SOURCES OF TRENDS IN WATER-QUALITY DATA FOR SELECTED STREAMS IN TEXAS, 1975–89 WATER YEARS

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PLATE

[Plate is in pocket]

FIGURES

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	3,785	kiloliter per day
square mile (mi^2)	2.590	square kilometer
ton per day (ton/d)	907.2	kilogram per day

Abbreviations:

BOD, biochemical oxygen demand
mg/L, milligram per liter
NO_2, nitrite
NO_3, nitrate
SO_4, sulfate
WTP, wastewater treatment plant

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Abstract

Sources of trends in water-quality data for selected streams in Texas for the 1975–89 water years were investigated in this study. The investigation of sources was confined to distinct geographic patterns in the trend indicators for one constituent or for a group of related constituents.

The probable source of trend patterns in nutrients and measures of oxygen in the Trinity River Basin was changes in the wastewater treatment facilities in the Dallas-Fort Worth metropolitan area. A pattern of increased concentrations of inorganic constituents in the upper Colorado River Basin resulted from emergency releases of water from the Natural Dam Lake, a salinity control structure. Trend patterns in inorganic constituents in the Rio Grande Basin were a result of increasing concentrations in the Pecos River and, to a lesser extent, the Rio Grande above the Amistad Reservoir, combined with the effects of reservoir regulation. A pattern of increasing concentrations of organic plus ammonia nitrogen and ammonia nitrogen was detected for the 1975–86 water years for stations with low concentrations (generally less than 5 milligrams per liter) of these nitrogen species. The trends were no longer evident when the period of trend analysis was extended to the 1989 water year. A positive bias in the data caused by the addition of mercuric chloride tablets to preserve nutrient samples during 1980–86 was the probable source of this trend pattern. A pattern of increasing concentrations in dissolved sulfate in the eastern part of the State was a result of a positive bias in the analytical results of a turbidimetric method of sulfate analysis. The source of a statewide pattern of increased pH in streams could not be identified.

INTRODUCTION

Trend analysis is a method used to estimate the overall change in long-term water-quality data for a selected period. A trend indicator is used on a map to represent the direction of monotonic change of constituent concentrations or physical properties in streams as an up arrow, a down arrow, or a dot. An upward-pointing arrow indicates increasing concentrations, a downward-pointing arrow indicates decreasing concentrations, and a dot indicates that no change in concentration was detected. The single trend indicator provides information for that site only, but when combined with the indicators from other sites for the same constituent and the same period, provide useful spatial information about the trends. A map of trend indicators from many sites will show geographical areas of streams or rivers with increasing or decreasing concentrations. Comparable spatial patterns of trend indicators in other constituents might provide further evidence that an area of related trends exists and, possibly, some idea of the potential source of the related trends. This approach to trend analysis is especially useful for large data bases with many sites and many constituents. Detailed examination of the time series data for each site for each constituent is time consuming and might not show important spatial relations. The use of trend patterns to determine which constituents and areas to examine in more detail is a practical way to use trend analysis with large data bases.

Long-term water-quality data for streams in Texas are abundant. A network of water-quality stations on principal streams has been operated in Texas for more than 20 years by the U.S. Geological Survey in cooperation with the Texas Water Development Board and other State, Federal, and local agencies. Initial results of trend analysis of water-quality data from selected stations (pl. 1) has been completed and described by Schertz (1990). This report discusses the source of selected geographic trend patterns shown in the initial trend results.

Background

A previous study of trends in water-quality data for selected streams in Texas (Schertz, 1990) provided the basis for much of the information for this study; a summary of the results is given here.

Water-quality data from 185 stations in Texas that had at least 10 years of record between 1968 and 1986 were used for the trend study. Inorganic, nutrient, trace metal, and pesticide constituents and physical properties of water were included in the study data base. The periods examined for trends were the 1968–86 water years and 1975–86 water years. Stations included in the analysis for each period had sufficient data to represent that period. One hundred and seventeen stations had sufficient data for the 1975–86 water years (Schertz, 1990, pl. 1). Trend indicators from this period were shown on maps for each constituent for each station, and the maps were examined for geographical trend patterns.

Several geographical trend patterns were evident for inorganic constituents for the 1975–86 water years. Areas of increasing concentrations in the upper reaches of the Red, Brazos, and Colorado River Basins and increasing concentrations in the Rio Grande Basin are evident for almost all dissolved ions, total hardness, and specific conductance. Increases in sulfate concentrations in streams in the eastern coastal region of the State were detected where trends in the other dissolved ions showed either decreasing concentrations or no trends.

Distinct patterns of trend indicators were detected in the Trinity River Basin for related nutrient and dissolved oxygen constituents. Although not quite as distinct, there was evidence of related trend patterns in the same constituents in the San Antonio River Basin.

Increasing values of pH are evident for streams throughout the State. An increase in pH indicates that the water is more alkaline, but trends in alkalinity indicated predominantly decreasing values.

Concentrations of selected trace elements and pesticides were generally small and often less than the analytical detection limit. Few trends in concentrations were detected for any of the constituents and none of the constituents demonstrated any geographical trend patterns.

Purpose and Scope

This is the third and final report of an investigation of temporal and spatial trends in the water quality of Texas streams and rivers. The scope of the study included (1) analysis of the data for trends, (2) evaluation and documentation of the methods used for data analysis, and (3) examination of the data, trends, and ancillary data to determine possible sources of the trends.

The analysis of the data for trends was presented in Schertz (1990). The evaluation and documentation of the methods used for data analysis were presented in Schertz and others (1991). This report addresses the examination of the data, trends, and ancillary data to determine possible sources of the trends.

Method of Study

The results of trend analysis yield a trend slope and a p-value. The trend slope is an estimate of the rate of change in the data units per year. The p-value is the attained level of significance of the trend test which is defined as the probability of incorrectly rejecting the null hypothesis of no trend. Trend indicators, which are up arrows, down arrows, and dots shown on maps presented in this report, are used to represent the direction of trend slopes that have a p-value less than or equal to 0.1. The investigation of sources of trends in water-quality data in Texas was confined to distinct spatial patterns in the trend indicators for one constituent or for a group of related constituents. Generally, the trend patterns selected for discussion in this report could be attributed to an identifiable source. An exception was made for the statewide trend pattern in pH. Although a source for this pattern was not identified, the pattern of trend indicators was so distinct that discussion on the efforts to identify the source is warranted.

The period of study was extended from the 1975–86 water years to the 1975–89 water years for this investigation. Maps showing the statistically significant ($p \leq 0.1$) trend indicators from the 1975–89 period were compared to maps of the significant trend indicators from the 1975–86 period. Generally, the trend patterns remained the same for the 1975–89 period.

The procedures used to select the sites and data for trend analysis are described in Schertz (1990). The techniques used for trend analysis of water-quality data that had seasonal variations, streamflow variations, missing values, and censored data also are discussed in Schertz (1990) and, in more detail, in Schertz and others (1991). As described in these previous studies, trend analysis is applied to both unadjusted and flow-adjusted data. The criteria in table 1 are used to determine which trend result will be reported as the "best trend result." The best trend result is represented by an indicator on the trend maps and is also listed on the tables of trend results in this study.

A trend slope represents the overall change in a data record as a linear change for the selected period. This slope does not provide any information about the short-term, nonlinear variations in the data, but these short-term variations are critical to understanding the source of trends. A smoothing procedure (Cleveland, 1979) was used to fit a curve to water-quality time-series data to highlight short-term variations in the data. Where possible, data from other sources were used to help explain these short-term variations in the data.

The most common purpose of trend analysis is to find changes in the data that are due to some change in the environment. However, a trend might result not only from a change in the environment, but also from a change in any of the many components of sample collection, processing, and analysis. Therefore, information on the accuracy of water-quality measurements was examined for evidence of change that could have resulted in water-quality trends.

SOURCES OF TRENDS

The following discussions on sources of trends begin by describing the geographic pattern of trend indicators from Schertz (1990) that led to further investigation. Discussion of the evidence used to determine the probable source of the trend pattern follows. Finally, specific difficulties or successes with the interpretation of the trends are described. An important part of this effort to further the use of long-term water-quality data is to understand what possible complications might be encountered.

Wastewater Treatment Plant Effluent

Spatial patterns of trend indicators in the Trinity River Basin near the Dallas-Fort Worth metropolitan area showed increasing concentrations of dissolved oxygen, percent saturation of dissolved oxygen, and nitrite plus nitrate and decreasing concentrations of biochemical oxygen demand (BOD), ammonia nitrogen, organic nitrogen, ammonia plus organic nitrogen, and total phosphorus for the 1975–86 water years. The same patterns persisted in the trend results for the 1975–89 water years. Goals of wastewater treatment include decreasing the BOD and converting ammonia and other forms of nitrogen to nitrate. These constituents and the direction of the trends indicate that changes in municipal waste treatment could be the source of the trends. Maps of the trend indicators for concentrations of BOD, dissolved oxygen, nitrite plus nitrate, and ammonia nitrogen are shown in figure 1.

Table 1. *Criteria for selecting the best trend result for uncensored constituents*

[--, not applicable]

Trend code (tables 2, 4, 5, 7, 9, 11 and 13)	Significant[1] correlation of concentration to discharge	Significant[1] correlation of flow-adjusted concentration to discharge	Significant[1] flow-adjustment model	Best trend result
U	No	--	--	Unadjusted concentrations
F	Yes	No	Yes	Flow-adjusted concentrations
**	Yes	Yes	--	Unadjusted concentrations
**	Yes	--	No	Unadjusted concentrations

[1] Selected level of significance is 0.10.

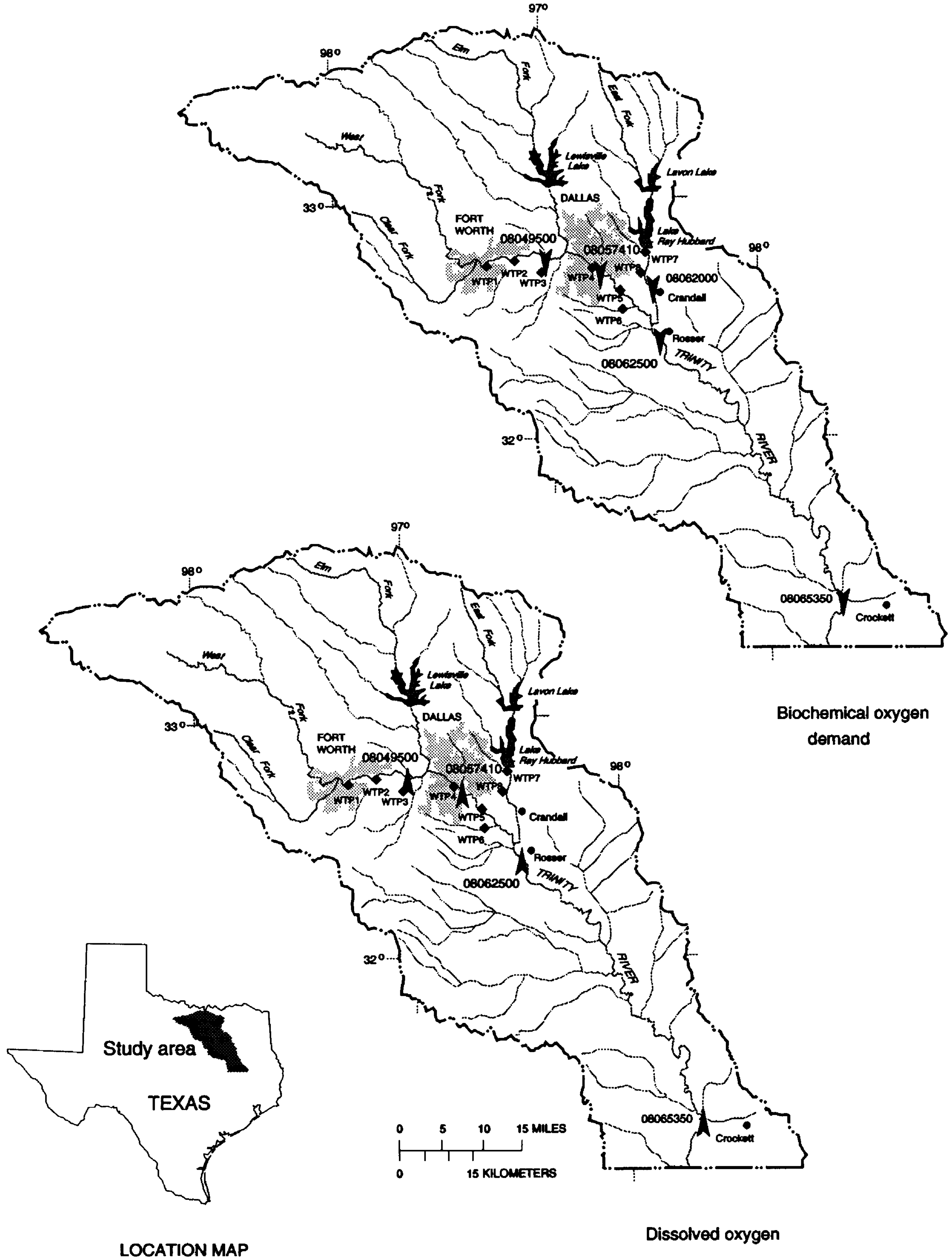

Figure 1. Trends in concentrations of biochemical oxygen demand, dissolved oxygen, nitrite plus nitrate, and ammonia at selected sites in the Trinity River Basin for the 1975–89 water years.

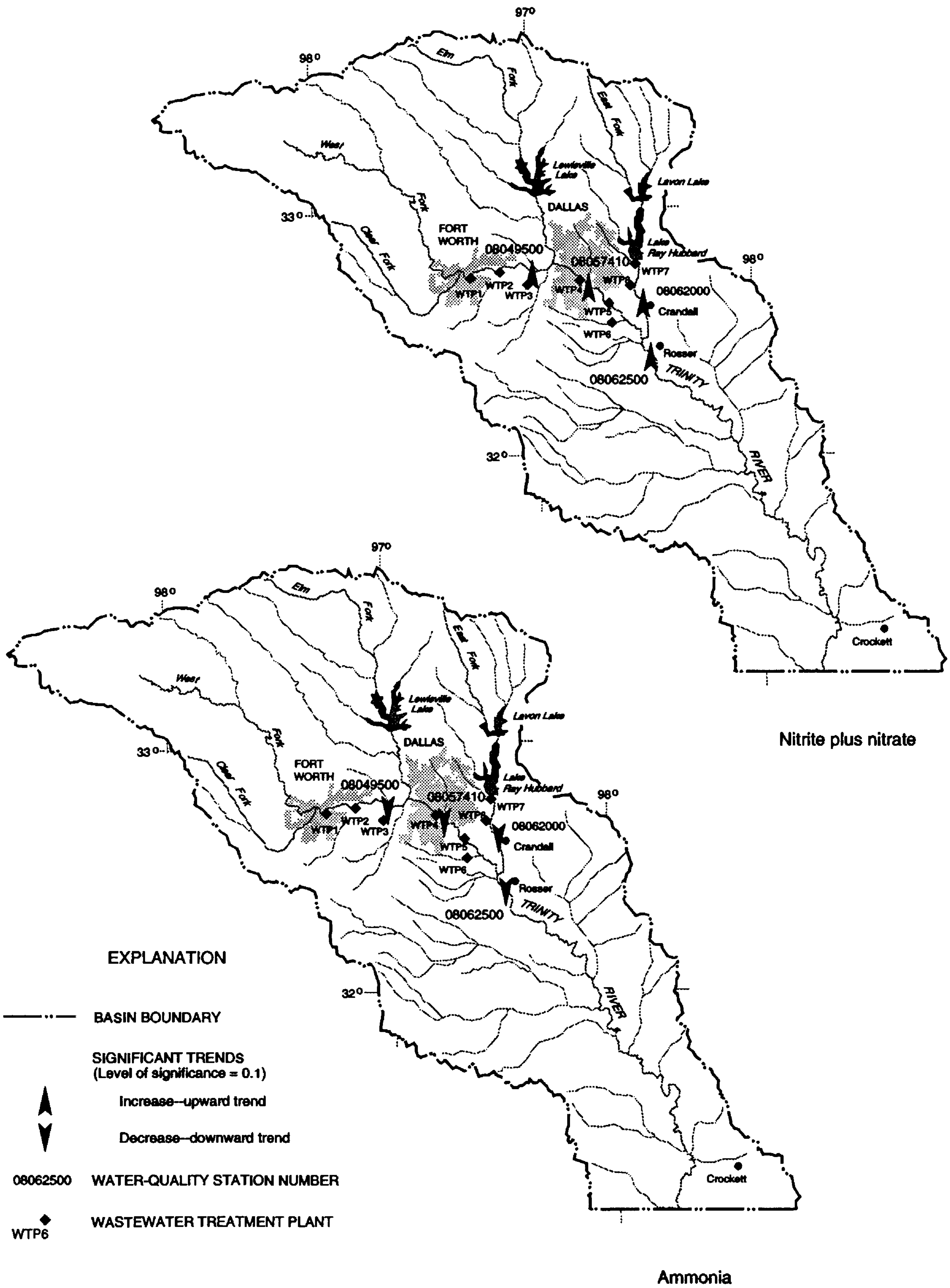

Figure 1. Continued.

Statistical summaries of the data and trend results of analysis for the constituents shown in figure 1 are listed in table 2.

Much of the flow in the Trinity River is controlled by releases from the numerous reservoirs in the basin, which have a combined storage capacity of approximately 6 million acre-ft. Reservoirs having about 3.5 million acre-ft of storage capacity are located upstream of Rosser, Texas. Lake Livingston, the largest reservoir in the Trinity River Basin, has a conservation storage capacity of 1.788 million acre-ft. Approximately two-thirds of the water use in the Trinity River Basin (7.30 Mgal/d) is from surface-water reservoirs and streams (L.F. Land, U.S. Geological Survey, written commun., 1991). Municipalities use about 75 percent of this water. An additional 280 Mgal/d is imported from other basins and about 90 Mgal/d is from ground water (L.F. Land, U.S. Geological Survey, written commun., 1991).

Approximately 60 percent of the water diverted from streams or reservoirs for municipal use is returned to the Trinity River as sewage effluent. Because of regulated flow from reservoirs and the large amount of water returned to the river as effluent, much of the flow in the Trinity River during the summer months is sewage effluent. The sum of the mean monthly effluent from all wastewater treatment plants and the mean monthly streamflow at the Trinity River near Rosser station (08062500), which is downstream from all the plants, are shown for water years 1975–89 in figure 2. The sum of the mean monthly effluent from the wastewater treatment plants is not an exact representation of the effluent that reaches the Rosser station, as it does not account for losses in streamflow between the plants and the station. But the estimate clearly demonstrates that sewage effluent is often a predominant source of the streamflow in the Trinity River and, therefore, a predominant factor in the overall quality of the Trinity River.

The Trinity River Basin is the most populated basin in Texas. Population in the upper part of the Trinity River Basin, and mainly in the Dallas-Fort Worth metropolitan area, has increased greatly in the past 20 years. The population in the nine-county Dallas-Fort Worth Consolidated Metropolitan Statistical Area increased from 2.35 million in 1970 to about 3.75 million in 1990 (L.F. Land, U.S. Geological Survey, written commun., 1991).

In Texas, as in many areas of the Nation, population increases commonly have exceeded the ability of communities to adequately treat the increased municipal waste associated with the population increases. This was true for several of the major metropolitan areas in Texas. In the mid- to late 1980's, new or improved treatment facilities were put on line in the Dallas-Fort Worth metropolitan area, Austin, and San Antonio. During 1969–71 the North Central Texas Council of Governments and its consultants developed the Upper Trinity River Basin Comprehensive Sewerage Plan. This plan recommended an areawide comprehensive sewerage system covering much of the upper Trinity River Basin that called for upgrading existing wastewater treatment facilities, closing outdated facilities, and constructing new facilities (Brush and Promise, 1990). The locations of the major wastewater treatment facilities that now discharge into the Trinity River system in the Dallas-Fort Worth metropolitan area are shown in figure 1. The treatment capacities of the facilities are listed in table 3.

A determination of the BOD of a stream generally is considered to be a useful way to express stream pollution loads (Hem, 1985). The results of a BOD determination are commonly expressed in terms of weight of oxygen consumed by microorganisms per unit volume of the sample. Monthly mean concentrations of BOD from the eight major wastewater treatment facilities in the Dallas-Fort Worth metropolitan area are shown in relation to the BOD concentrations measured at the nearest downstream station on the Trinity River (figs. 3–6). The locations of the stations on the Trinity River are shown in figure 1.

The Fort Worth Riverside facility (fig. 3) contributed significant BOD concentrations to the Trinity River until it was closed in 1979. Increases in BOD concentrations were evident at the Fort Worth Village Creek facility (fig. 3) from 1979 to 1981. Decreases in BOD concentrations in the Trinity River were first achieved in late 1981 and have generally been less than 10 mg/L since 1983. The closing of the Fort Worth Riverside Facility and the changes in the Fort Worth Village Creek facility are reflected in the BOD concentrations measured at the West Fork Trinity River near Grand Prairie station (08049500). Maximum concentrations in BOD were near 30 mg/L in 1978, decreased to about 15 mg/L in 1982, and have been less than 10 mg/L since 1984.

Monthly mean concentrations of BOD at the Dallas Central facility (fig. 4) ranged from 50 to 100 mg/L until 1977 when they decreased to generally less than 15 mg/L. Since 1987, the concentrations have

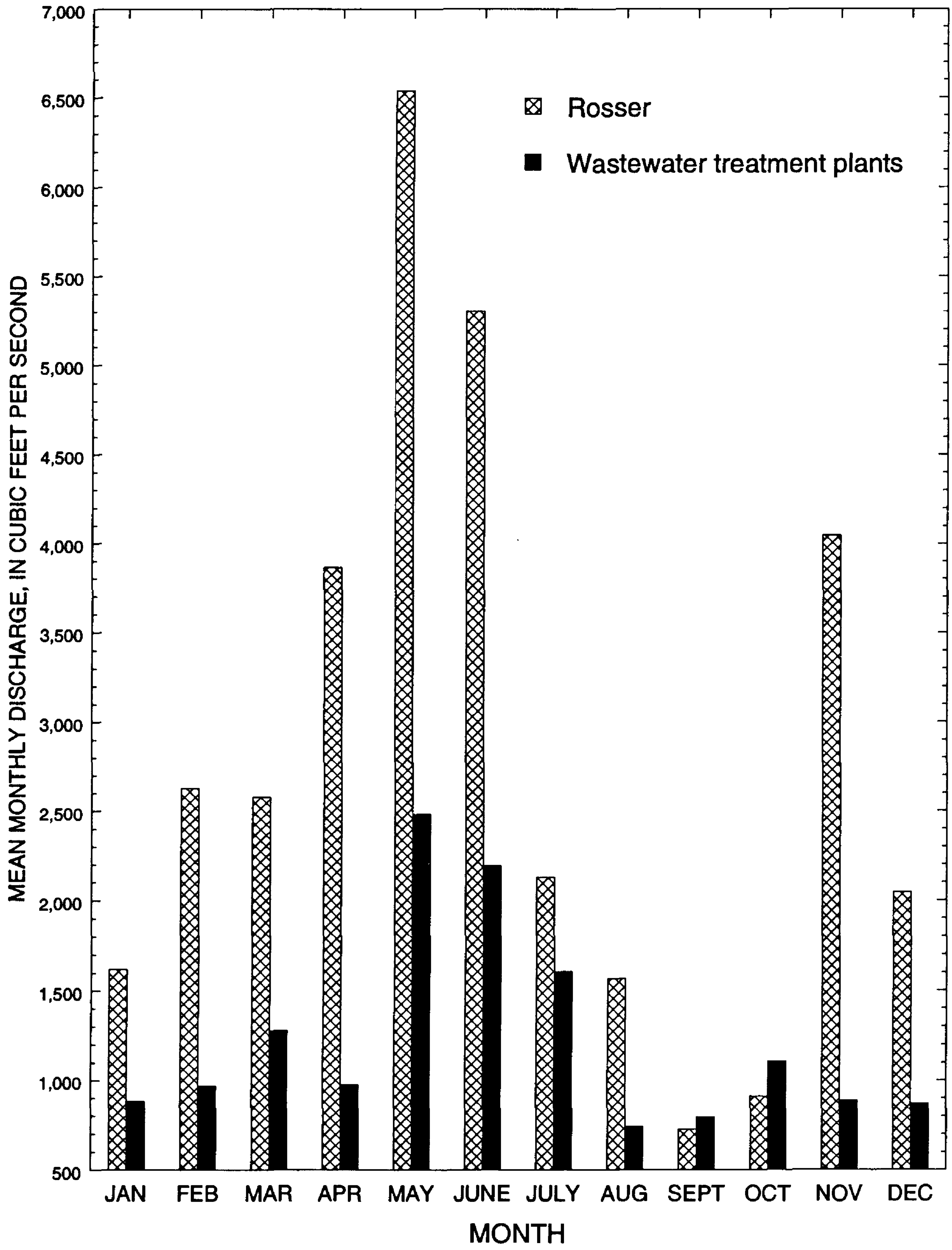

Figure 2. Mean monthly discharge at the Trinity River near Rosser, Texas, station (08062500) and the sum of the mean monthly effluent from the wastewater treatment plants in the area for 1975–89.

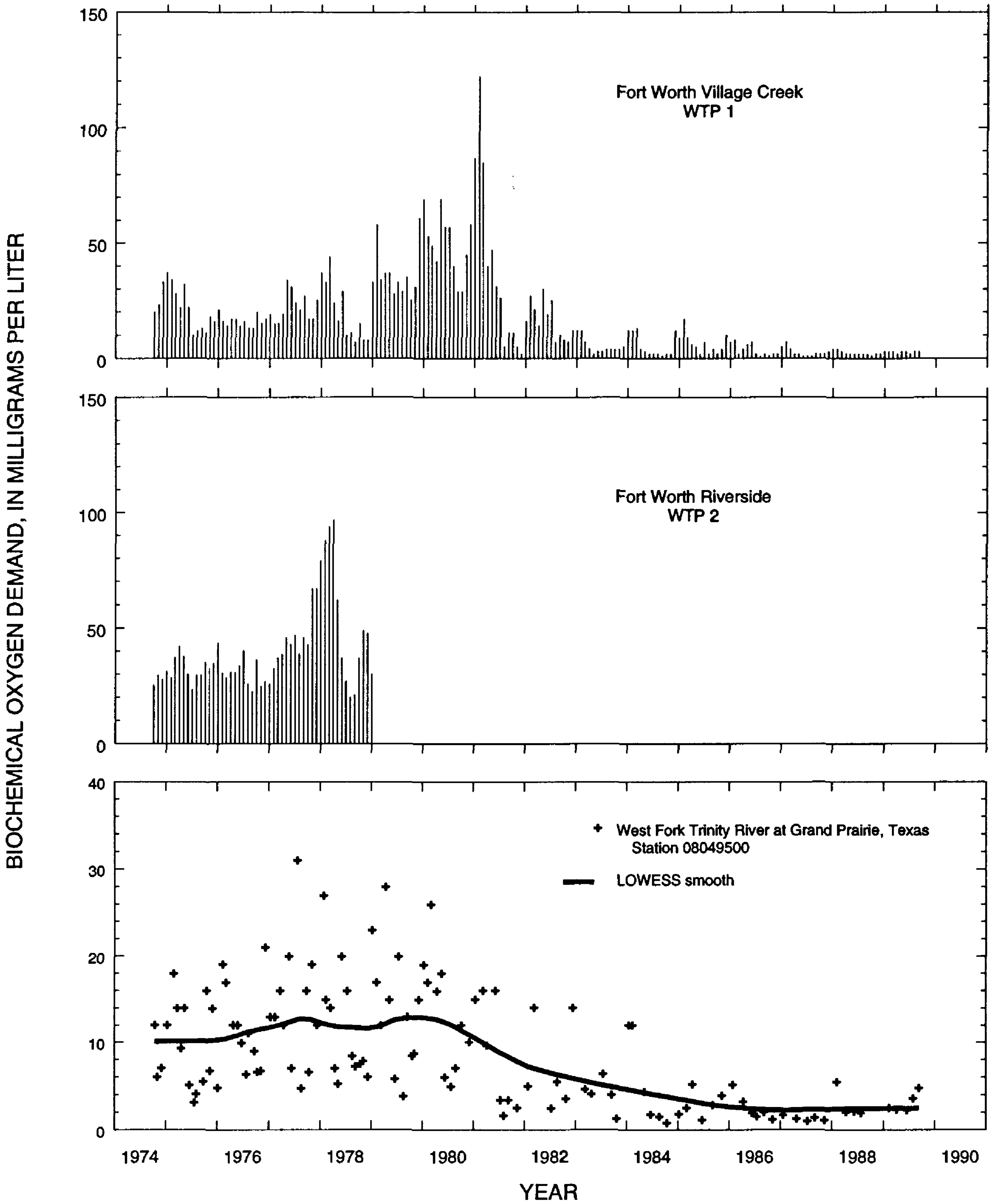

Figure 3. Monthly mean biochemical oxygen demand (BOD) concentrations in the effluent from wastewater treatment plants (WTP) Fort Worth Village Creek and Fort Worth Riverside and instantaneous BOD concentrations in the West Fork Trinity River at Grand Prairie, Texas, 1975–89 water years.

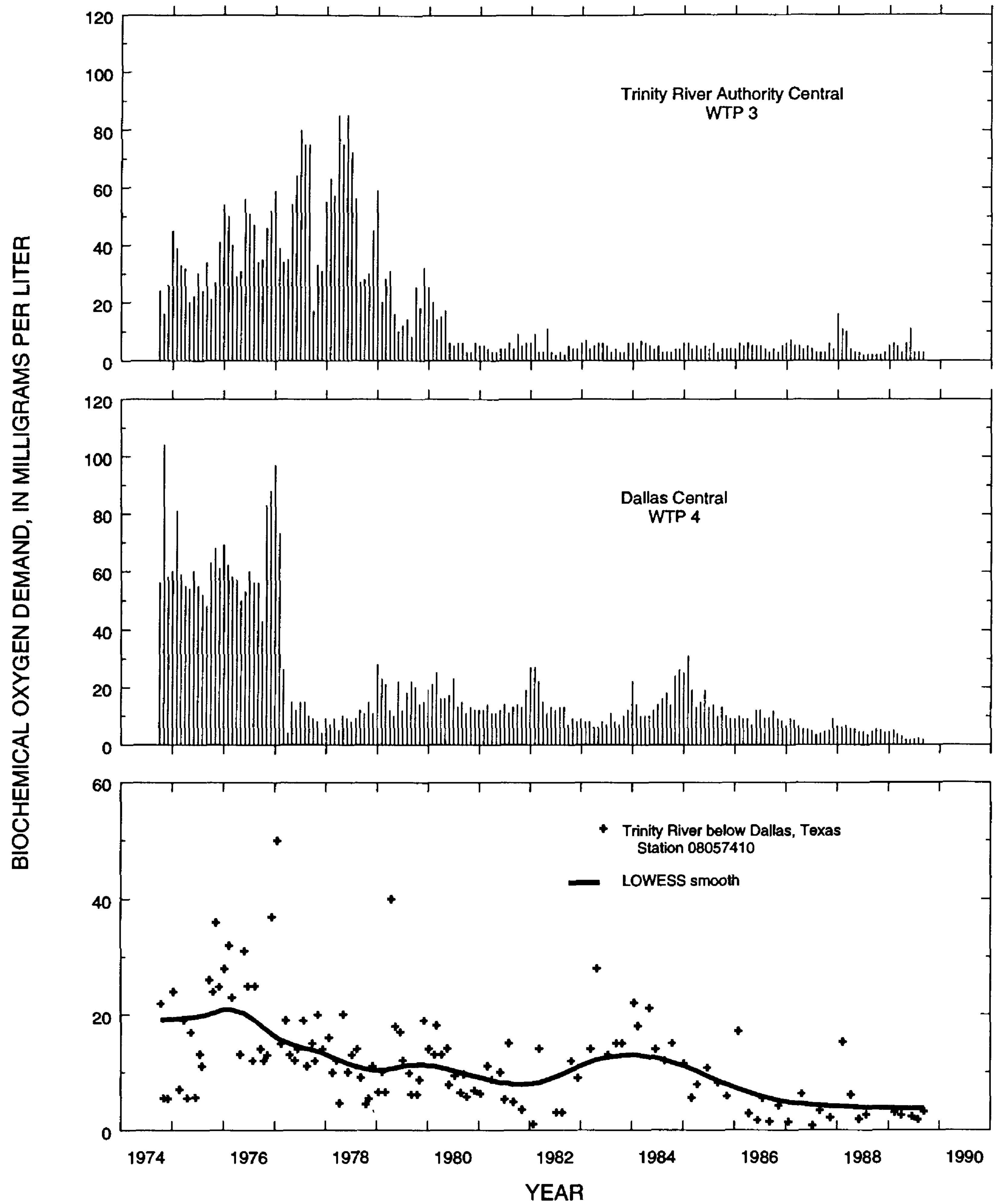

Figure 4. Monthly mean biochemical oxygen demand (BOD) concentrations in the effluent from wastewater treatment plants (WTP) Trinity River Authority Central and Dallas Central and instantaneous BOD concentrations in the Trinity River below Dallas, Texas, 1975–89 water years.

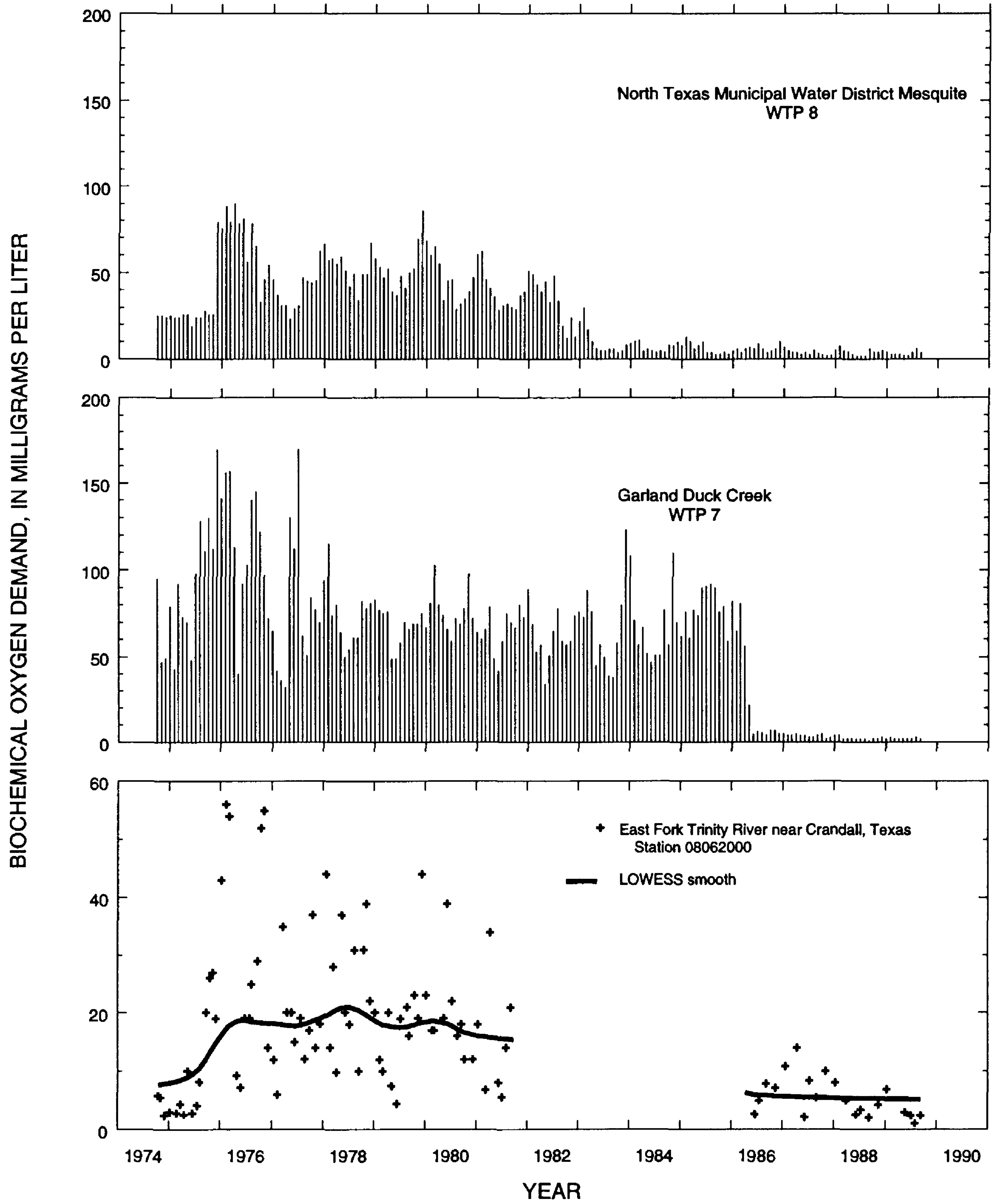

Figure 5. Monthly mean biochemical oxygen demand (BOD) concentrations in the effluent from wastewater treatment plants (WTP) North Texas Municipal Water District Mesquite and Garland Duck Creek and instantaneous BOD concentrations in the East Fork Trinity River near Crandall, Texas, 1975–89 water years.

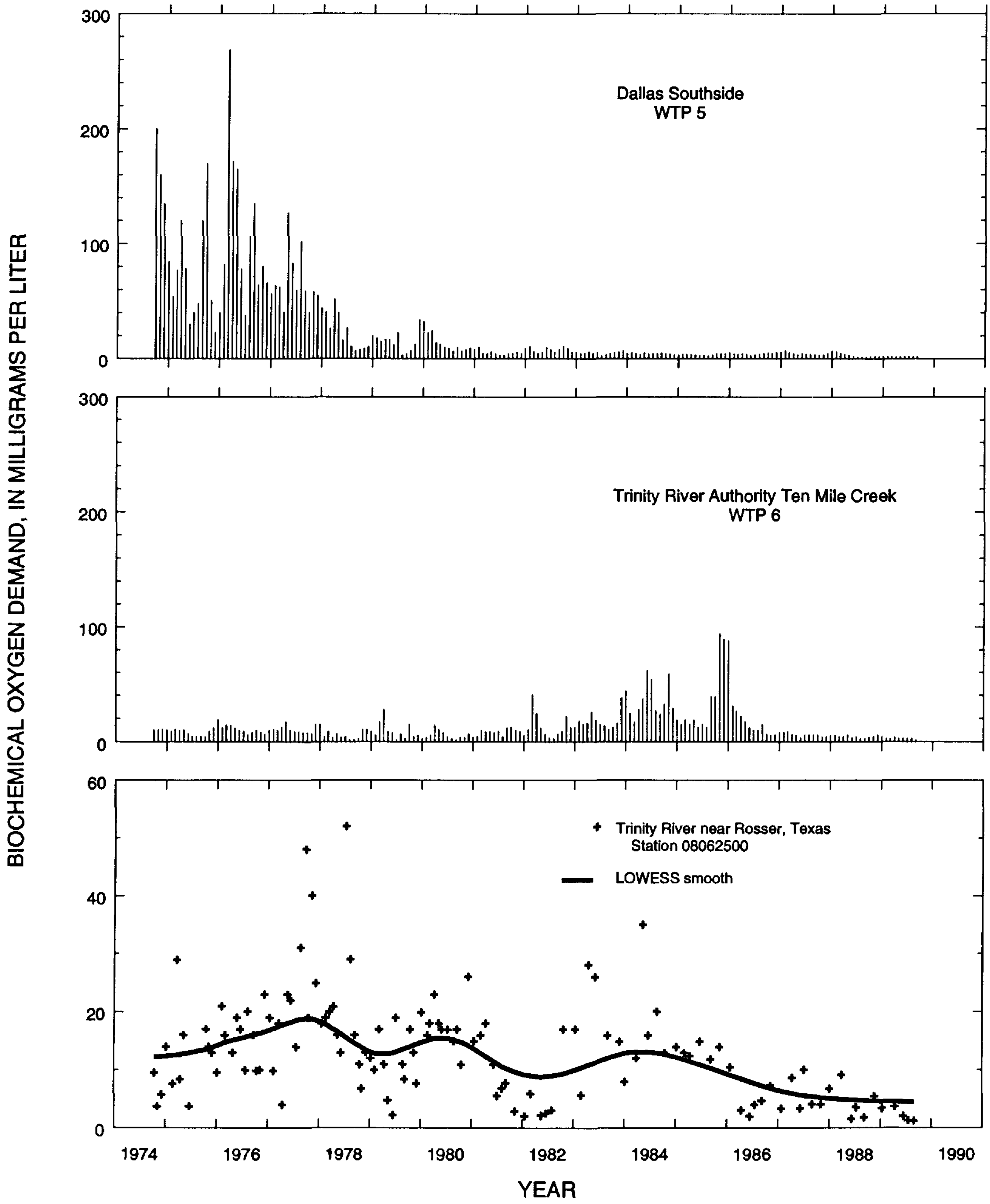

Figure 6. Monthly mean biochemical oxygen demand (BOD) concentrations in the effluent from wastewater treatment plants (WTP) Dallas Southside and Trinity River Authority Ten Mile Creek and instantaneous BOD concentrations in the Trinity River near Rosser, Texas, 1975–89 water years.

Table 2. *Statistical summary and trend results of selected water-quality data for selected stations in the Trinity River Basin, Texas, for the 1975–89 water years*

[N, number of observations used for trend analysis; p, attained significance of trend test; dis., dissolved; mg/L, milligrams per liter; --, insufficient data to calculate value; % sat., percent saturation; BOD, biochemical oxygen demand; tot., total; e, parameter is estimated for censored constituents with a log-probability regression procedure; Org., Organic; TREND CODES: U, best trend is trend in unadjusted concentrations; F, best trend is trend in flow-adjusted concentrations]

Station number: 08048543 Station name: West Fork Trinity River at Beach Street, Fort Worth, Texas

Latitude: 324506 Longitude: 971721 Drainage area: 2,685.0 square miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Oxygen dis., mg/L	103	9.73	7.8	9.4	11.4	0	--	--	--	U
Oxygen dis., % sat.	103	107.93	86	97	119	0	--	--	--	U
BOD, 5 day, mg/L	99	3.84	2.1	2.7	4.9	0	--	--	--	U
NO2 + NO3 tot., mg/L	108	e .42	.190	.340	.590	108	0.00	0.00	0.955	U
Ammonia tot., mg/L	109	e .23	.060	.150	.300	109	.00	-2.15	.112	U
Org. nitrogen, mg/L	106	.97	.675	.850	1.02	0	--	--	--	U
Ammonia + org. nitrogen, mg/L	108	1.22	.80	1.1	1.4	0	--	--	--	U
Phosphorus tot., mg/L	108	e .18	--	.130	.190	108	-.01	-3.33	.001	U

Station number: 08049500 Station name: West Fork Trinity River at Grand Prarie, Texas

Latitude: 324546 Longitude: 965942 Drainage area: 3,056.0 sqnare miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Oxygen dis., mg/L	128	5.27	3.4	5.5	7.4	78	0.24	4.47	0.000	F
Oxygen dis., % sat.	128	59.10	39	63	80	78	3.15	5.33	.000	F
BOD, 5 day, mg/L	124	9.11	3.5	7.0	14	81	-.92	-10.06	.000	U
NO2 + NO3 tot., mg/L	131	e 2.87	.960	2.10	4.60	131	.20	6.96	.001	U
Ammonia tot., mg/L	132	e 2.78	.260	1.30	3.90	132	-.17	-6.06	.000	U
Org. nitrogen, mg/L	130	2.31	1.00	1.50	2.10	79	-.04	-1.76	.129	F
Ammonia + org. nitrogen, mg/L	131	4.97	1.8	3.0	6.2	79	-.28	-5.67	.000	F
Phosphorus tot., mg/L	131	e 3.11	1.40	2.40	3.70	131	-.10	-3.22	.008	U

Station number: 08057410 Station name: Trinity River below Dallas, Texas

Latitude: 324226 Longitude: 964408 Drainage area: 6,278.0 square miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Oxygen dis., mg/L	128	4.71	2.6	4.6	6.6	83	0.24	5.18	0.000	F
Oxygen dis., % sat.	128	51.69	32	55	71	83	3.06	5.92	.000	F
BOD, 5 day, mg/L	125	12.49	5.8	12	16	81	-1.06	-8.52	.000	F
NO2 + NO3 tot., mg/L	130	e 2.31	.780	1.80	3.20	130	.25	10.80	.000	U
Ammonia tot., mg/L	130	e 4.66	.940	3.80	7.70	130	-.49	-10.62	.000	U
Org. nitrogen, mg/L	129	2.69	1.05	1.90	3.85	82	-.08	-3.03	.020	F
Ammonia + org. nitrogen, mg/L	129	7.33	3.0	6.4	12	82	-.46	-6.28	.000	F
Phosphorus tot., mg/L	131	e 3.59	1.50	3.50	4.80	131	-.17	-4.64	.003	U

Table 2. *Statistical summary and trend results of selected water-quality data for selected stations in the Trinity River Basin, Texas, for the 1975–89 water years—Continued*

Station number: 08062000 Station name: East Fork Trinity River near Crandall, Texas

Latitude: 323819 Longitude: 962917 Drainage area: 1,256.0 square miles

Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
	Descriptive statistics					Best trend results				
Oxygen dis., mg/L	101	3.49	0.3	3.1	5.8	63	0.10	2.84	0.130	F
Oxygen dis., % sat.	101	37.78	4	33	63	63	1.64	4.35	.239	F
BOD, 5 day, mg/L	101	16.72	6.4	14	21	63	-.38	-2.28	.099	F
NO2 + NO3 tot., mg/L	99	e .98	.030	.140	.650	99	.05	4.60	.000	U
Ammonia tot., mg/L	100	e 6.31	1.00	3.90	11.0	100	-.21	-3.29	.021	U
Org. nitrogen, mg/L	99	3.36	1.00	2.00	4.00	61	.00	.12	.916	F
Ammonia + org. nitrogen, mg/L	99	9.79	2.2	9.5	16	62	-.06	-.64	.631	F
Phosphorus tot., mg/L	100	e 3.63	1.00	3.30	5.30	100	-.10	-2.63	.099	U

Station number: 08062500 Station name: Trinity River near Rosser, Texas

Latitude: 322535 Longitude: 962746 Drainage area: 8,146.0 square miles

Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent perr year	p	Trend code
	Descriptive statistics					Best trend results				
Oxygen dis., mg/L	125	4.77	3.3	4.6	6.4	85	0.21	4.49	0.000	F
Oxygen dis., % sat.	126	51.35	36	53	69	85	2.60	5.07	.000	F
BOD, 5 day, mg/L	126	13.33	6.6	13	17	85	-.84	-6.34	.000	F
NO2 + NO3 tot., mg/L	123	e 2.69	1.00	2.00	3.70	123	.24	8.82	.000	U
Ammonia tot., mg/L	128	e 4.01	.530	2.10	7.00	128	-.43	-10.60	.000	U
Org. nitrogen, mg/L	126	1.97	.997	1.45	2.30	83	-.06	-2.95	.133	F
Ammonia + org. nitrogen, mg/L	126	5.89	1.7	4.0	9.4	83	-.32	-5.35	.000	F
Phosphorus tot., mg/L	128	e 3.03	1.20	2.30	4.20	128	-.07	-2.31	.170	U

Station number: 08065350 Station name: Trinity River near Crockett, Texas

Latitude: 312018 Longitude: 953922 Drainage area: 13,911.0 square miles

Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
	Descriptive statistics					Best trend results				
Oxygen dis., mg/L	116	7.22	5.7	7.2	8.9	80	0.10	1.42	0.039	F
Oxygen dis., % sat.	112	78.81	67	81	92	80	1.24	1.58	.008	F
BOD, 5 day, mg/L	114	4.51	1.8	3.0	4.8	79	-.18	-3.88	.018	F
NO2 + NO3 tot., mg/L	110	e 2.61	.910	2.10	4.10	110	.06	2.18	.347	U
Ammonia tot., mg/L	114	e .48	.050	.100	.440	114	.00	.00	.213	U
Org. nitrogen, mg/L	114	1.28	.847	1.10	1.70	78	-.02	-1.80	.096	F
Ammonia + org. nitrogen, mg/L	114	1.68	1.0	1.3	2.0	79	-.03	-1.66	.171	F
Phosphorus tot., mg/L	116	e 1.28	.430	.760	1.80	116	-.01	-.97	.345	U

Table 3. *Major wastewater treatment plants and treatment capacities in the Dallas-Fort Worth metropolitan area, Texas*

[Mgal/d, million gallons per day; WTP, wastewater treatment plant]

Wastewater treatment plant	Current capacity (Mgal/d)	WTP number
Fort Worth Village Creek	120	1
Fort Worth Riverside	discontinued 1979	2
Trinity River Authority Central	115	3
Dallas Central	150	4
Dallas Southside	90	5
Trinity River Authority Ten Mile Creek	20	6
Garland Duck Creek	24	7
North Texas Municipal Water District Mesquite	12.6	8

been less than 10 mg/L. The Trinity River Authority Central facility (fig. 4) had increasing monthly mean BOD concentrations from 1974 to 1979. During this period, the monthly mean BOD concentrations reached 85 mg/L. By the mid-1980's, the concentrations were all less than 10 mg/L. The Trinity River below Dallas station (08057410) (fig. 4), which is downstream of the Dallas Central and Trinity River Authority Central wastewater treatment plants, had BOD concentrations of about 20 mg/L in the late 1970's that decreased to generally less than 5 mg/L in the late 1980's.

Monthly mean concentrations of BOD in the effluent from the Garland and Mesquite facilities (fig. 5) decreased somewhat later than the other facilities. The monthly mean concentrations in the effluent from the Mesquite facility decreased from about 50 mg/L to less than 10 mg/L in 1983. The monthly mean concentrations in the effluent from the Garland facility, which were as high as 170 mg/L from 1975–77, decreased from about 50 to 100 mg/L to less than 10 mg/L in early 1986. The East Fork Trinity River near Crandall station (08062000) (fig. 5) had BOD concentrations near 60 mg/L in 1976–77 when the concentrations in the effluent from the Garland facility were greater than 150 mg/L. BOD was not measured at the Crandall station from 1982 to 1985; the BOD concentrations from 1986 to 1989 were consistently less than 10 mg/L.

Effluent from the Dallas Southside facility (fig. 6) had monthly mean concentrations of BOD that were greater than 200 mg/L in the late 1970's, but were consistently less than 10 mg/L by 1981. Monthly mean concentrations of BOD in effluent from the Trinity River Authority Ten Mile Creek facility (fig. 6) were consistently low except for 1984–86 when the concentrations were sometimes near 100 mg/L. The BOD concentrations at the Trinity River near Rosser station (08062500) (fig. 6) have decreased from about 20 mg/L in the late 1970's to less than 10 mg/L in the late 1980's.

The monthly mean concentrations of BOD in effluent from the wastewater treatment facilities are used as indicators of the quality of the effluent from these facilities to the Trinity River. Concentrations of water-quality constituents are measured periodically at stations on the Trinity River to indicate the quality of the water in the river. Graphs of the stream concentrations of dissolved oxygen, ammonia, and nitrite plus nitrate from the stations on the Trinity River (figs. 7–9) reflect the changes in the quality of the effluent from the wastewater treatment facilities as indicated by the graphs of BOD concentrations (figs. 3–6). The first station shown in each of the set of six graphs in figures 7–9 is upstream from all the wastewater treatment plants. The other stations are shown in downstream order. The increases in dissolved oxygen concentrations observed in all the stations downstream of the wastewater treatment facilities (fig. 7) correspond to the decreases in BOD concentrations that were observed in figures 3–6. Decreases in concentrations of ammonia (fig. 8) and increases in nitrite plus nitrate concentrations (fig. 9) at stations downstream of the wastewater treatment facilities reflect the process of wastewater treatment that converts as much of the nitrogen as possible to nitrate.

The quantity of data to provide supporting evidence for the source of the trends in the Trinity River

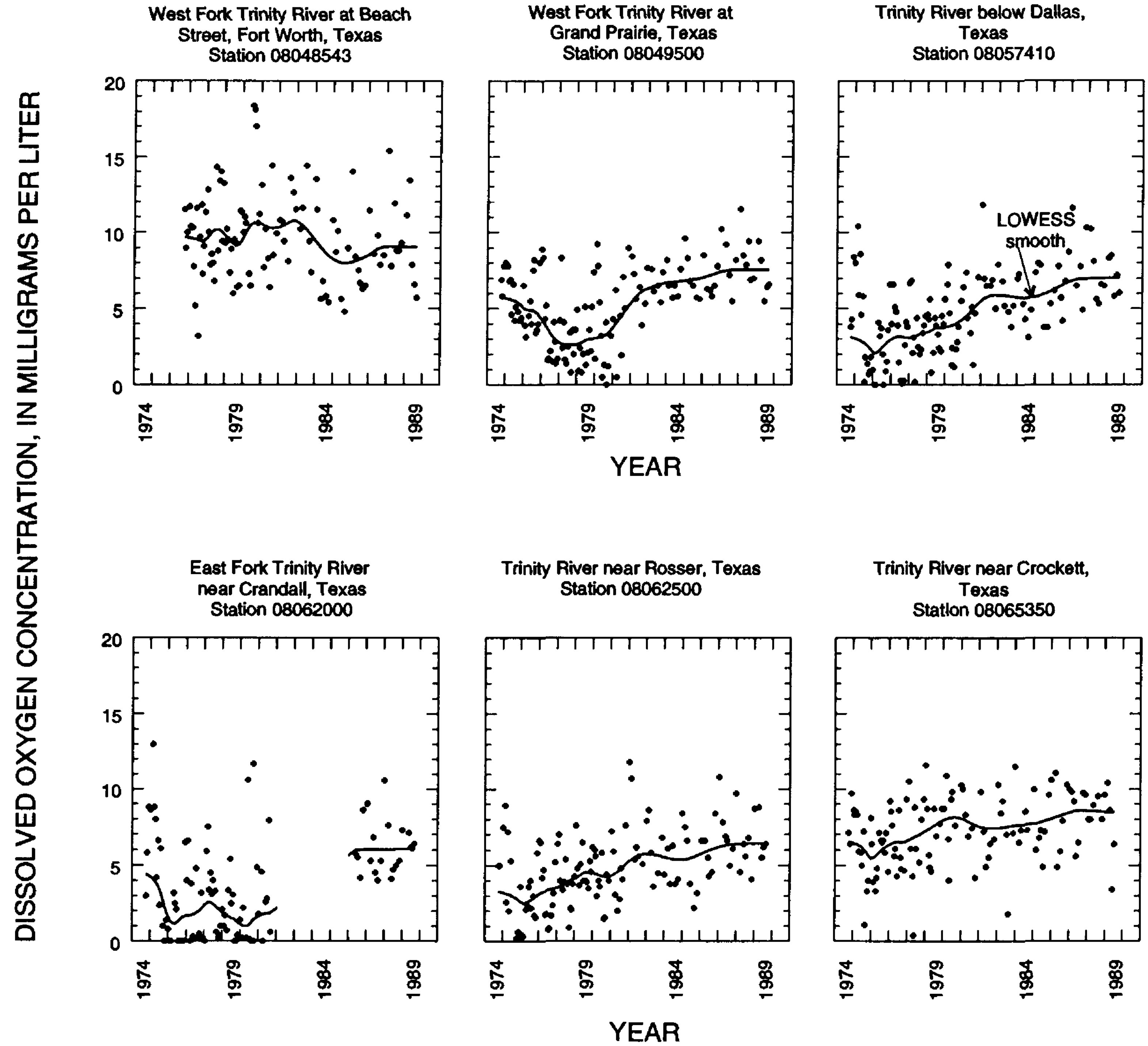

Figure 7. Variations in dissolved oxygen concentrations for selected stations in the Trinity River Basin, Texas, 1975–89 water years.

Basin was unique. It has proven to be a rare occurrence for ancillary data to span the time required and to be of the precise nature needed to refute or support a possible source of trend. Fortunately, in this case, there is not only well documented ancillary data from the North Central Texas Council of Governments, but correlation from the patterns of several constituents at several sites that provide the supporting evidence.

Salinity Control Project

Spatial patterns of trend indicators in the upper Colorado River Basin showed increasing concentrations of dissolved inorganic constituent concentrations for the 1975–86 water years. The same patterns persisted in the trend results for the 1975–89 water years. Maps of the trend indicators for concentrations of dissolved sulfate, dissolved chloride, and sum of dissolved solids are shown in figure 10. Northwestern Texas, which includes the upper Colorado River, is plagued by saline surface water. Salinity of freshwater systems generally is expressed in terms of the concentration of dissolved solids in the water (Dunne and Leopold, 1978). The predominant ions that contribute to the sum of dissolved solids in the surface water in the

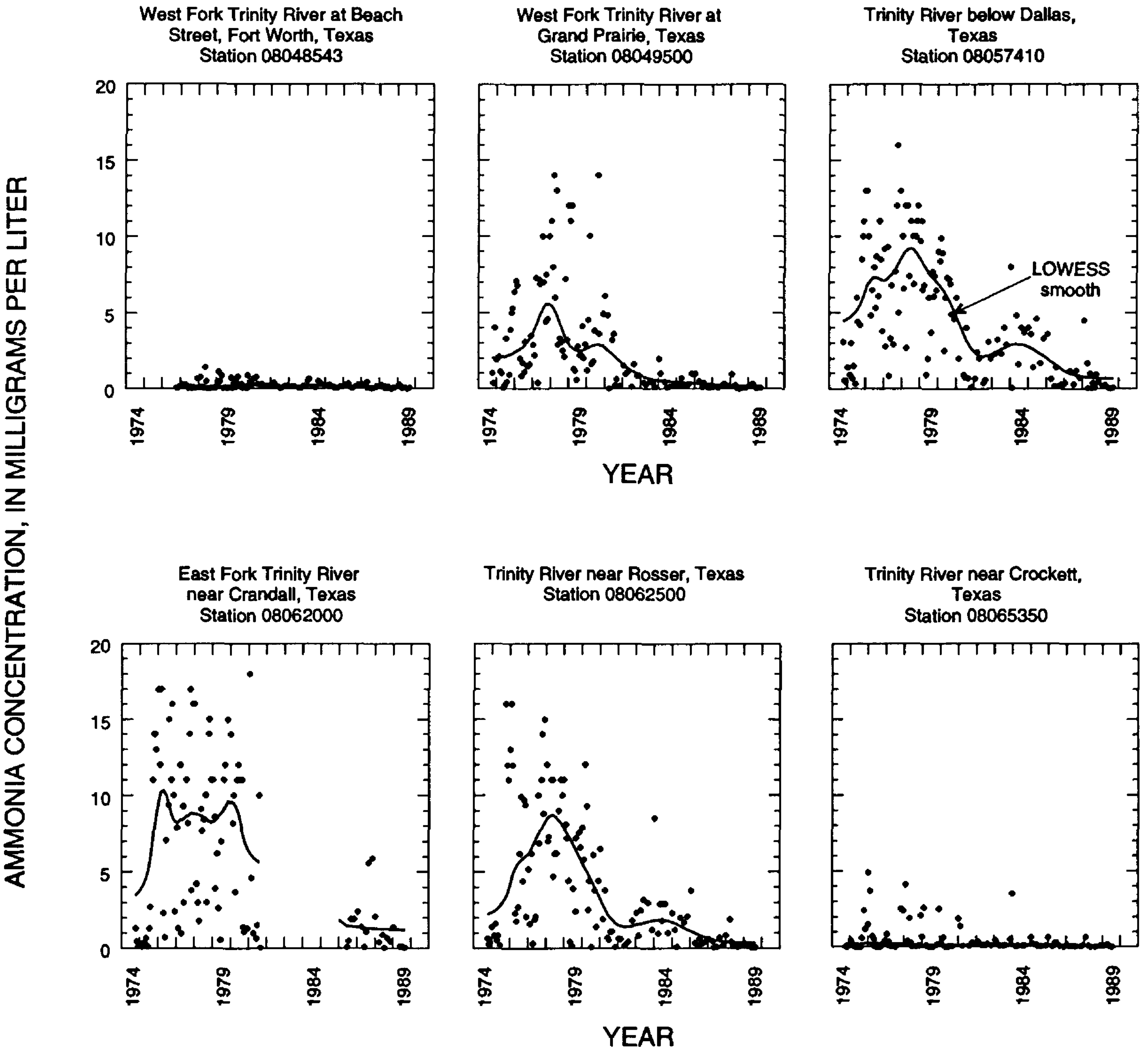

Figure 8. Variations in ammonia concentrations for selected stations in the Trinity River Basin, Texas, 1975–89 water years.

upper Colorado River are sodium, chloride, calcium, bicarbonate, and sulfate (Andrews and Schertz, 1986). Seepages of highly mineralized ground water are the primary source of the elevated concentrations of dissolved solids in the surface water in this area, but by-products of oil and gas exploration and production also contribute (Texas Department of Water Resources, 1984).

The U.S. Environmental Protection Agency (1988) has set a secondary maximum contaminant level of 500 mg/L dissolved solids in drinking water. This is about the only guideline available for acceptable levels of salinity. Surface water in the upper Colorado River Basin is considerably more saline than this. The median concentrations of dissolved solids for sites in the area were generally 1,000 mg/L or higher. The Beals Creek near Westbrook station (08123800) had the highest salinity levels with a median concentration of dissolved solids of 5,800 mg/L for the 1975–89 water years (table 4).

Efforts to lessen salinity levels in streams in northwestern Texas have led to numerous salinity control projects designed to remove the most saline surface water from the main streams and rivers to some type of storage facility. The stored water is then allowed to evaporate. The mechanism for the removal of the saline water varies from project to project, but the storage facility is, most often, a type of holding pond. The

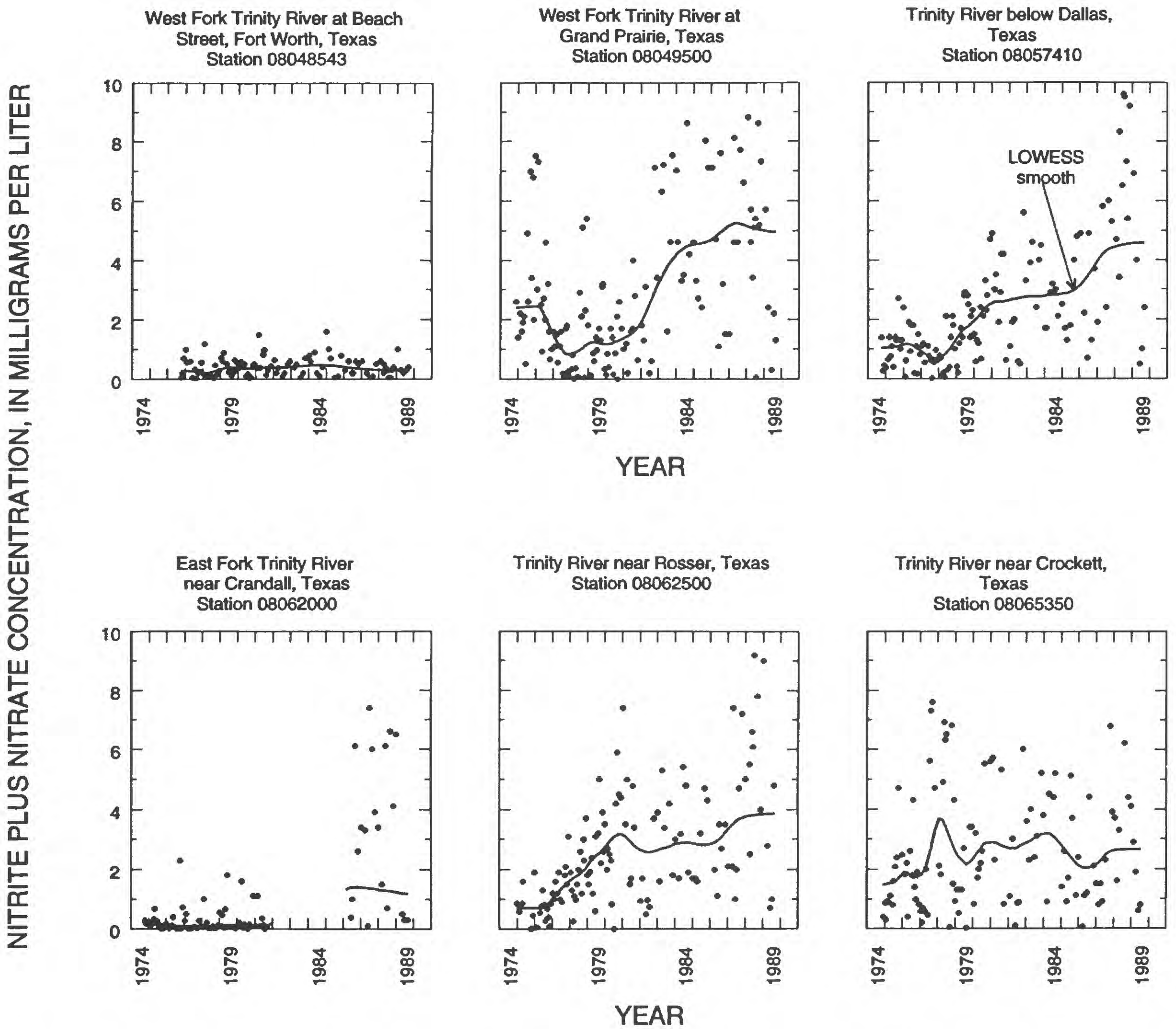

Figure 9. Variations in nitrite plus nitrate concentrations for selected stations in the Trinity River Basin, Texas, 1975–89 water years.

Colorado River Municipal Water District constructed a system of pumps in the Beals Creek Basin in 1974 to pump water from Beals Creek to Natural Dam Lake for the permanent storage of saline water. Before 1986, the only known water losses from Natural Dam Lake had been by evaporation.

Runoff from precipitation in the upper Colorado River Basin and Beals Creek Basin in the late 1980's resulted in unexpected large volumes of water stored in Natural Dam Lake that were deemed a hazard to the structural integrity of the dam. To reduce stress on the dam, releases of water from the lake first occurred during September–December 1986. Precipitation continued to be above normal during the next few years and resulted in two more periods of release (January–July 1987 and July–August 1988) from Natural Dam Lake. The total quantity of water released from the lake was estimated to be between 60,000 and 75,000 acre-ft (Slade and De La Garza, 1989).

The effect of the water released from Natural Dam Lake on the dissolved solids in the upper Colorado River Basin is demonstrated in figure 11 with the monthly mean loads of the sum of dissolved solids at four stations. The Colorado River at Colorado City station (08121000), which is upstream from Beals Creek, had loads of dissolved solids that were typical

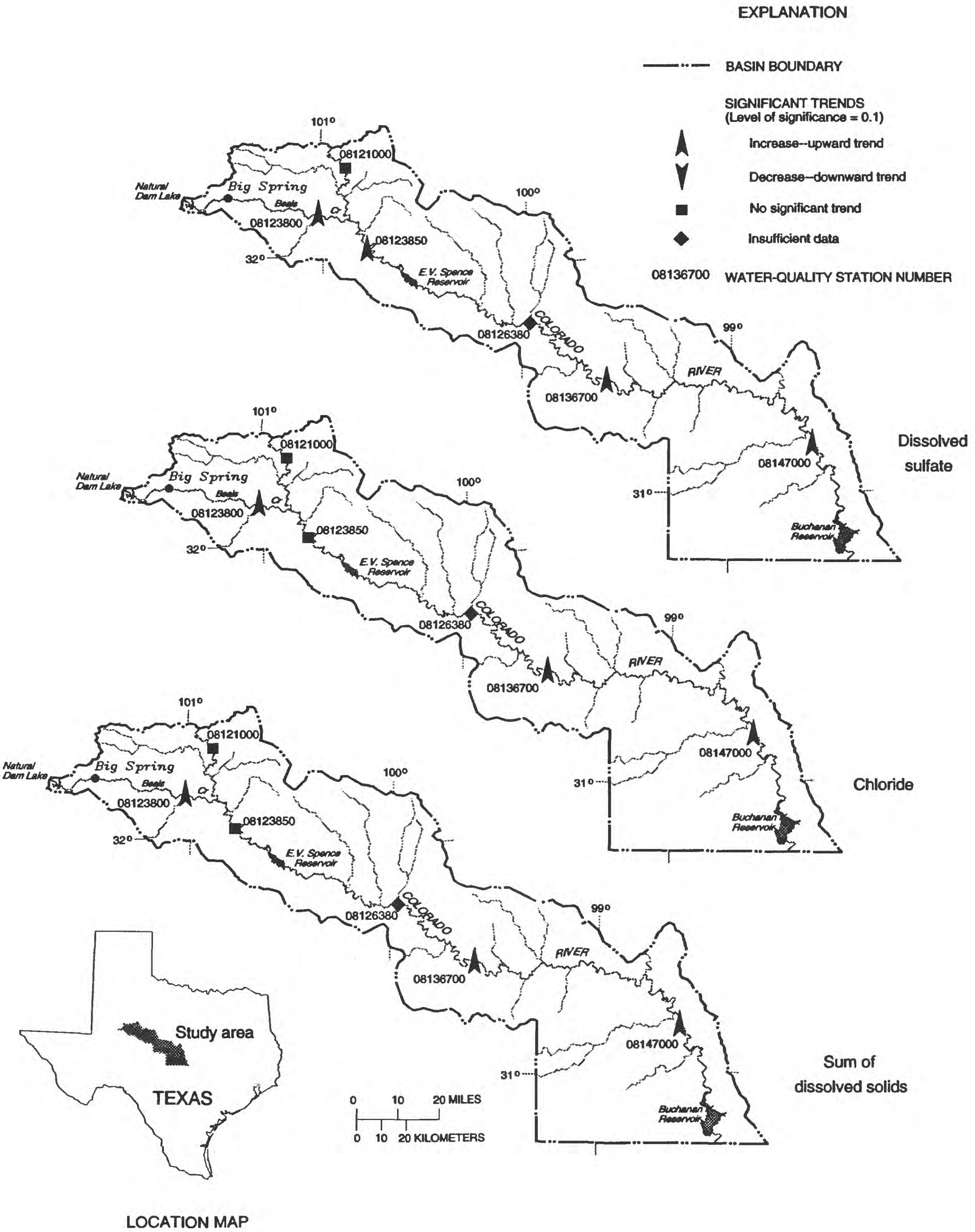

Figure 10. Trends in concentrations of dissolved sulfate, dissolved chloride, and sum of dissolved solids at selected stations in the upper Colorado River Basin for the 1975–89 water years.

Table 4. *Statistical summary and trend results of selected water-quality data for selected stations in the upper Colorado River Basin, Texas, for the 1975–89 water years*

[N, number of observations used for trend analysis; p, attained significance of trent test; mg/L; milligrams per liter; TREND CODES: U, best trend is trend in unadjusted concentrations; F, best trend is trend in flow-adjusted concentrations]

Station number: 08121000 — Station name: Colorado River at Colorado City, Texas

Latitude: 322333 — Longitude: 1005242 — Drainage area: 3,966.0 square miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	113	1,134.81	670	1,100	1,600	82	9.76	0.86	0.315	F
Chloride dissolved, mg/L	113	2,873.20	1,200	2,000	3,700	82	10.28	.36	.553	F
Dissolved solids sum, mg/L	113	6,451.19	3,100	5,100	8,500	82	23.06	.36	.584	F

Station number: 08123800 — Station name: Beals Creek near Westbrook, Texas

Latitude: 321157 — Longitude: 1010049 — Drainage area: 9,802.0 square miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	114	1,411.54	740	1,400	2,100	81	41.00	2.90	0.051	U
Chloride dissolved, mg/L	114	2,282.83	1,300	2,300	3,300	81	50.00	2.19	.063	U
Dissolved solids sum, mg/L	114	5,726.93	3,200	5,800	8,200	81	148.33	2.59	.042	U

Station number: 08123850 — Station name: Colorado River above Silver, Texas

Latitude: 320307 — Longitude: 1004556 — Drainage area: 14,910.0 square miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	129	1,196.43	500	1,200	1,700	85	22.17	1.85	0.061	F
Chloride dissolved, mg/L	129	1,555.37	740	1,500	2,200	85	6.50	.42	.632	F
Dissolved solids sum, mg/L	129	4,265.38	2,000	4,100	5,900	85	39.51	.93	.383	F

Station number: 08126380 — Station name: Colorado River near Ballinger, Texas

Latitude: 314255 — Longitude: 1000134 — Drainage area: 16,358.0 square miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	112	709.80	280	605	1,100	82	31.43	4.43	0.000	F
Chloride dissolved, mg/L	111	368.88	200	380	510	81	8.85	2.40	.043	F
Dissolved solids sum, mg/L	112	1,743.93	900	1,700	2,500	82	66.75	3.80	.001	F

Table 4. *Statistical summary and trend results of selected water-quality data for selected stations in the upper Colorado River Basin, Texas, for the 1975–89 water years—Continued*

Station number: 08136700 — Station name: Colorado River near Stacy, Texas

Latitude: 312937 — Longitude: 993425 — Drainage area: 24,192.0 square miles

Water-quality property or constituent	Descriptive statistics: Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	Best trend results: N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	109	296.25	160	270	410	77	14.82	5.00	0.000	F
Chloride dissolved, mg/L	109	337.90	200	350	440	77	9.08	2.69	.006	F
Dissolved solids sum, mg/L	109	1,083.77	700	1,100	1,400	77	31.15	2.87	.001	F

Station number: 08147000 — Station name: Colorado River near San Saba, Texas

Latitude: 311304 — Longitude: 983351 — Drainage area: 21,217.0 square miles

Water-quality property or constituent	Descriptive statistics: Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	Best trend results: N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	126	109.38	44	87	140	82	5.35	4.89	0.002	F
Chloride dissolved, mg/L	125	141.82	72	130	180	82	5.04	3.55	.010	F
Dissolved solids sum, mg/L	126	571.84	370	520	670	82	10.83	1.89	.073	U

for average hydrologic conditions during 1986–88. Dissolved-solids loads for the Beals Creek near Westbrook station (08123800), which typically range from 1,000 to 3,000 ton/d, were extremely high during 1986–88 with the highest load of 217,000 ton/d in June 1987. The Colorado River above Silver station (08123850) immediately downstream from the inflow of Beals Creek also had peaks of dissolved-solids loads during the same period as Beals Creek with the highest load of 262,000 ton/d in June 1987. Increased loads of dissolved solids are also evident at the Colorado River near Ballinger station (08126380) during 1986–88 even though the water is impounded in E.V. Spence Reservoir before it reaches this station. Runoff from above average precipitation during 1986–88 also resulted in substantial releases from E.V. Spence Reservoir, thus the peak loads below the reservoir were observed during the same month as the peak loads above the reservoir without any delay from the impoundment. High dissolved-solids loads are observed for several months downstream of the reservoir, because of impoundment of the saline inflow in the reservoir.

Trend analysis of the sum of dissolved-solids concentrations for stations in the upper Colorado River Basin showed increasing concentrations for Beals Creek near Westbrook (08123800) and the stations on the Colorado River downstream of E.V. Spence Reservoir for 1974–89 (fig. 10). Graphs of the dissolved-solids concentrations during 1974–89 for stations in the upper Colorado River Basin are shown in figure 12. The stations where upward trends were detected show a pattern of increasing concentrations after 1986. The Colorado River above Silver station (08123850), which is downstream of Beals Creek and upstream of E.V. Spence Reservoir, did not show a detectable trend in the dissolved-solids concentrations. Only a few instantaneous measurements of the saline water released from Natural Dam Lake were made at station 08123850. These high values can be seen on figure 12, but are insufficient to result in a trend. Impoundment of the saline water in E.V. Spence results in a steady flow of water with high dissolved-solids concentrations

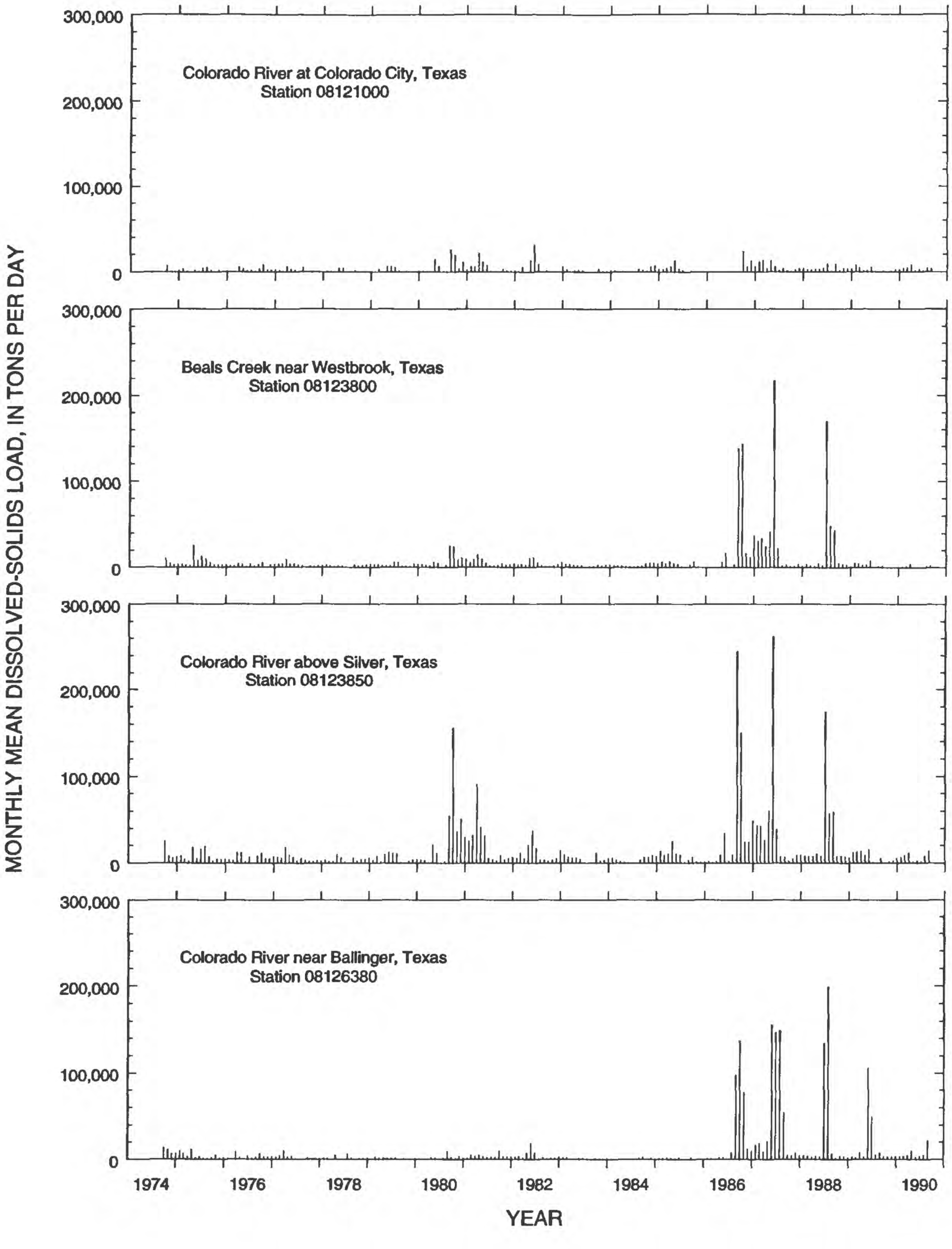

Figure 11. Monthly mean dissolved-solids load for selected stations in the upper Colorado River Basin, Texas, 1974–90.

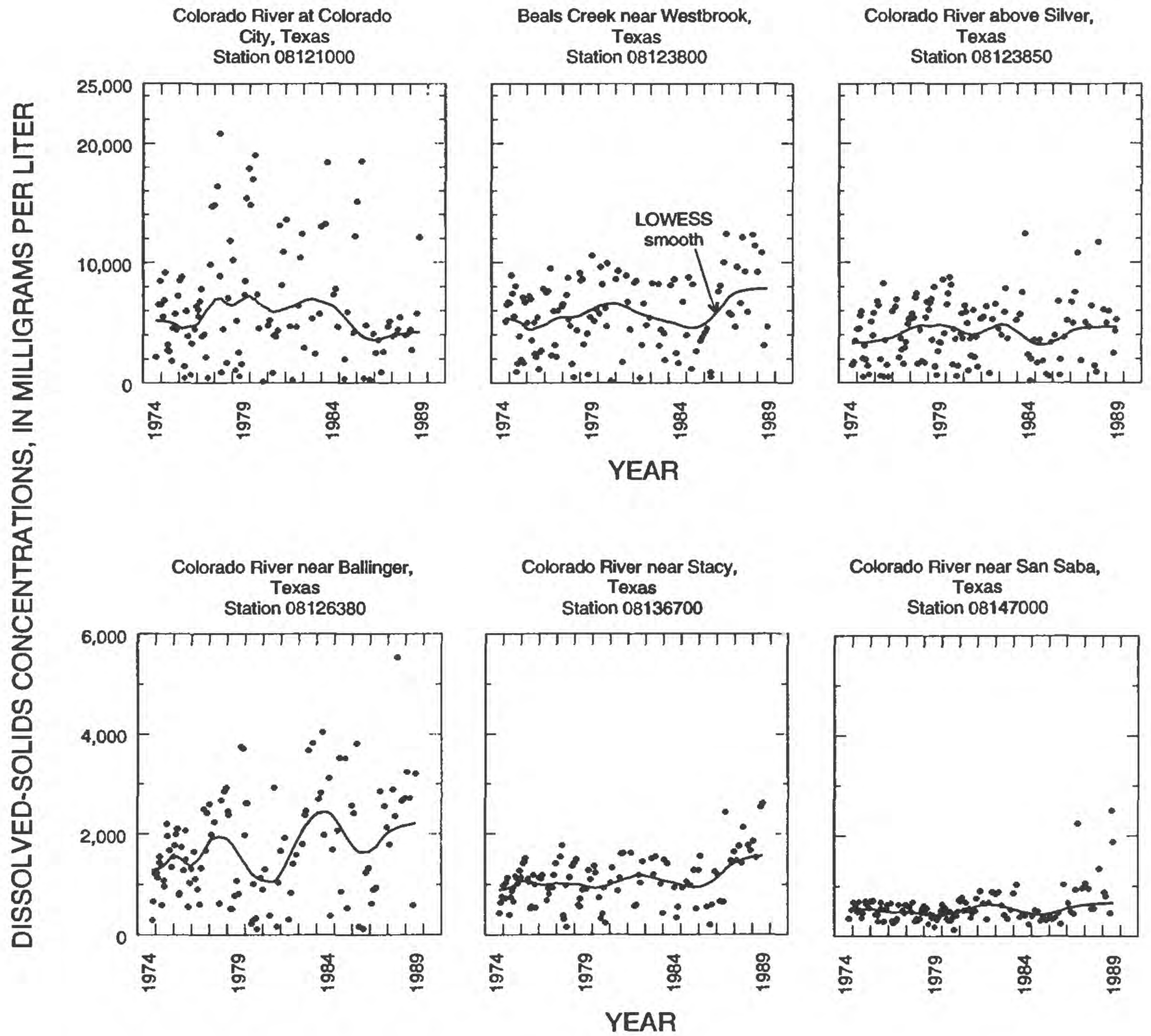

Figure 12. Variations in dissolved-solids concentrations for selected stations in the upper Colorado River Basin, Texas, 1975–89 water years.

downstream of the reservoir. The increased concentrations of dissolved solids are evident at the Colorado River near Ballinger station (08126380), the Colorado River near Stacy station (08136700), and the Colorado River near San Saba station (08147000) (fig. 12).

The trends in the inorganic constituents in the upper Colorado River Basin are due to releases of saline water from Natural Dam Lake in 1986, 1987, and 1988. The upward trends are not indicative of future trends in these constituent concentrations in this basin. An extension of the period of analysis probably would show fewer indications of upward trends as the concentrations return to background levels.

Reservoir Regulation

Spatial patterns of trend indicators in the Rio Grande Basin showed increasing concentrations of dissolved inorganic constituents for the 1975–86 water years. The same patterns persisted in the trend results for the 1975–89 water years. Maps of the trend indicators for dissolved sulfate, dissolved chloride, and sum of dissolved solids are shown in figure 13. The Rio Grande flows into Texas about 20 mi northwest of the city of El Paso and flows southeast to the Gulf of Mexico. The river forms the southern border of Texas and the international boundary between the United States

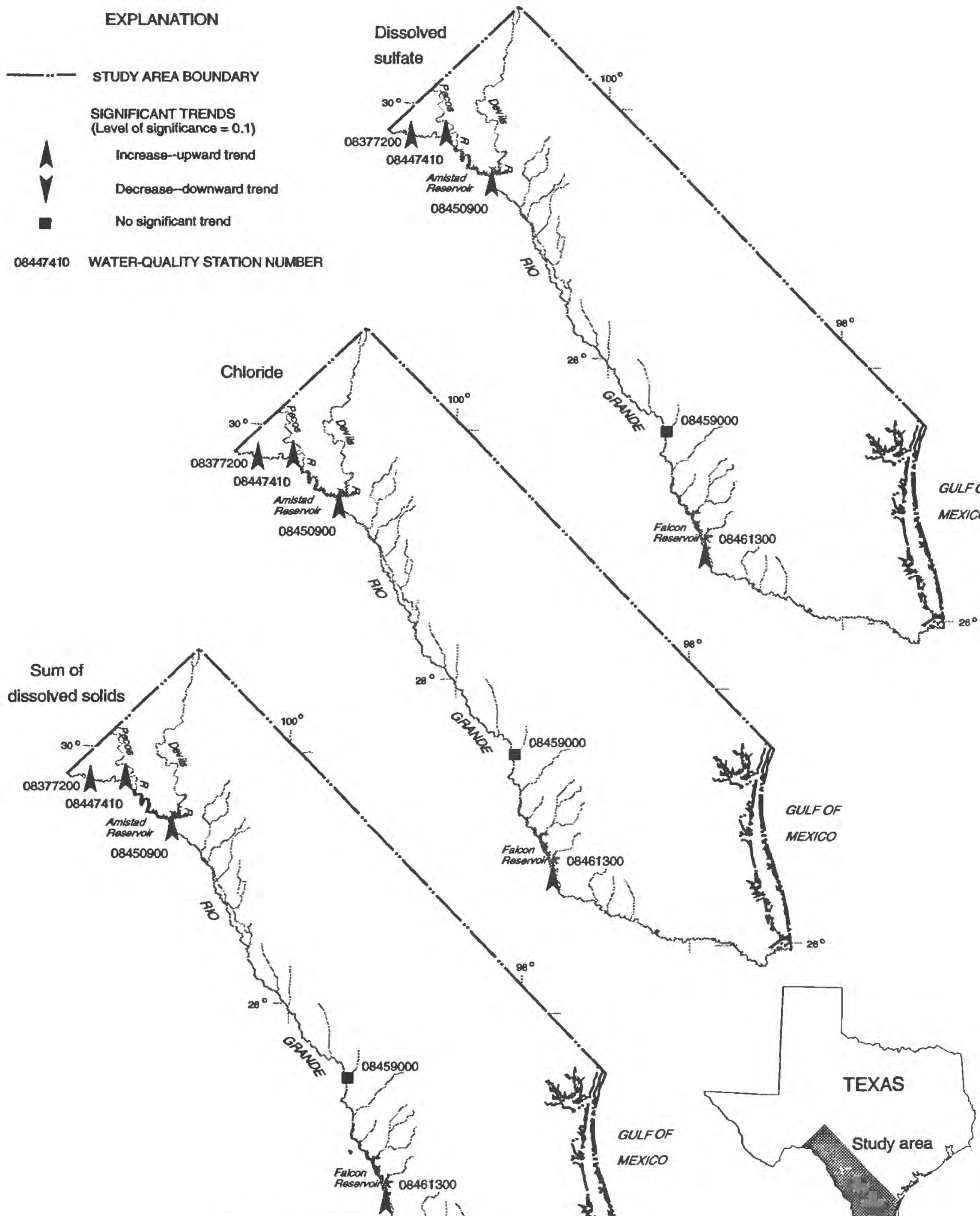

Figure 13. Trends in concentrations of dissolved sulfate, dissolved chloride, and sum of dissolved solids at selected stations in the Rio Grande Basin for the 1975–89 water years.

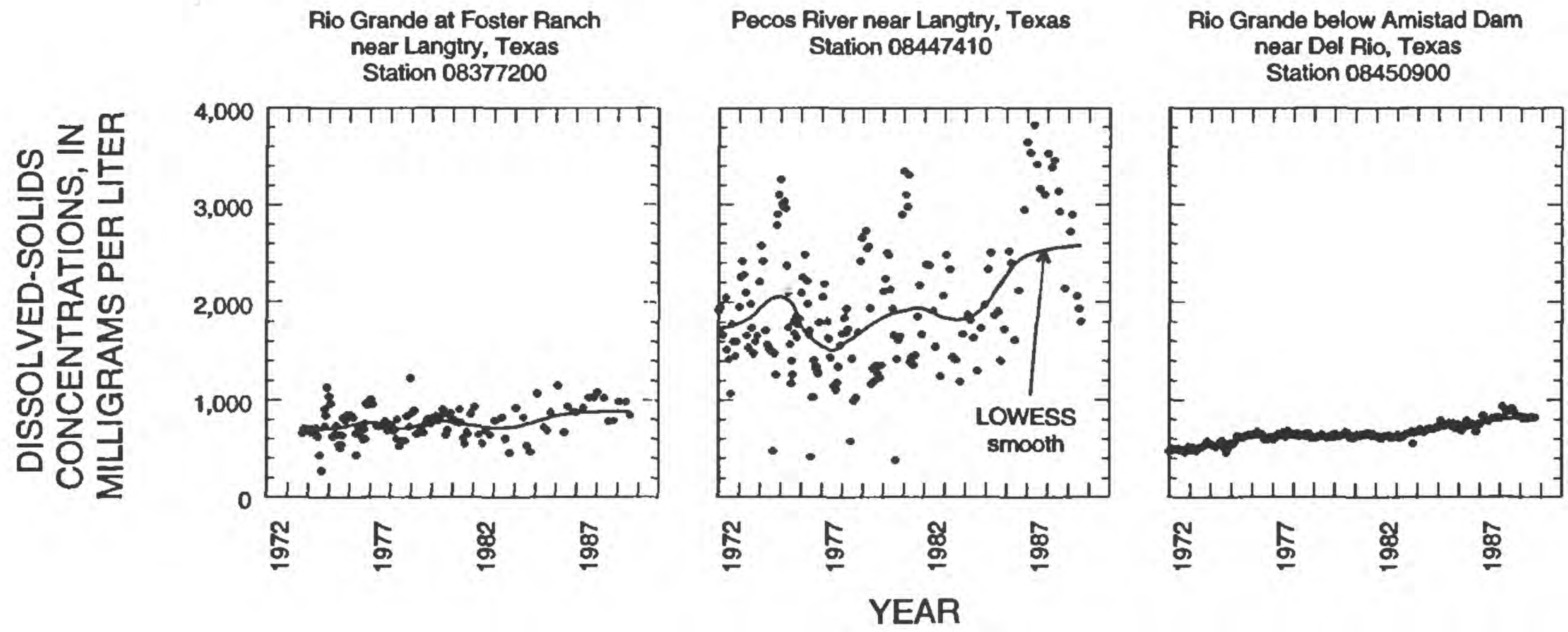

Figure 14. Variations in dissolved-solids concentrations for selected stations in the Rio Grande Basin, Texas, 1972–89 water years.

and Mexico. Reservoirs, diversions, and substantial withdrawals modify the flow in the Rio Grande throughout its length.

International Amistad Reservoir and International Falcon Reservoir were constructed for water storage and flood control. Falcon Reservoir was completed in 1953 and has a conservation storage of 2,667.6 thousand acre-ft. Amistad Reservoir was completed in 1968 and has a conservation storage of 3,383.7 thousand acre-ft (Texas Department of Water Resources, 1984). The Rio Grande, Pecos River, and Devils River are the major contributors of inflow to Amistad Reservoir. The major contributor of inflow to Falcon Reservoir is the Rio Grande.

Tributaries to Amistad Reservoir vary substantially in quality. The Rio Grande is generally good quality water with dissolved-solids concentrations near 750 mg/L. The Devils River is exceptionally good quality water with dissolved-solids concentrations near 220 mg/L. The Pecos River, however, is generally poor quality water with dissolved-solids concentrations near 1,800 mg/L (table 5). The salinity of the Pecos River is a result of natural discharge of saline ground water in New Mexico before the river flows into Texas. Graphs of the dissolved-solids concentrations in the Rio Grande and the Pecos River just upstream of Amistad Reservoir are shown in figure 14, along with dissolved-solids concentrations in the Rio Grande just downstream of the reservoir. All three of these sites, Rio Grande at Foster Ranch near Langtry (08377200), Pecos River near Langtry (08447410), and Rio Grande below Amistad Dam near Del Rio (08450900) have significant trends of increasing dissolved-solids concentrations for the 1975–89 water years. The graphs show data from 1972–89 so that the pattern of concentrations before 1975 can be seen. Concentrations of dissolved solids for the Devils River from 1978–89 ranged from 200 to 260 mg/L. The smoothed lines through the concentrations of dissolved solids in the Rio Grande and the Pecos River near Langtry show increases in the concentrations in about 1985. However, the concentrations in the outflow of the reservoir show a more steady increase beginning in about 1983.

The concentrations of inorganic constituents in a reservoir are influenced by the quantity and quality of water that flows into the reservoir, the quantity of water released from the reservoir, and evaporation. The monthly mean contents of Amistad Reservoir from 1970–89 are shown in figure 15. The amount of water stored in the reservoir tripled from about 1,000 thousand acre-ft to about 4,000 thousand acre-ft in 1972. Flow records for the tributaries show that the Devils River had particularly high flows during this period and contributed a substantial portion of the increased contents in Amistad Reservoir. The quantity of water from the Devils River that was stored in the reservoir

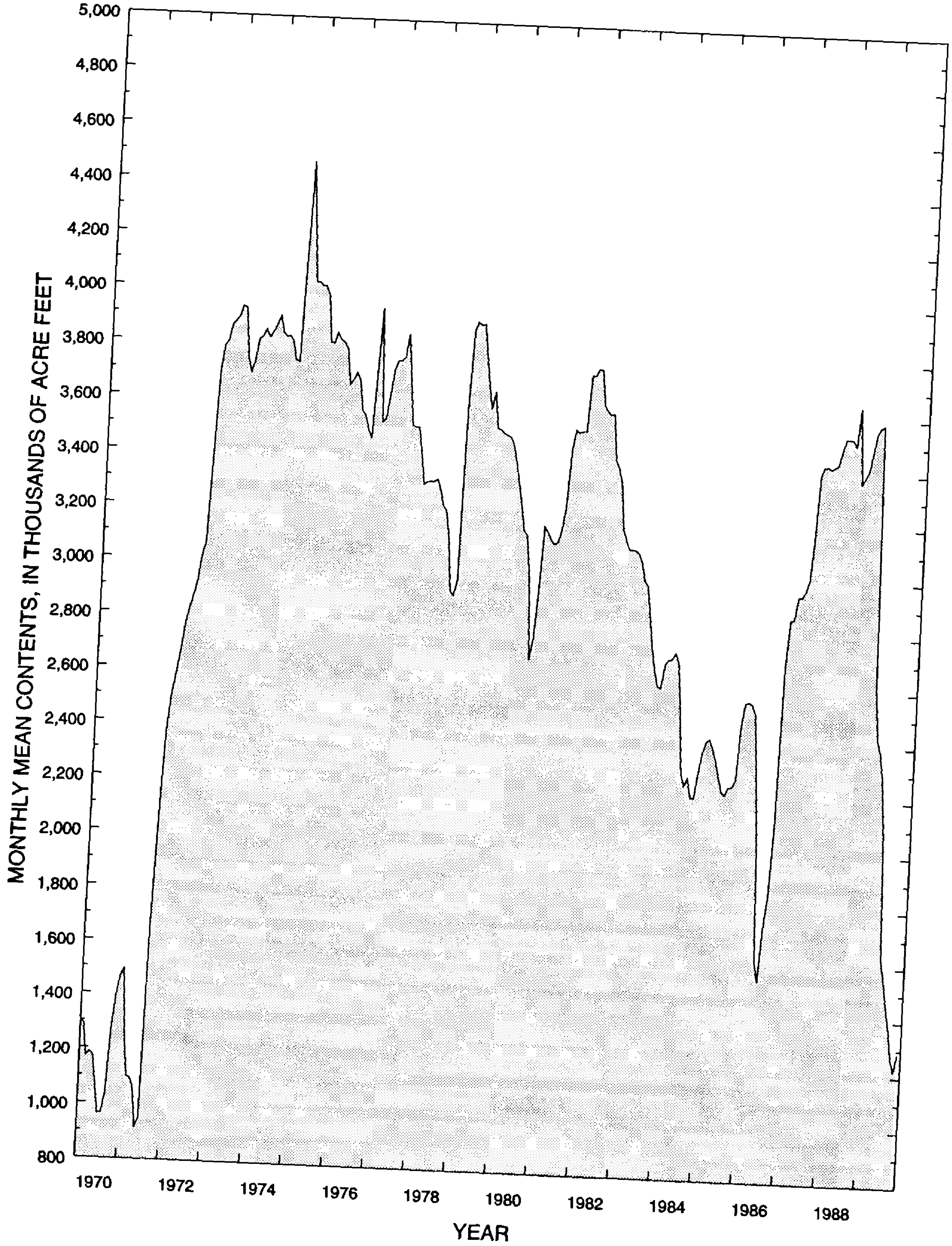

Figure 15. Monthly mean contents in Amistad Reservoir, Texas, 1970–89.

Table 5. *Statistical summary and trend results of selected water-quality data for selected stations in the Rio Grande Basin, Texas, for the 1975–89 water years*

[N, number of observations used for trend analysis; p, attained significance of trent test; mg/L; milligrams per liter; --, insufficient data to calculate value; TREND CODES: U, best trend is trend in unadjusted concentrations; F, best trend is trend in flow-adjusted concentrations]

Station number: 08377200 Station name: Rio Grande at Foster Ranch near Langtry, Texas

Latitude: 294650 Longitude: 1014520 Drainage area: 80,742.0 square miles

Descriptive statistics / Best trend results

Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	129	302.25	270	300	330	55	3.45	1.14	0.047	F
Chloride dissolved, mg/L	130	98.18	60	80	120	55	4.09	4.16	.000	F
Dissolved solids sum, mg/L	127	771.98	660	770	850	55	15.02	1.95	.008	F

Station number: 08447410 Station name: Pecos River near Langtry, Texas

Latitude: 294810 Longitude: 1012645 Drainage area: 35,179.0 square miles

Descriptive statistics / Best trend results

Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile	75th percentile (median)	N	Units per	Percent per year	p year	Trend code
Sulfate dissolved, mg/L	144	441.38	300	400	550	87	13.33	3.02	0.000	U
Chloride dissolved, mg/L	144	756.32	520	710	980	87	17.86	2.36	.001	U
Dissolved solids sum, mg/L	143	1,990.77	1,400	1,800	2,500	87	48.75	2.45	.001	U

Station number: 08450900 Station name: Rio Grande below Amistad Dam near Del Rio, Texas

Latitude: 292500 Longitude: 1010200 Drainage area: 123,143.0 square miles

Descriptive statistics / Best trend results

Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	180	232.33	210	230	260	180	6.00	2.58	0.000	U
Chloride dissolved, mg/L	180	132.77	110	130	140	180	5.00	3.77	.000	U
Dissolved solids sum, mg/L	179	684.87	630	650	740	179	15.54	2.27	.000	U

Station number: 08459000 Station name: Rio Grande at Laredo, Texas

Latitude: 272945 Longitude: 992925 Drainage area: 132,578.0 square miles

Descriptive statistics / Best trend results

Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	114	195.73	180	200	220	0	--	--	--	U
Chloride dissolved, mg/L	133	101.83	91	100	120	0	--	--	--	U
Dissolved solids sum, mg/L	114	587.23	540	600	650	0	--	--	--	U

Table 5. *Statistical summary and trend results of selected water-quality data for selected stations in the Rio Grande Basin, Texas, for the 1975–89 water years—Continued*

Station number: 08461300 Station name: Rio Grande below Falcon Dam, Texas

Latitude: 263325 Longitude: 991005 Drainage area: 159,270.0 square miles

	Descriptive statistics					Best trend results				
Water-quality property or constituent	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
Sulfate dissolved, mg/L	180	235.00	210	240	260	180	3.00	1.28	0.000	U
Chloride dissolved, mg/L	180	120.18	100	120	130	180	3.18	2.65	.000	U
Dissolved solids sum, mg/L	180	646.37	600	650	700	180	8.83	1.37	.000	U

resulted in low concentrations of dissolved solids in the outflow (station 08450900) (fig. 14) in 1972. High flows in all of the tributaries to Amistad Reservoir in October 1974 increased the total volume in the reservoir from about 4,000 thousand acre-ft to its peak stage of 4,471 thousand acre-ft. The dissolved-solids concentrations in the outflow decreased after the flood, but then increased to about 650 mg/L during the next year. The concentrations remain fairly constant at about 650 mg/L until 1983 when the concentrations begin to steadily increase to about 800 mg/L in 1989, with a few values near 900 mg/L in 1988.

The graphs of the dissolved-solids concentrations for the inflows and the outflow (fig. 14) do not conclusively show that the pattern in the outflow is a result of the concentrations in the inflows. An estimate of the concentration of dissolved solids in the reservoir for 1972–89 was determined from the estimated loads of dissolved solids in the inflows (stations 08377200 and 08447410), the quantity of the outflow (station 08450900), and the contents of the reservoir. A comparison of the actual concentrations of dissolved solids in the outflow to the estimated concentrations of the reservoir is shown in figure 16. The estimated concentrations show that the loads of dissolved solids in the inflows do result in a steady increase in the dissolved-solids concentrations of the reservoir.

Falcon Reservoir is about 200 mi downstream on the Rio Grande from Amistad Reservoir. Many small tributaries with concentrations of dissolved solids less than 500 mg/L improve the quality of the water in the Rio Grande before it enters Falcon Reservoir (Texas Department of Water Resources, 1984). Plots of the dissolved-solids concentrations of the Rio Grande above and below Falcon Reservoir are shown in figure 17. The inflow (station 08459000) was sampled only through 1986 but still indicates the general level of dissolved-solids concentrations flowing into Falcon Reservoir and an increase in the concentrations in about 1982 that corresponds to the increase in concentrations in the outflow from Amistad Reservoir. Data from the outflow (station 08461300) indicate an overall increase in the concentrations of dissolved solids, but with many more fluctuations in the concentrations than are shown in the inflow. Monthly mean contents of Falcon Reservoir (fig. 18) indicate that the contents of the reservoir have fluctuated similarly. When the contents of the reservoir increase, the dissolved-solids concentrations in the outflow tend to decrease. When the contents of the reservoir decrease, the dissolved-solids concentrations in the outflow tend to increase. This pattern indicates that the reservoir fills with high flow, low concentration water that gradually becomes more concentrated from low flow, high concentration water until it is diluted by the next high flow. The overall increase in the dissolved-solids concentrations in the reservoir is probably a continuing effect from increased concentrations of dissolved solids in the Pecos River and, to a lesser extent, the Rio Grande above the Amistad Reservoir. The dissolved-solids concentrations at sites downstream of Falcon Reservoir have similar patterns, but with less magnitude.

Impoundment of streamflow in a reservoir and the decisions to increase or decrease the volume of a reservoir are human activities that have a direct effect on the water quality downstream. Regulation can be used to decrease the salinity of a reservoir by allowing the contents of the reservoir to increase when the

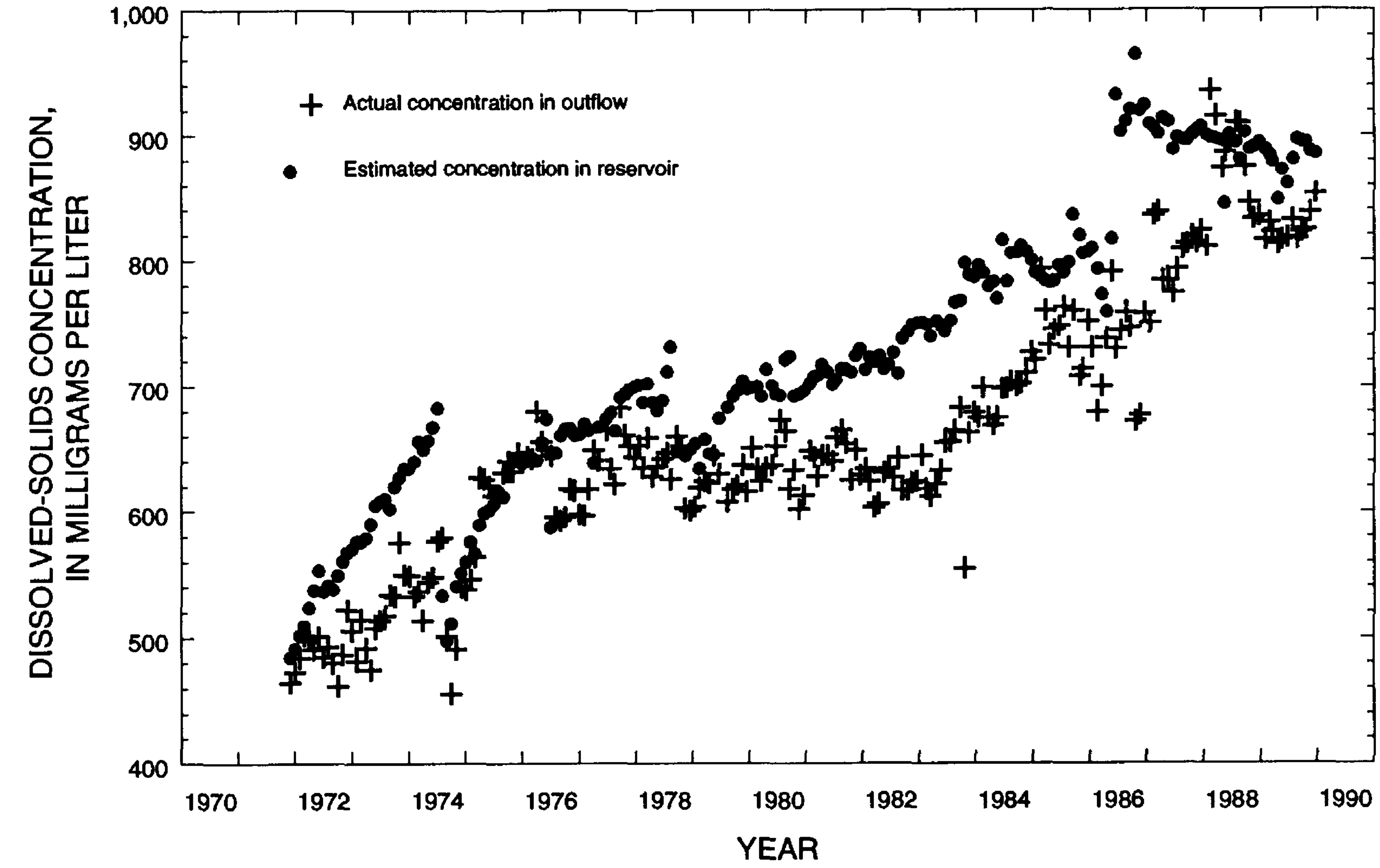

Figure 16. Estimated dissolved-solids concentration in Amistad Reservoir, Texas, and actual dissolved-solids concentration at the outflow from the reservoir, Rio Grande below Amistad Dam near Del Rio, Texas (station 08450900), 1972–89 water years.

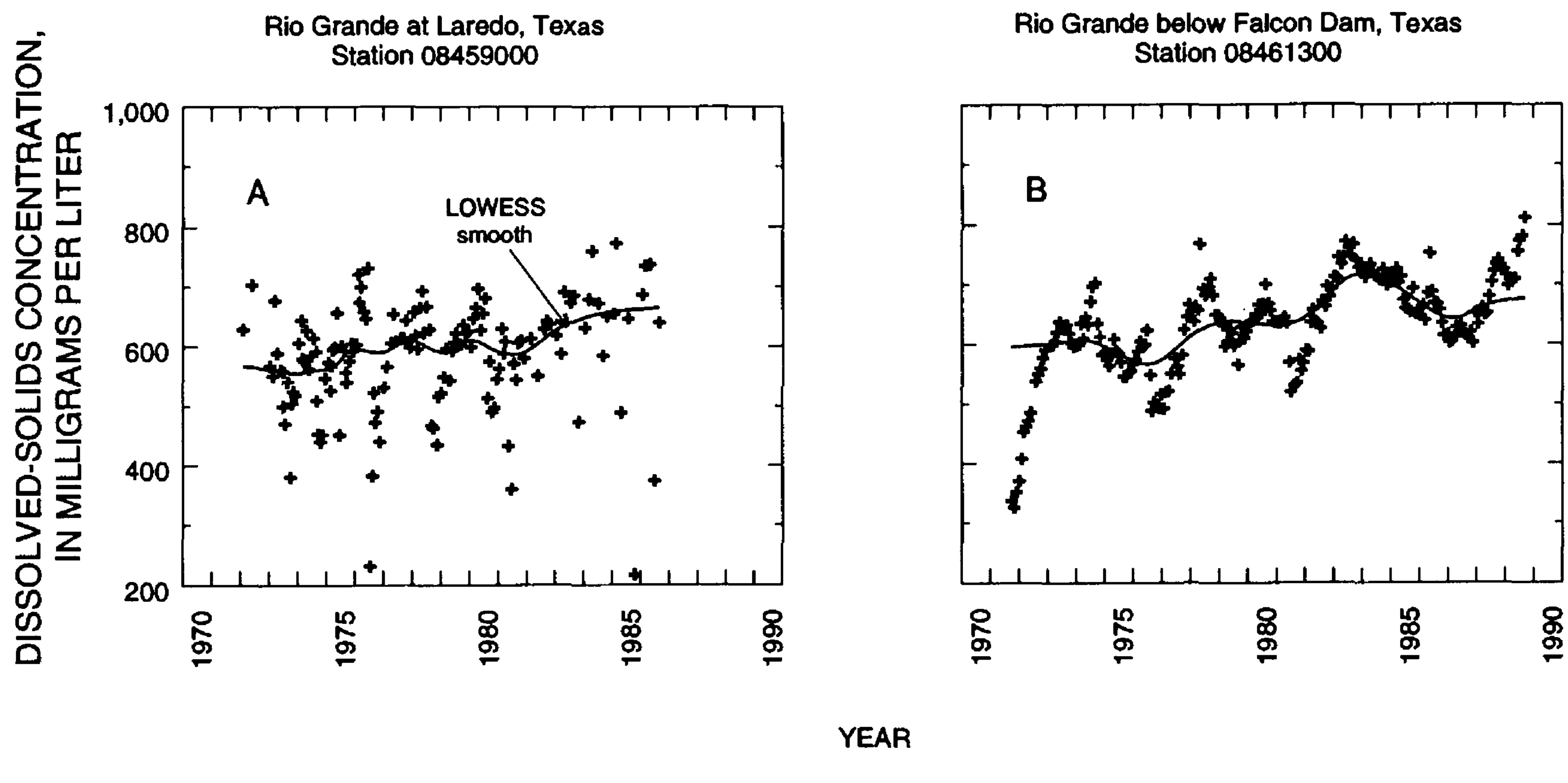

Figure 17. Variations in dissolved-solids concentrations for stations (A) above and (b) below Falcon Reservoir, Texas, 1972–89 water years.

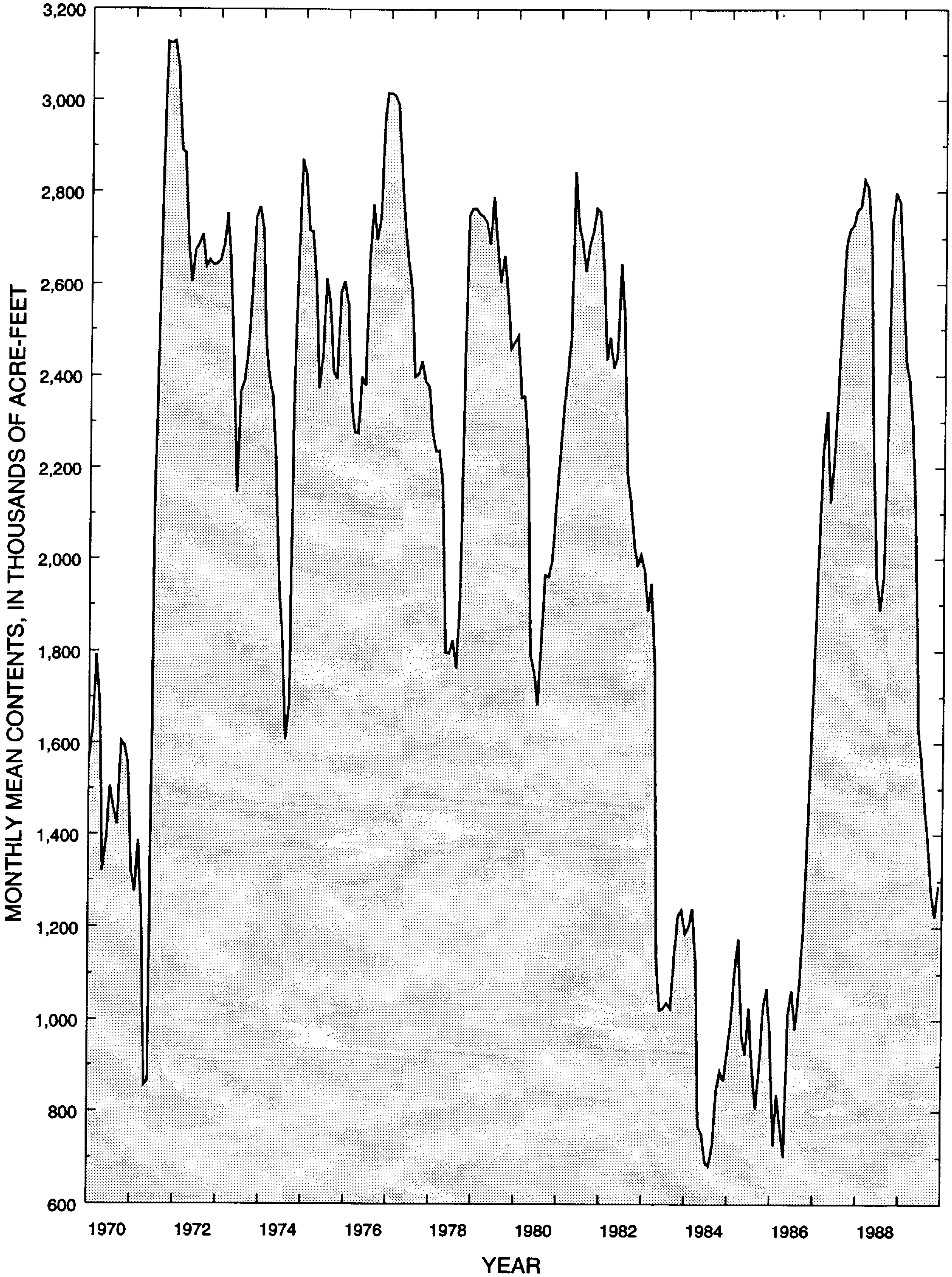

Figure 18. Monthly mean contents in Falcon Reservoir, Texas, 1970–89.

salinity of the inflow is low. But the impoundment of water can also prolong the effects of increased salinity in the inflow. The periods of high concentrations of dissolved solids in the Pecos River are detected below Amistad Reservoir and the rest of the Rio Grande Basin as long-term trends in the concentration, instead of sharp increases and decreases in dissolved-solids concentrations.

Analytical Methods

Nitrogen

Spatial patterns of trend indicators in the San Antonio River Basin showed increasing concentrations of ammonia plus organic nitrogen, total phosphorus, and BOD and decreasing concentrations of dissolved oxygen and nitrite plus nitrate for the 1975–86 water years. These constituents and the direction of the trends indicated that changes in municipal waste treatment could be the source of the trends. However, the patterns of trend indicators were not evident for the 1975–89 water years. Examination of graphs of concentrations of ammonia plus organic nitrogen and ammonia nitrogen for the 1975–89 period showed a pattern of higher concentrations for these constituents from 1980 to about 1985. Further investigation revealed a similar pattern for stations throughout the State with concentrations less than 5 mg/L of ammonia plus organic nitrogen and ammonia nitrogen. Maps of the trends for ammonia plus organic nitrogen and for ammonia nitrogen for the 1975–86 water years and the extended period of 1975–89 water years are shown in figures 19 and 20. The stations that showed trends in ammonia plus organic nitrogen for the 1975–89 water years are listed in table 6. The summary statistics for ammonia plus organic nitrogen from those stations for this period are shown in table 7. The stations that showed trends in ammonia nitrogen for the 1975–89 water years are listed in table 8. The summary statistics for ammonia nitrogen from those stations for the same period are shown in table 9. The number of trends in the State showing increasing concentrations of ammonia plus organic nitrogen changed from 21 for the 1975–86 water years to 4 for the 1975–89 water years. The number of trends in the State showing increasing concentrations of ammonia nitrogen changed from 25 for the 1975–86 water years to 11 for the 1975–89 water years.

Because of the number of similar trends and similar period of higher concentrations in the early 1980's throughout the State, the possible influence of field and laboratory methods was investigated. A bias in the concentrations of ammonia plus organic nitrogen and ammonia nitrogen in the early 1980's was documented by the laboratory. Several investigations conducted by laboratory personnel in late 1983 and early 1984 indicated that mercuric chloride tablets used for field preservation of nutrient samples during 1980–86 probably introduced a positive bias for these constituents. The laboratory investigations showed the range of the bias to be 0.003 to 0.06 mg/L for blanks for ammonia nitrogen and 0.17 to 0.52 mg/L for blanks for ammonia plus organic nitrogen. There was evidence that the bias could be higher in environmental samples. The higher bias for ammonia nitrogen was probably due to an additional positive matrix effect from the sodium chloride carrier used in the mecuric chloride tablets (Merle Shockey, written commun., 1992). Before 1984, the blanks and standards used in the analytical method for ammonia plus organic nitrogen and ammonia nitrogen were not treated with mercuric chloride tablets. In 1984, after the bias had been detected and attributed to the tablets, the tablets were then used to preserve the laboratory blanks and standards in an attempt to correct the bias. This lowered the bias, but did not eliminate it. In 1986, the preservation of nutrient samples with the mercuric chloride tablets was discontinued and ampoules of mercuric chloride solution were used instead.

Sites that demonstrated a trend of increasing concentrations in ammonia plus organic nitrogen and ammonia nitrogen for 1975–86 that could be attributed to the analytical bias generally had a median concentration less than 5 mg/L. The bias has a proportionally greater influence at these sites. Natural variations in concentrations for sites that had median concentrations greater than 5 mg/L generally masked the variations due to the analytical bias. Extension of the period of analysis to 1989 generally caused the trends to disappear. This was probably because the use of the tablets was discontinued in 1986 and the analytical values were no longer positively biased.

Although the pattern of trends for the stations in the San Antonio River Basin led to the discovery of the effect of the analytical bias, they were not the only stations that were affected. Time series graphs of ammonia nitrogen concentrations from other stations in the State that also demonstrate the possible effect of the bias from the mercuric chloride tablets are shown in figure 21. Similarly, figure 22 shows time series graphs

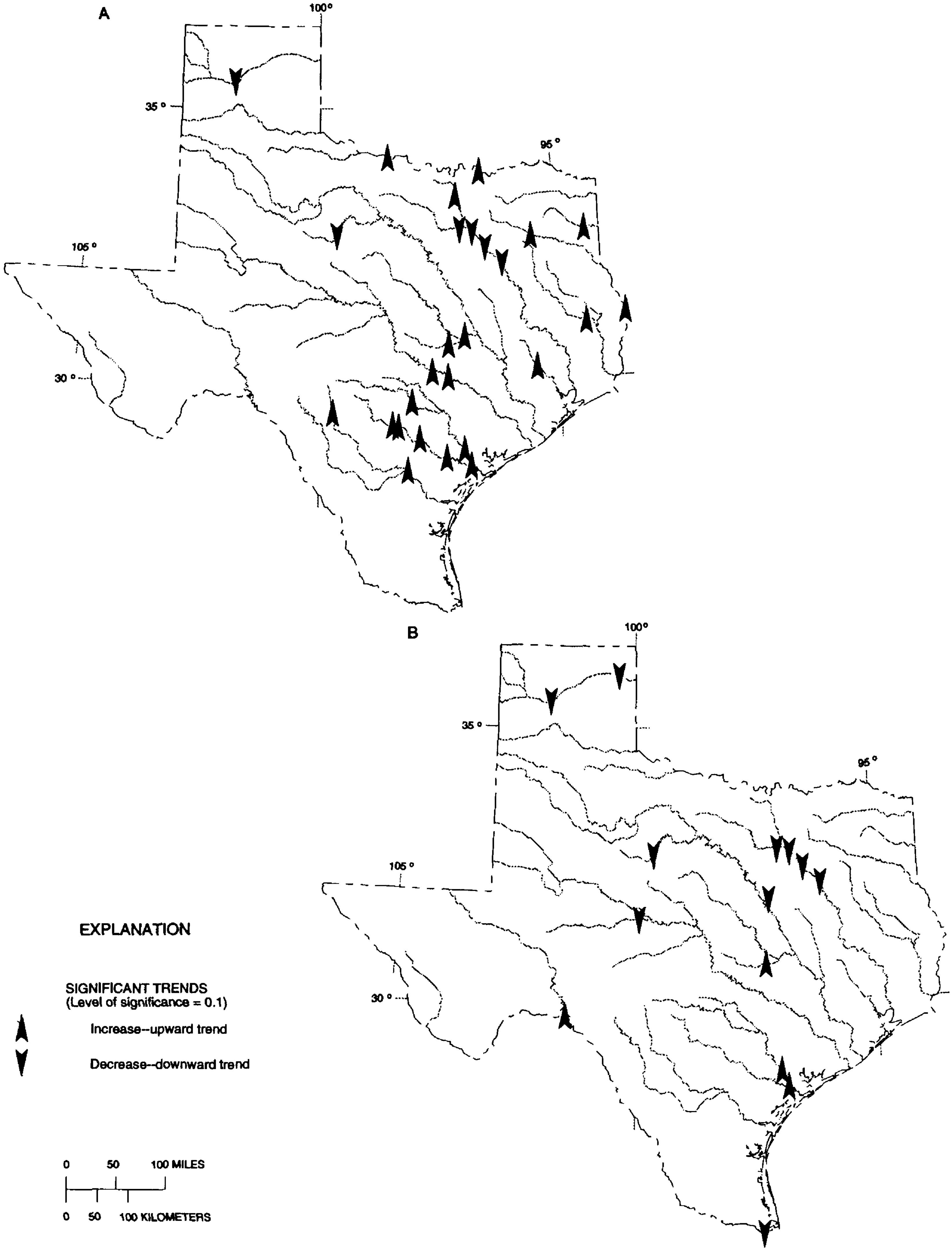

Figure 19. Trends in concentrations of ammonia plus organic nitrogen at selected stations in Texas for (A) 1975–86 and (B) 1975–89 water years.

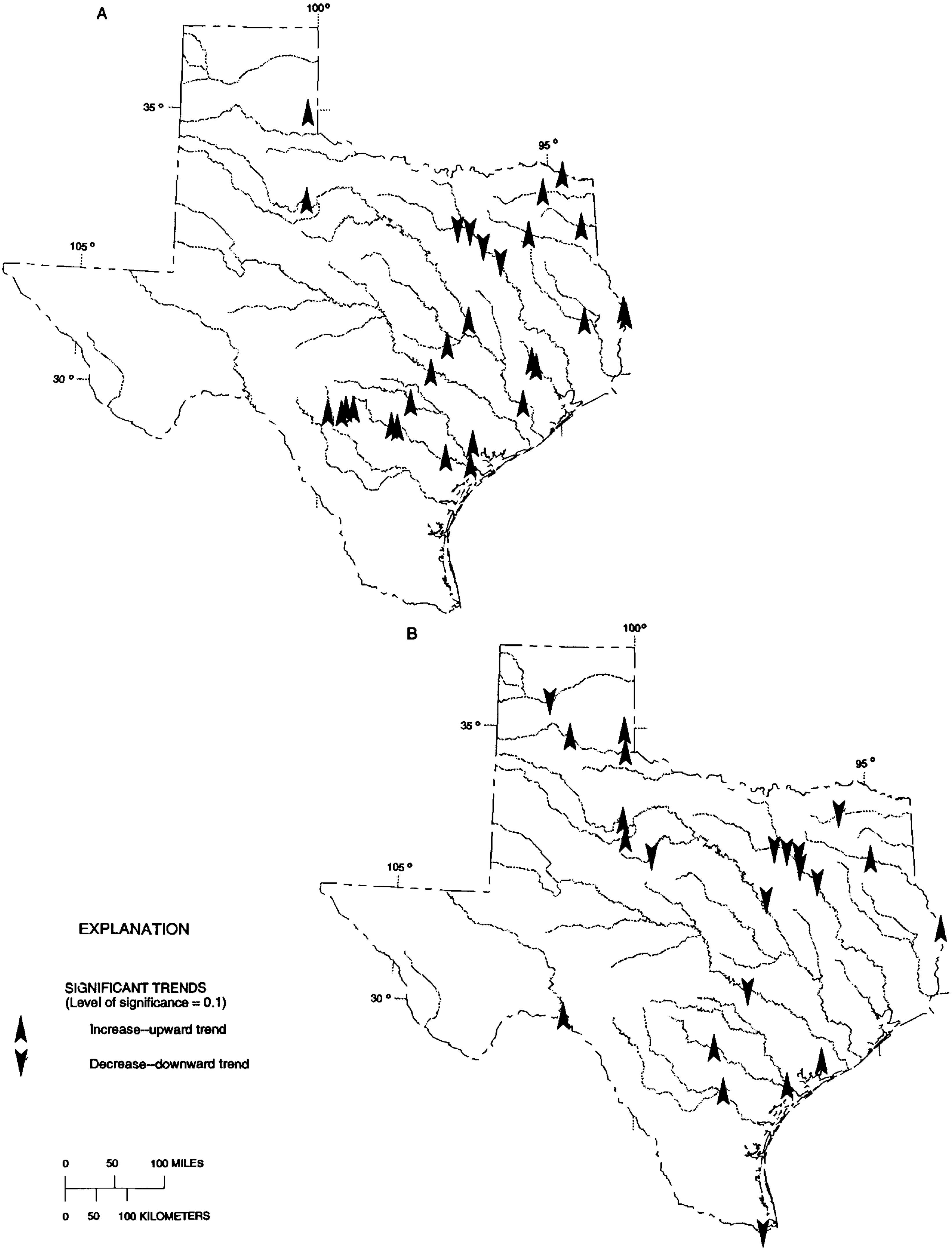

Figure 20. Trends in concentrations of ammonia nitrogen at selected stations in Texas for (A) 1975–86 and (B) 1975–89 water years.

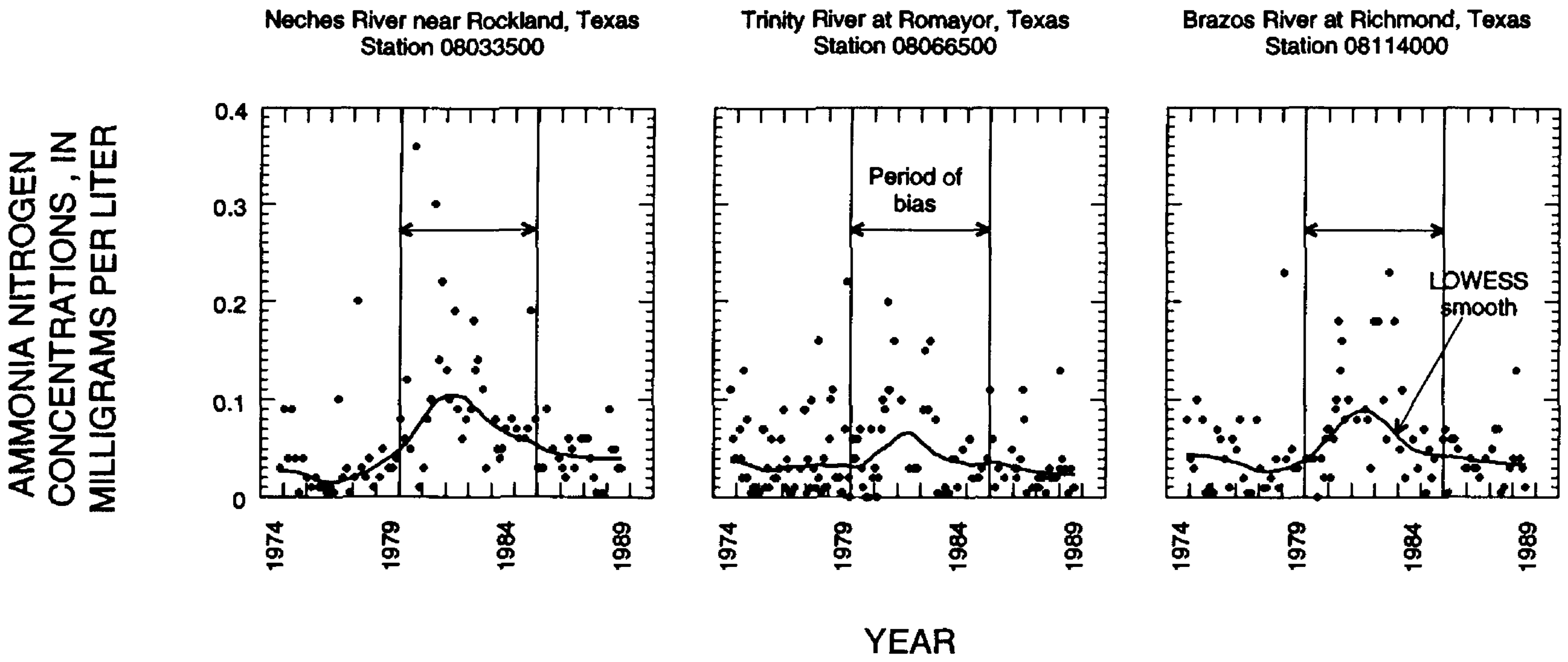

Figure 21. Variations in ammonia nitrogen concentrations for selected stations in Texas, 1975–89 water years.

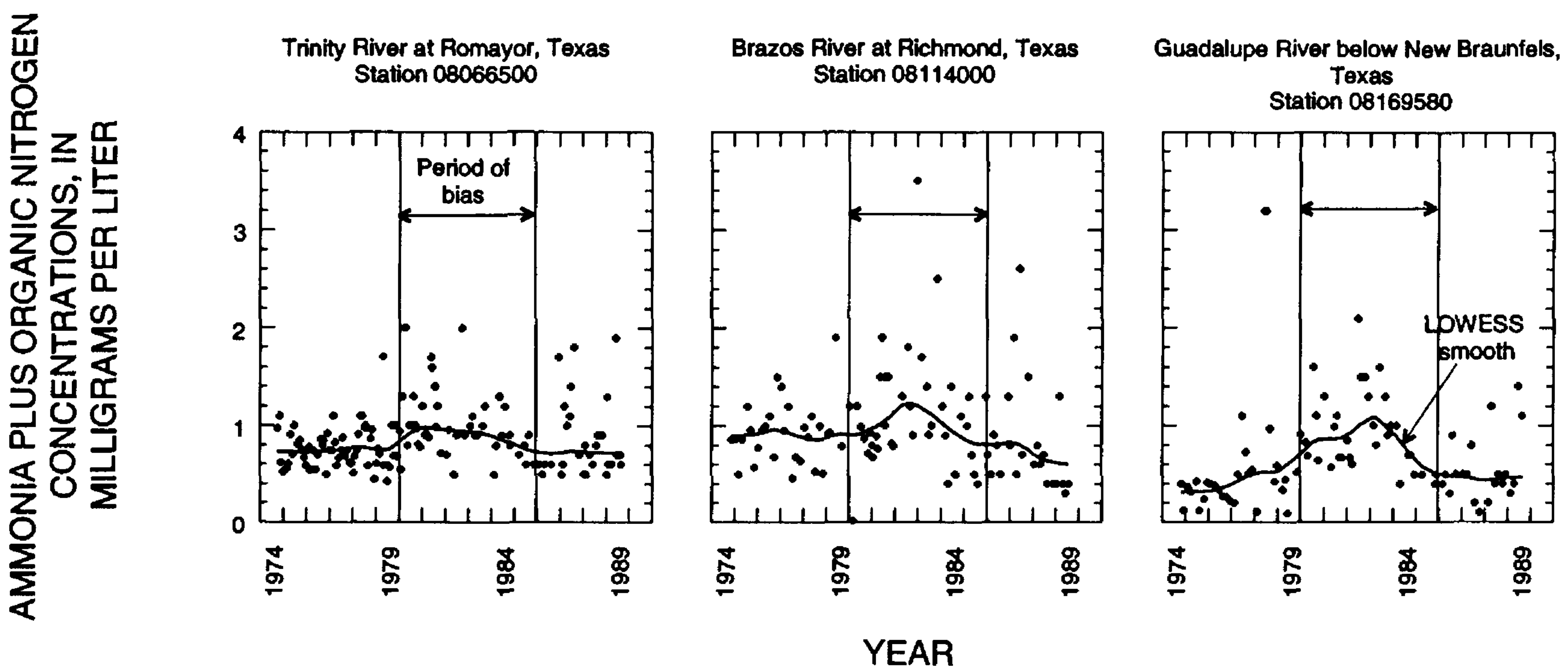

Figure 22. Variations in ammonia plus organic nitrogen concentrations for selected stations in Texas, 1975–89 water years.

of ammonia plus organic nitrogen concentrations. The smoothed line in each of the graphs shows a distinct rise in the overall concentrations of these constituents in about 1980. The concentrations show a general decrease beginning in about 1984 when the mercuric tablets were added to the blanks and standards in an attempt to correct the bias. In 1986, when use of the tablets was discontinued, the concentrations return to normal levels of variation.

Determination of a source for the patterns of increasing and decreasing concentrations in nutrients and oxygen that indicated possible influence by wastewater effluent in the San Antonio River Basin has been complicated by the analytical bias on the nutrient values. The trends for BOD and dissolved oxygen in the San Antonio River Basin for the 1975–86 water years also disappeared in the extended period of analysis. Examination of the graphs of these constituents

Table 6. *Water-quality stations in Texas with trends in concentrations of ammonia plus organic nitrogen for the 1975–89 water years*

Station number	Station name
07227500	Canadian River near Amarillo, Texas
07228000	Canadian River near Canadian, Texas
08049500	West Fork Trinity River at Grand Prairie, Texas
08057410	Trinity River below Dallas, Texas
08062500	Trinity River near Rosser, Texas
08062700	Trinity River at Trinidad, Texas
08084100	Deadman Creek near Nugent, Texas
08093500	Aquilla Creek near Aquilla, Texas
08105700	San Gabriel River at Laneport, Texas
08136500	Concho River at Paint Rock, Texas
08176500	Guadalupe River at Victoria, Texas
08447410	Pecos River near Langtry, Texas
08475000	Rio Grande near Brownsville, Texas

Table 7. *Statistical summary and trend results of ammonia plus organic nitrogen for stations in Texas with trends for the 1975–89 water years*

[N, number of observations used for trend analysis; p, attained significance of trend test; percentiles in milligrams per liter; TREND CODES: U, best trend is trend in unadjusted concentrations; F, best trend is trend in flow-adjusted concentrations]

Station number	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
07227500	89	2.7	0.50	1.1	3.2	79	-0.14	-5.22	0.000	F
07228000	137	.96	.60	.88	1.2	82	-.04	-3.81	.001	F
08049500	131	5.0	1.80	3.0	6.2	79	-.28	-5.67	.000	F
08057410	129	7.3	3.00	6.4	12	82	-.46	-6.28	.000	F
08062500	126	5.9	1.67	4.0	9.4	83	-.32	-5.35	.000	F
08062700	130	4.8	1.47	2.9	7.5	84	-.24	-4.99	.000	F
08084100	89	6.2	1.95	3.6	7.7	83	-.24	-3.87	.000	U
08093500	85	1.2	.70	.99	1.5	73	-.03	-2.54	.063	U
08105700	125	.71	.40	.6	.79	60	.02	2.15	.010	U
08136500	90	1.2	.90	1.2	1.5	84	-.02	-1.71	.060	U
08176500	116	.60	.36	.51	.79	30	.02	2.87	.064	F
08447410	128	.55	.31	.49	.64	83	.01	2.05	.052	F
08475000	124	1.0	.68	.90	1.1	81	-.02	-1.96	.003	U

(figs. 23–24) indicates that there was some influence in the Medina and San Antonio Rivers that could have been related to wastewater treatment effluent. The BOD concentrations begin to increase in about 1979, peak in about 1985, and return to original levels by 1988. Similarly, the dissolved oxygen concentrations show a general decrease in about 1979, reach the lowest levels in about 1985, and return to original levels by 1989. Ancillary data from the city of San Antonio were not detailed enough to refute or support the possibility that the trends were the result of wastewater treatment. Improvements have been made in the wastewater treatment facilities in San Antonio, and subsequent trend analysis in the San Antonio area should reflect these improvements. Because of the bias in the ammonia plus organic nitrogen and ammonia nitrogen

Table 8. *Water-quality stations in Texas with trends in concentrations of ammonia nitrogen for the 1975–89 water years*

Station number	Station name
07227500	Canadian River near Amarillo, Texas
07297910	Prairie Dog Town Fork Red River near Wayside, Texas
07299540	Prairie Dog Town Fork Red River near Childress, Texas
07300000	Salt Fork Red River near Wellington, Texas
07342500	South Sulphur River near Cooper, Texas
08020000	Sabine River near Gladewater, Texas
08025360	Sabine River at Toledo Bend Dam, Texas
08049500	West Fork Trinity River at Grand Prairie, Texas
08057410	Trinity River below Dallas, Texas
08062000	East Fork Trinity River near Crandall, Texas
08062500	Trinity River near Rosser, Texas
08062700	Trinity River at Trinidad, Texas
08080500	Double Mountain Fork Brazos River near Aspermont, Texas
08082000	Salt Fork Brazos River near Aspermont, Texas
08084100	Deadman Creek near Nugent, Texas
08093500	Aquilla Creek near Aquilla, Texas
08158650	Colorado River below Austin, Texas
08162600	Tres Palacios River near Midfield, Texas
08181800	San Antonio River near Elmendorf, Texas
08188800	Guadalupe River near Tivoli, Texas
08210000	Nueces River near Three Rivers, Texas
08447410	Pecos River near Langtry, Texas
08475000	Rio Grande near Brownsville, Texas

concentrations, the trends in these constituents cannot be used as support for the trends in oxygen. Without any more reliable evidence than is available in this area, it is not possible to attribute the patterns in the data to any specific source.

Sulfate

Spatial patterns of trend indicators in the eastern part of the State showed increasing concentrations of dissolved sulfate for the 1975–86 water years. The same pattern persisted in the trend results for the 1975–89 water years. Maps of the trend indicators for concentrations of dissolved sulfate are shown in figure 25. Sulfate trend patterns throughout the State were generally consistent with other inorganic constituents, but the increasing concentrations of sulfate detected in the eastern part of the state were anomalous. Most of the other inorganic constituents showed a few trends of both increasing and decreasing concentrations without any distinct pattern in this area. Although potential sources of sulfate such as paper mills and coal-fired power plants exist in the area, there was no evidence in the sulfate concentrations of influence from a particular source or sources.

The National Water Quality Laboratory documented the discovery of a positive bias in sulfate concentrations in December 1989. A turbidimetric method for sulfate analysis that had been in use since October 1982 could result in a bias of approximately 2 mg/L in samples with sulfate concentrations less than about 75 mg/L. The bias was not consistent among samples and could be influenced by other characteristics of each sample, such as color and turbidity. Review of the sites in east Texas that demonstrated a positive trend in sulfate concentrations showed that the concentrations were generally less than 75 mg/L and often had median concentrations less than 20 mg/L.

Table 9. *Statistical summary and trend results of ammonia nitrogen for stations in Texas with trends for the 1975–89 water years*

[N, number of observations used for trend analysis; p, attained significance of trend test; percentiles in milligrams per liter; TREND CODES: U, best trend is trend in unadjusted concentrations]

Station number	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
07227500	90	1.04	0.05	0.10	0.88	90	-0.01	-1.39	0.005	U
07297910	102	.15	.05	.11	.18	102	.01	6.09	.001	U
07299540	44	.38	.15	.37	.51	44	.10	24.96	.000	U
07300000	85	.11	.04	.10	.15	85	.01	5.10	.060	U
07342500	61	.10	.05	.08	.13	61	-.01	-6.82	.024	U
08020000	42	.08	.03	.06	.11	42	.02	26.17	.000	U
08025360	70	.05	.02	.03	.08	70	.00	.00	.096	U
08049500	132	2.78	.25	1.3	3.9	132	-.17	-6.06	.000	U
08057410	130	4.66	.93	3.8	7.5	130	-.49	-10.62	.000	U
08062000	100	6.31	.98	3.9	11.	100	-.21	-3.29	.021	U
08062500	128	4.01	.47	2.1	7.0	128	-.43	-10.60	.000	U
08062700	107	3.10	.25	1.5	5.1	107	-.18	-5.83	.000	U
08080500	53	.14	.04	.09	.16	53	.01	7.11	.035	U
08082000	97	.25	.09	.19	.34	97	.01	4.87	.007	U
08084100	90	2.82	.09	.71	4.8	90	-.07	-2.49	.000	U
08093500	84	.17	.03	.06	.12	84	.00	.00	.031	U
08158650	127	.61	.11	.21	.68	127	-.01	-1.10	.088	U
08162600	61	.09	.01	.05	.10	61	.00	.00	.059	U
08181800	124	2.62	.90	1.9	4.1	124	.18	6.86	.022	U
08188800	88	.08	.03	.05	.09	88	.00	.00	.053	U
08210000	129	.20	.04	.06	.14	129	.00	.00	.029	U
08447410	105	.04	.02	.03	.06	105	.00	.00	.009	U
08475000	106	.21	.02	.06	.13	106	-.01	-2.60	.001	U

Although the sites in eastern Texas fit the basic criterion of median sulfate concentrations less than 75 mg/L for data that might be affected by the bias in the turbidimetric method, more evidence that the pattern of trends was indeed an artifact of the bias was needed. The area considered for evaluation was expanded to include the whole State, since a method-related trend source would potentially affect all stations. The trends in dissolved sulfate for all stations with sufficient data for the 1975–89 water years are shown in figure 26 (tables 10 and 11). All stations that had 75 percent of sulfate concentrations less than 75 mg/L and sufficient data for trend analysis for the 1975–89 water years were selected from the 185 stations included in the trend study. Color analyses were retrieved for these stations and the mean of the available values was calculated for each station. Color values were not available for every station, so values from a station were considered representative of other stations in the same river basin and the same geographic regions. The mean color values ranged from 0 to 135 units. A specific level of color where interference in the sulfate determination occurred was never identified since other characteristics of the sample matrix could also affect the bias. But the presence of color did contribute to a bias. So, an arbitrary value of greater than 20 for color was used to further screen the selected stations. These selected stations and the trend indicators for the 1975–89 water years are shown in figure 27. The sites in eastern Texas are clearly most susceptible to the laboratory bias in sulfate measurements because of the presence of color in the water and concentrations of sulfate that are generally less than 75 mg/L.

Further support for the conclusion that the sulfate trends in eastern Texas were related to the bias was found in the results of comparison data from the

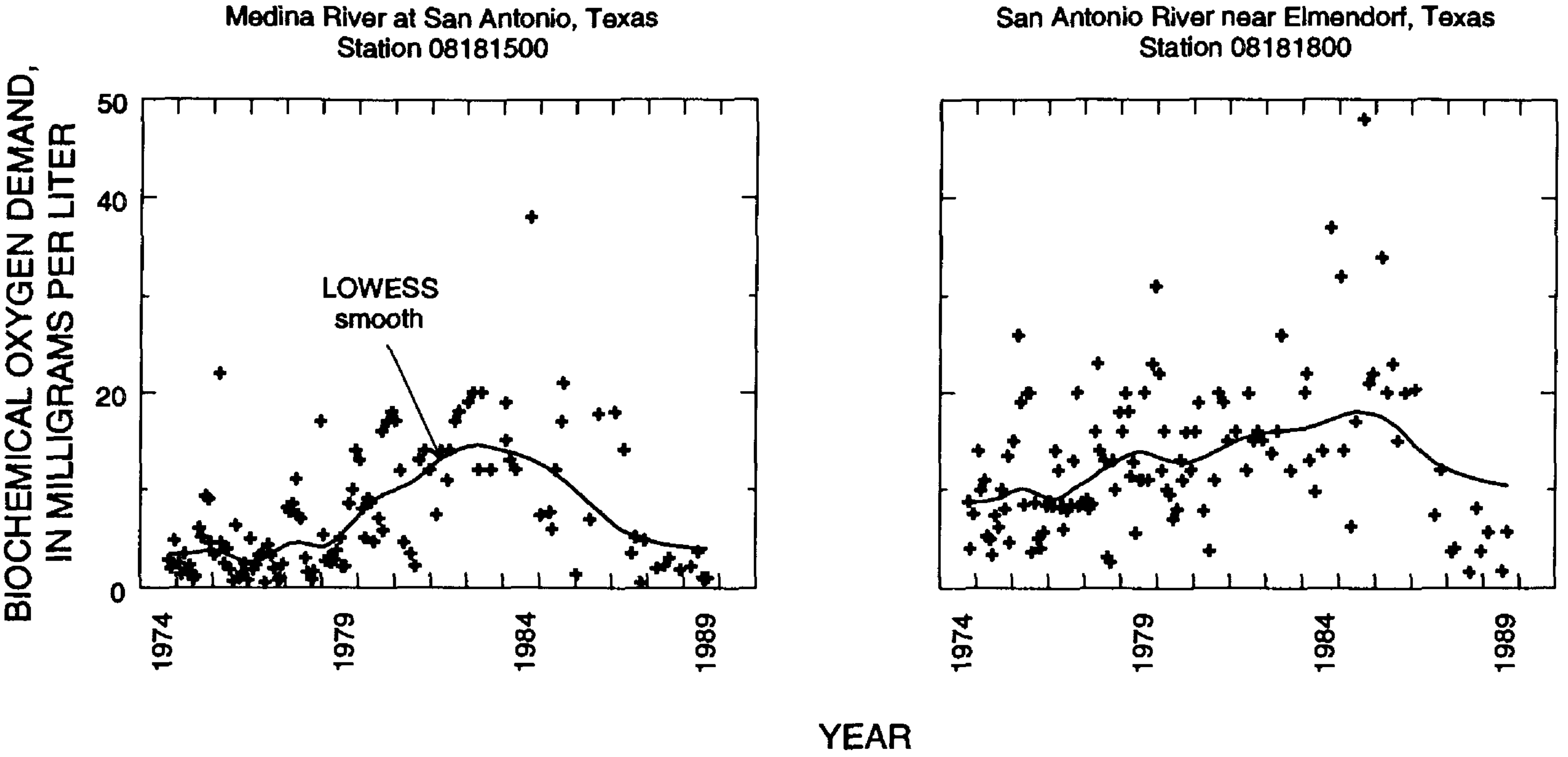

Figure 23. Variations in biochemical oxygen demand concentrations for selected stations in the San Antonio River Basin, Texas, 1975–89 water years.

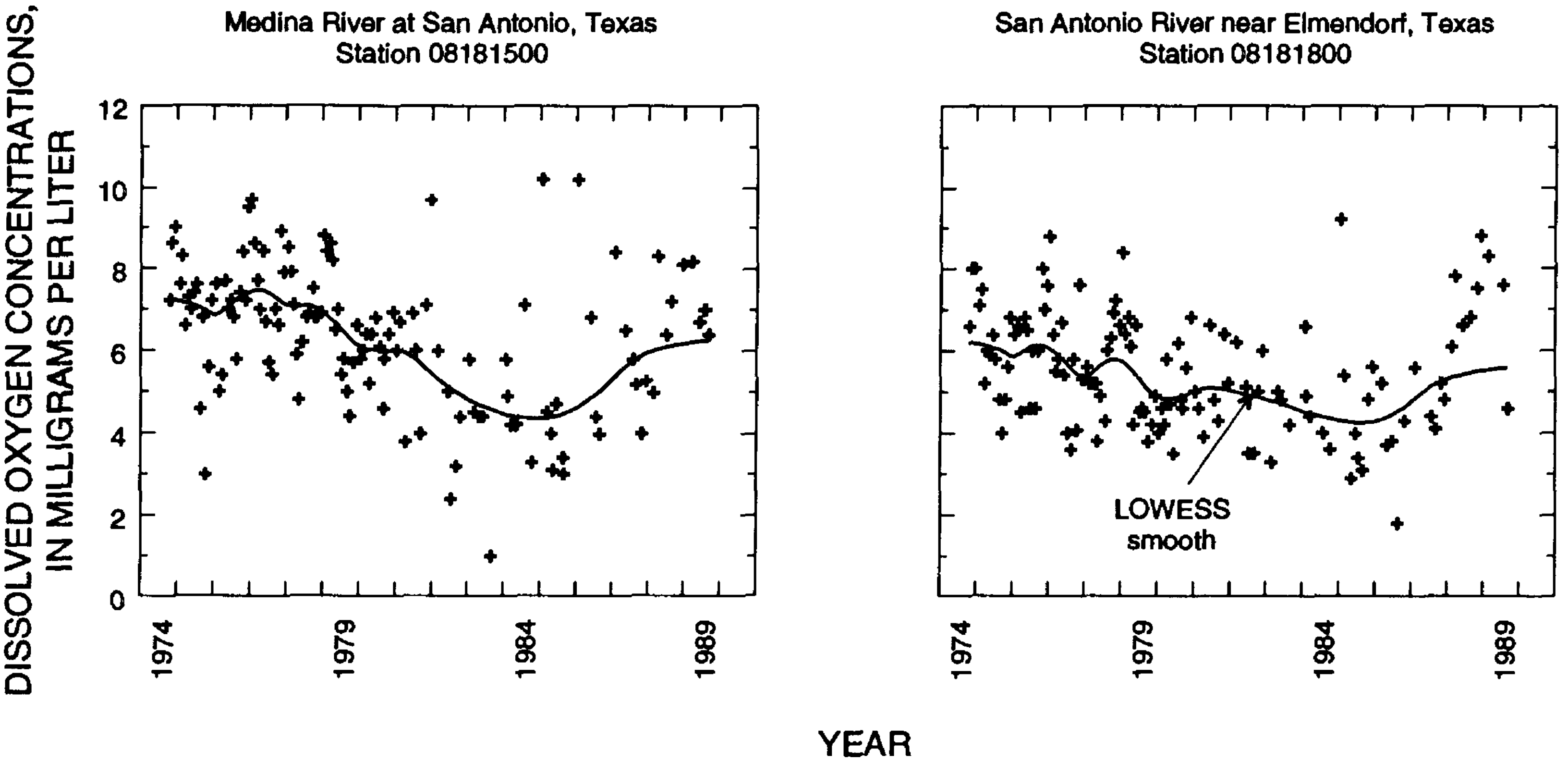

Figure 24. Variations in dissolved oxygen concentrations for selected stations in the San Antonio River Basin, Texas, 1975–89 water years.

National Water Quality Laboratory. Paired analytical results were provided by the laboratory for blank corrected and uncorrected sulfate values for several months in early 1990. The difference in these paired results for sites in Texas was greatest in eastern Texas.

The graphs of the sulfate concentrations for the 1975–89 water years did not provide immediate evidence of a shift in the sulfate values in October 1982. The difference in the overall values was generally small and almost undetectable in graphs. Figure 28

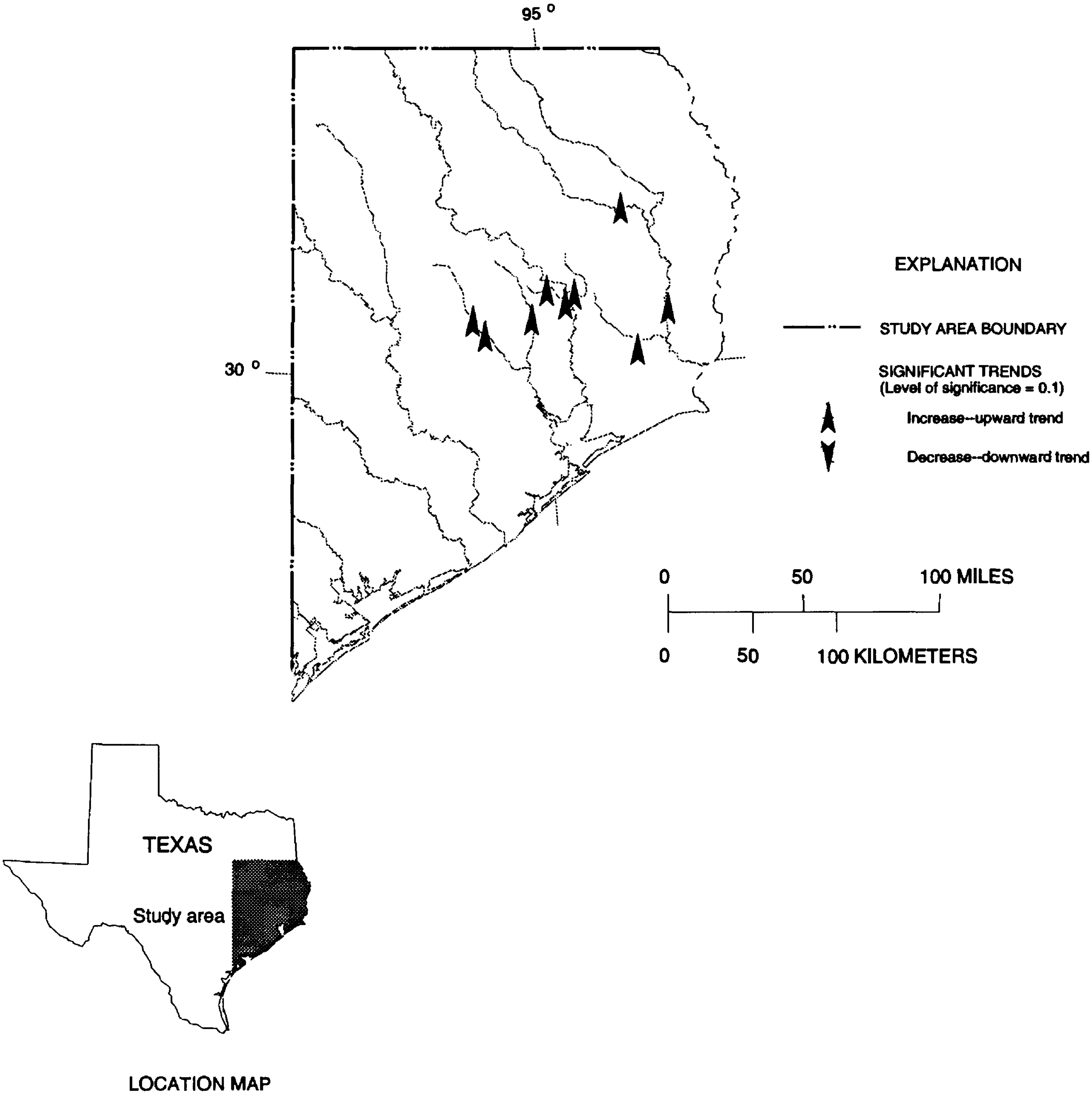

Figure 25. Trends in concentrations of dissolved sulfate at selected stations in eastern Texas for the 1975–89 water years.

shows examples of sulfate concentrations from three stations. The first station (07343500) had a median sulfate concentration of 31 mg/L. The only visible shift in values after October 1982 is in the lowest concentrations. The low values before 1982 are less than the low values after October 1982. The second station (08041000) has a median sulfate concentration of 21 mg/L. Once again, the only visible change is in the low values. The third station (08066400) has a median sulfate concentration of 5.6 mg/L, and only for the extremely low values is the shift in the concentrations visible for the range of values.

Trend analysis indicated a regional occurrence of increased sulfate concentrations, but without prior

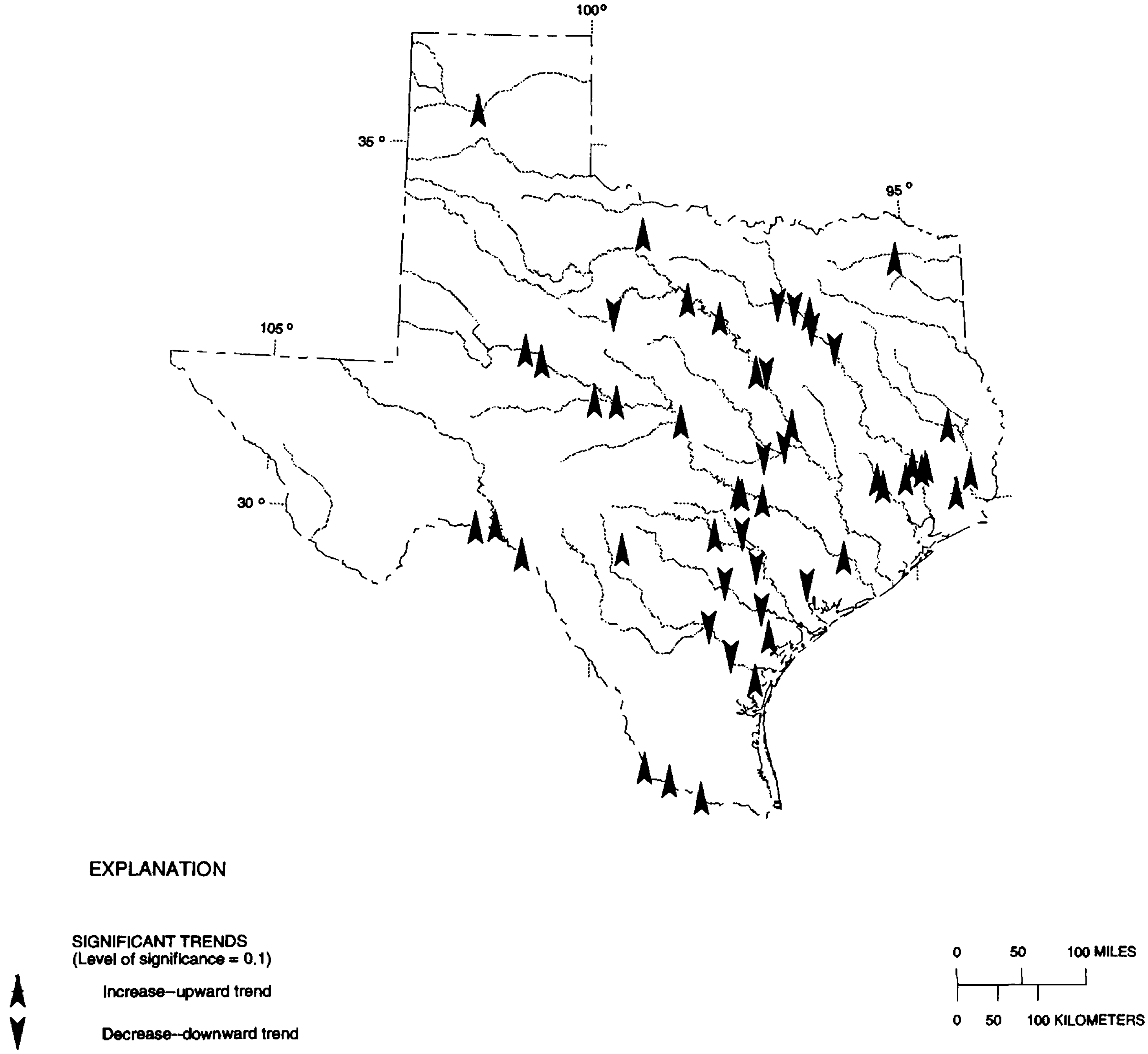

Figure 26. Trends in concentrations of dissolved sulfate at selected stations in Texas for the 1975–89 water years.

knowledge of the bias identified by the laboratory, even close inspection of time series graphs would not have provided the answers. A certain amount of error is associated with every analytical value. Consistency in data collection, sample handling, and method of analysis can reduce the error, but never remove it. Occasionally, a quantifiable error can be identified for specific samples. Knowledge of the source and magnitude of this type of error is invaluable and necessary information to future evaluations of this data.

Undetermined

Numerous trend patterns evident for the constituents in this trend study did not receive further investigation. These patterns usually occurred in a small geographical area and had no known source. Although these trend results might prove useful in future studies, they were not analyzed in this study. There were also unsuccessful attempts to determine the source of several patterns; no discussion of these

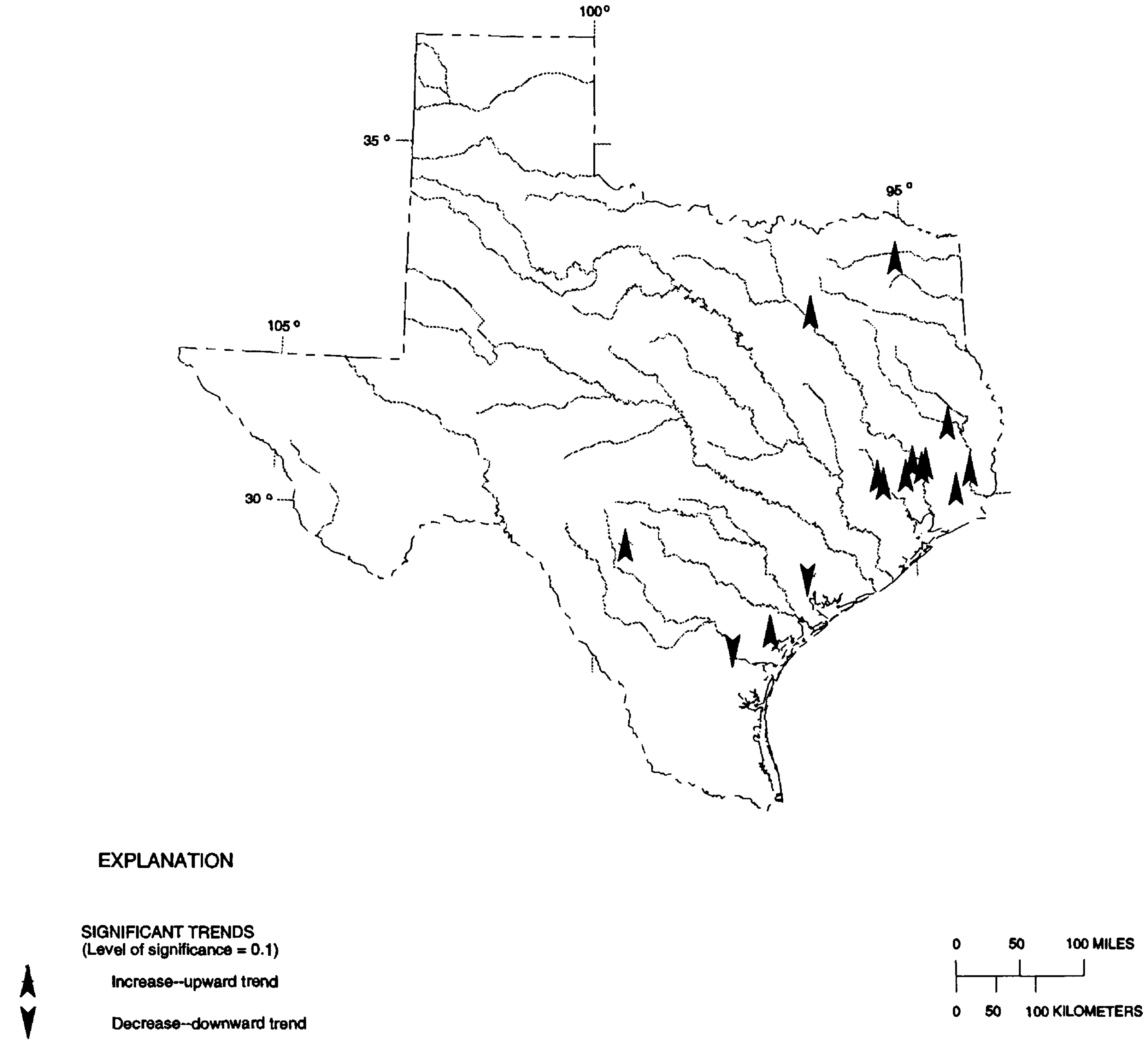

Figure 27. *Trends in concentrations of dissolved sulfate at stations in Texas with 75 percent of concentrations less than 75 milligrams per liter and median color values greater than 20 for the 1975–89 water years.*

attempts is included in this report. However, one trend pattern with no identifiable source had such a significant pattern that discussion of the unsuccessful attempts to identify a source is warranted.

Results of the trend analysis of pH demonstrated a statewide pattern of increasing pH (fig. 29). Texas is a large state with diverse influences on the quality of the surface water. A single environmental factor would not be likely to influence the hydrology of the entire State. A method-related influence would be a more likely source of a statewide trend pattern.

The graphs of pH values were examined for all stations that had sufficient data for trend analysis for the 1975–89 water years. The examination of the data was not restricted to sites that demonstrated a trend (tables 12 and 13) because method-related effects on data should influence all data even if the result was not strong enough to produce a trend. Figure 30 shows the smoothed lines through the pH data from selected sites throughout the State. Several features of the graphs are evident: (1) changes in the values toward higher values appeared to be gradual rather than abrupt, and (2) there

Table 10. *Water-quality stations in Texas with trends in concentrations of dissolved sulfate for the 1975–89 water years*

[Code: *, station has 75 percent of concentrations less than 75 milligrams per liter and median color values greater than 20]

Station number	Station name	Code
07227500	Canadian River near Amarillo, Texas	
07312100	Wichita River near Mabelle, Texas	
07343500	White Oak Creek near Talco, Texas	*
08033500	Neches River near Rockland, Texas	*
08041000	Neches River at Evadale, Texas	*
08041700	Pine Island Bayou near Sour Lake, Texas	*
08049500	West Fork Trinity River at Grand Prairie, Texas	
08057410	Trinity River below Dallas, Texas	
08062000	East Fork Trinity River near Crandall, Texas	*
08062500	Trinity River near Rosser, Texas	
08062700	Trinity River at Trinidad, Texas	
08066300	Menard Creek near Rye, Texas	*
08066400	Big Creek near Shepherd, Texas	*
08066500	Trinity River at Romayor, Texas	*
08067650	West Fork San Jacinto River below Lake Conroe near Conroe, Texas	*
08068000	West Fork San Jacinto River near Conroe, Texas	*
08070000	East Fork San Jacinto River near Cleveland, Texas	*
08084100	Deadman Creek near Nugent, Texas	
08088600	Brazos River near Graford, Texas	
08090800	Brazos River near Dennis, Texas	
08092600	Brazos River at Whitney Dam near Whitney, Texas	
08093500	Aquilla Creek near Aquilla, Texas	
08098290	Brazos River near Highbank, Texas	
08105700	San Gabriel River at Laneport, Texas	
08106500	Little River at Cameron, Texas	
08123800	Beals Creek near Westbrook, Texas	
08123850	Colorado River above Silver, Texas	
08136500	Concho River at Paint Rock, Texas	
08136700	Colorado River near Stacy, Texas	
08147000	Colorado River near San Saba, Texas	
08158000	Colorado River at Austin, Texas	
08158650	Colorado River below Austin, Texas	
08159200	Colorado River at Bastrop, Texas	
08162000	Colorado River at Wharton, Texas	
08164000	Lavaca River near Edna, Texas	*
08172000	San Marcos River at Luling, Texas	
08175000	Sandies Creek near Westhoff, Texas	
08186000	Cibolo Creek near Falls City, Texas	
08188500	San Antonio River at Goliad, Texas	
08189500	Mission River at Refugio, Texas	*
08198000	Sabinal River near Sabinal, Texas	*
08210000	Nueces River near Three Rivers, Texas	
08211000	Nueces River near Mathis, Texas	*
08211520	Oso Creek at Corpus Christi, Texas	
08377200	Rio Grande at Foster Ranch near Langtry, Texas	
08447410	Pecos River near Langtry, Texas	
08450900	Rio Grande below Amistad Dam near Del Rio, Texas	
08461300	Rio Grande below Falcon Dam, Texas	
08464700	Rio Grande at Fort Ringgold Rio Grande City, Texas	
08469200	Rio Grande below Anzalduas Dam, Texas	

Table 11. *Statistical summary and trend results of dissolved sulfate for stations in Texas with trends for the 1975–89 water years*

[N, number of observations used for trend analysis; p, attained significance of trend test; *, 75 percent of concentrations less than 75 milligrams per liter and median color values greater than 20; percentiles in milligrams per liter; TREND CODES: U, best trend is trend in unadjusted concentrations; F, best trend is trend in flow-adjusted concentrations]

Station number	Sample size	Mean	25th percentile	50th percentile (median)	75th percentile	N	Units per year	Percent per year	p	Trend code
07227500	121	363.59	190	320	510	82	7.55	2.08	0.039	F
07312100	102	732.74	660	750	830	78	12.72	1.74	.000	F
07343500 *	111	38.84	19	31	56	75	1.06	2.73	.058	F
08033500 *	87	28.20	22	28	32	78	.40	1.42	.044	U
08041000 *	125	20.83	17	21	24	85	.30	1.44	.006	U
08041700 *	113	11.87	7.2	11	15	76	.46	3.90	.000	F
08049500	123	87.31	68	83	110	78	-1.11	-1.27	.008	F
08057410	122	93.30	80	97	110	83	-1.11	-1.19	.012	F
08062000 *	90	45.38	31	48	55	61	.98	2.15	.003	F
08062500	121	77.51	53	79	100	85	-1.04	-1.35	.003	F
08062700	132	74.88	48	81	100	84	-1.29	-1.73	.000	F
08066300 *	112	5.73	3.5	5.3	7.4	82	.33	5.77	.000	U
08066400 *	114	5.68	4.1	5.6	7.0	84	.33	5.84	.000	F
08066500 *	140	34.76	28	34	41	86	.52	1.49	.005	F
08067650 *	64	7.42	5.0	7.0	9.0	35	.29	3.88	.000	U
08068000 *	145	10.13	6.8	9.6	12	86	.58	5.72	.000	F
08070000 *	91	7.10	4.4	6.5	10	69	.50	7.11	.000	F
08084100	91	206.01	170	200	240	80	-3.07	-1.49	.008	F
08088600	102	368.33	308	380	440	56	10.00	2.71	.008	U
08090800	109	307.70	205	320	410	80	11.44	3.72	.002	F
08092600	105	202.38	150	200	255	72	6.04	2.98	.000	F
08093500	111	159.23	88	150	210	77	-6.75	-4.24	.000	F
08098290	124	138.75	100	130	180	77	4.00	2.88	.003	U
08105700	124	31.95	25	30	36	60	-.66	-2.07	.001	F
08106500	125	40.26	28	41	53	82	-.43	-1.06	.071	F
08123800	114	1,411.54	738	1,400	2,100	81	41.00	2.90	.051	U
08123850	129	1,196.43	500	1,200	1,700	85	22.17	1.85	.061	F
08136500	129	237.40	175	250	300	87	4.78	2.02	.001	F
08136700	109	296.25	155	270	410	77	14.82	5.00	.000	F
08147000	126	109.38	44	87	140	82	5.35	4.89	.002	F
08158000	122	35.59	32	35	39	71	.32	.91	.006	F
08158650	97	42.63	35	40	48	81	1.00	2.35	.000	U
08159200	84	45.46	37	43	51	75	.81	1.78	.001	U
08162000	132	38.67	34	38	43	82	.46	1.18	.030	F
08164000 *	114	20.48	17	20	26	79	-.43	-2.09	.002	U
08172000	109	30.94	28	31	33	84	-.19	-.62	.071	U
08175000	113	79.72	44	79	110	82	-4.38	-5.49	.000	U
08186000	121	193.96	140	210	250	81	-3.62	-1.86	.001	F
08188500	135	99.47	78	110	120	82	-1.04	-1.05	.050	F
08189500 *	108	40.68	26	42	53	30	1.02	2.51	.074	F
08198000 *	58	26.24	24	26	29	44	.20	.75	.045	F
08210000	129	148.61	61	120	215	85	-9.97	-6.71	.000	F
08211000 *	94	49.00	34	48	62	71	-1.73	-3.53	.000	U
08211520	103	203.79	160	200	260	43	6.84	3.36	.005	F
08377200	129	302.25	270	300	330	55	3.45	1.14	.047	F
08447410	144	441.38	300	395	550	87	13.33	3.02	.000	U
08450900	180	232.33	210	230	257	180	6.00	2.58	.000	U
08461300	180	235.00	210	240	260	180	3.00	1.28	.000	U
08464700	180	243.61	210	240	270	168	3.28	1.35	.000	F
08469200	180	277.11	240	270	300	168	2.66	.96	.012	F

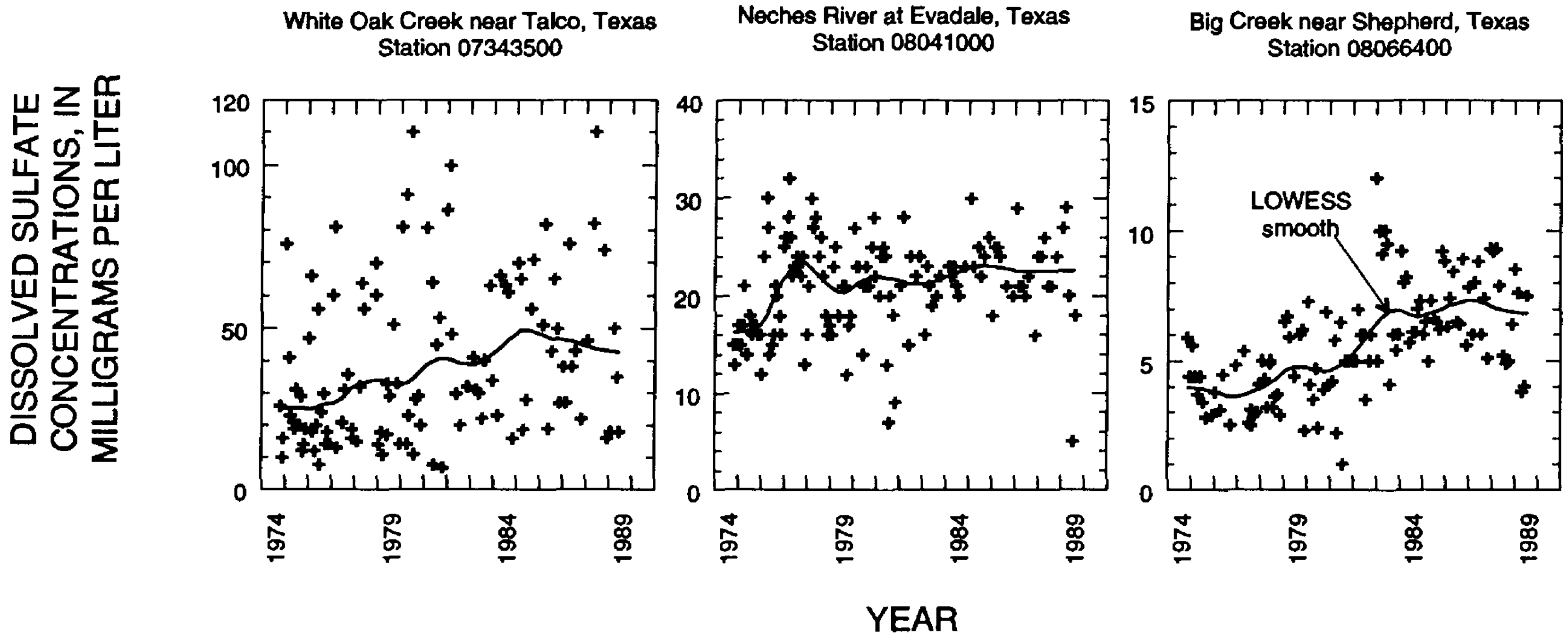

Figure 28. Variations in dissolved sulfate concentrations for selected stations in Texas, 1975–89 water years.

are a variety of patterns in the pH data from selected sites. A change in methods would more likely produce an abrupt and simultaneous change in the values at multiple sites. A variety of patterns indicates that there are a variety of influences on the pH values rather than any single influence.

The patterns in the pH data from sites in the same general area were compared to look for local influences. Some consistencies were noted in the patterns of the graphs when examined by area, but none of the patterns could be related to a specific source.

Several possibilities of a change in the methods for determining pH were considered. The instruments used to measure pH have changed and improved for the 1975–89 water years, but improved abilities to measure pH does not mean that the values would necessarily be higher. Before the 1975 water year, the pH determined by the laboratory was stored in the data base. The field determination of pH was stored in the data base after that time. Although the field and lab pH values are usually different, the influence from this switch cannot be seen in the trend results for the 1975–89 period. Therefore, the known changes in pH methods can not be identified as the source of the trends, and none of the identifiable patterns can be attributed to a specific source. The data show that pH values in Texas are generally higher in 1989 than in 1975, but no reason or reasons for the increase can be identified at this time.

SUMMARY OF CONCLUSIONS

The investigation of sources of trends in water-quality data in Texas was confined to distinct spatial patterns in the trend indicators for one constituent or group of related constituents. The original period of study for trend analysis was the 1975–86 water years, but was extended to the 1975–89 water years for the investigation of the sources of trends.

Spatial patterns of trend indicators in the Trinity River Basin near the Dallas-Fort Worth metropolitan area showed increasing concentrations of dissolved oxygen, percent saturation of dissolved oxygen, and nitrite plus nitrate and decreasing concentrations of biochemical oxygen demand (BOD), ammonia nitrogen, organic nitrogen, ammonia plus organic nitrogen, and total phosphorus for the 1975–86 water years. The same patterns persisted in the trend results for the 1975–89 water years. These constituents and the direction of the trends indicate that changes in municipal waste treatment could be the source of the trends. The relation of monthly mean concentrations of BOD from the eight major wastewater treatment facilities in the Dallas-Fort Worth metropolitan area to the BOD concentrations measured at the nearest downstream station on the Trinity River provided evidence that the trends were related to changes in municipal waste treatment. Increases in dissolved oxygen concentrations, decreases in ammonia nitrogen concentrations, and increases in nitrite plus nitrate concentrations in the Trinity River correspond to the BOD trends and

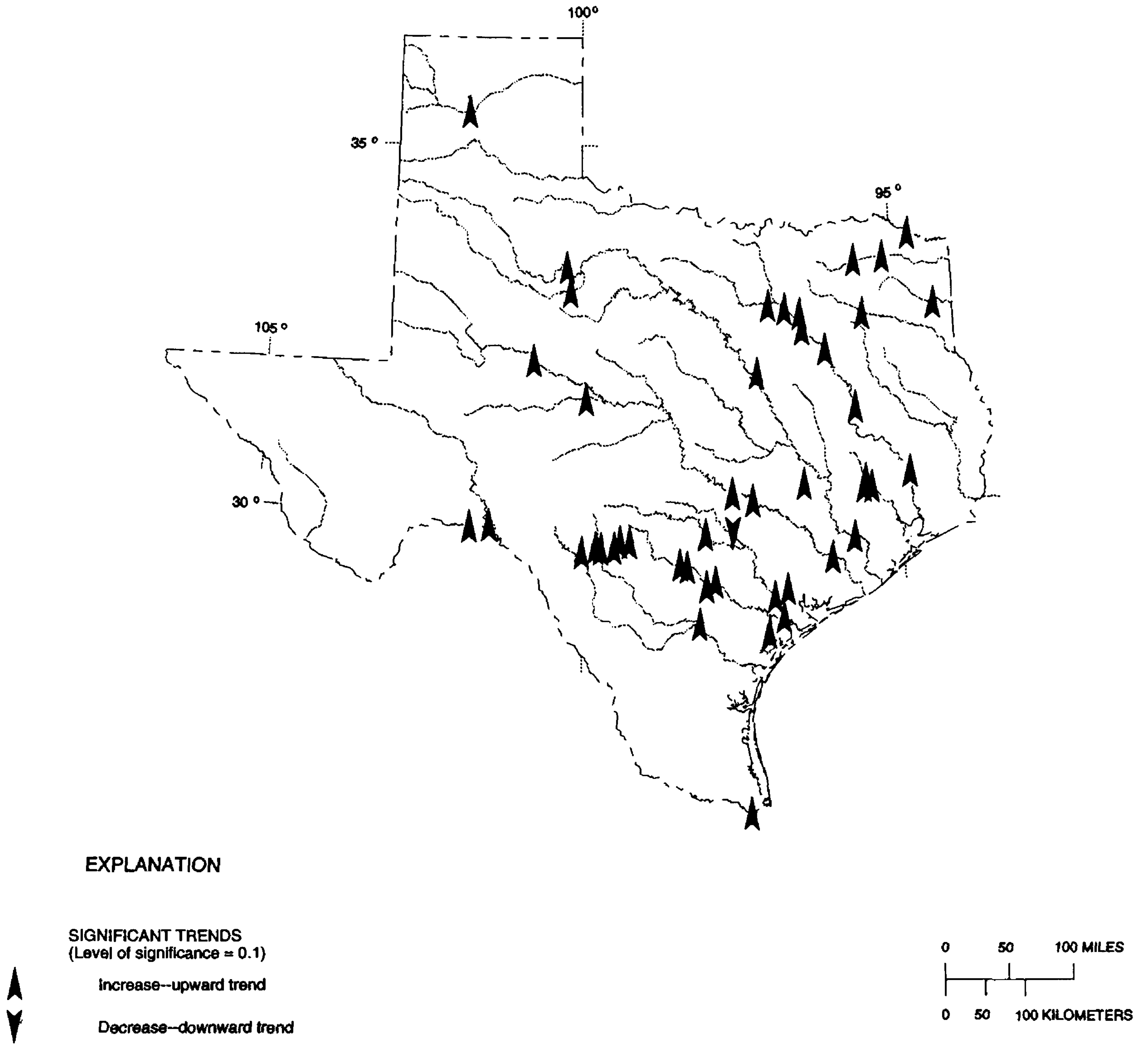

Figure 29. Trends in pH at selected stations in Texas for the 1975–89 water years.

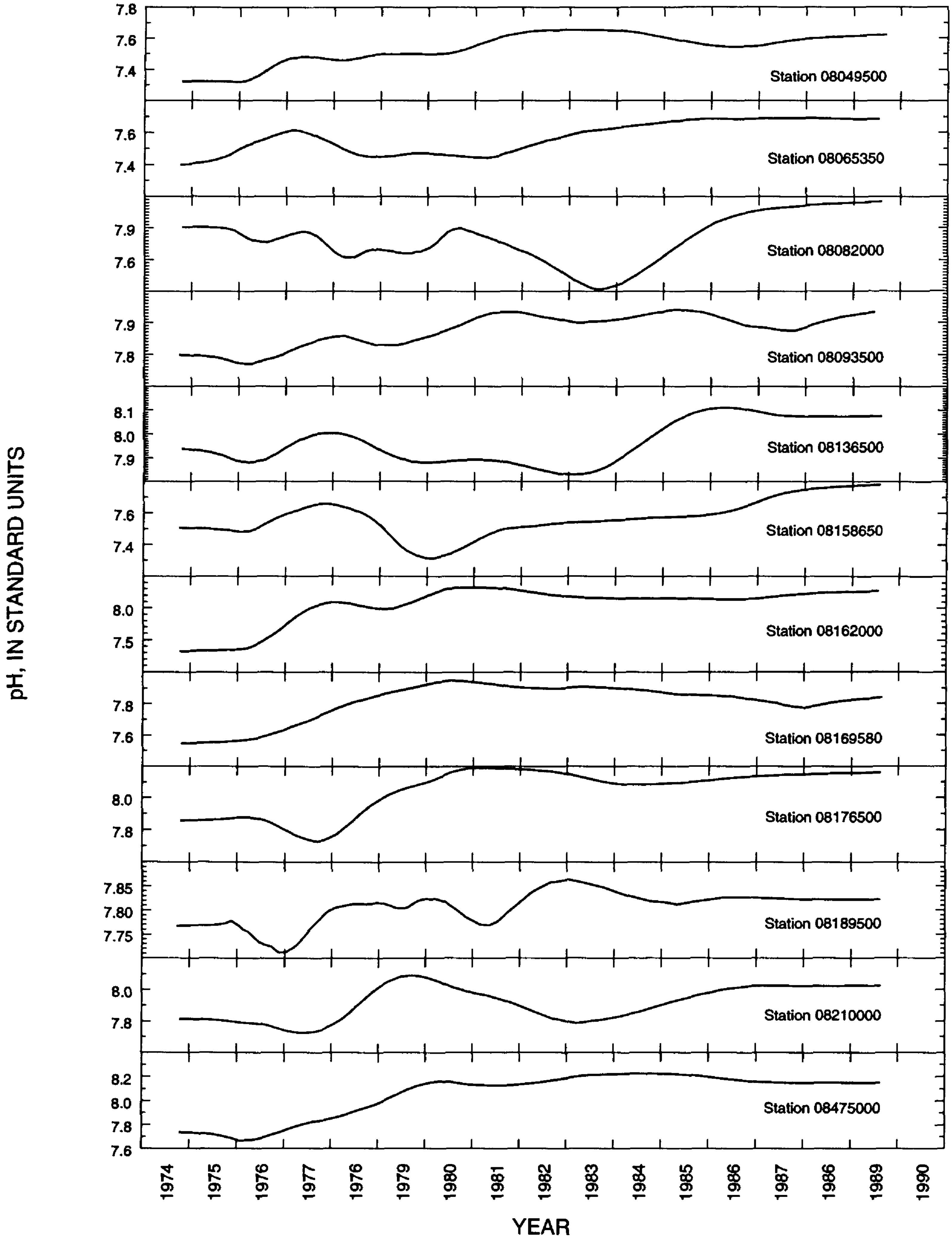

Figure 30. Variations in smoothed pH values for selected stations in Texas, 1975–89 water years.

Table 12. *Water-quality stations in Texas with trends in pH for the 1975–89 water years*

Station number	Station name
07227500	Canadian River near Amarillo, Texas
07336820	Red River near De Kalb, Texas
07342500	South Sulphur River near Cooper, Texas
07343200	Sulphur River near Talco, Texas
07346070	Little Cypress Creek near Jefferson, Texas
08018500	Sabine River near Mineola, Texas
08049500	West Fork Trinity River at Grand Prairie, Texas
08057410	Trinity River below Dallas, Texas
08062000	East Fork Trinity River near Crandall, Texas
08062500	Trinity River near Rosser, Texas
08062700	Trinity River at Trinidad, Texas
08065350	Trinity River near Crockett, Texas
08066500	Trinity River at Romayor, Texas
08067650	West Fork San Jacinto River below Lake Conroe near Conroe, Texas
08067900	Lake Creek near Conroe, Texas
08068000	West Fork San Jacinto River near Conroe, Texas
08080500	Double Mountain Fork Brazos River near Aspermont, Texas
08082000	Salt Fork Brazos River near Aspermont, Texas
08093500	Aquilla Creek near Aquilla, Texas
08110000	Yegua Creek near Somerville, Texas
08114000	Brazos River at Richmond, Texas
08123850	Colorado River above Silver, Texas
08136500	Concho River at Paint Rock, Texas
08158650	Colorado River below Austin, Texas
08159200	Colorado River at Bastrop, Texas
08162000	Colorado River at Wharton, Texas
08164600	Garcitas Creek near Inez, Texas
08172000	San Marcos River at Luling, Texas
08176500	Guadalupe River at Victoria, Texas
08181500	Medina River at San Antonio, Texas
08181800	San Antonio River near Elmendorf, Texas
08183500	San Antonio River near Falls City, Texas
08186000	Cibolo Creek near Falls City, Texas
08189200	Copano Creek near Refugio, Texas
08190000	Nueces River at Laguna, Texas
08195000	Frio River at Concan, Texas
08196000	Dry Frio River near Reagan Wells, Texas
08198000	Sabinal River near Sabinal, Texas
08200000	Hondo Creek near Tarpley, Texas
08201500	Seco Creek at Miller Ranch near Utopia, Texas
08210000	Nueces River near Three Rivers, Texas
08377200	Rio Grande at Foster Ranch near Langtry, Texas
08447410	Pecos River near Langtry, Texas
08475000	Rio Grande near Brownsville, Texas

Table 13. *Statistical summary and trend results of pH for stations in Texas with trends for the 1975–89 water years*

[N, number of observations used for trend analysis; p, attained significance of trend test; percentiles in standard units; TREND CODES: U, best trend is trend in unadjusted concentrations; F, best trend is trend in flow-adjusted concentrations]

Station number	Sample size	Mean	25th percentile (median)	50th percentile	75th percentile	N	Units per year	Percent per year	p	Trend code
07227500	110	8.09	8.0	8.1	8.3	81	0.01	0.15	0.036	U
07336820	116	7.92	7.7	8.0	8.2	80	.03	.34	.003	F
07342500	94	7.59	7.4	7.6	7.8	68	.02	.28	.059	F
07343200	108	7.63	7.5	7.7	7.8	79	.02	.22	.006	U
07346070	104	6.47	6.2	6.5	6.8	77	.02	.35	.055	F
08018500	117	7.10	6.8	7.1	7.3	77	.02	.28	.021	U
08049500	129	7.52	7.4	7.5	7.7	78	.02	.25	.001	F
08057410	128	7.34	7.2	7.3	7.5	83	.01	.15	.024	F
08062000	103	7.48	7.3	7.5	7.7	63	.03	.39	.001	F
08062500	127	7.45	7.3	7.4	7.6	85	.02	.22	.004	F
08062700	132	7.52	7.3	7.5	7.7	84	.04	.50	.000	F
08065350	118	7.55	7.3	7.6	7.8	80	.01	.19	.017	F
08066500	141	7.81	7.5	7.9	8.2	86	.04	.54	.000	F
08067650	65	7.34	7.0	7.4	7.6	35	.05	.68	.003	U
08067900	78	7.06	6.8	7.0	7.3	51	.03	.43	.004	U
08068000	147	7.13	6.9	7.2	7.4	87	.03	.43	.000	U
08080500	106	7.86	7.7	7.9	8.0	79	.03	.32	.000	U
08082000	119	7.85	7.7	7.9	8.0	46	.01	.11	.083	U
08093500	103	7.88	7.7	7.9	8.0	75	.01	.16	.029	F
08110000	54	7.36	7.0	7.3	7.6	34	.04	.58	.010	U
08114000	124	7.94	7.7	8.0	8.2	81	.02	.24	.023	F
08123850	126	7.96	7.7	8.0	8.3	85	.04	.50	.001	U
08136500	110	7.96	7.8	8.0	8.1	86	.01	.13	.037	U
08158650	128	7.58	7.4	7.5	7.8	83	.01	.16	.088	U
08159200	84	7.87	7.6	7.9	8.1	75	.02	.32	.023	U
08162000	132	7.96	7.7	8.1	8.3	82	.04	.48	.000	F
08164600	103	7.88	7.7	7.9	8.1	75	.01	.17	.046	F
08172000	74	8.06	7.9	8.1	8.2	55	-.01	-.12	.009	U
08176500	116	7.97	7.8	8.0	8.2	30	.02	.20	.074	F
08181500	124	7.76	7.6	7.7	7.9	79	.02	.26	.000	U
08181800	123	7.65	7.5	7.7	7.8	78	.02	.30	.000	U
08183500	96	7.63	7.4	7.6	7.8	57	.03	.36	.002	F
08186000	127	7.96	7.7	7.9	8.1	82	.02	.21	.032	F
08189200	65	7.21	6.9	7.2	7.5	24	.05	.69	.004	F
08190000	62	7.83	7.7	7.9	8.0	44	.02	.26	.004	U
08195000	61	7.93	7.8	7.9	8.1	44	.02	.25	.003	U
08196000	60	7.89	7.7	7.9	8.1	44	.03	.34	.000	F
08198000	59	7.89	7.8	7.9	8.0	43	.01	.16	.074	U
08200000	58	7.92	7.8	8.0	8.0	42	.02	.29	.040	F
08201500	59	8.07	7.9	8.0	8.2	43	.02	.30	.019	F
08210000	131	7.89	7.7	7.9	8.1	85	.02	.19	.011	F
08377200	132	7.83	7.7	7.8	8.0	55	.02	.29	.019	U
08447410	147	7.90	7.8	7.9	8.1	87	.02	.23	.005	U
08475000	123	7.99	7.8	8.0	8.2	80	.03	.35	.000	F

provided further evidence that changes in the wastewater treatment capabilities had changed the quality of the water in the Trinity River.

Spatial patterns of trend indicators in the upper Colorado River Basin showed increasing concentrations of dissolved inorganic constituents for the 1975–86 water years. The same patterns persisted in the trend results for the 1975–89 water years. The increases in concentrations of inorganic constituents in Beals Creek and the Colorado River resulted from releases of saline water from Natural Dam Lake from 1986 to 1988. Northwestern Texas, which is plagued by saline surface water, has numerous salinity control projects to lessen the effects of salinity on the main streams and rivers. Natural Dam Lake was constructed to permanently store saline water pumped from Beals Creek. Before 1986, the only known water losses from Natural Dam Lake had been by evaporation. Precipitation in the upper Colorado River Basin and Beals Creek Basin in the late 1980's resulted in unexpected large volumes of water stored in Natural Dam Lake that were deemed a hazard to the structural integrity of the dam. Between September 1986 and August 1988, an estimated 60,000 to 75,000 acre-ft of water was released from Natural Dam Lake to reduce the stress on the dam.

Spatial patterns of trend indicators in the Rio Grande Basin showed increasing concentrations of dissolved inorganic constituents for the 1975–86 water years. The same patterns persisted in the trend results for the 1975–89 water years. The trends in the inorganic constituents in the Rio Grande primarily result from increased salinity in the Pecos River and, to a lesser extent, in the Rio Grande above Amistad Reservoir. Reservoirs, diversions, and substantial withdrawals modify the flow in the Rio Grande throughout its length. Tributaries to the Rio Grande vary substantially in quality. The Pecos River, which flows into Amistad Reservoir, is the most saline of the tributaries because of natural discharge of saline ground water into the river in New Mexico before the river enters Texas. Regulation can be used to decrease the salinity of a reservoir by allowing the storage of the reservoir to increase when the salinity of the inflow is low. But impoundment of water in the reservoir can also prolong the effects of increased salinity in the inflow. Arid areas such as the Rio Grande Basin where salinity is a problem can benefit from the ability of a reservoir to dilute the most saline water in exchange for the long duration effect.

Examination of concentrations of ammonia plus organic nitrogen and ammonia nitrogen in selected rivers for 1975–89 indicated a pattern of higher concentrations in 1980. These concentrations remained high until about 1985, when they began to decrease. Further investigation revealed a similar statewide pattern for stations with concentrations less than 5 mg/L of ammonia plus organic nitrogen and ammonia nitrogen. A bias in the concentrations of ammonia plus organic nitrogen and ammonia nitrogen in the early 1980's was documented by the laboratory. Several investigations conducted by laboratory personnel in late 1983 and early 1984 indicated that mercuric chloride tablets used for field preservation of nutrient samples from 1980 to 1986 probably introduced a positive bias for these constituents. Extending the period of analysis to 1989 caused the trends to disappear, probably because use of the tablets was discontinued in 1986.

A pattern of increasing concentrations in dissolved sulfate was evident in the eastern part of the State from the trends for 1975–86 and 1975–89. Trend patterns for sulfate in other parts of the State were consistent with those of most of the other inorganic constituents, but the pattern of trends in this area was unique to sulfate. The National Water Quality Laboratory documented the discovery of a positive bias in sulfate concentrations in December 1989. A turbidimetric method for sulfate analysis that had been in use since October 1982 could have resulted in a bias of approximately 2 mg/L in samples that had sulfate concentrations less than about 75 mg/L.

Numerous trend patterns evident for the constituents in this study did not receive further investigation. These patterns usually occurred for a small area and had no known source. Although those results might prove useful in future studies, they were not analyzed in this study. However, one trend pattern with no identifiable source was such a significant pattern that discussion of the unsuccessful attempts to identify a source was warranted. Results of the trend analysis of pH demonstrated a statewide pattern of increasing pH. Texas is a large state with diverse influences on the quality of surface water. It is unlikely that a single environmental factor would influence the hydrology of the entire State. A method-related influence would be a more likely source of a statewide trend pattern. The graphs of pH values were examined for all stations that had sufficient data for trend analysis for the 1975–89 water years. The changes in the values toward higher values appeared to be gradual rather than abrupt, and there were a variety of patterns rather than a single, identifiable pattern. A few consistencies were identified in the patterns of the graphs for stations that were local to each other, but none could be related to a source. Therefore, the known changes in pH methods cannot be identified as the source of the trends, and none of the identifiable patterns can be attributed to a specific source. The data show that pH values in Texas are generally higher in 1989 than in 1975, but no reason or reasons can be identified at this time.

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