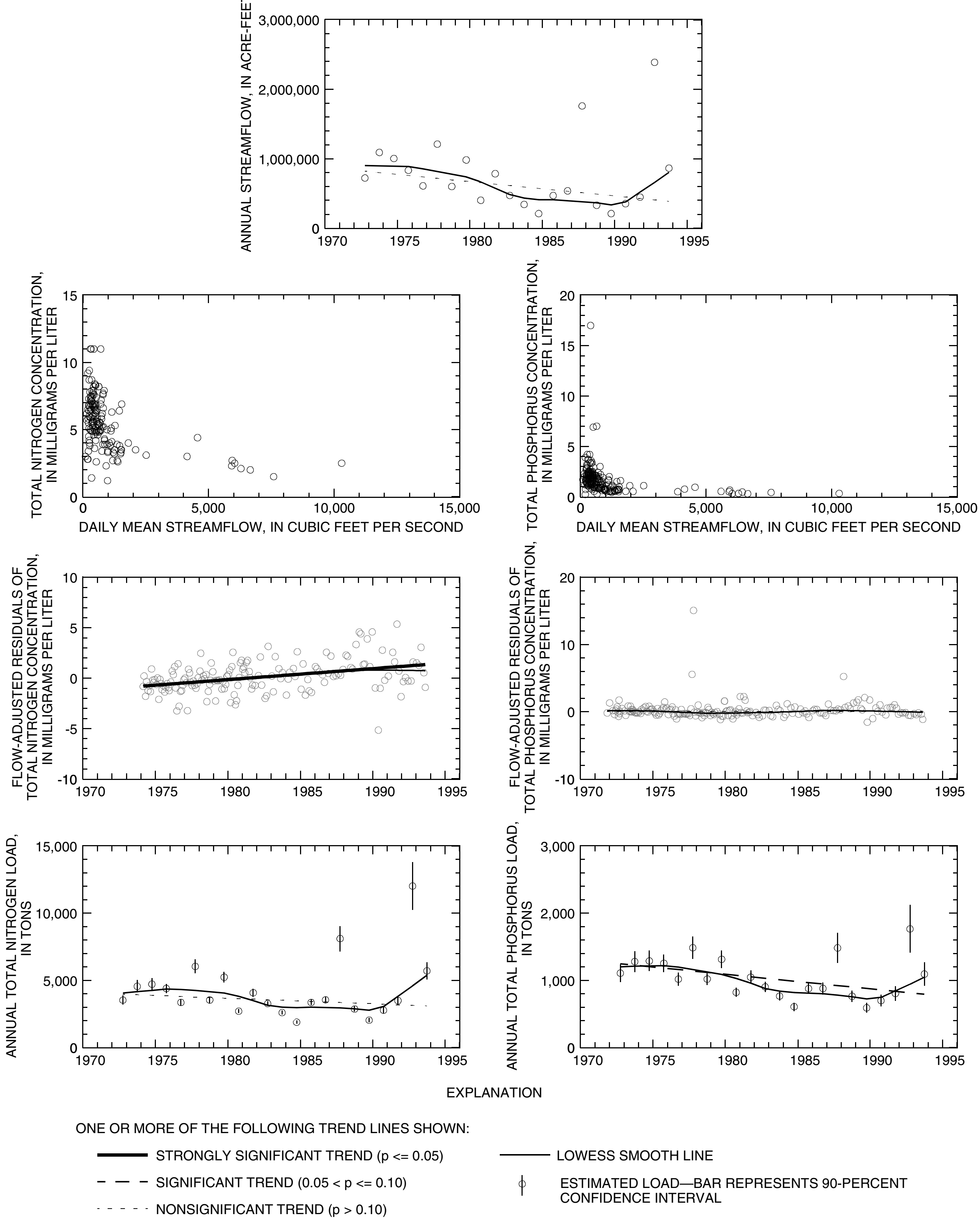


Figure 9. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for San Antonio River, Tex. (SAN) (08188500).

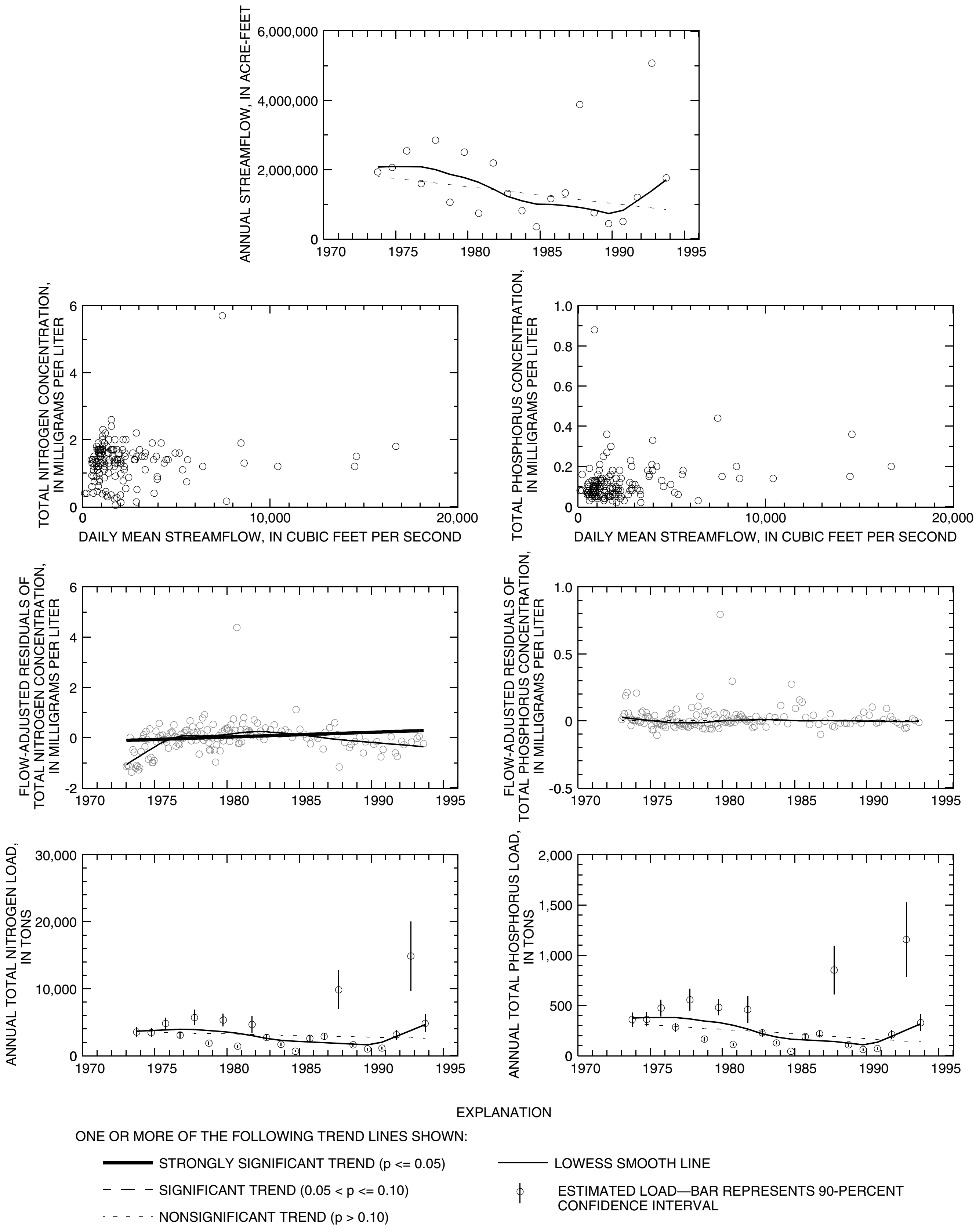


Figure 10. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Guadalupe River, Tex. (GUA) (08176500).

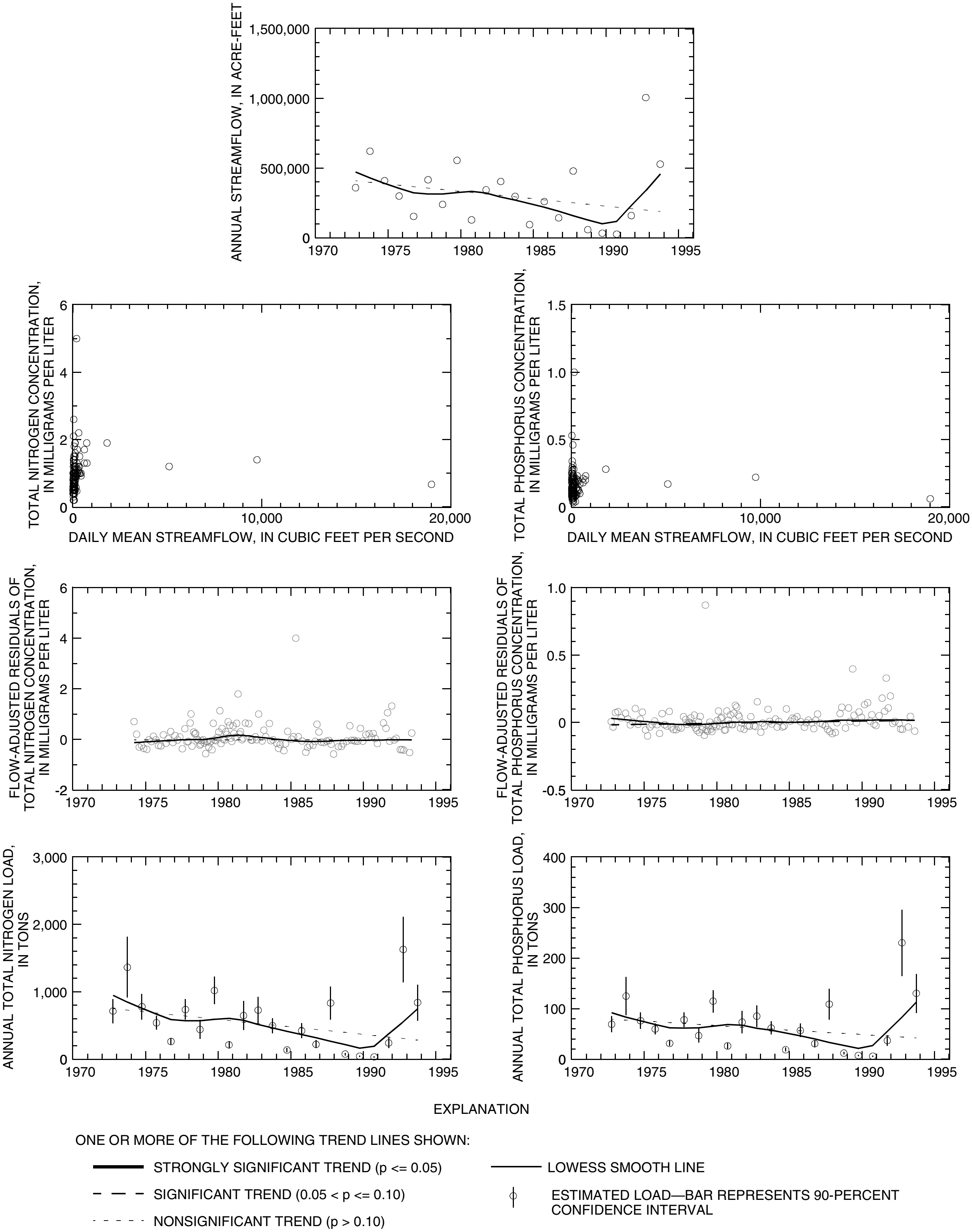


Figure 11. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Lavaca River, Tex. (LAV) (08164000).

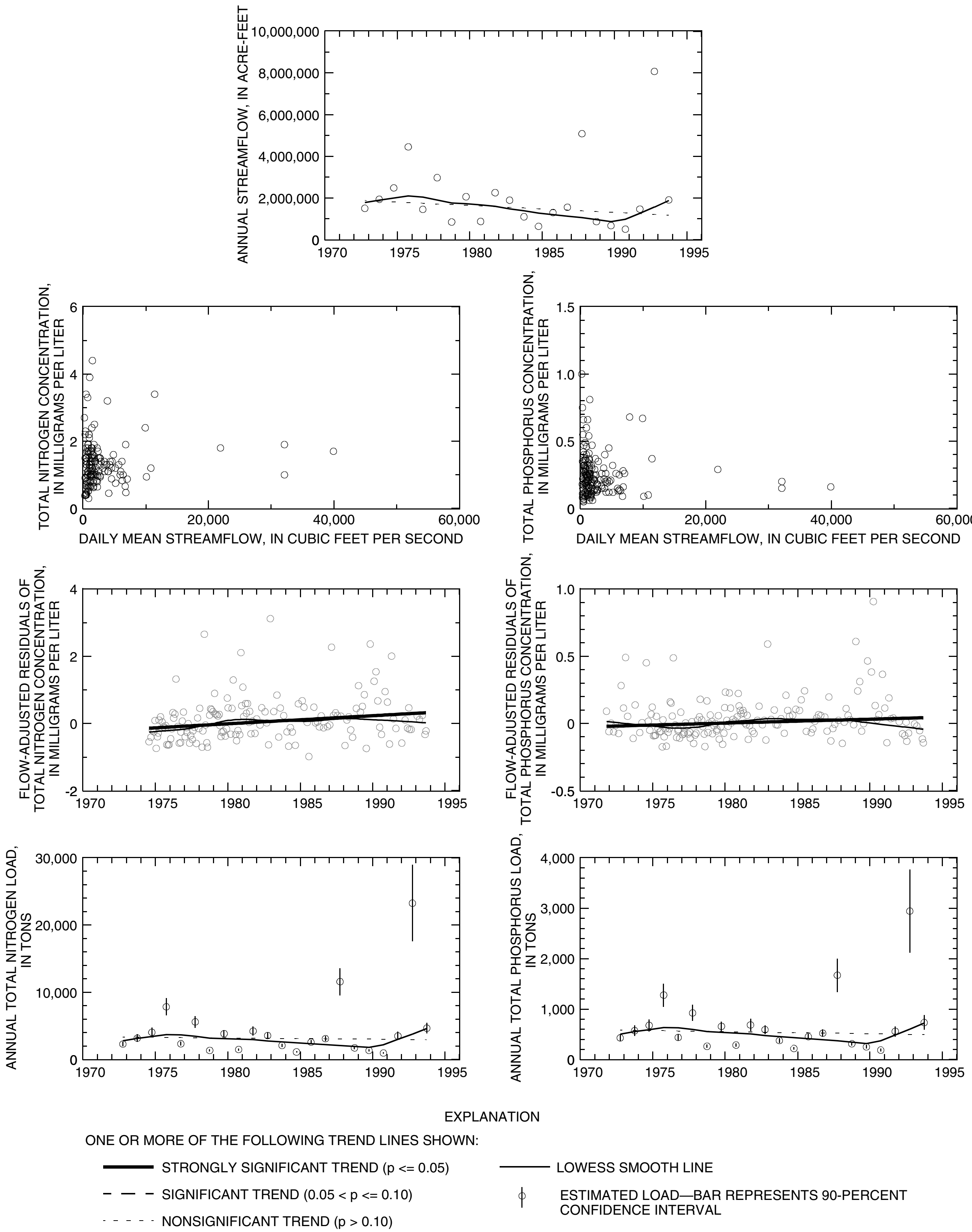
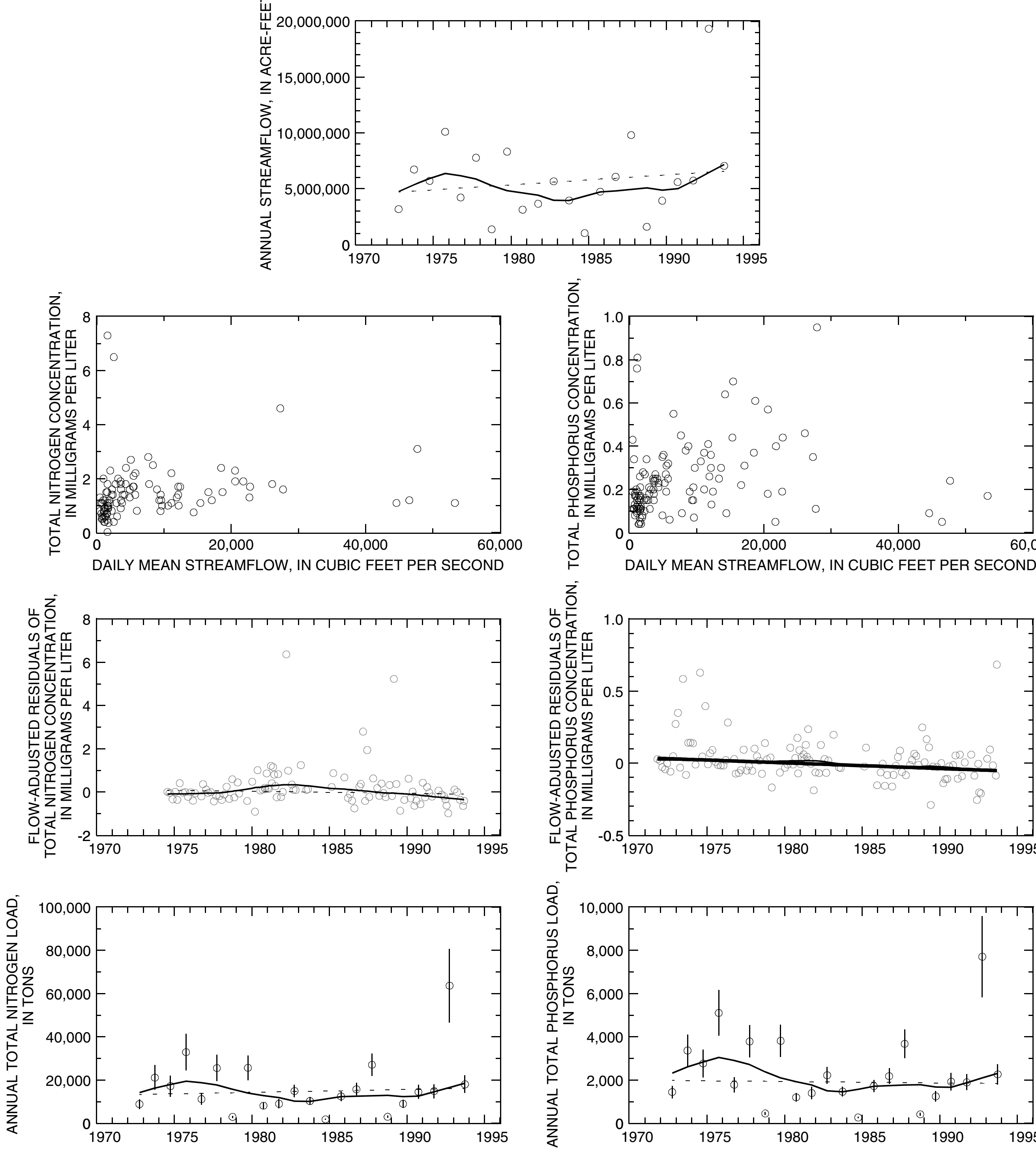


Figure 12. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Colorado River, Tex. (COL) (08162000).



EXPLANATION

ONE OR MORE OF THE FOLLOWING TREND LINES SHOWN:

STRONGLY SIGNIFICANT TREND (p <= 0.05)

SIGNIFICANT TREND (0.05 < p <= 0.10)

NONSIGNIFICANT TREND (p > 0.10)

LOWESS SMOOTH LINE

ESTIMATED LOAD—BAR REPRESENTS 90-PERCENT CONFIDENCE INTERVAL

Figure 13. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Brazos River, Tex. (BRZ) (08114000).

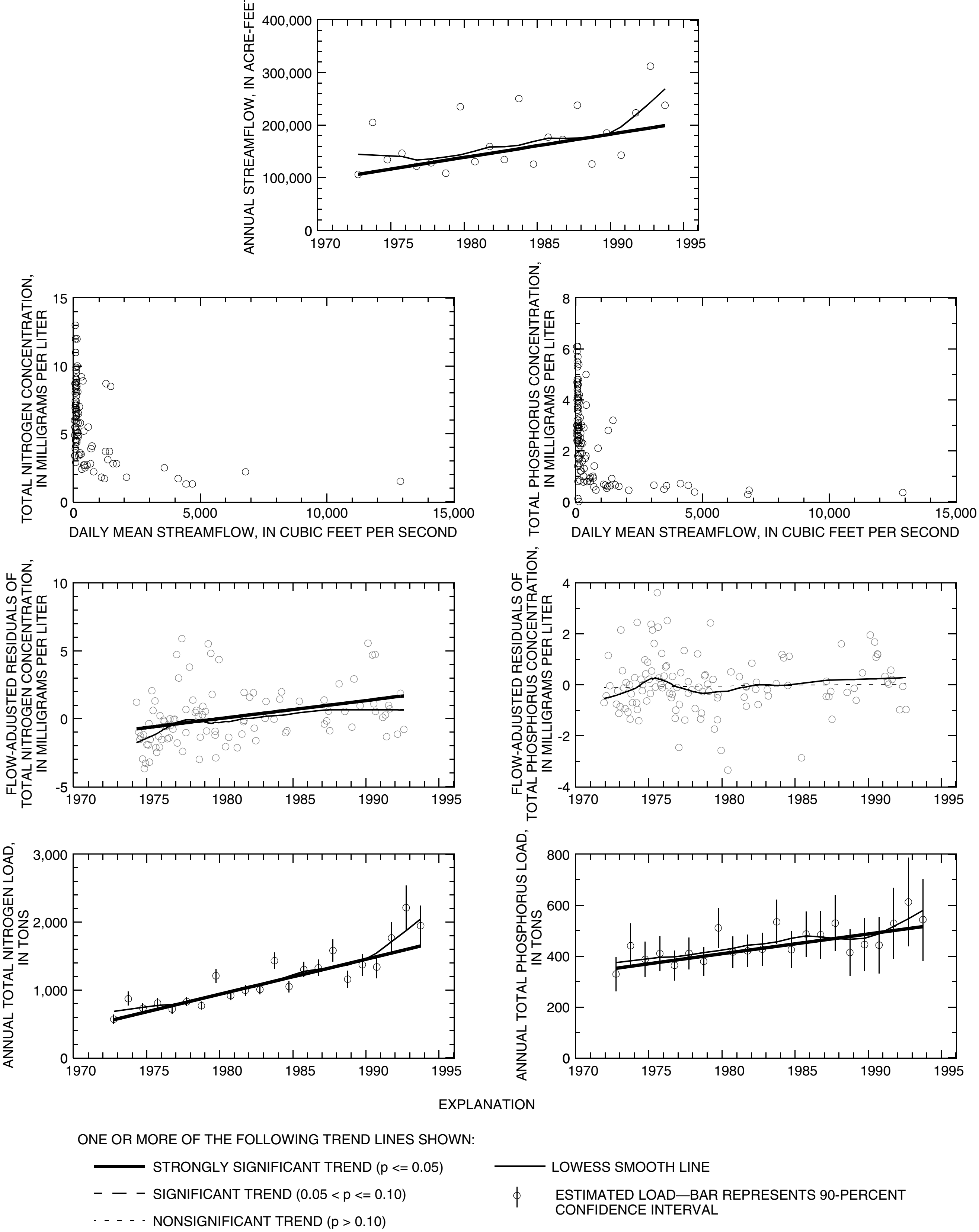


Figure 14. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Brays Bayou, Tex. (BRA) (08075000).

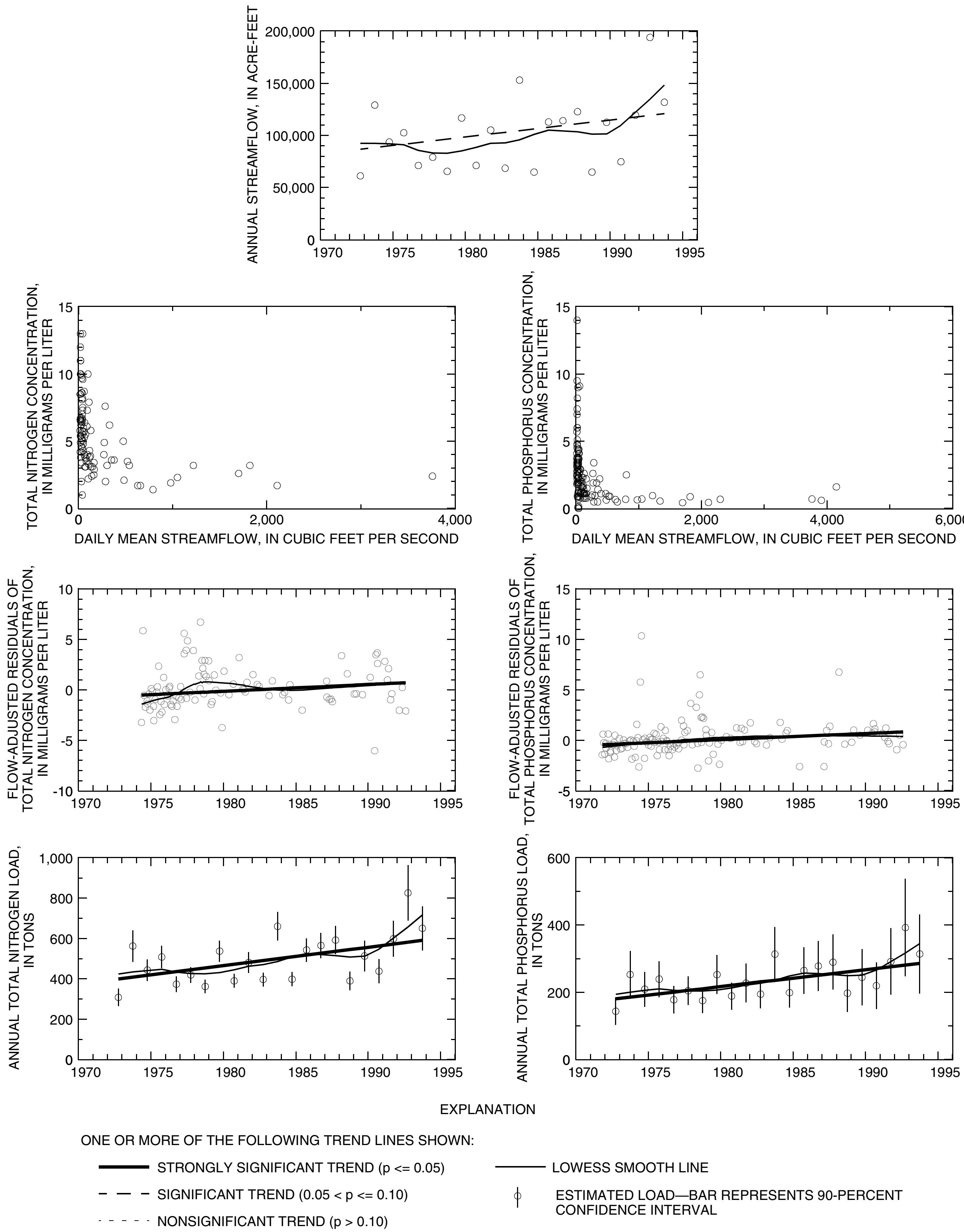


Figure 15. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Whiteoak Bayou, Tex. (WHI) (08074500).

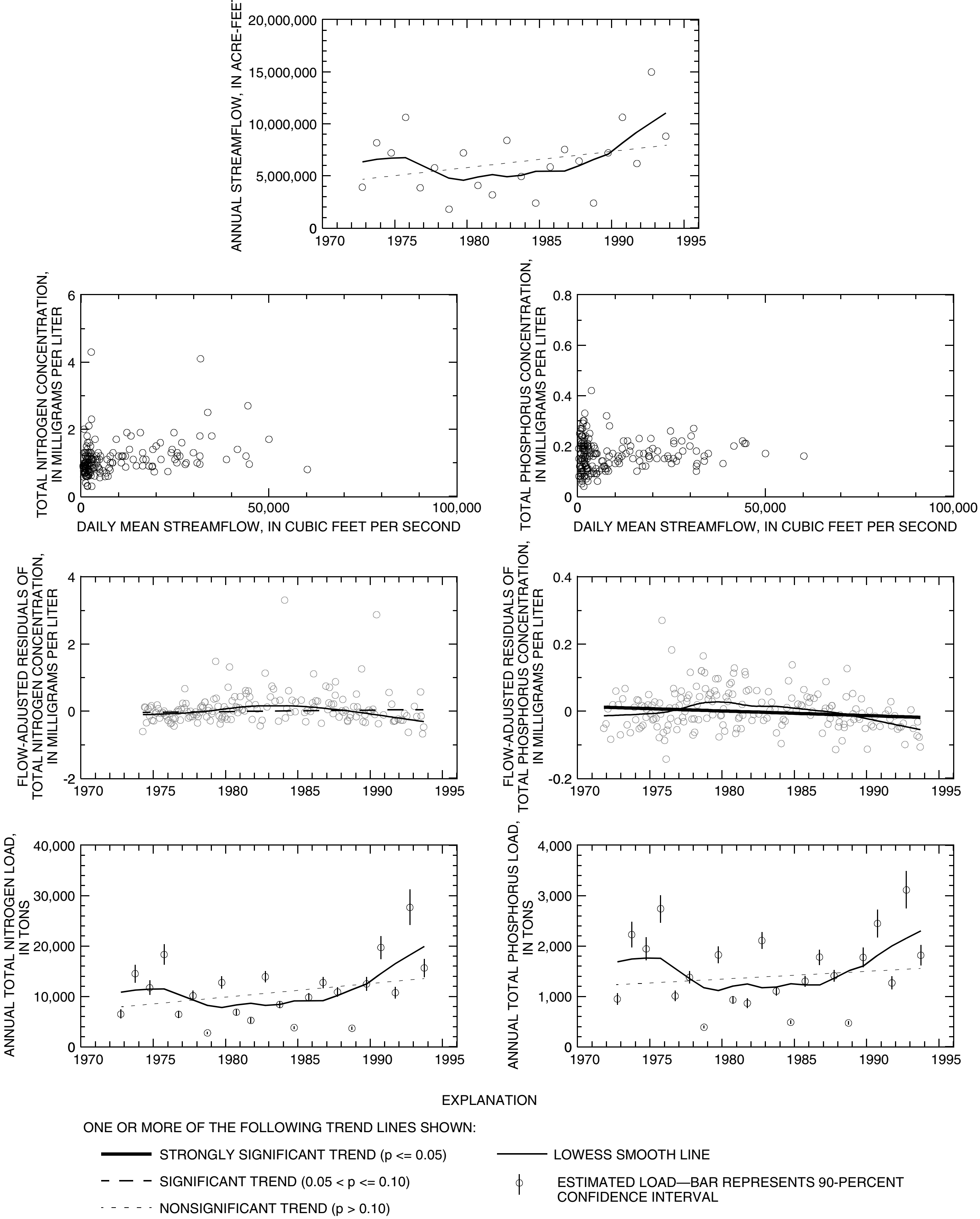


Figure 16. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Trinity River, Tex. (TRI) (08066500).

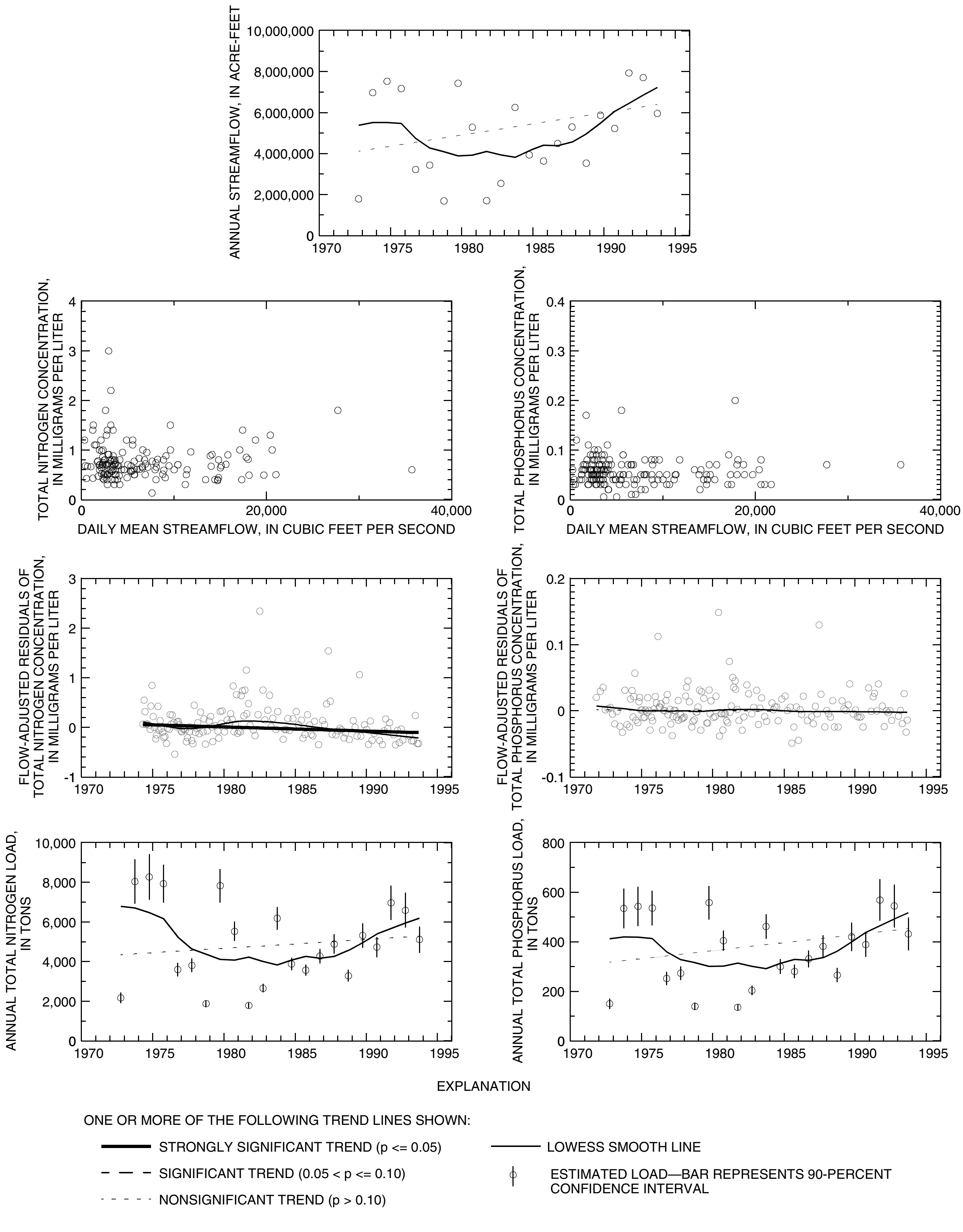


Figure 17. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Neches River, Tex. (NEC) (08041000).

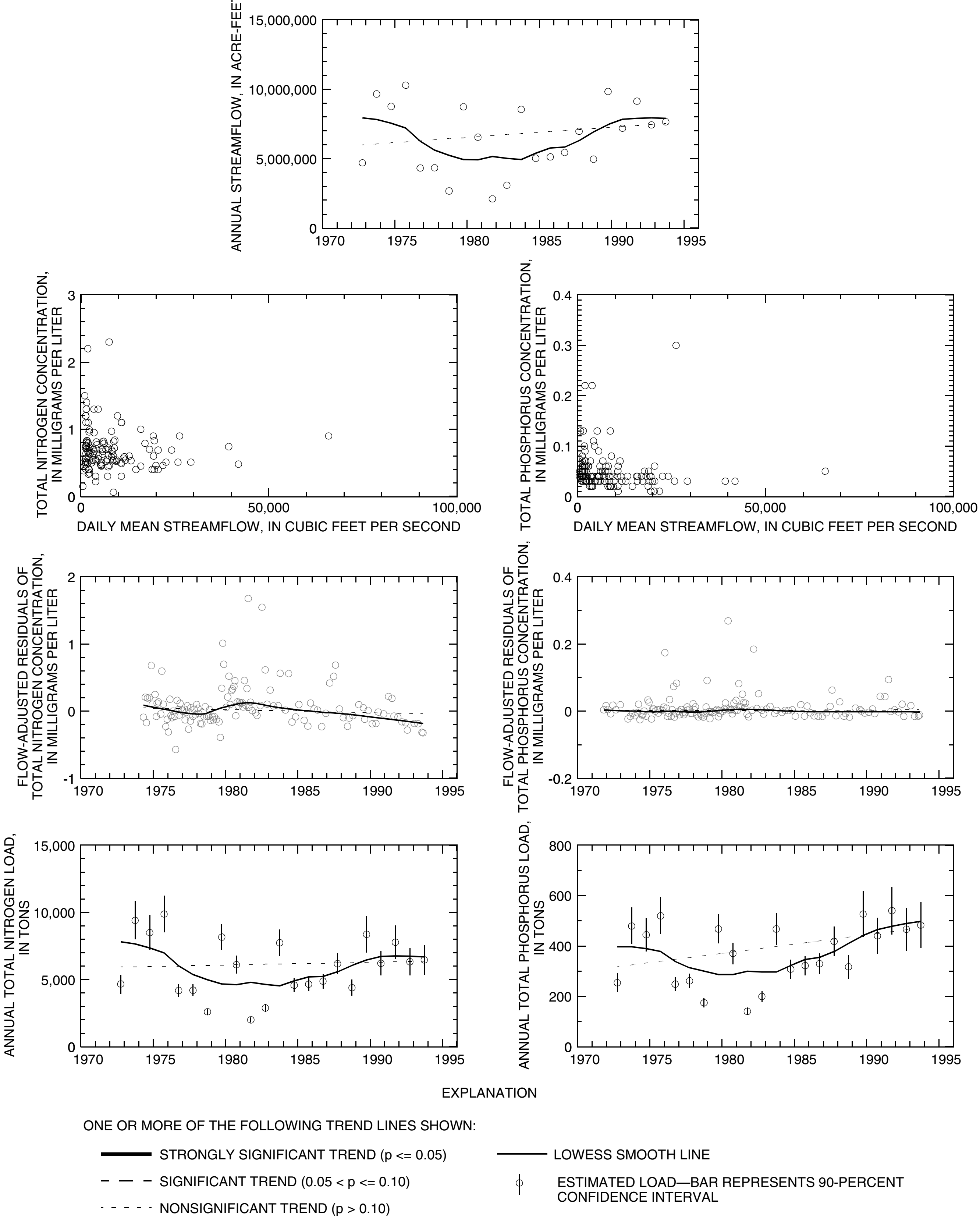


Figure 18. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Sabine River, Tex. (SAB) (08030500).

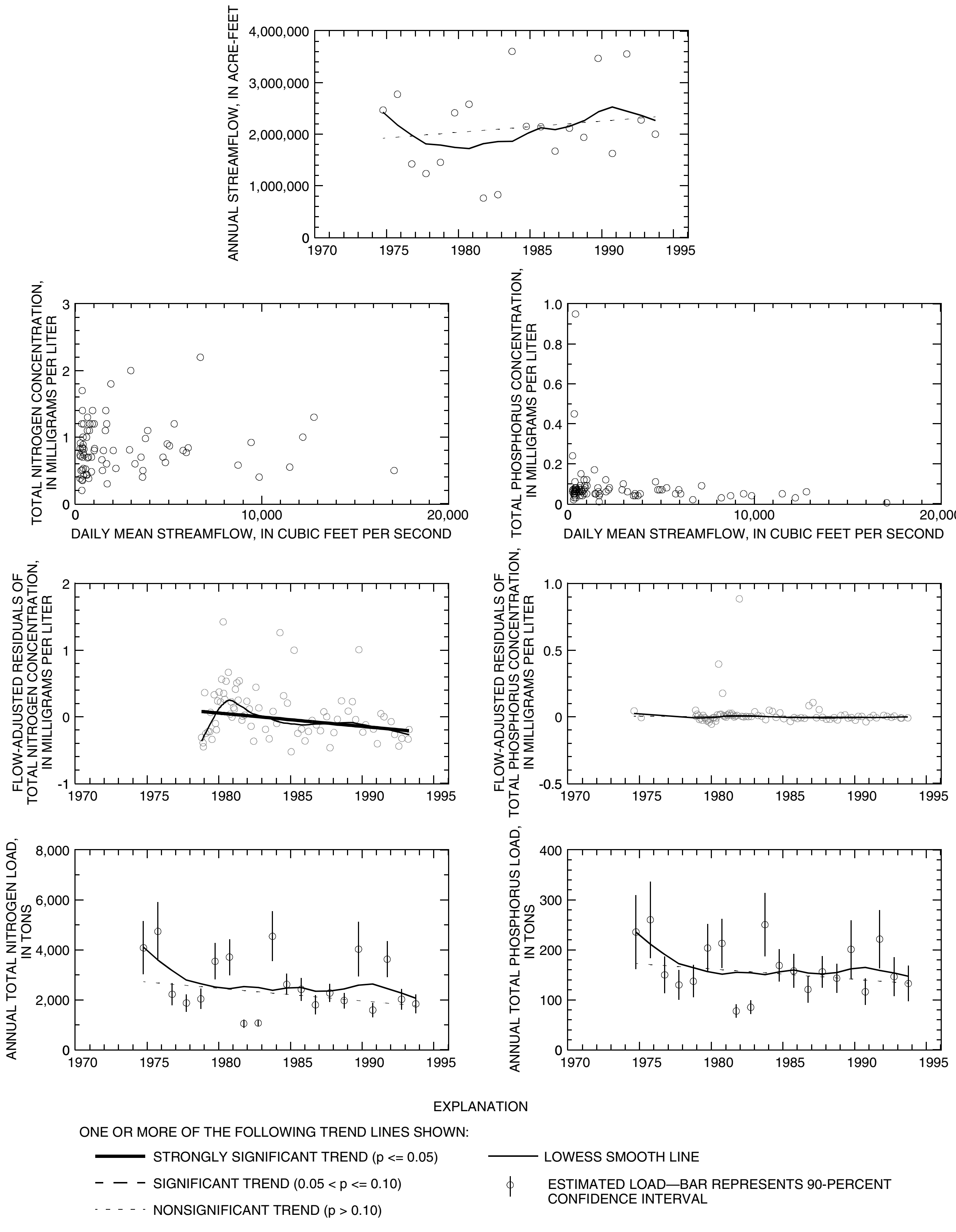


Figure 19. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Calcasieu River, La. (CAL) (08015500).

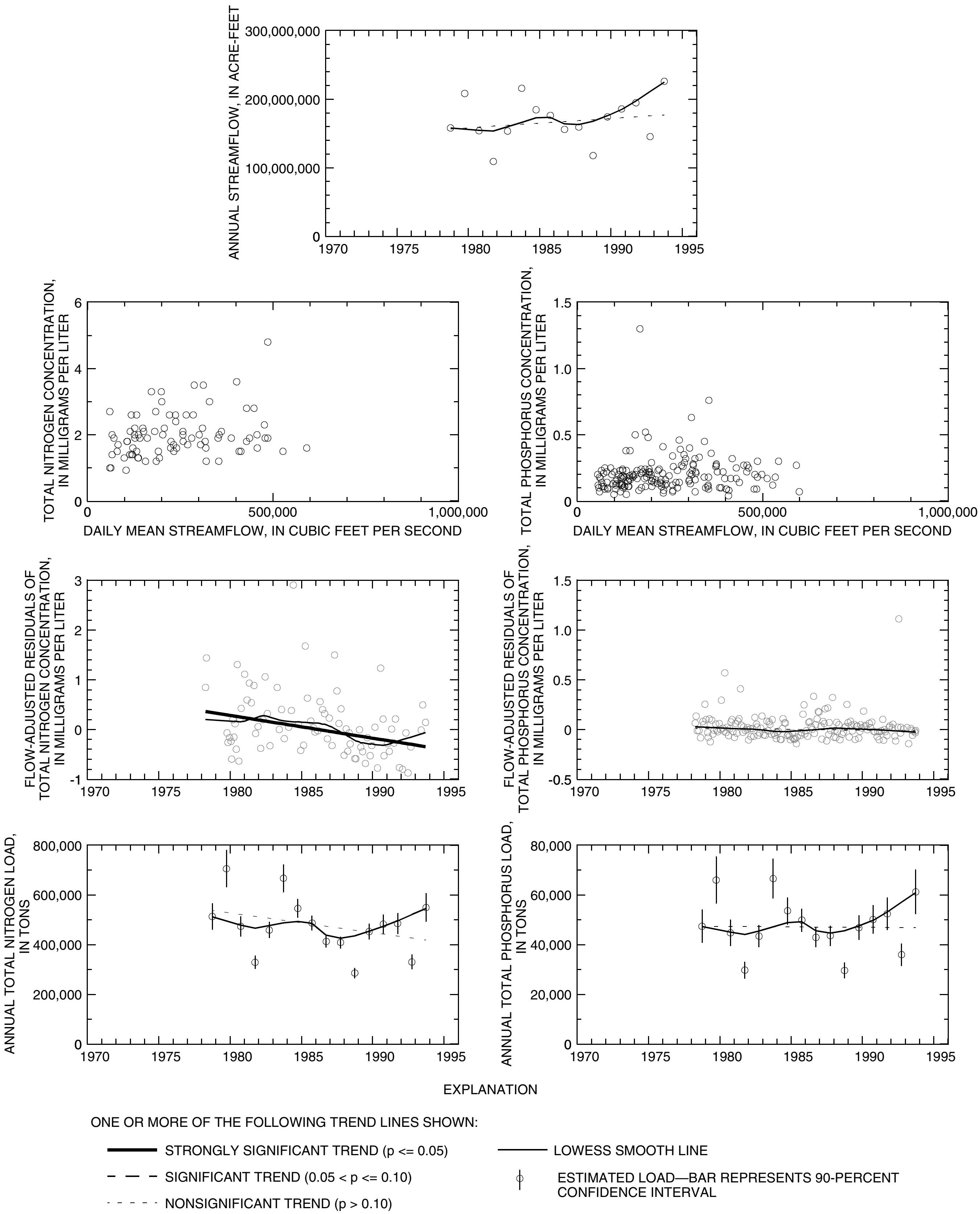


Figure 20. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Atchafalaya River, La. (ATC) (07381495).

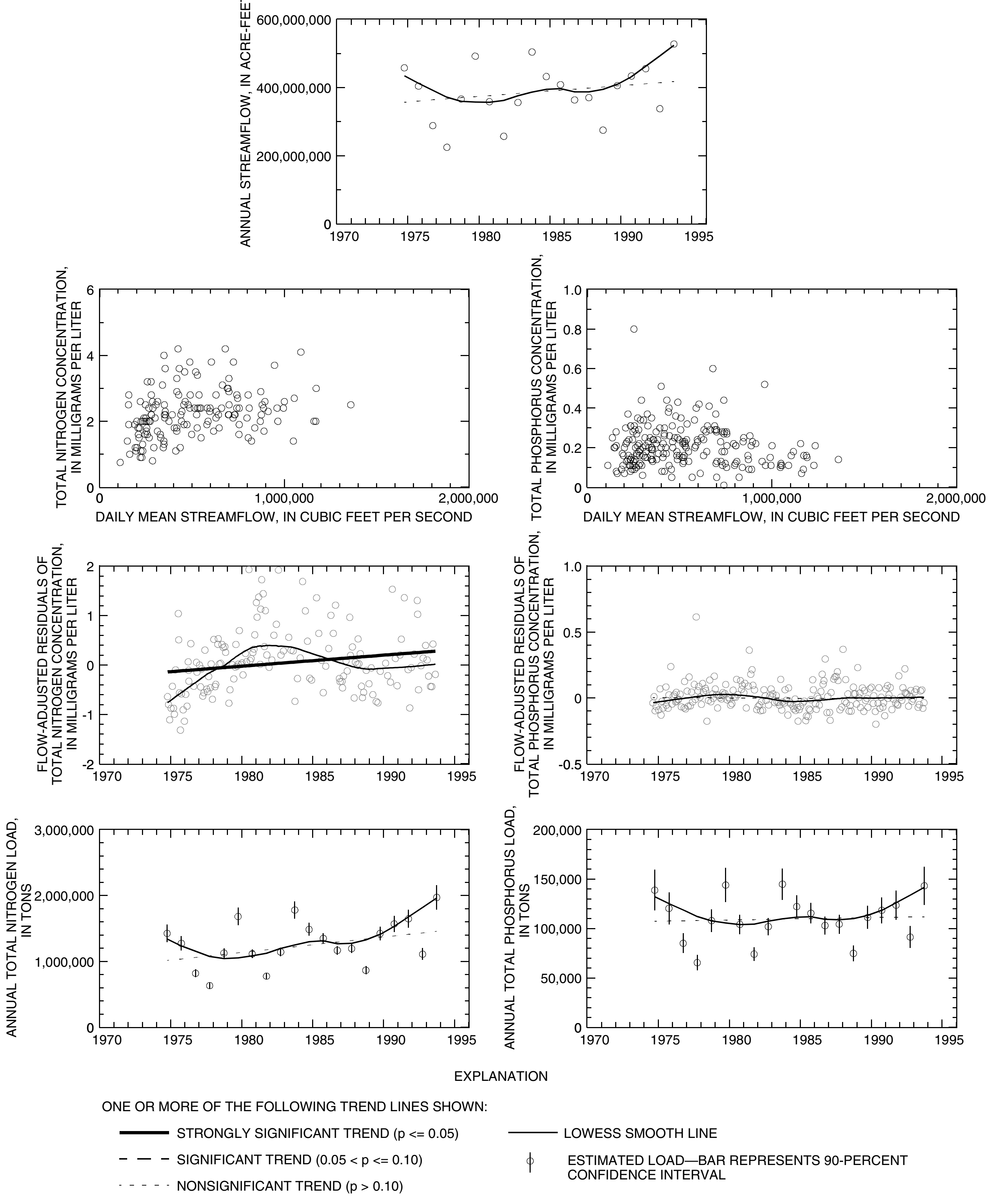


Figure 21. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Mississippi River, La. (MIS) (07373420).

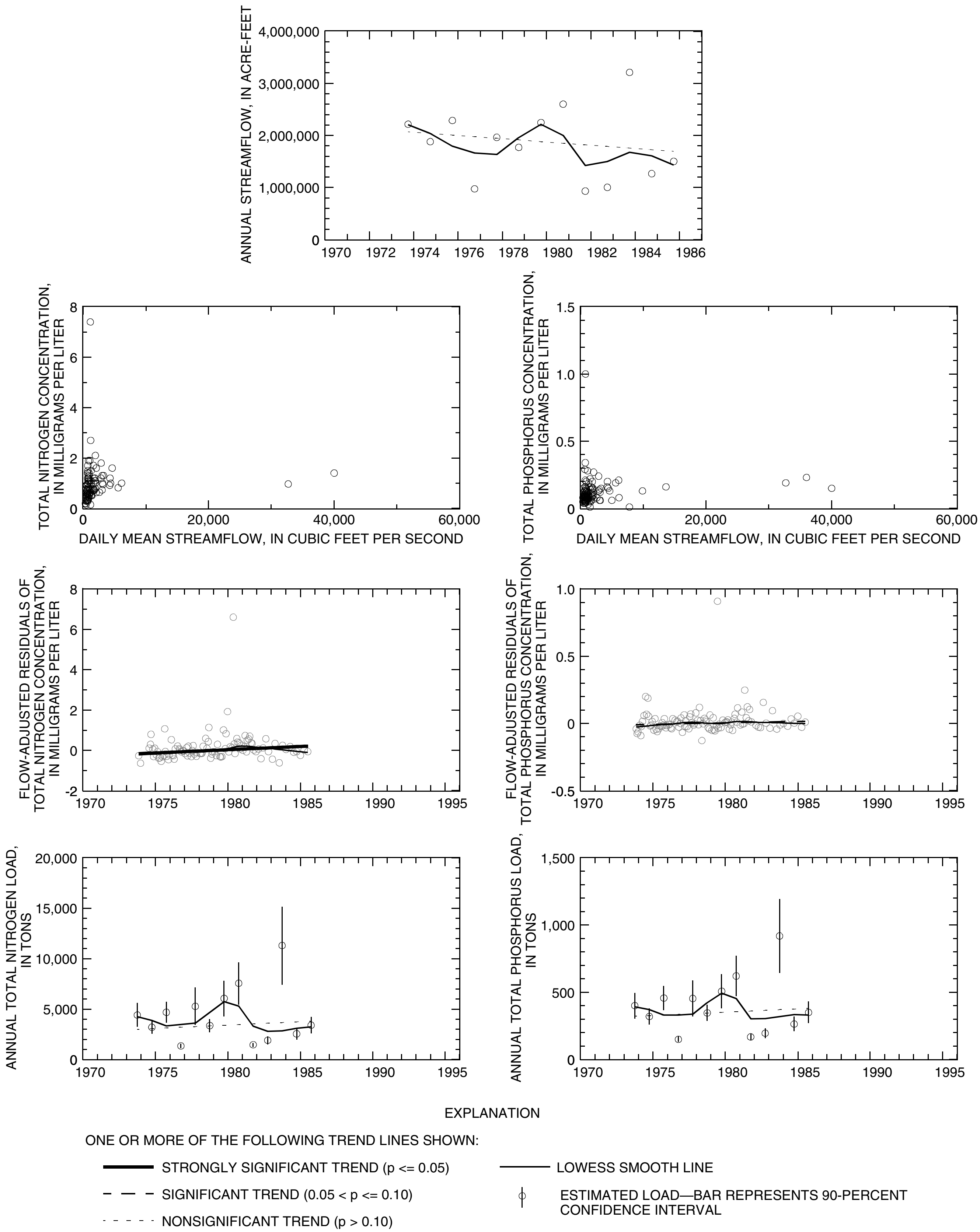


Figure 22. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Amite River, La. (AMI) (07378510).

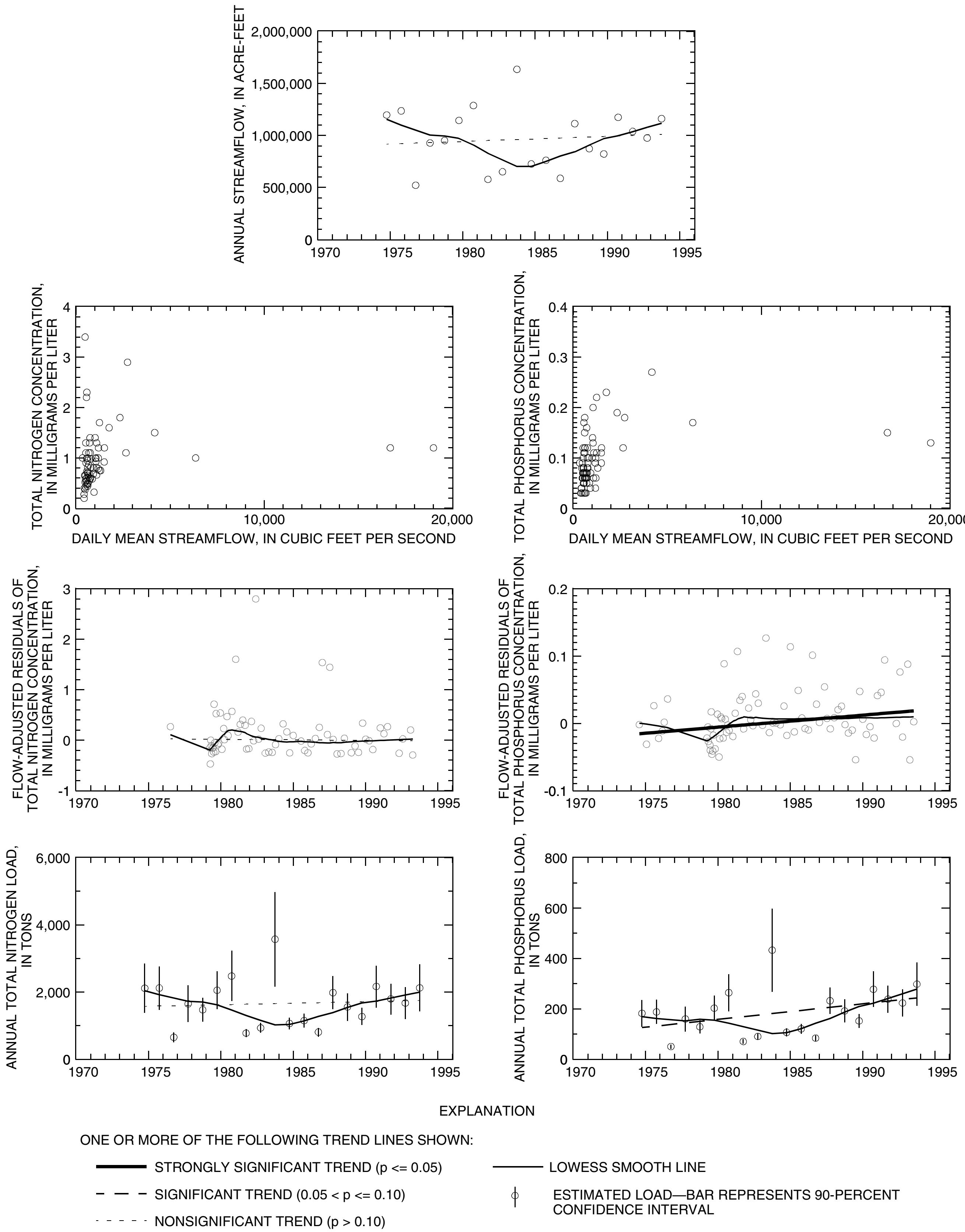


Figure 23. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Tangipahoa River, La. (TAN) (07375500).

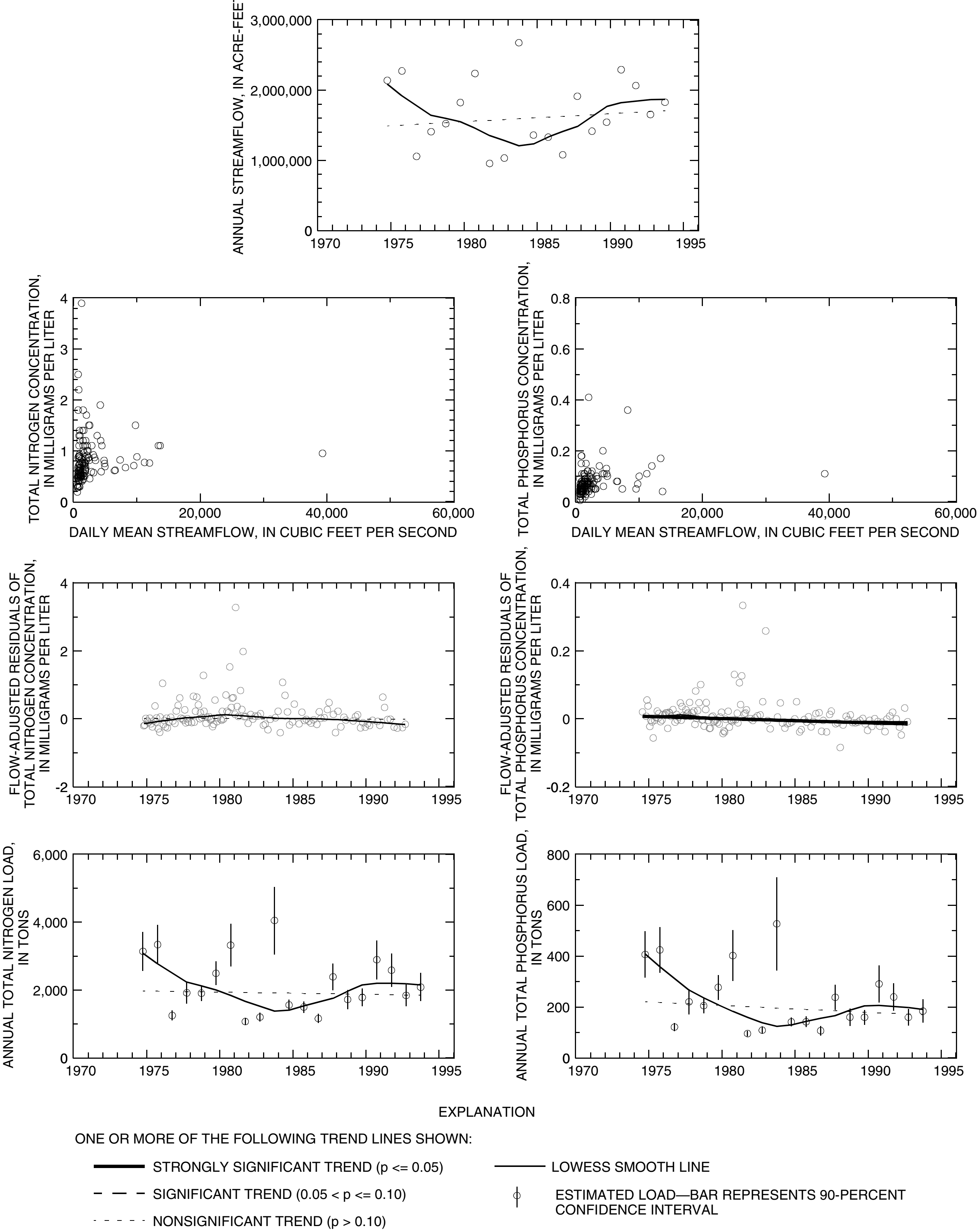


Figure 24. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Bogue Chitto, La. (CHI) (02492000).

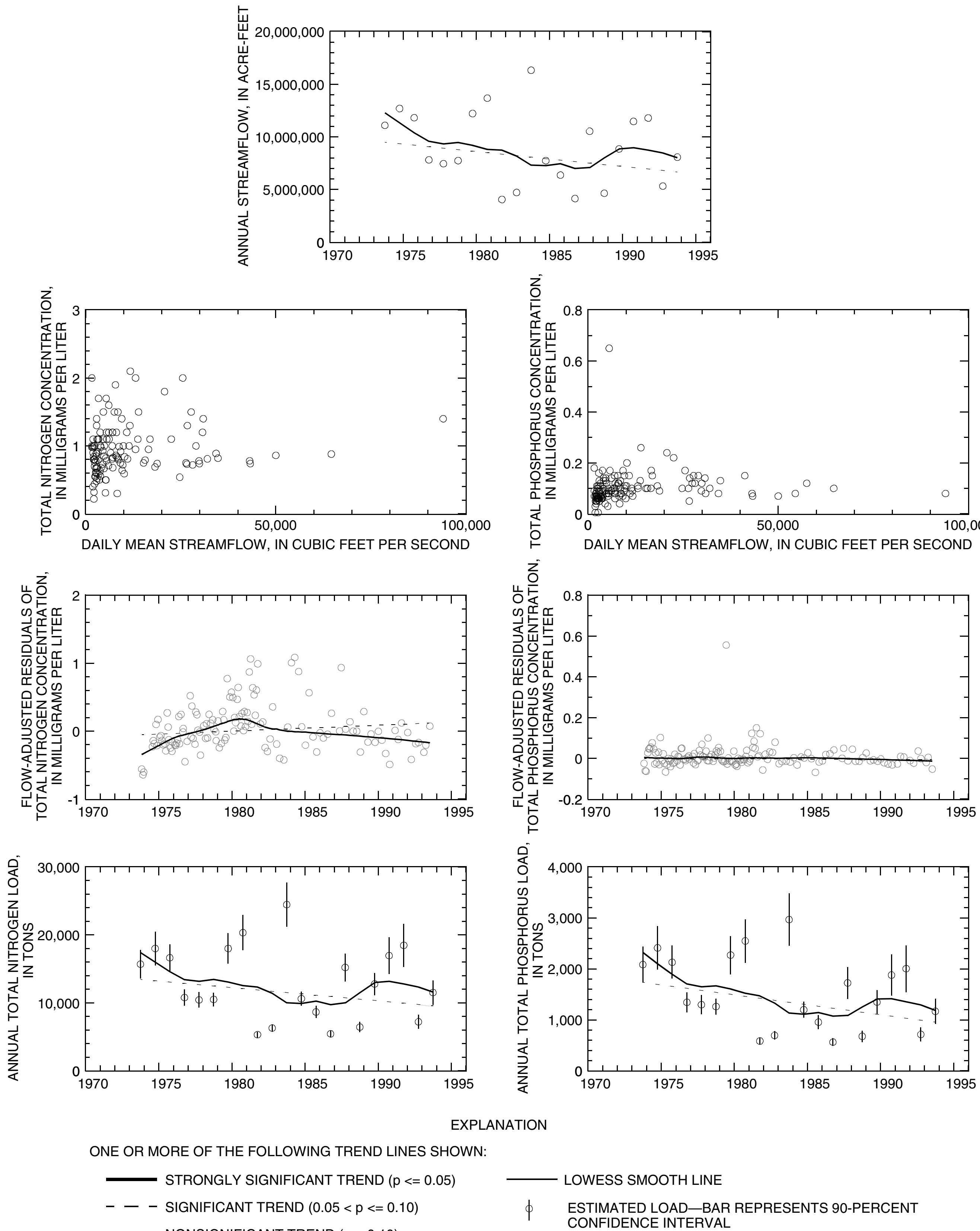


Figure 25. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Pearl River, La. (PRL) (02489500).

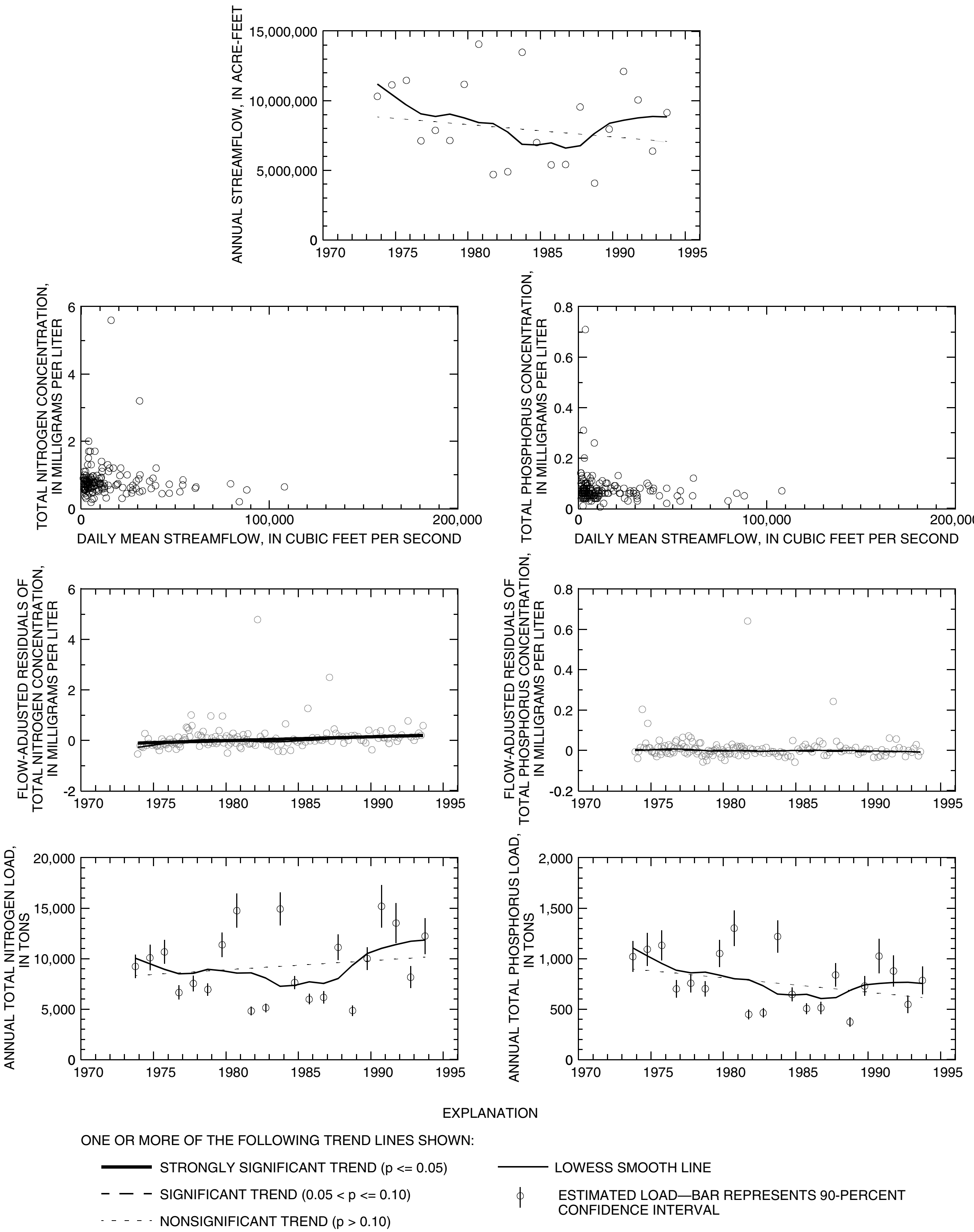


Figure 26. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Pascagoula River, Miss. (PAS) (02479020).

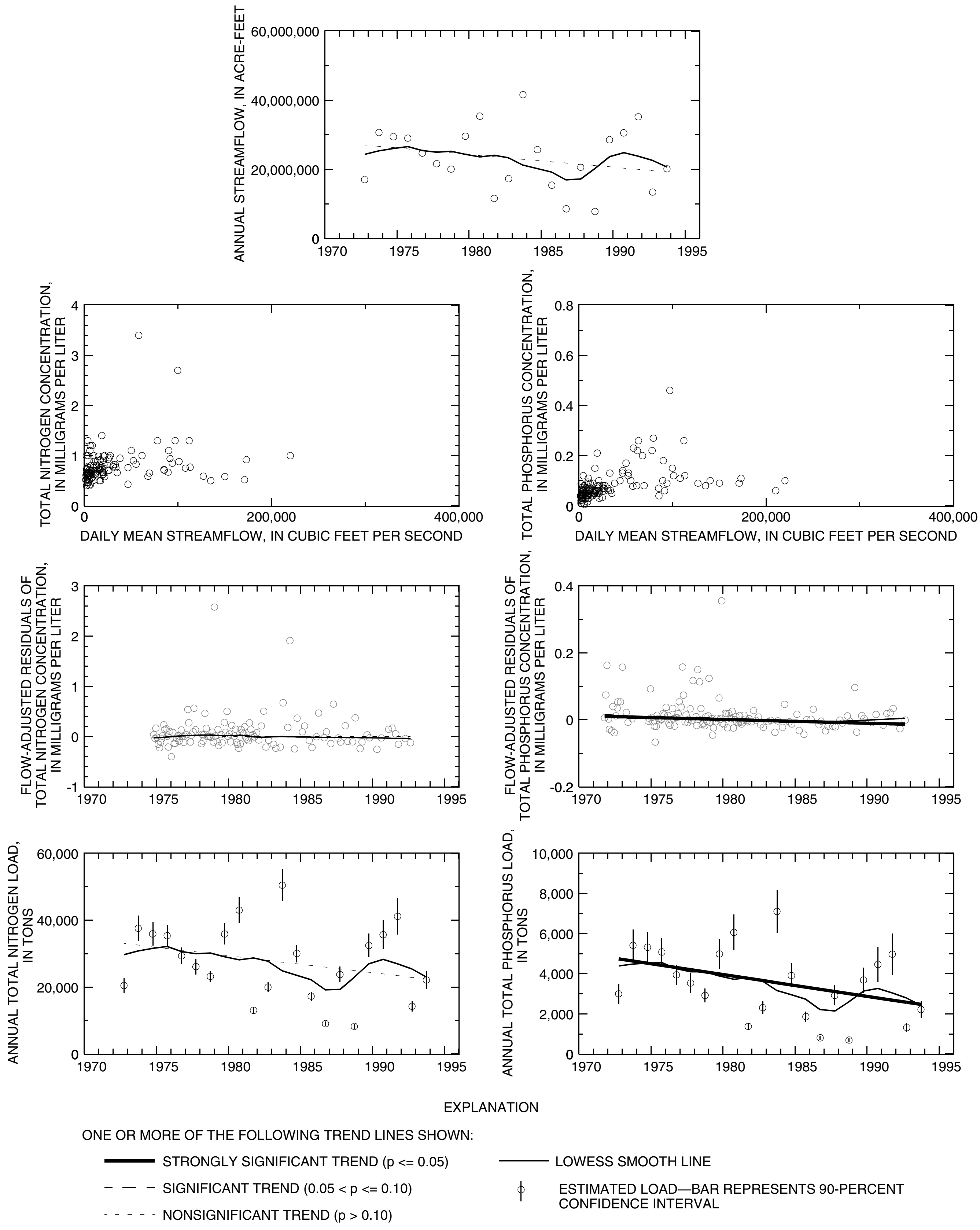


Figure 27. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Tombigbee River, Ala. (TOM) (02469762).

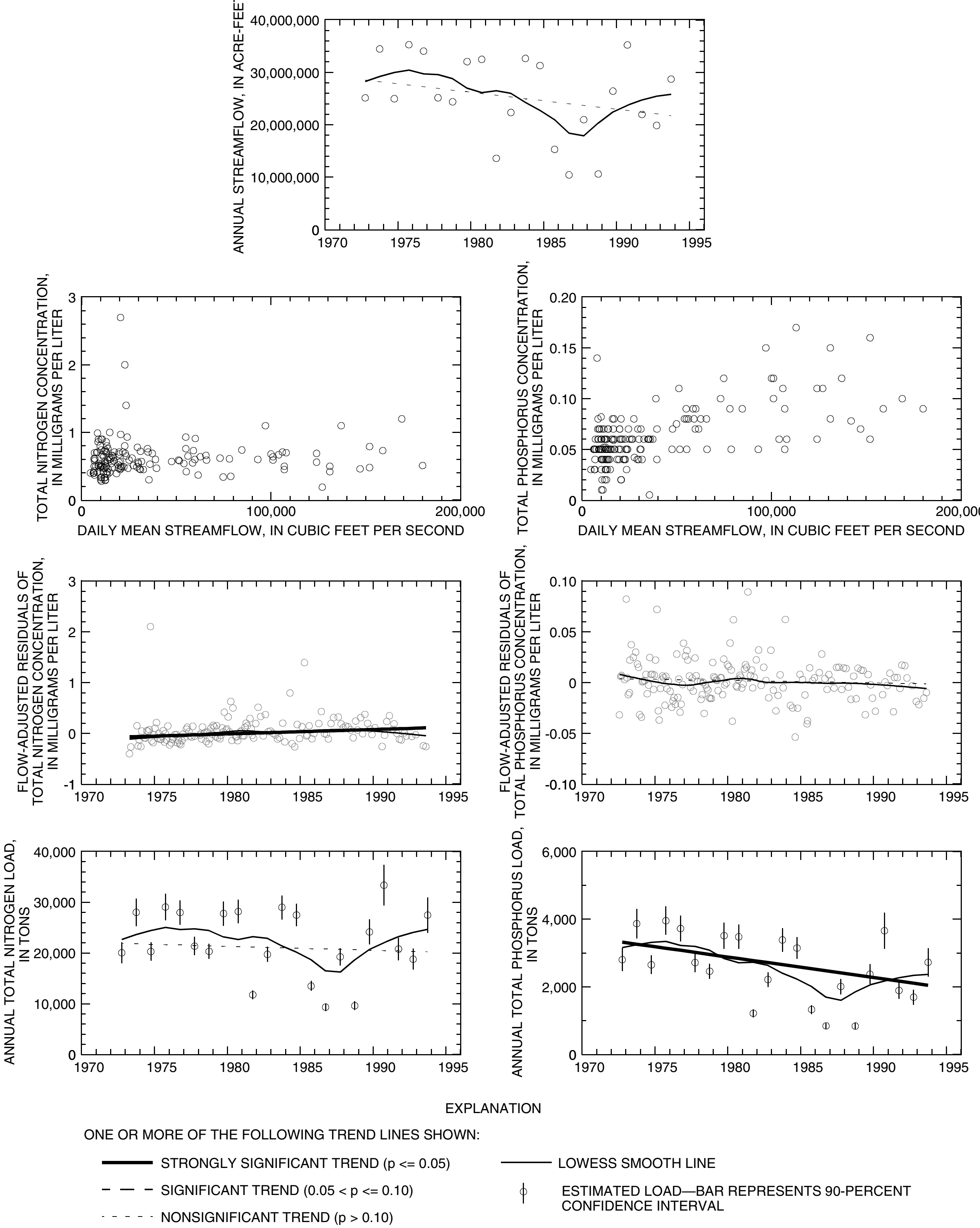


Figure 28. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Alabama River, Ala. (ALA) (02429500).

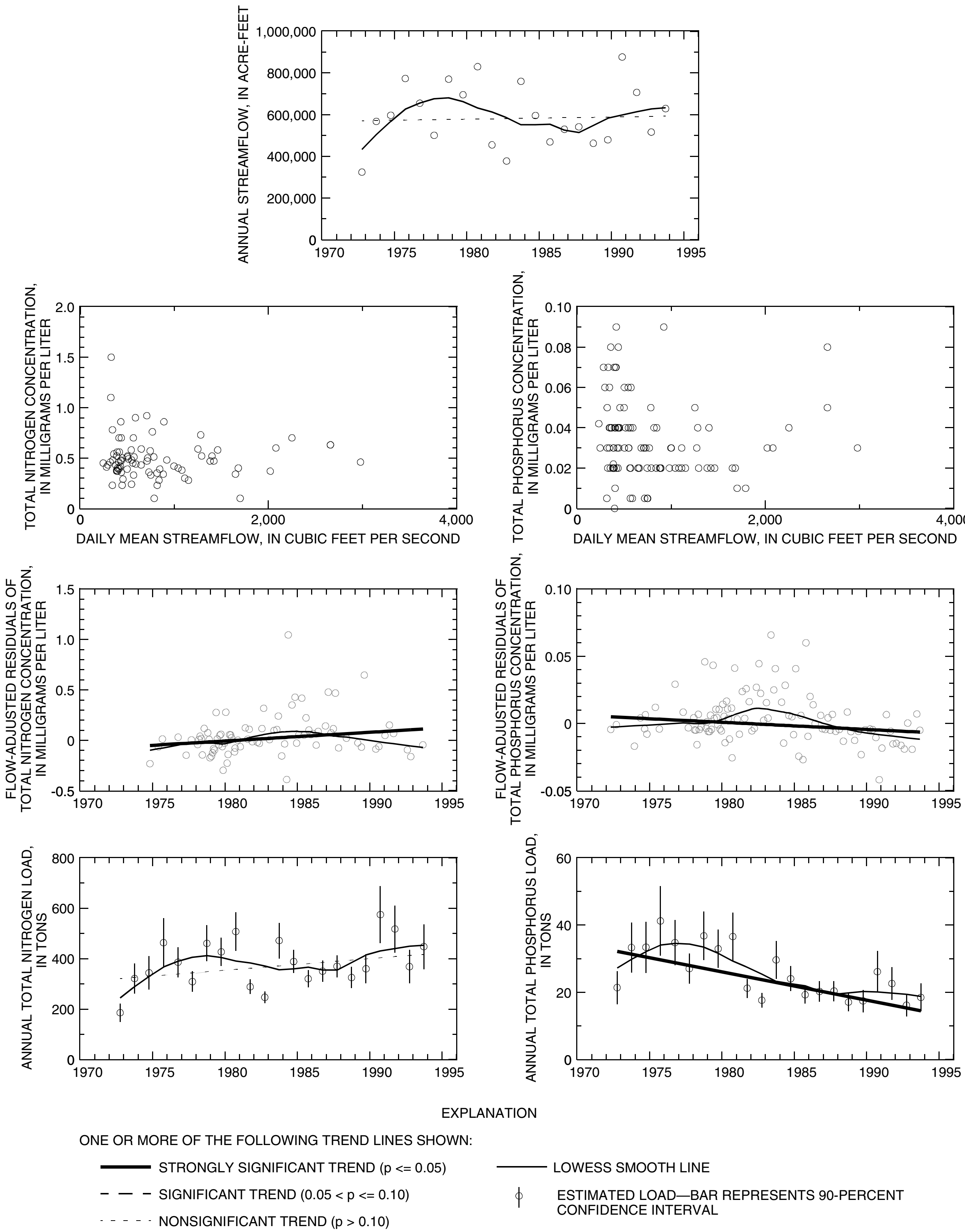


Figure 29. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Perdido River, Fla. (PER) (02376500).

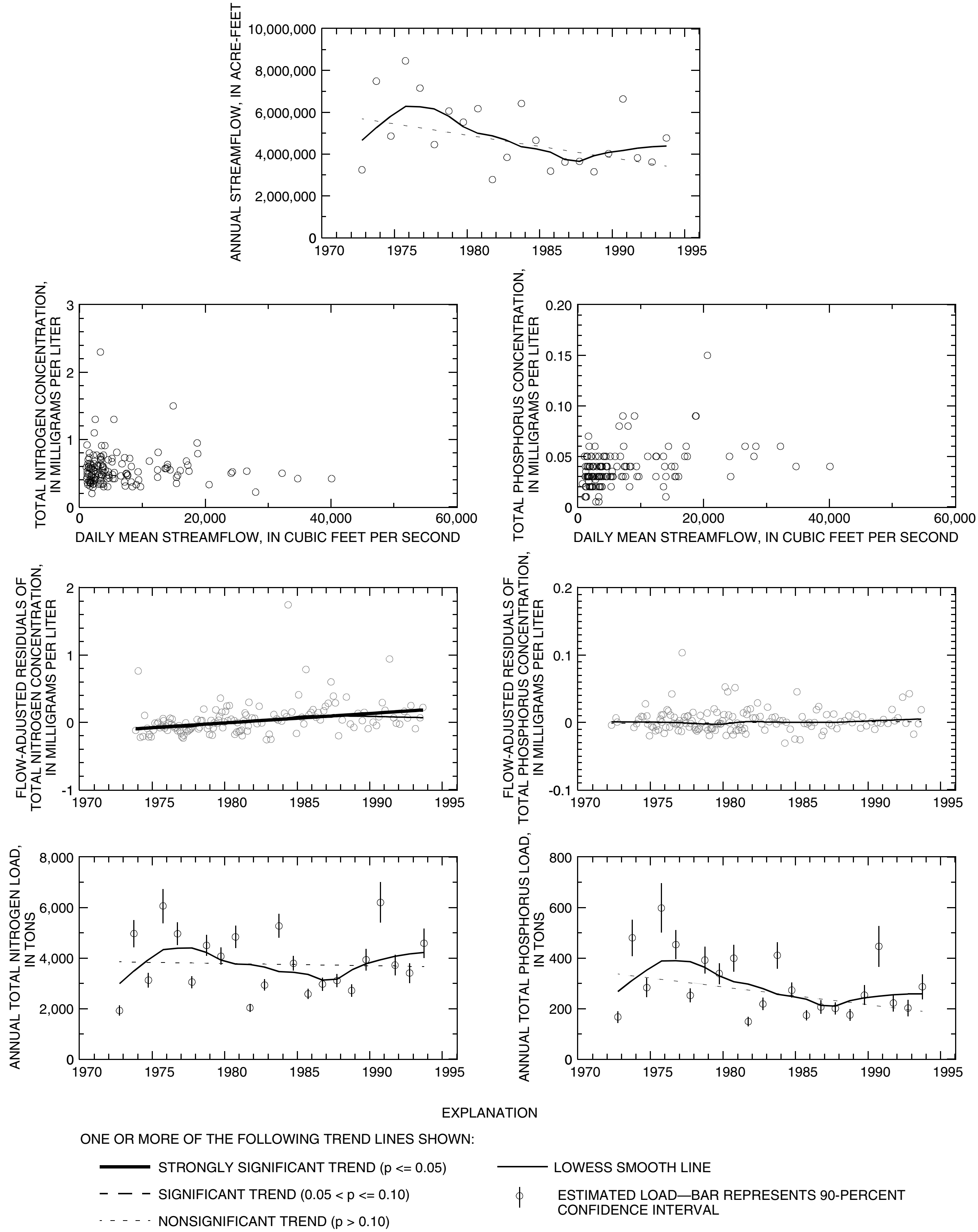


Figure 30. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Escambia River, Fla. (ESC) (02375500).

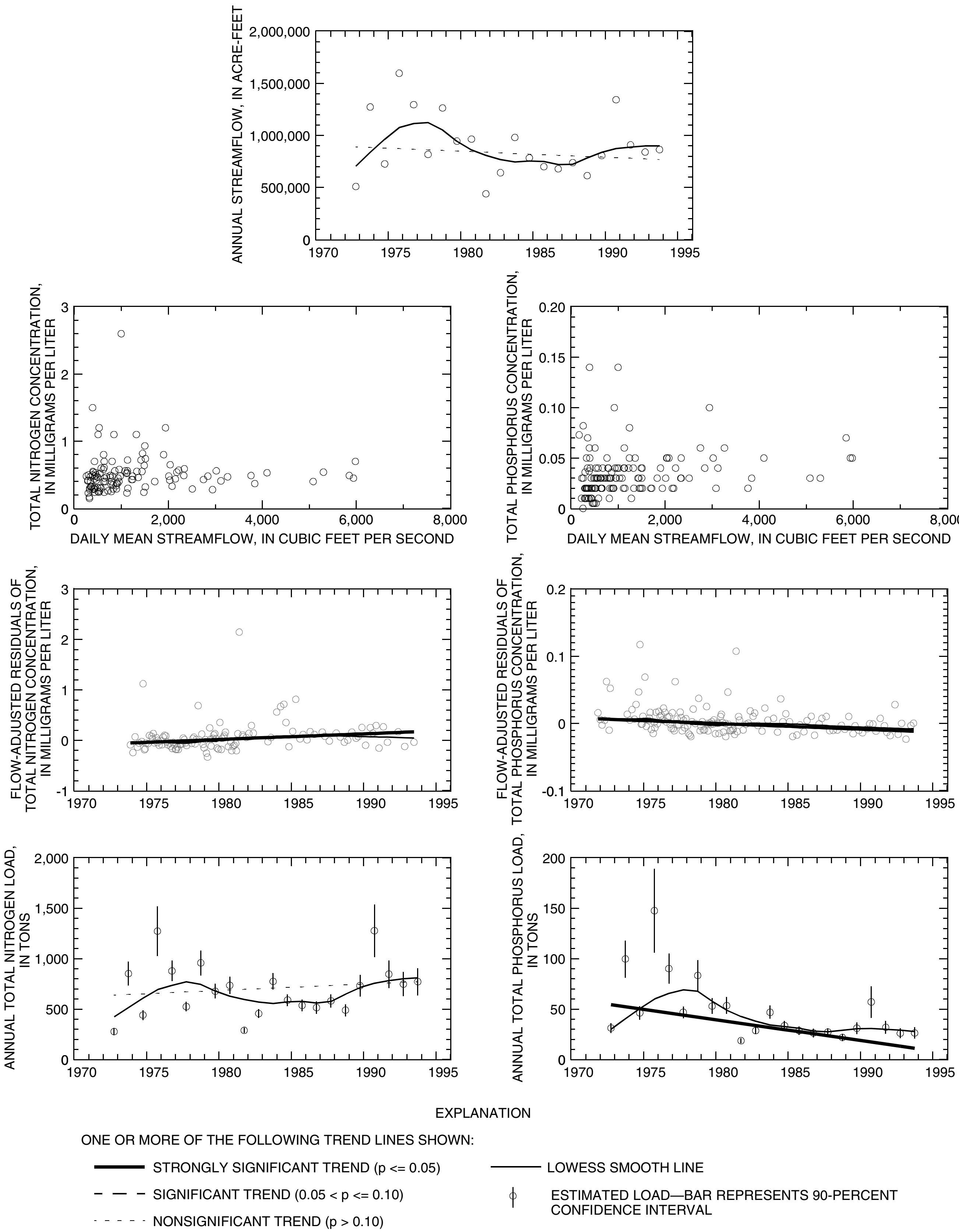


Figure 31. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Yellow River, Fla. (YEL) (02368000).

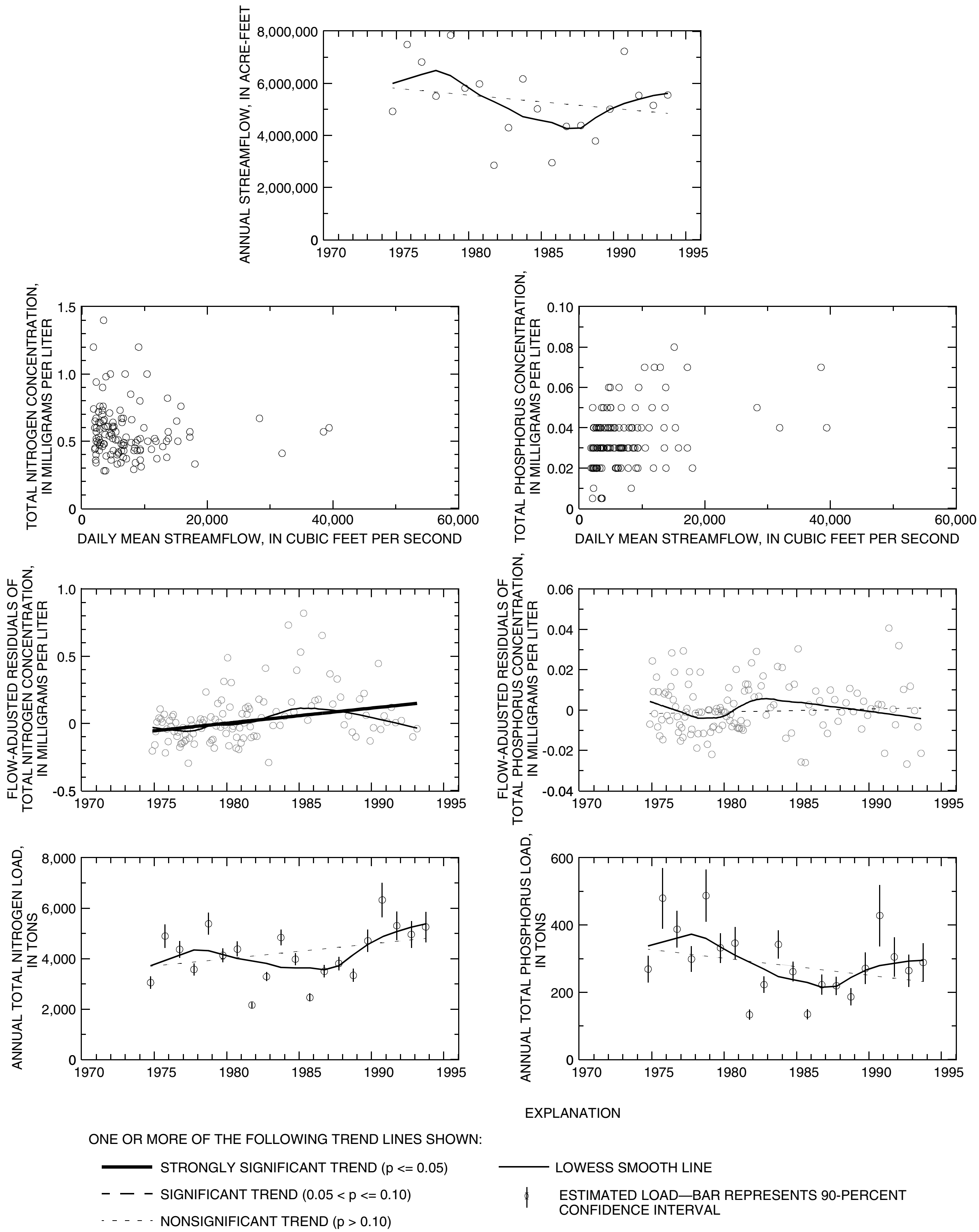


Figure 32. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Choctawhatchee River, Fla. (CHO) (02366500).

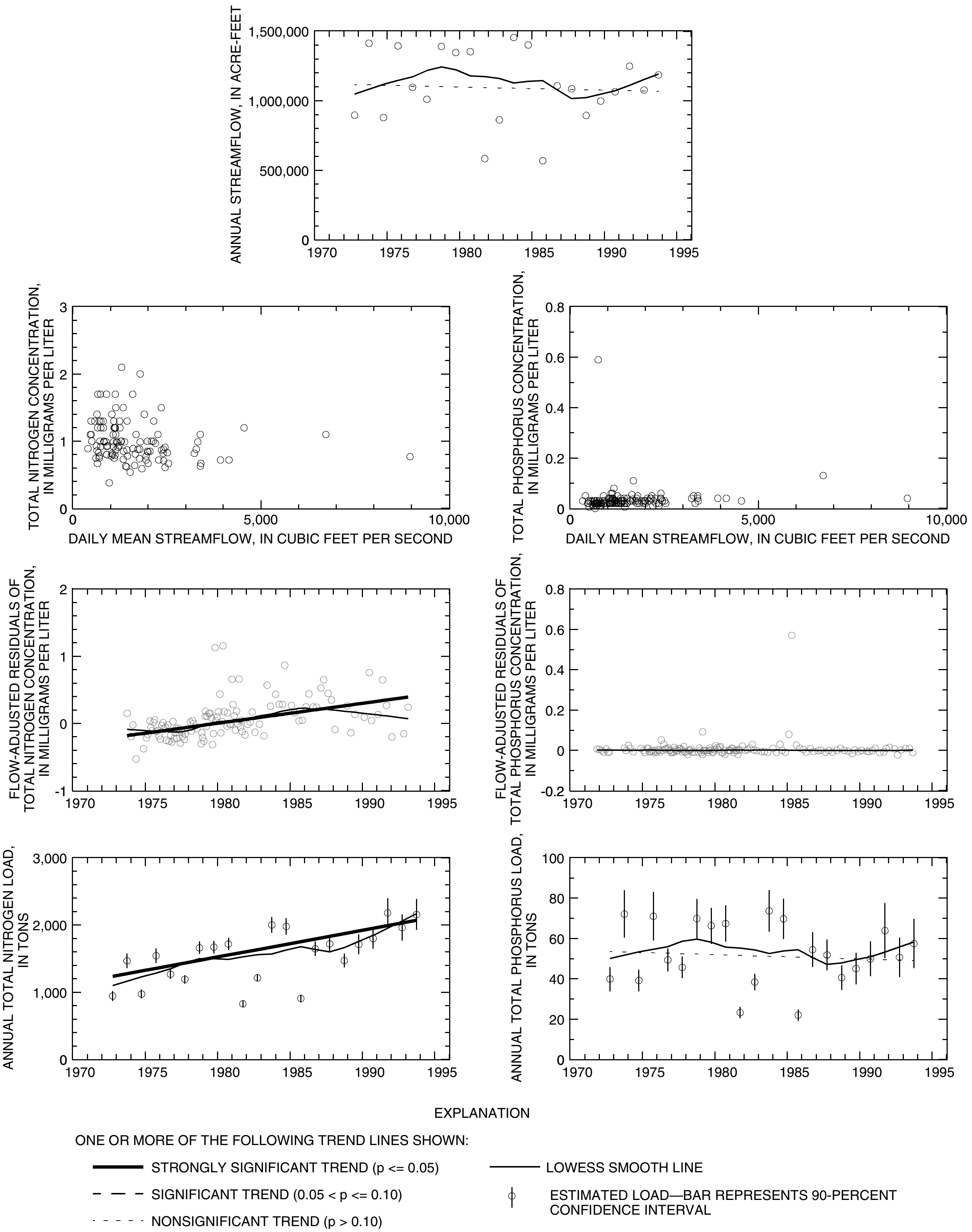


Figure 33. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Chipola River, Fla. (CHP) (02359000).

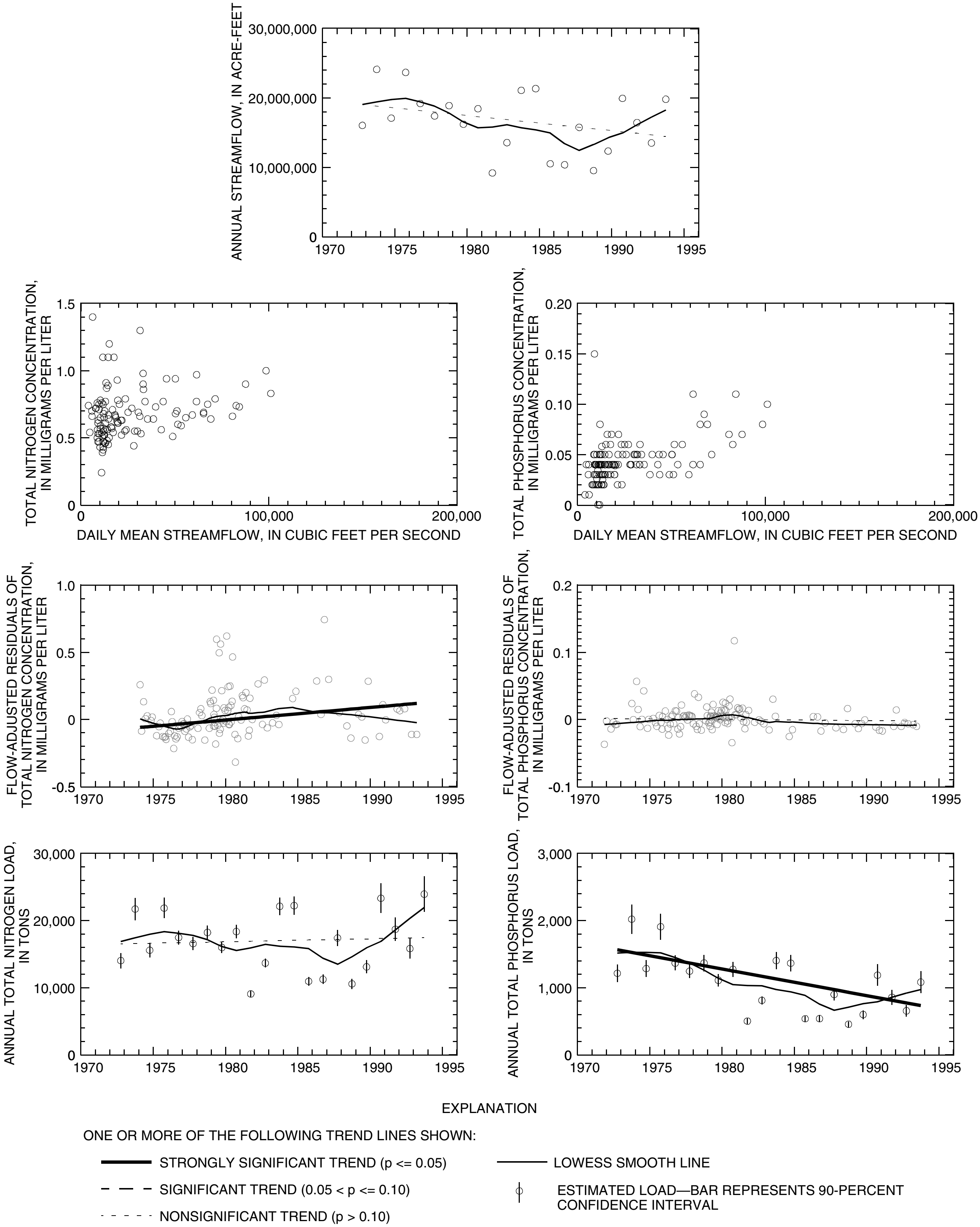


Figure 34. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Apalachicola River, Fla. (APA) (02358000).

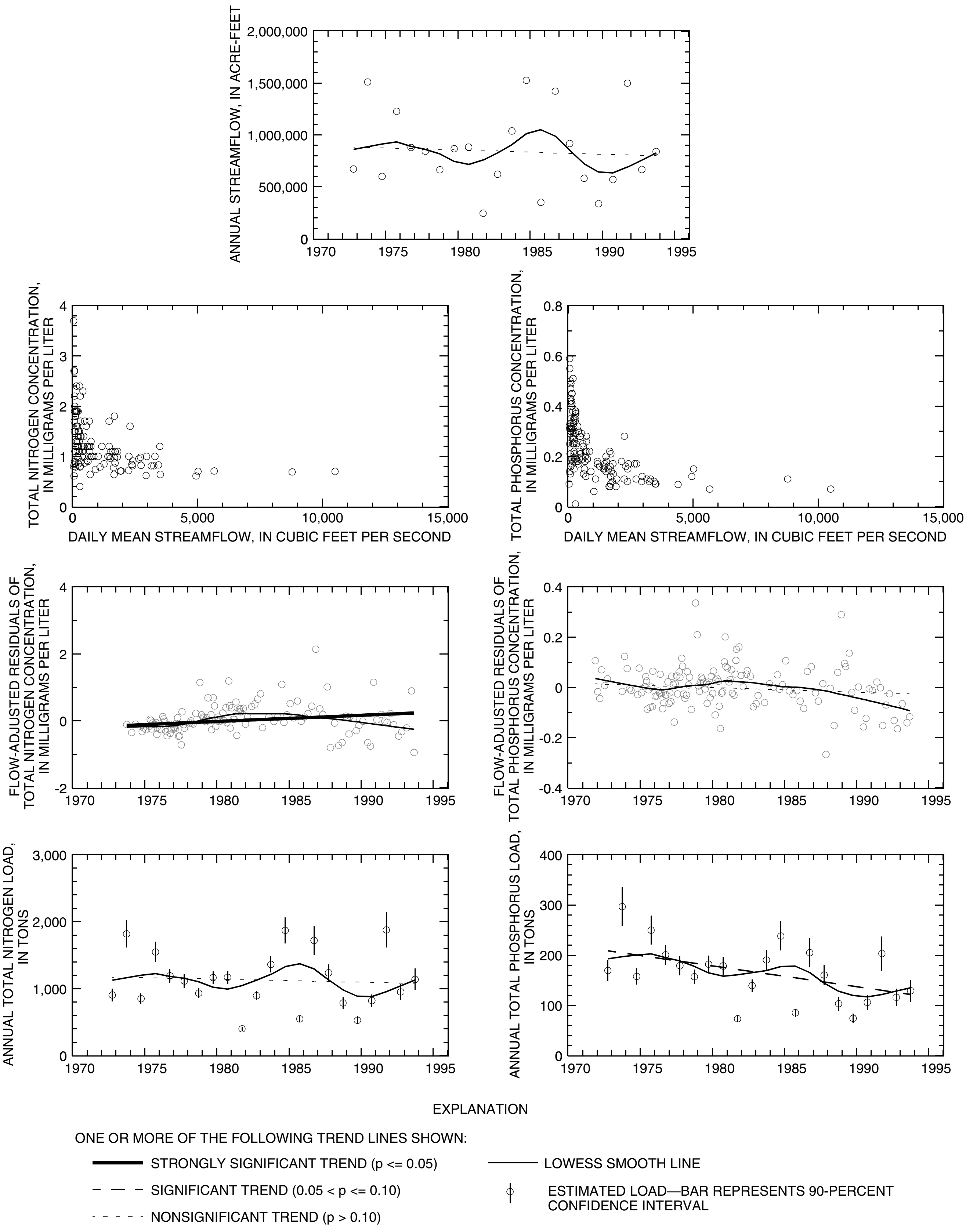


Figure 35. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Ochlockonee River, Fla. (OCH) (02329000).

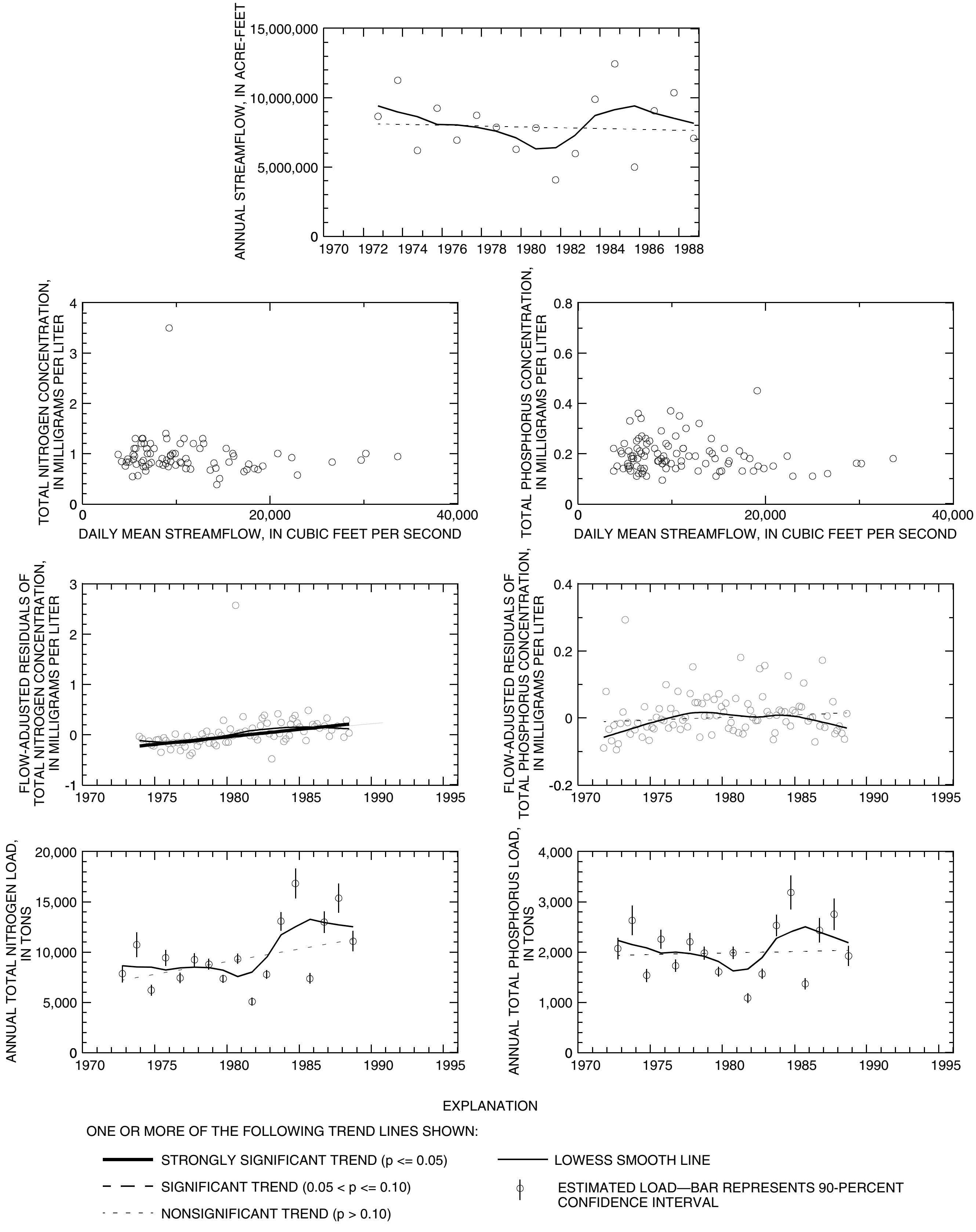


Figure 36. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Suwannee River, Fla. (SUW) (02323500).

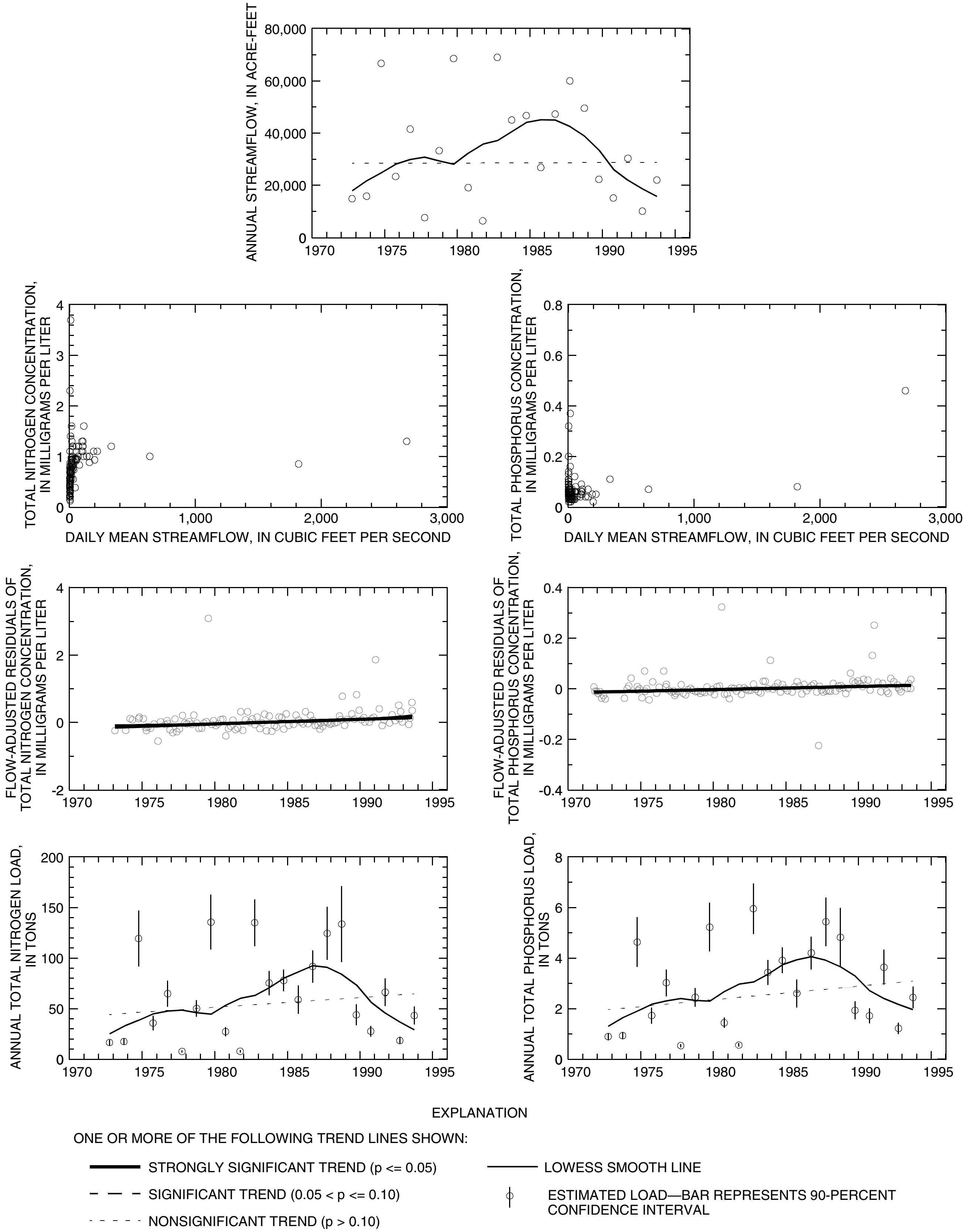


Figure 37. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Anclote River, Fla. (ANC) (02310000).

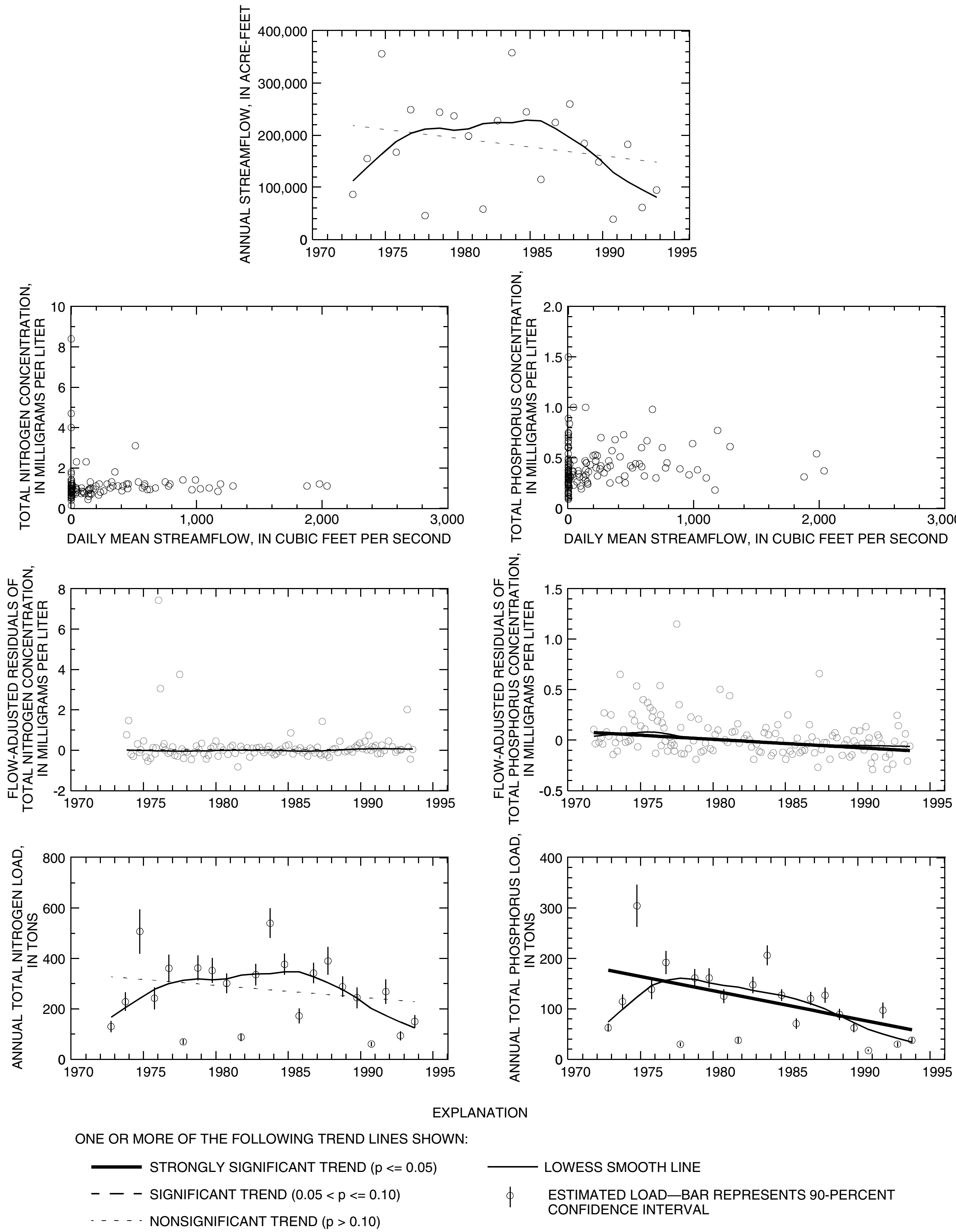


Figure 38. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Hillsborough River, Fla. (HIL) (02304000).

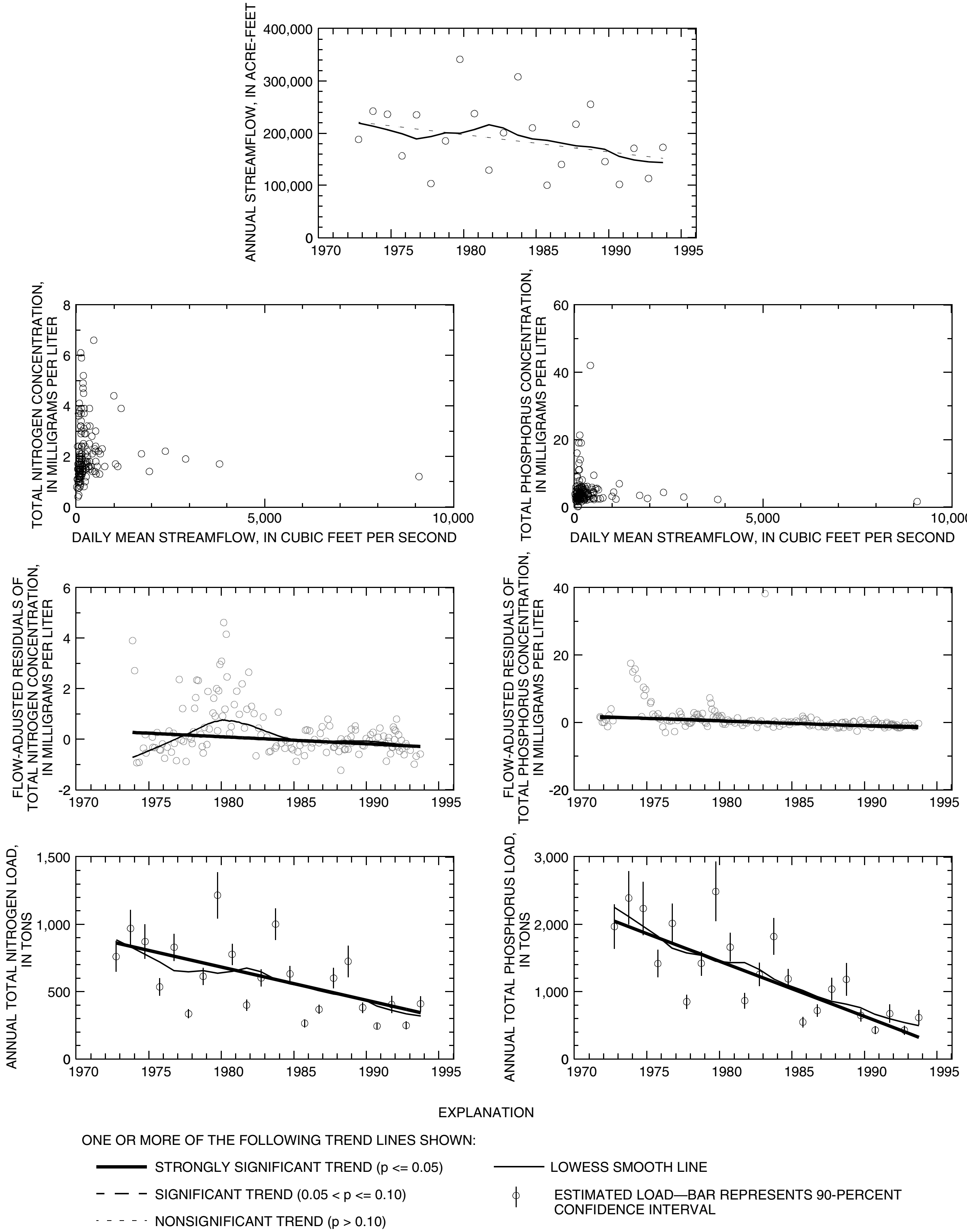


Figure 39. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Alafia River, Fla. (ALF) (02301500).

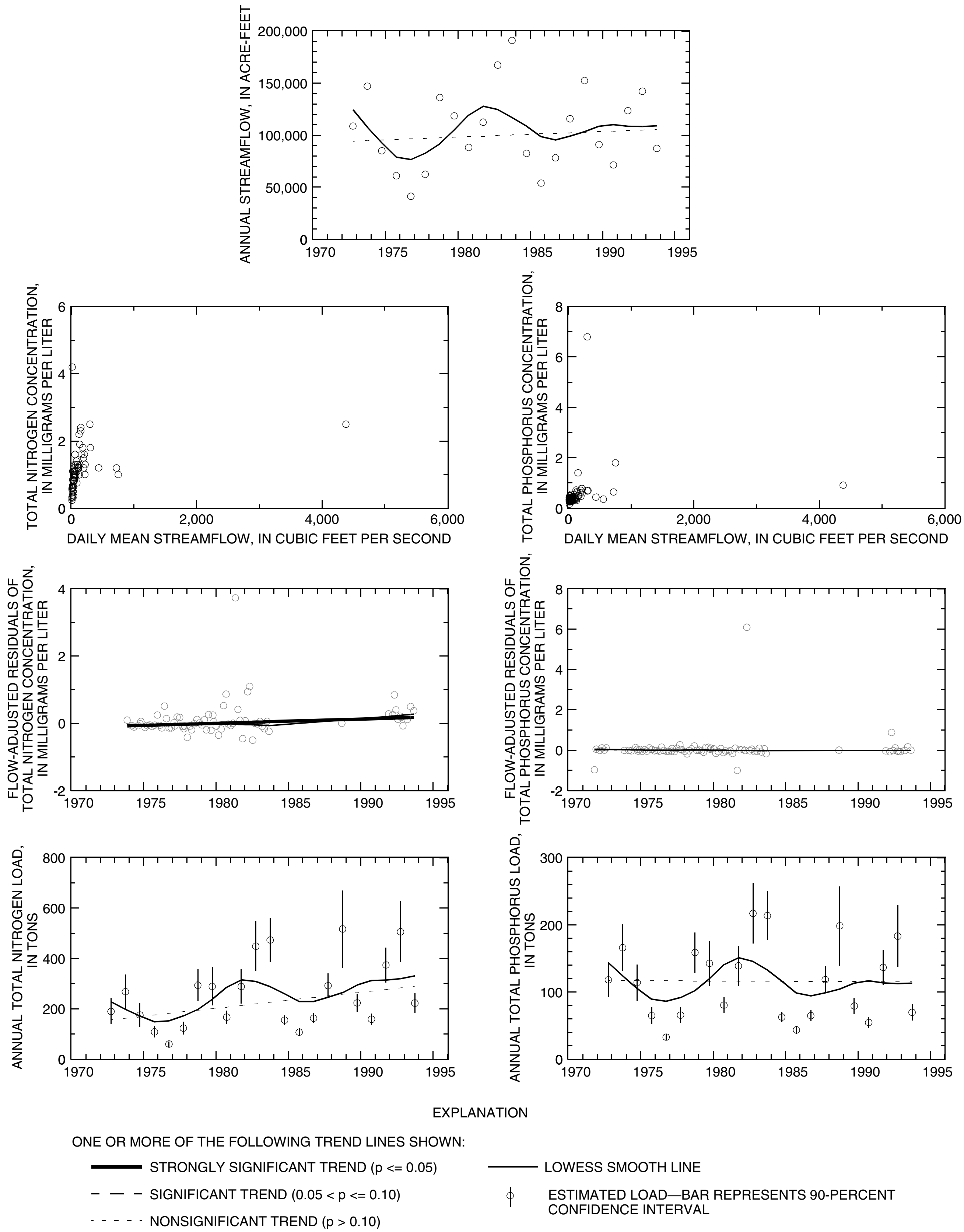


Figure 40. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Little Manatee River, Fla. (MAN) (02300500).

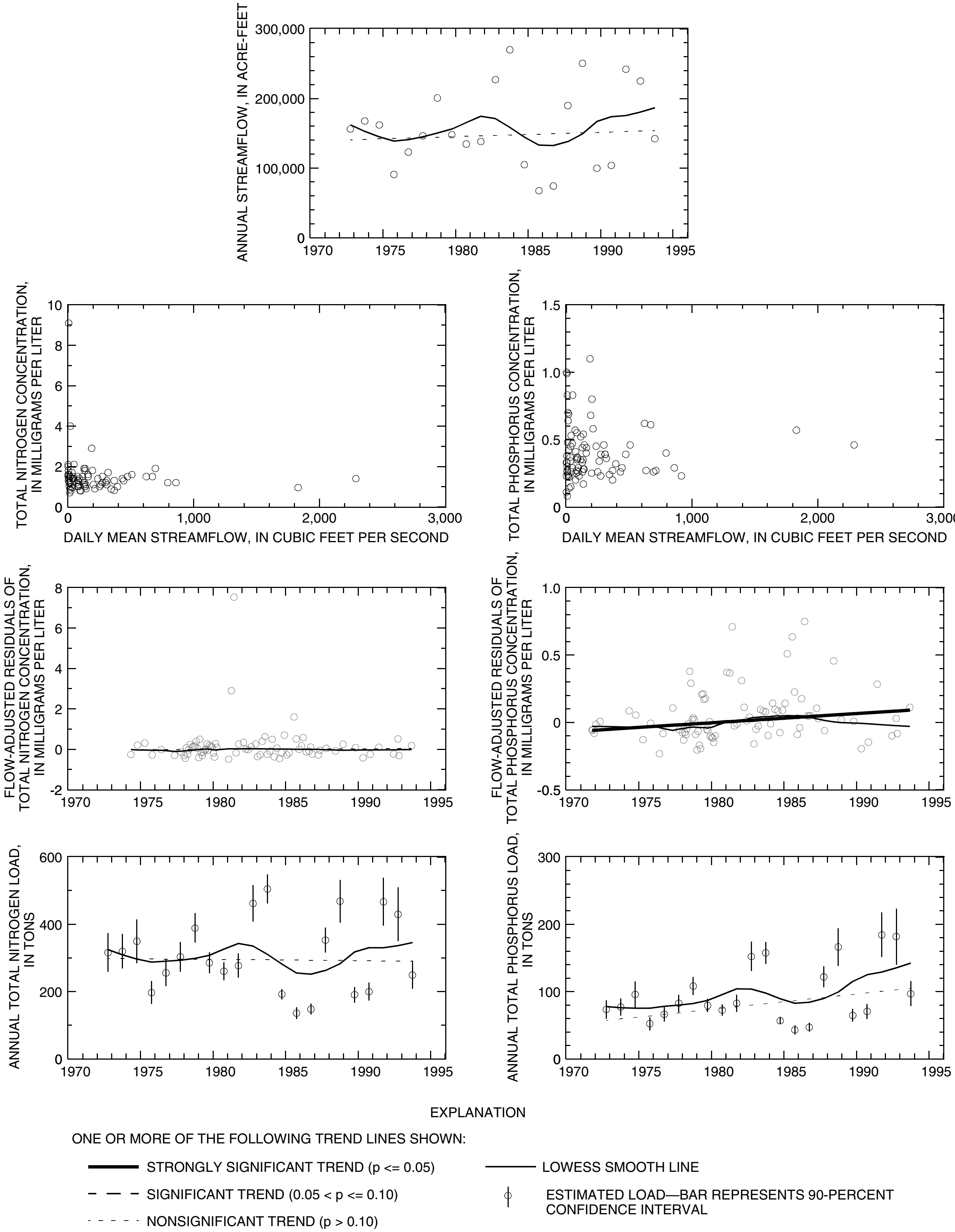


Figure 41. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Myakka River, Fla. (MYA) (02298830).

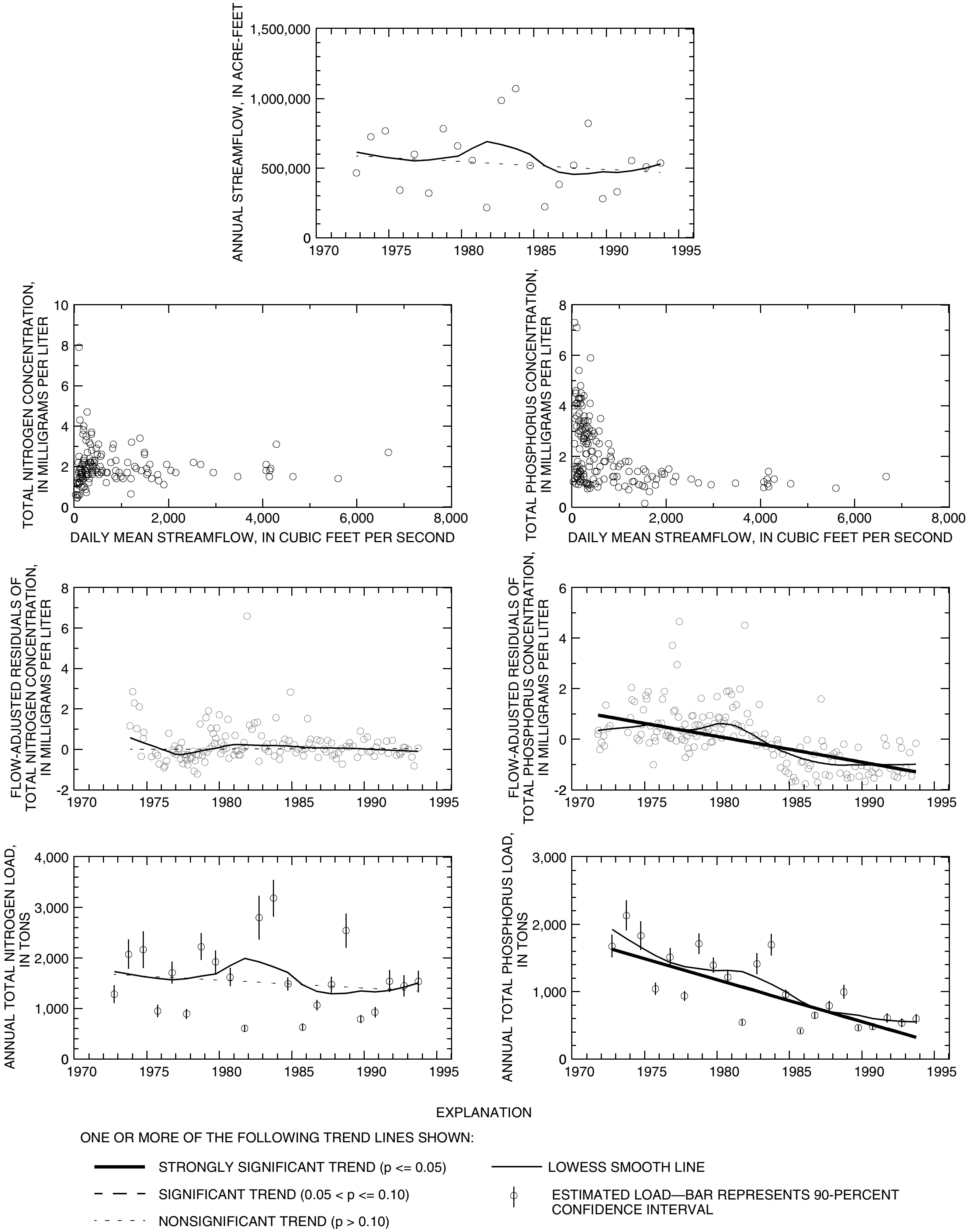


Figure 42. Relation of total nitrogen and total phosphorus concentration to daily mean streamflow and temporal trends in annual streamflow, in flow-adjusted residuals of total nitrogen and total phosphorus concentration, and in estimated annual total nitrogen and total phosphorus loads for Peace River, Fla. (PEA) (02296750).