EFFECTS OF WASTEWATER EFFLUENT ON THE SOUTH PLATTE RIVER FROM LITTLETON TO DENVER

by Norman E. Spahr and Steven R. Blakely

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CONVERSION FACTORS AND RELATED INFORMATION

Inch-pound units in this report may be expressed as metric units by use of the following conversion factors:

To convert inch-pound units	*Multiply by*	*To obtain metric units*
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot squared (ft^2)	0.0929	meter squared
foot per second (ft/s)	0.3048	meter per second
foot per second squared (ft/s^2)	0.3048	meter per second squared
gallon (gal)	3.785	liter
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second
inch (in.)	2.540	millimeter
mile	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square inch ($in.^2$)	6.452	square centimeter

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°F = 1.8°C + 32$$

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ABSTRACT

The U.S. Geological Survey's one-dimension steady-state water-quality model was used to investigate the effects of the effluent from the Bi-City Wastewater Treatment Plant on the South Platte River. The Bi-City Wastewater Treatment Plant is operated by the cities of Littleton and Englewood. The model was calibrated for a 14.5-mile reach for dissolved oxygen, 5-day carbonaceous biochemical oxygen demand and for organic, ammonia, nitrite, and nitrate nitrogen using data collected during September 1983. Model verification was completed using data collected during October 1982 and January 1984 for all constituents except nitrite nitrogen. Nitrite nitrogen could not be verified for the cold-water conditions of January 1984. Measured benthic sediment oxygen demand used in the model ranged from 1.01 to 2.77 grams per square meter per day.

Un-ionized-ammonia concentrations were calculated using simulated total ammonia nitrogen and ranges of pH values. These calculations indicate that during warm-water conditions un-ionized-ammonia concentrations may be greater than the temporary stream standard of 0.1 milligram per liter unless the ammonia nitrogen concentrations discharged are reduced.

Model simulations were made for an estimated 7-day, 10-year discharge of 18 cubic feet per second, upstream from the outfall of the wastewater treatment plant. Two groups of simulations were made for both warm- and cold-water conditions. In the first group of simulations, variations were made in effluent 5-day carbonaceous biochemical oxygen demand and effluent discharge. In the second group of simulations, the amount of nitrification within the wastewater treatment plant was varied by changing the amount of nitrogen discharged as ammonia and nitrate. As the amount of nitrogen discharged in the form of nitrate was increased, the ammonia concentrations decreased in the stream reach and the minimum dissolved oxygen increased.

The extent of the mixing zone downstream of the wastewater treatment plant outfall was determined by injecting Rhodamine WT dye into the effluent. The results of three mixing-zone measurements indicate that during low-flow conditions the downstream extent of the mixing zone is 0.8 mile below the outfall of the wastewater treatment plant.

INTRODUCTION

Recent and continuing population growth in the cities of Littleton and Englewood, Colorado, has placed increasing pressure on the capacity of the Littleton-Englewood Wastewater Treatment Plant (Bi-City WWTP), which discharges treated effluent into the South Platte River, to meet established water-quality criteria for discharged effluent. Additionally, there are plans to significantly increase the volume of effluent from the Bi-City WWTP in the future. To study the effects of discharging treated effluent into the South Platte River under current and predicted future low-flow conditions, the cities of Littleton and Englewood entered into a cooperative agreement with the U.S. Geological Survey to study the waste-assimilative capacity of the South Platte River.

A steering committee was formed by representatives of the cities of Littleton and Englewood, the Colorado Department of Health, the Denver Regional Council of Governments, the U.S. Environmental Protection Agency, and the Director of the Bi-City WWTP. The steering committee was formed to ensure that the necessary data and analysis would be provided to answer questions regarding the review of the Bi-City WWTP discharge permit. The steering committee also provided review of data collection, data analysis, and report preparation.

Objectives

The primary objective of the study is to define and evaluate hydraulic conditions and processes that influence the waste-assimilative capacity of the South Platte River during steady-state low-flow conditions. Specific objectives are to:

1. Calibrate and verify a one-dimensional steady-state water-quality model for a 14.5-mile reach of the South Platte River.
2. Compute un-ionized-ammonia concentrations in the South Platte River.
3. Simulate water-quality conditions of the South Platte River for various operational levels of the Bi-City WWTP.
4. Determine the extent of the mixing zone downstream from the Bi-City WWTP.

Scope

The reach of the South Platte River studied is from just downstream from Chatfield Reservoir in Arapahoe County to the U.S. Geological Survey streamflow-gaging station at 50th Avenue in Denver (fig. 1). The steady-state water-quality model used for this study was calibrated for the reach from the streamflow-gaging station at Littleton (5 miles downstream from Chatfield Reservoir) downstream for 14.5 miles to the streamflow-gaging station at 50th Avenue.

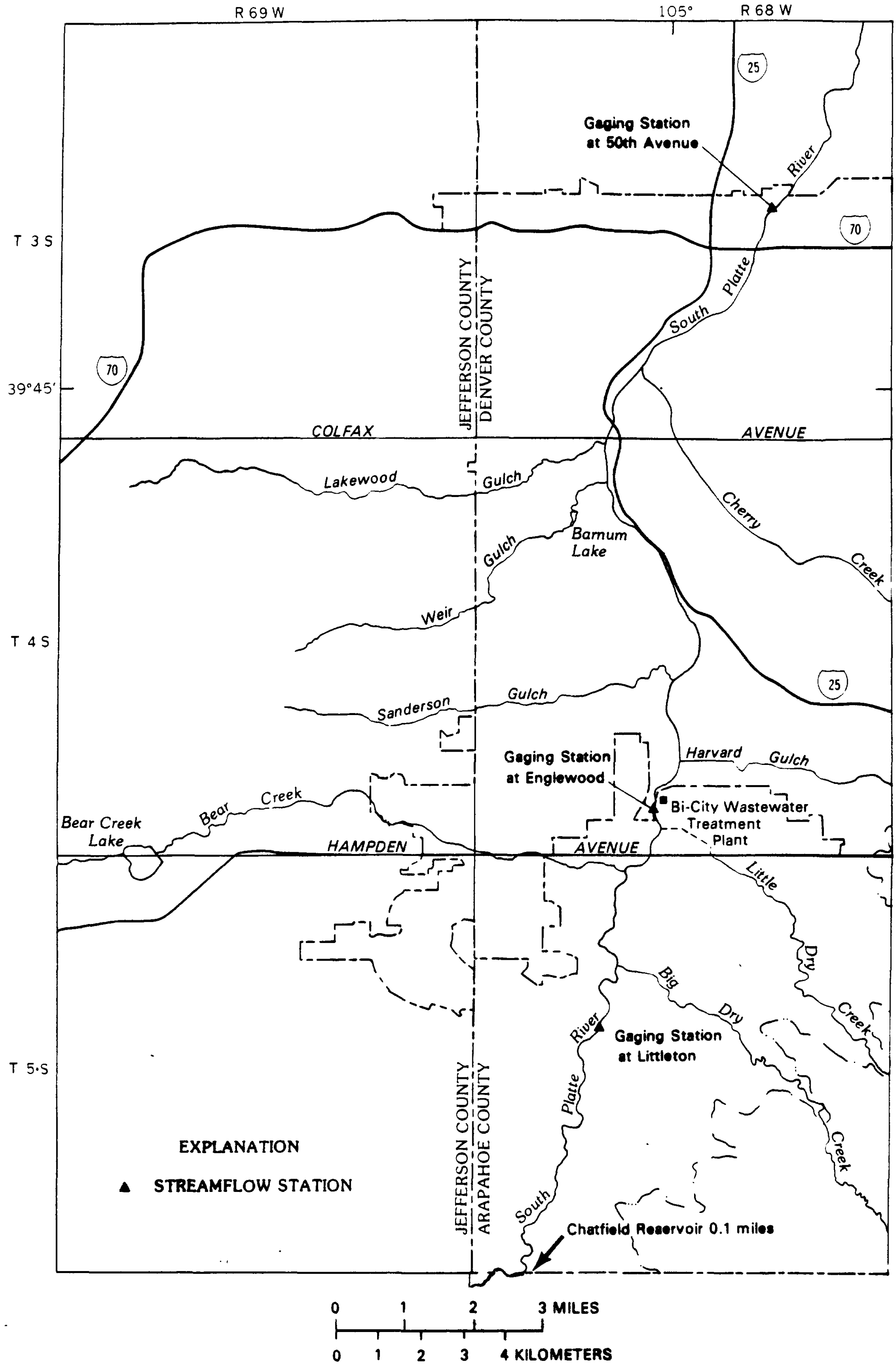

Figure 1.--South Platte River study area.

Acknowledgments

The authors are grateful to Joe Clayton, Water Commissioner responsible for the upstream segment of the study reach, Bill Bates of the Denver Water Department, Jack Unit of the U.S. Army Corps of Engineers, and Hal Simpson, assistant State Engineer, for their cooperation in obtaining regulation of streamflow during the data-collection phase of the study.

ONE-DIMENSIONAL STEADY-STATE STREAM WATER-QUALITY MODEL

The mathematical model used in this study was developed by the U.S. Geological Survey, and is documented by Bauer and others (1979). The model is based on the Streeter-Phelps (1925) oxygen-sag equation, with additional features for computation of conservative constituents and nitrogen components. The model is formulated to operate under the assumption of steady-state flow rate of stream and waste discharges. In addition, all waste discharges are assumed to be fully mixed in any cross section of the model reach.

In a general application of the model, the study reach is divided into subreaches. In this study, subreach boundaries were set by the locations of point-waste discharge or tributary inputs. At the beginning of each of the subreaches, waste or tributary discharge and water-quality constituents are specified by the model user. Subreach discharges are computed by the model by adding the discharge from a tributary or other input with the discharge of the upstream subreach. Where withdrawals occur, model discharge is computed by subtracting the withdrawl from the upstream subreach discharge. Within any subreach, the discharge is held constant, and a mass-balance is performed on the modeled constituents at the beginning of the subreach. At selected distances downstream, concentrations of the modeled constituents are calculated, until the beginning of the next subreach is encountered. This process is continued through all model subreaches.

Constituents modeled in this study are 5-day carbonaceous biochemical oxygen demand (CBOD), total organic nitrogen, total ammonia nitrogen, total nitrite nitrogen, total nitrate nitrogen, dissolved oxygen, and dissolved solids.

MODEL CALIBRATION AND VERIFICATION

Prior to simulating non-measured conditions, a mathematical model must be calibrated and verified. Calibration involves adjusting model parameters (reaction coefficients) until modeled and observed results show similarity within a predefined margin of error. The model is then verified, using one or more data sets that are independent of the calibration data set, to determine if modeled and observed results agree within the defined margin of error. Once the model is calibrated and verified, it may be used to simulate other conditions. It is desirable to have calibration and verification data sets for flow conditions as close as possible to those for which simulations are to be made. In this study, simulations were based on the 7-day low-flow discharge, with a recurrence interval of 10 years (Q 7,10); however, a Q 7,10 flow condition could not be created, by regulation of Chatfield Reservoir releases, for the data-collection efforts.

Data Collection

Data used for model calibration and verification were collected during three periods of flow regulation of the South Platte River: October 1982, September 1983, and January 1984. A data-collection period in March 1983 had to be discontinued due to a storm that created runoff and non-steady- state flow conditions. Data collected during these periods is presented by Spahr and others (1984). Flow regulation was used to create a steady-state discharge condition. Flow from Chatfield Reservoir was regulated for 5 consecutive days during each of these periods. Water-quality and discharge data were collected during a 24-hour period near the end of each of the 5 days of regulation. Data collected during September 1983 were used for the calibration data set. During this period, flow from Chatfield Reservoir was regulated at 10 ft^3/s (cubic feet per second). Data collected during the October 1982 and January 1984 periods were used for verification-data sets. Flow was regulated during the October 1982 period at 30 ft^3/s and during the January 1984 period at 10 ft^3/s. Traveltime data were collected for selected subreaches during the October 1982 and January 1984 periods. Reaeration data were collected for selected subreaches during the September 1983 period.

During the 24-hour data-collection periods, water-quality and discharge data were collected at 18 sites in the South Platte River and at 26 tributary and industrial-municipal effluent sites. Site reference codes for this study, site names, U.S. Geological Survey station numbers, and distances upstream from the end of the study reach for each measurement site are listed in table 1. Site reference codes were developed using the following criteria. Instream sites (sites in the South Platte River) were prefixed with an "SP", and tributary, municipal, and industrial inflows were given a "TR" prefix. Instream site numbers were numbered beginning with 100 for the most upstream site and increased by 100 for each additional site downstream. Inflow site numbers were selected by their physical location to instream sites. Inflow sites between SP-100 and SP-200 were numbered between 100 and 200. For example, TR-310 and TR-320 are between SP-300 and SP-400. Site TR-310 is nearest SP-300 and site TR-320 is further downstream. Locations of instream-measurement sites are shown in figure 2. Tributary-, municipal-, and industrial-site locations are shown in figure 3.

Intervals at which water-quality samples were collected at each site during the 24-hour periods were dependent upon the expected influence that particular inflow would have on the South Platte River. Samples were collected every 4 hours for the South Platte River instream sites. Collected samples were analyzed for 5-day CBOD, total Kjeldahl nitrogen, total ammonia nitrogen, total nitrite nitrogen, and total nitrite plus nitrate nitrogen. Total organic nitrogen was calculated from total ammonia and total Kjeldahl nitrogen, and total nitrate nitrogen was computed from nitrite and nitrite plus nitrate nitrogen. Data and methods of laboratory analysis are given by Spahr and others (1984). Field measurements of dissolved oxygen, temperature, pH, and specific conductance were made at the time each water-quality sample was collected. Two or more discharge measurements were made at each of the water-quality sample-collection sites. Discharge values for the Bi-City WWTP and withdrawal volumes for domestic water supply were provided by the cities of Littleton and Englewood.

Table 1.--*Water-quality sampling and discharge measurement sites for the South Platte River, tributaries, and other inflows*

Figure and site number		Site reference code	U.S. Geological Survey station number	River miles upstream from SP-1700	Site name
2	1	SP-100	393418105022300	18.67	South Platte River near Colorado Highway 470
2	2	SP-200	06710000	14.51	South Platte River at Littleton
3	1	TR-210	393750105005100	13.40	Big Dry Creek at mouth
2	3	SP-300	393855105004800	11.89	South Platte River above Bear Creek
3	2	TR-310	06711500	11.82	Bear Creek at mouth, at Sheridan
3	3	TR-320	393935105000500	10.84	Little Dry Creek at mouth
3	4	TR-330	393936105000600	10.78	Storm sewer at Dartmouth Avenue (west bank)
2	4	SP-400	06711565	10.44	South Platte River at Englewood
3	5	TR-410	394003105001300	10.25	Unnamed creek above PSCO dam (west bank)
3	6	TR-420	394005105000300	10.13	Bi-City WWTP effluent (east bank)
3	7	TR-440	394016104595100	9.82	Arapahoe PSCO effluent (west bank)
3	8	TR-460	394029104594800	9.56	Harvard Gulch at mouth
2	5	SP-500	394042104595100	9.32	South Platte River at Evans Avenue
2	6	SP-600	06711590	8.48	South Platte River at Florida Avenue, at Denver
3	9	TR-610	06711610	8.44	Sanderson Gulch at mouth, at Denver
2	7	SP-700	394128104594700	8.27	South Platte River below footbridge, below Florida Avenue
2	8	SP-800	394141104593300	7.94	South Platte River above Mississippi Avenue
3	10	TR-810	394149104592900	7.79	Storm sewer at Mississippi Avenue (east bank)
2	9	SP-900	394210104594100	7.33	South Platte River above Sante Fe overpass
2	10	SP-1000	394241104595900	6.68	South Platte River below Alameda Avenue
2	11	SP-1100	394321105000500	5.59	South Platte River above Vallejo Street
3	11	TR-1110	394321105000600	5.59	Storm sewer at Vallejo Street
2	12	SP-1100A	394345105005800	5.29	South Platte River above 8th Avenue bridge
3	12	TR-1120	394352105010000	4.96	Lakewood WWTP Effluent above Weir Gulch
3	13	TR-1130	06711622	4.95	Weir Gulch at mouth

Table 1.--*Water-quality sampling and discharge measurement sites for the South Platte River, tributaries, and other inflows*--Continued

Figure and site number		Site reference code	U.S. Geological Survey station number	River miles upstream from SP-1700	Site name
3	14	TR-1135	394405105010000	4.78	Zuni Street Power Plant #1 (west bank)
3	15	TR-1140	394414105010200	4.53	Zuni Street Power Plant #2 (east bank trough)
3	16	TR-1145	394416105010400	4.56	Zuni Street Power Plant #3 (west bank)
3	17	TR-1150	06711800	4.38	Lakewood Gulch at mouth, at Denver
3	18	TR-1160	394424105010200	4.33	Sloans Lake outfall (old 15th Avenue bridge)
2	13	SP-1200	394433105005800	4.15	South Platte River above 17th Avenue underpass
3	19	TR-1210	394434105005800	4.14	Ellis Foods effluent
2	14	SP-1300	394502105004700	3.63	South Platte River at 7th Street, near Confluence Park
3	20	TR-1305	394503105004800	3.62	Storm sewer at 7th Street above Confluence Park
3	21	TR-1310	394513105002600	3.14	Cherry Creek at mouth
2	15	SP-1400	06714000	2.73	South Platte River at Denver
3	22	TR-1420	394543104595400	2.38	Storm sewer at 23rd Street bridge
2	16	SP-1500	394602104590500	1.54	South Platte River above 31st Street bridge
3	23	TR-1510	394603104590400	1.53	Ice Plant effluent at 31st Street bridge
3	24	TR-1520	06714100	1.06	Thirty-Sixth Street storm sewer at Denver
2	17	SP-1600	394634104583800	0.80	South Platte River below 38th Street bridge
3	25	TR-1610	394635104583800	0.79	Storm sewer below 38th Street bridge
3	26	TR-1620	394709104583000	0.12	Storm sewer 200 yards above SP-1700
2	18	SP-1700	06714130	0.00	South Platte River at 50th Avenue, at Denver

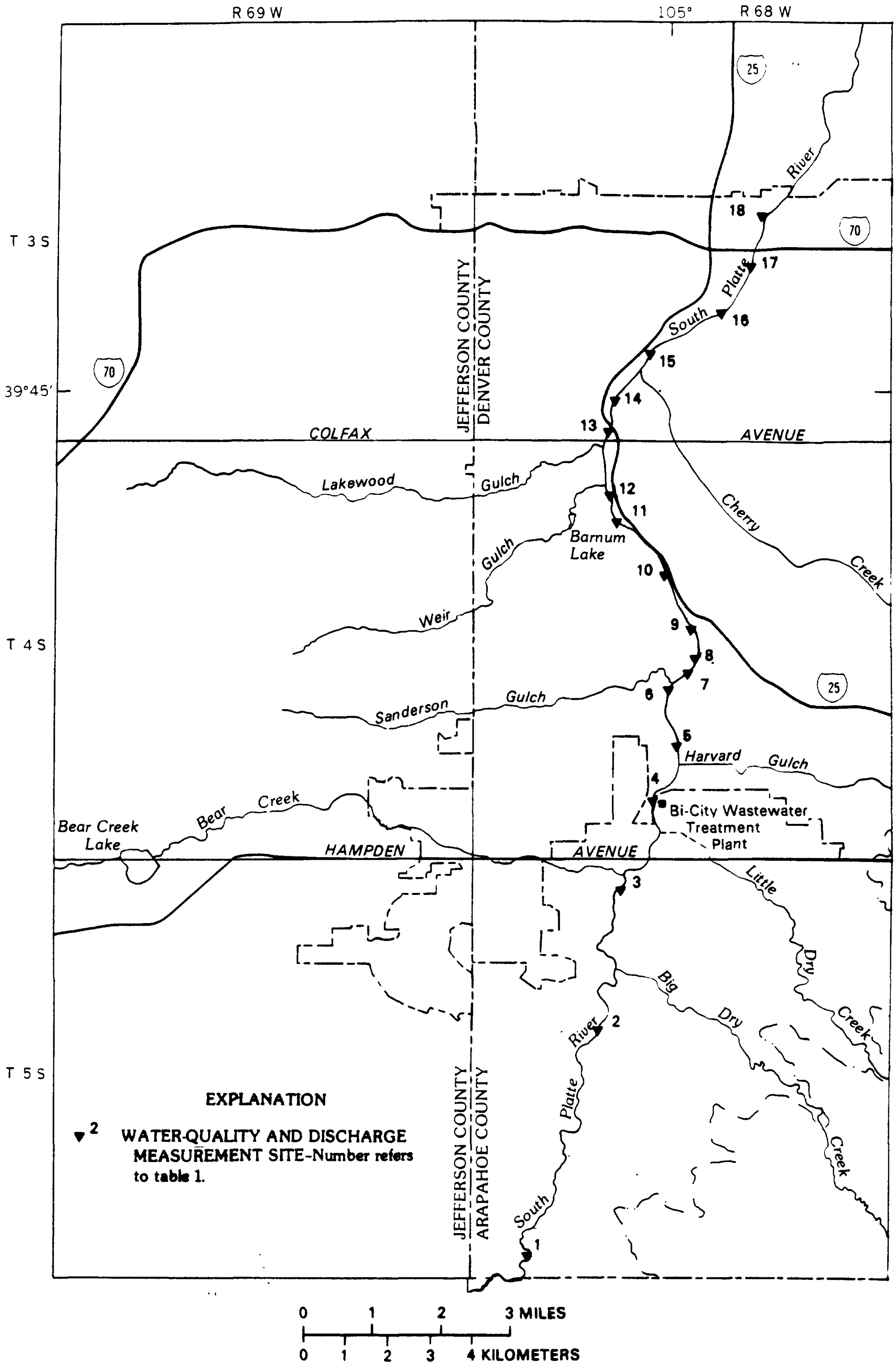

Figure 2.--Location of South Platte River water-quality and discharge measurement sites.

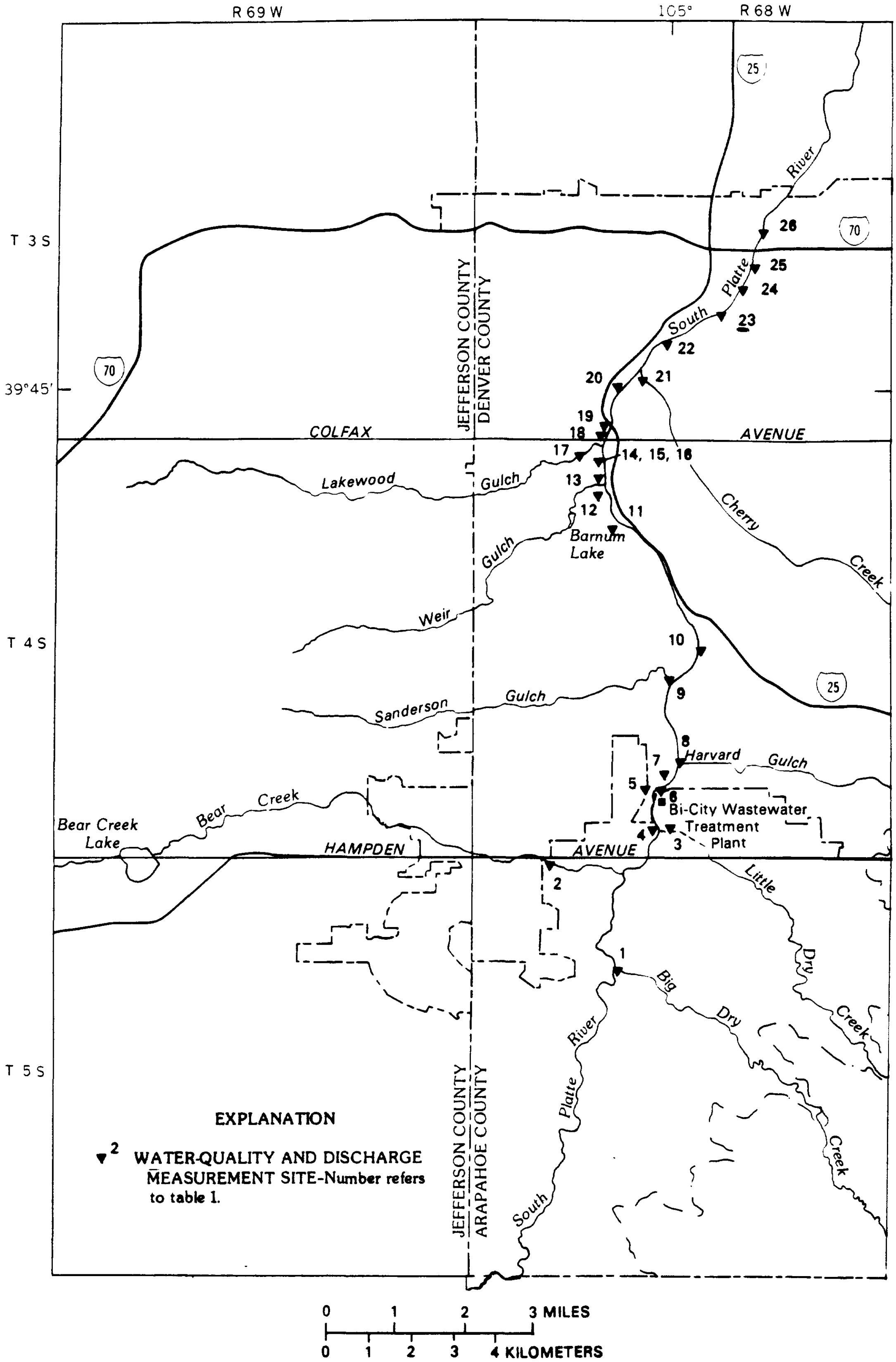

Figure 3.--Location of tributary, municipal, and industrial water-quality and discharge measurement sites.

Preparation of Data for Model Input

Physical and water-quality data are necessary for operation of the model. Physical data are used to describe the physical processes and characteristics of the study reach. Water-quality data are used to describe the chemical properties of the study reach.

Physical Data

Physical data required for operation of the model are discharge, subreach average depth and width, subreach traveltime, and reaeration coefficients. Discharge measurements of tributary, industrial, and municipal inflows normally were made at least twice during the 24-hour data-collection periods; averages of the measured values were used in the model.

Channel-geometry measurements were made during 24-hour data-collection periods at selected sites along the South Platte River. These measurements provided data on stream widths, which were used to determine average model subreach widths for calibration and verification.

Comparisons of model-computed and measured South Platte River discharges for the September 1983, October 1982, and January 1984 model runs are shown in figure 4. Variations in measured discharge values shown in figure 4 are primarily due to the diurnal cycle in effluent discharge from the Bi-City WWTP. As shown in figure 4, the measured variations are downstream from the Bi-City WWTP effluent (mile 10.1). Model-computed discharges are less than measured discharges. The difference is probably in part due to interactions with ground water and in part due to the release of water from bank storage. Bank storage of water may have been present, because streamflow before the regulation periods was greater than the regulated streamflow. This difference between model-computed and measured streamflow was considered to be acceptable. The model is capable of allowing additional water to be added through a linear-runoff algorithm, but the quantity and water-quality data needed would be estimates. The authors decided that, because the model calibrated and verified, estimating the linear-runoff components would not be necessary.

Using traveltime data collected during the flow-regulation periods, traveltime-versus-discharge relations were determined for each of the model subreaches. These relations have the form:

$$\text{Traveltime} = A \times \text{Discharge}^{B}, \qquad (1)$$

where A and B are coefficients determined by drawing lines through log-log graphs of traveltime versus discharge.

Average subreach velocities were computed from the traveltime relations. The velocities, widths, and discharge values were used to compute average subreach depths by the following equation:

$$\text{Depth} = \text{Discharge}/(\text{Velocity} \times \text{Width}). \qquad (2)$$

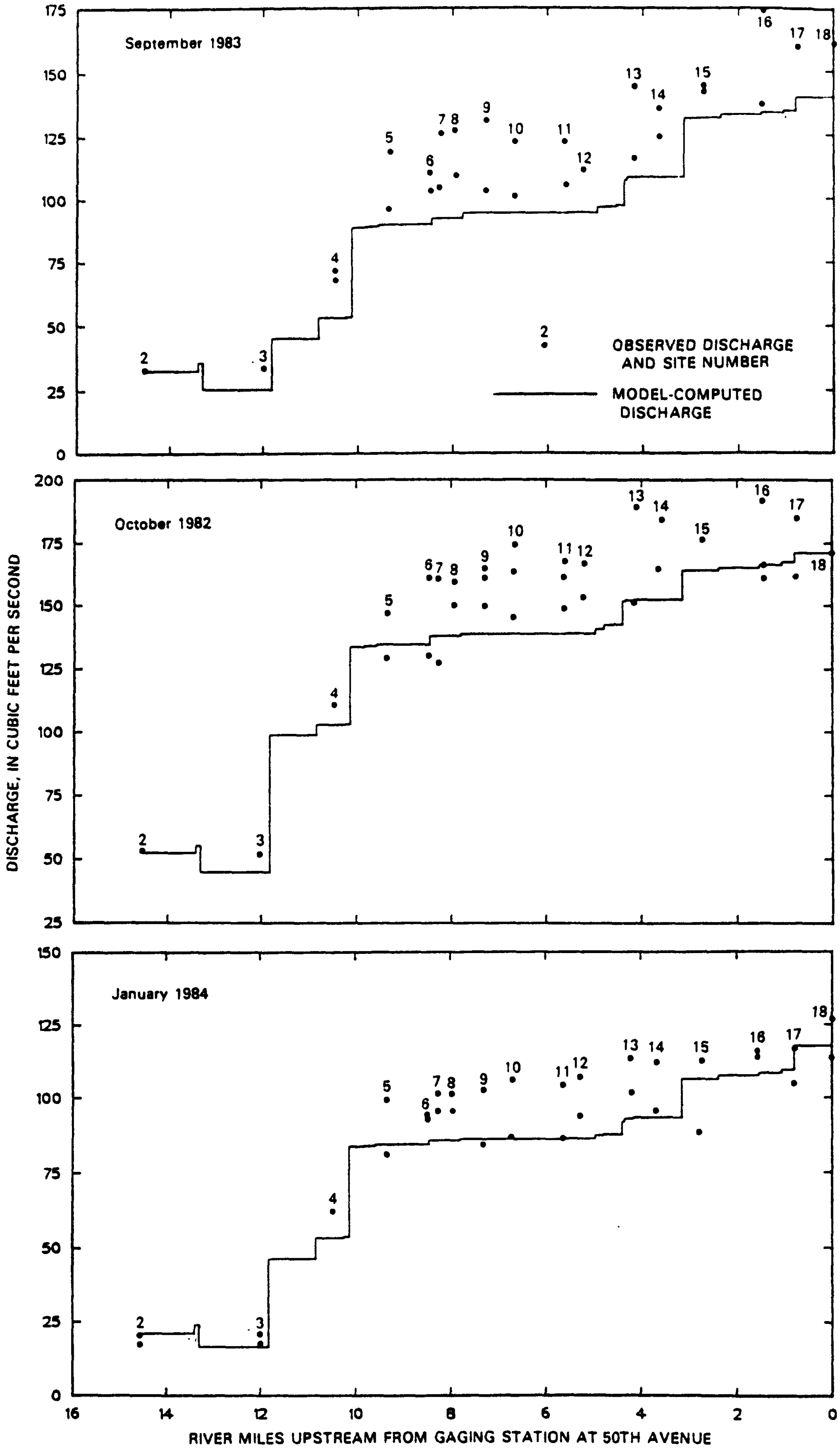

Figure 4.--Observed and model-computed South Platte River discharge for the September 1983, October 1982, and January 1984 model runs.

Equation 2 was used because of the great variability of depths found in the study reach. Large amounts of concrete block, rock, and other material were found throughout the study reach. This material created large differences in depth within a few feet of any given cross section.

Reaeration measurements were made on selected reaches during the September 1983 flow-regulation period; these values are given in table 2. A comparison

Table 2.--*Measured reaeration coefficients for the South Platte River*

Subreach as defined by site reference codes[1]	Reaeration coefficients (day^{-1} base e at 20° Celsius)			
	Peak method		Area method	
	Ethylene	Propane	Ethylene	Propane
SP-400 to SP-500	11.5	10.3	11.2	11.8
SP-500 to SP-600	8.2	9.2	8.2	8.5
SP-600 to SP-800	8.7	7.4	8.4	10.5
SP-400 to SP-800	9.1	9.0	9.1	9.7
SP-1300 to SP-1400	31.9	35.8	23.8	26.9
SP-1400 to SP-1500	5.3	4.0	8.9	7.6
SP-1500 to SP-1700	12.7	12.7	11.1	15.0
SP-1300 to SP-1700	14.1	14.5	13.5	15.2

[1]See table 1 for description of site reference codes.

of measured values to reaeration values estimated by empirical and semi-empirical equations found in the literature showed that an equation presented by Cadwallader and McDonnell (1969) most accurately estimated reaeration rates for the model reach. The Cadwallader and McDonnell equation is:

$$K2 = [25.7 \times (U \times s \times g)^{0.5} / H] \times 2.303, \qquad (3)$$

where K2 = reaeration coefficient, base e units at 20°C, in day^{-1};
U = mean velocity, in feet per second;
s = slope, in feet per foot;
g = acceleration of gravity, in feet per second squared;
H = mean depth, in feet.

Equation 3 was used to estimate reaeration coefficients for input to the model; these coefficients were based on water temperature of 20°C. The coefficients for 20°C were adjusted to observed water temperatures using the following equation (Elmore and West, 1961):

$$K2_T = K2_{(20)} \times (1.0241)^{(T-20)}, \qquad (4)$$

where T = observed temperature, in degrees Celsius.

Discharge, water temperatures, reaeration coefficients, and traveltime used in the calibration and verification data sets are listed in table 3.

Table 3.--*Physical data used in model calibration and verification*

[CAL, calibration data set of September 1983; VER1, verification data set of October 1982; VER2, verification data set of January 1984]

Model subreach	River mileage at ends of subreach		Model run	Discharge change at beginning of subreach (cubic feet per second)	Mean water temperature of subreach (° Celsius)	Reaeration rate in subreach (day^{-1}, base e at stream temperature)	Traveltime in subreach (hours)
	Upstream	Downstream					
1	14.51	13.40	CAL	[1]32.5	15	7.7	3.0
			VER1	[1]52.5	13	8.3	2.6
			VER2	[1]21.0	3	5.7	3.4
2	13.40	13.30	CAL	3.2	15	7.7	.6
			VER1	2.8	13	8.3	.5
			VER2	3.1	3	5.7	.7
3	13.30	11.82	CAL	-10.2	15	7.7	3.2
			VER1	-10.1	14	8.5	2.7
			VER2	-7.5	3	5.7	3.6
4	11.82	10.84	CAL	19.8	15	7.7	2.1
			VER1	53.8	13	8.5	1.7
			VER2	29.8	3	5.7	2.1
5	10.84	10.25	CAL	8.1	14	7.5	.9
			VER1	4.1	13	8.3	.7
			VER2	7.0	2	5.6	.9
6	10.25	10.13	CAL	.4	14	7.5	.2
			VER1	.3	14	8.3	.2
			VER2	.4	2	5.6	.2
7	10.13	9.82	CAL	35.0	15	7.7	.8
			VER1	30.7	14	8.5	.7
			VER2	29.9	6	6.1	.9
8	9.82	9.56	CAL	.4	15	7.7	.2
			VER1	.4	14	8.5	.2
			VER2	.2	6	6.1	.2
9	9.56	8.44	CAL	.6	15	7.7	2.9
			VER1	.6	15	8.5	2.2
			VER2	.5	6	6.1	3.0
10	8.44	7.79	CAL	2.4	15	7.7	1.5
			VER1	3.3	14	8.7	1.1
			VER2	1.3	6	6.1	1.6
11	7.79	5.59	CAL	2.0	16	7.9	6.4
			VER1	.8	15	8.5	4.8
			VER2	.5	5	6.0	6.8
12	5.59	4.96	CAL	.3	16	5.7	1.8
			VER1	.2	15	6.2	1.3

Table 3.--*Physical data used in model calibration and verification*--Continued

Model subreach	River mileage at ends of subreach		Model run	Discharge change at beginning of subreach (cubic feet per second)	Mean water temperature of subreach (° Celsius)	Reaeration rate in subreach (day^{-1}, base e at stream temperature)	Traveltime in subreach (hours)
	Upstream	Downstream					
13	4.96	4.95	CAL	0.0	16	5.7	0.1
			VER1	.2	15	6.2	.1
			VER2	.0	6	4.3	.1
14	4.95	4.78	CAL	2.1	16	5.6	.5
			VER1	1.5	15	6.2	.4
			VER2	1.0	6	4.3	.5
15	4.78	4.56	CAL	.2	16	5.6	.6
			VER1	1.6	15	6.2	.4
			VER2	.3	6	4.3	.6
16	4.56	4.38	CAL	.6	16	5.6	.5
			VER1	.3	15	6.2	.4
			VER2	.0	6	4.3	.5
17	4.38	4.33	CAL	10.0	16	5.6	.1
			VER1	9.0	15	6.2	.1
			VER2	4.2	6	4.3	.1
18	4.33	4.14	CAL	1.1	16	5.6	.5
			VER1	.4	14	6.2	.4
			VER2	1.0	7	4.4	.5
19	4.14	3.14	CAL	.1	16	9.4	1.9
			VER1	.3	14	10.7	1.5
			VER2	.4	5	7.1	2.1
20	3.14	2.38	CAL	23.3	15	6.9	1.0
			VER1	11.6	14	7.0	.9
			VER2	13.1	5	5.2	1.2
21	2.38	1.53	CAL	1.2	15	6.9	.9
			VER1	1.0	14	7.0	.8
			VER2	1.2	5	5.2	1.1
22	1.53	1.06	CAL	.8	15	10.4	.8
			VER1	1.3	14	10.7	.7
			VER2	.8	5	7.8	.9
23	1.06	0.79	CAL	.8	15	10.4	.3
			VER1	1.1	14	10.7	.3
			VER2	1.1	5	7.8	.4
24	0.79	0.00	CAL	5.2	15	10.4	1.1
			VER1	3.6	14	10.7	1.0
			VER2	8.2	5	7.8	1.2

[1]South Platte River discharge for beginning of model reach.

Water-Quality Data

Water-quality data necessary for model operation include dissolved oxygen, 5-day CBOD, and nitrogen species. These data are required for the beginning of the model reach, for inflows within the model reach, and at several instream sites along the model reach. Data for the inflows are averages of values measured during the 24-hour data collection periods. Data for the instream sites are used as a check of model-computed values during calibration and verification. Water-quality data used as input for calibration and verification of the model are listed in table 4.

Table 4.--*Water-quality input data used in model calibration and verification*

[CBOD, carbonaceous biochemical oxygen demand; CAL, calibration data set of September 1983; VER1, verification data set of October 1982; VER2, verification data set of January 1984]

Model subreach	Model run	5-day CBOD	Total organic nitrogen	Total ammonia nitrogen	Total nitrite nitrogen	Total nitrate nitrogen	Dissolved-oxygen deficit[1]
		(milligrams per liter)					
1	CAL	2.3	0.58	0.10	0.02	0.70	[2]7.5
	VER1	2.2	.70	.05	.01	.28	[2]8.1
	VER2	2.7	.43	.05	.02	.02	[2]10.3
2	CAL	2.1	1.52	0.12	0.02	5.68	0.8
	VER1	1.6	1.66	0.04	0.02	4.72	0.6
	VER2	4.8	1.20	0.11	0.06	5.60	0.9
3	CAL	0	0	0	0	0	0
	VER1	0	0	0	0	0	0
	VER2	0	0	0	0	0	0
4	CAL	3.0	.50	.10	.01	.75	1.0
	VER1	2.7	.88	.04	.01	.19	.2
	VER2	4.4	.58	.16	.02	1.3	1.5
5	CAL	2.0	1.1	.14	.02	3.3	.8
	VER1	1.4	.96	.07	.03	2.7	.1
	VER2	4.5	1.3	.12	.05	2.8	.4
6	CAL	2.6	1.7	.09	.03	8.7	1.1
	VER1	2.1	1.9	.09	.19	6.2	1.1
	VER2	12.	1.8	.30	.16	5.8	1.5
7	CAL	13	2.9	16	.05	0.00	.8
	VER1	19	9.1	18	.03	.02	0.0
	VER2	18	2.5	18	.04	.05	.7
8	CAL	8.9	1.4	.14	.02	.58	- .6
	VER1	1.8	4.3	.15	.06	5.1	-1.1
	VER2	1.4	1.4	0.18	0.17	5.4	0.8

Table 4.--*Water-quality input data used in model calibration and verification*--Continued

Model subreach	Model run	5-day CBOD	Total organic nitrogen	Total ammonia nitrogen	Total nitrite nitrogen	Total nitrate nitrogen	Dissolved-oxygen deficit[1]
		(milligrams per liter)					
9	CAL	4.6	1.2	0.13	0.05	2.5	1.6
	VER1	2.4	2.1	.05	.03	2.9	-.2
	VER2	15	2.3	.52	.10	2.2	1.1
10	CAL	4.4	1.1	.12	.03	1.5	.3
	VER1	3.0	1.4	.05	.02	1.0	-.3
	VER2	3.8	2.2	.40	.13	2.2	.7
11	CAL	2.4	1.4	.12	.02	5.9	.4
	VER1	4.2	2.1	.04	.01	4.9	-.6
	VER2	5.6	1.1	.16	.05	5.0	.7
12	CAL	5.4	1.1	.16	.38	5.3	.8
	VER1	2.1	4.4	.07	.02	5.8	.4
	VER2	3.5	1.6	.30	.24	3.5	1.3
13	CAL	0	0	0	0	0	0
	VER1	7.8	5.0	12	0.21	0.05	1.7
	VER2	0	0	0	0	0	0
14	CAL	8.3	1.1	.15	.05	2.6	.9
	VER1	5.5	1.7	.07	.07	1.8	.9
	VER2	16	1.6	.28	.22	3.8	1.5
15	CAL	3.8	.80	2.9	.46	1.6	.5
	VER1	2.0	3.3	.53	.12	1.1	.6
	VER2	2.4	2.2	.11	.02	.18	1.0
16	CAL	1.4	.9	.19	.01	5.8	1.6
	VER1	1.8	2.2	.19	.01	4.6	.6
	VER2	0	0	0	0	0	0
17	CAL	2.1	.91	.09	.02	2.0	.4
	VER1	1.8	1.2	.09	.02	1.6	-.2
	VER2	5.6	1.2	.15	.08	3.2	.4
18	CAL	5.4	2.7	.07	.02	.33	.2
	VER1	6.0	6.0	.05	.02	.71	.1
	VER2	5.9	1.5	1.1	.04	.13	.7
19	CAL	1.2	0.49	.31	.02	.02	.8
	VER1	2.0	7.2	.39	.06	.04	1.0
	VER2	6.0	.47	.23	.03	.17	-1.4
20	CAL	3.0	1.2	.14	.03	4.2	-.1
	VER1	3.0	1.5	.05	.05	3.1	-.2
	VER2	7.0	1.8	.26	.10	3.9	.1

Table 4.--*Water-quality input data used in model calibration and verification*--Continued

Model subreach	Model run	5-day CBOD	Total organic nitrogen	Total ammonia nitrogen	Total nitrite nitrogen	Total nitrate nitrogen	Dissolved-oxygen deficit[1]
		(milligrams per liter)					
21	CAL	1.2	1.4	0.20	0.02	5.2	0.9
	VER1	2.0	4.4	.08	.01	2.8	- .1
	VER2	5.2	1.6	.18	.02	5.0	.6
22	CAL	2.4	1.3	.67	.07	4.8	.8
	VER1	2.1	1.8	.44	.12	5.0	1.5
	VER2	7.6	2.4	1.6	.63	6.4	3.7
23	CAL	7.2	1.6	.79	.14	2.2	.7
	VER1	6.6	3.3	.19	.07	1.4	.1
	VER2	9.2	2.8	.98	.13	1.8	.9
24	CAL	6.3	1.4	.12	.04	1.5	1.5
	VER1	5.9	2.2	.18	.06	2.2	.9
	VER2	54	3.2	.89	.18	3.4	1.6

[1]Dissolved-oxygen deficit is defined as the difference between observed and saturation concentrations.

[2]South Platte River dissolved oxygen at beginning of the model reach.

Benthic-Sediment Oxygen-Demand Data

Benthic-sediment oxygen-demand (BSOD) measurements were made at several sites throughout the study reach. Data from these measurements are presented by Spahr and others (1984). BSOD is an oxygen sink in the dissolved-oxygen part of the model. Both in-situ and in-vitro measurements of BSOD were made.

The respirometer used in the in-situ measurements was designed by John Gibbs and Steven Blakely of the U.S. Geological Survey, based on studies performed by Wells (1974), Pamatmat and Banse (1968), Boynton and others (1981), and Smith and others (1973). Information from BSOD studies on other rivers was also used in the design and methodology for this study (T. Braidich, U.S. Environmental Protection Agency, written commun., 1982; and F. G. Ziegler and others, Associated Water and Air Engineers, written commun., 1982). The respirometer consisted of a 2.7-liter clear-plastic dome with an area of approximately 549 square inches, fitted with a one-way valve to exhaust air bubbles, a submersible pump for circulation, and a dissolved-oxygen probe (with stirrer) connected to a continuous recorder. During the measurement, the respirometer was inserted into the stream bottom with a minimum of bottom disturbance, to a depth of approximately 1.5 inches. Evidence of an effective seal against interchange of stream water and water within the dome was given by a continuous decrease in the dissolved-oxygen measurement.

Eighteen in-situ measurements were made at six different sites during the flow-regulation periods. Site locations were selected based on suitability for placement of the respirometer and representative bottom type. Placement suitability was determined primarily by the ability to effect a seal with the stream bottom. Therefore, shale and other rock-type bottom material were not suitable for measurement.

In-vitro measurements were made for bottom material that was not suitable for in-situ measurements. The in-vitro respirometer was constructed using specifications provided by E. E. Gann (U.S. Geological Survey, written commun., 1982). This respirometer consisted of a clear-plastic 18.3-liter cyclinder to hold the sediment sample, a variable-speed peristaltic pump, and a dissolved-oxygen probe with a continuous recorder. Sediment was placed in the cyclinder to a depth of 1.5 inches; then air-saturated deionized water was circulated through the closed system while dissolved-oxygen measurements were made, until there was no discernable change in concentration.

All measured BSOD values except one agreed fairly well with data collected on the South Platte River by Braidich (1973); who reported three measurements of 1.26, 1.41 and 2.06 grams per square meter per day [$(gm/m^2)/d$] of BSOD. Excluding one anomolous measurement, the 21 values measured in this study ranged from 0.37 to 8.85 $(gm/m^2)/d$, with a mean of 1.92 and a standard deviation of 1.95 $(gm/m^2)/d$. The anomalous value was 29.1 $(gm/m^2)/d$. This measurement was made in a pooled reach, where the bottom type was mud and organic material only, and the possibility existed of warm cooling-water discharge to the pool from a Public Service of Colorado powerplant. This value is believed anomalous, in that it represents an unusual point in the river, probably a worst-case situation, not representative of other typical pooled areas in the river.

A report by O'Connell and Weeks (1965) quoting O'Connor (1964) states that BSOD values can range from 1 to 10 $(gm/m^2)/d$, and typically, will be within the range of 3 to 5 $(gm/m^2)/d$. Therefore, it appears that the BSOD data collected in this study are representative of conditions at the point where the measurements were made. A truly definitive study of BSOD in the study reach should explain for the large variability in bottom types, particularly in those shale and rocky bottoms where the methods available in this study were inadequate to determine BSOD. A method of sealing the respirometer against dissolved-oxygen recharge on a shale bottom type is not known.

Using measured values for BSOD for different bottom types and information on bottom material from the channel-geometry measurements, average subreach values of BSOD were determined. A value of 1.76 $(gm/m^2)/d$ was used for subreaches 1 to 5, 12 and 19; 2.77 $(gm/m^2)/d$ was used for subreaches 6 to 8 and 15; and 1.01 $(gm/m^2)/d$ was used for subreaches 9 to 11, 13 and 14, 16 to 18, and 20 to 24.

Calibration and Verification Results

Model calibration was performed using the data collected during September 1983. Criteria used for calibration were: (1) Model-computed concentrations were within 20 percent of the mean of the observed concentrations at site SP-500 (downstream from the effluent of the Bi-City WWTP; site 5 on fig. 2);

and (2) model-computed concentrations throughout the model reach followed the same general trend as the mean of the observed concentrations.

Within the model reach, three waterfalls occur that increase the concentration of dissolved oxygen in the South Platte River: at 3.10, 5.70, and 12.80 miles upstream from the streamflow-gaging station at 50th Avenue (SP-1700; site 18 on fig. 2). The equation used to estimate reaeration rates does not account for this type of reaeration; therefore, the predicted dissolved-oxygen concentrations would be smaller than the observed concentrations, unless the model accounted for these three waterfalls. It was assumed that the waterfalls increased the dissolved-oxygen concentration to saturation levels. This was accomplished in the model by setting the dissolved-oxygen deficit to zero at the river mileages corresponding to the waterfalls.

Reaction rates for 5-day CBOD, and the nitrogen species used to calibrate the model are given in table 5. Dissolved-solids concentration was modeled as a conservative constituent and does not have reaction coefficients.

Table 5.--*Model-calibration reaction rates*

[Forward, forward reaction rate; Decay, decay rate; all reaction rates are for 20° Celsius in units of day^{-1}; CBOD, carbonaceous biochemical oxygen demand]

Model sub-reach	5-day CBOD decay rate	Total organic nitrogen		Total ammonia nitrogen		Total nitrite nitrogen		Total nitrate nitrogen
		Forward	Decay	Forward	Decay	Forward	Decay	Decay
1	0.50	1.30	1.30	0.50	1.00	8.00	8.00	0.00
2	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
3	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
4	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
5	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
6	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
7	.50	1.30	1.30	.50	1.00	45.00	45.00	.00
8	.50	1.30	1.30	.50	1.00	45.00	45.00	.00
9	.50	1.30	1.30	.50	1.00	45.00	45.00	.00
10	.50	1.30	1.30	.50	1.00	25.00	25.00	.00
11	.50	1.30	1.30	.50	1.00	15.00	15.00	.00
12	.50	1.30	1.30	.50	1.00	15.00	15.00	.00
13	.50	1.30	1.30	.50	1.00	10.00	10.00	.00
14	.50	1.30	1.30	.50	1.00	10.00	10.00	.00
15	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
16	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
17	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
18	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
19	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
20	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
21	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
22	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
23	.50	1.30	1.30	.50	1.00	8.00	8.00	.00
24	.50	1.30	1.30	.50	1.00	8.00	8.00	.00

Results of calibration, using the reaction rates in table 5 and the September 1983 data set, are shown in figures 5 to 11. In figures 5 to 11, the Bi-City WWTP effluent enters the river at approximately river mile 10. The streamflow-gaging station, South Platte River at Littleton, is site 2; the streamflow-gaging station, South Platte River at 50th Avenue, is site 18 in figures 5 to 11.

Model-computed and observed total organic-nitrogen concentrations are shown in figure 5. Model results closely follow the trend of observed concentrations. At site 5, the model fails to yield results that are within 20 percent of the mean of observed concentrations. It appears that the measured concentration of total organic nitrogen in the effluent of the Bi-City WWTP was not large enough to account for the increase in concentrations found downstream. Varying the forward reaction or decay rate for total organic nitrogen would not achieve a better model prediction, because the model does not receive enough organic-nitrogen input from the Bi-City WWTP. No other source of total organic nitrogen was found within the reach immediately downstream from the Bi-City WWTP. However, uneven loading of total organic nitrogen from the Bi-City WWTP, that was not accounted for by the samples collected during the 24-hour period, may account for part of the unexplained increase observed downstream.

Model-computed and observed total ammonia-nitrogen concentrations for the September 1983 data set are shown in figure 6. Model-computed concentrations follow observed concentrations; model values are within 20 percent of the mean of the observed data at site 5.

Total nitrite-nitrogen computed and observed concentrations are shown in figure 7. The trend of model-computed concentations is somewhat similar to that of observed concentrations. Concentrations of total nitrite nitrogen are low throughout the study reach, as nitrite is a relatively unstable form of nitrogen in the nitrification process from ammonia to nitrate. Cain and others (1980) and Bauer and others (1978) found a rapid increase in total nitrite downstream of waste-water treatment plants; then, they found a gradual decay in concentrations farther downstream. Data for the South Platte River do not exhibit this type of concentration curve; instead, a gradual increase was observed in total nitrite nitrogen with distance downstream (fig. 7). The observed total nitrite-nitrogen concentration is a result of the type of treatment process occurring within the Bi-City WWTP. To achieve an approximate calibration of total nitrite, and to move nitrogen to the nitrate form (for nitrate calibration), very large forward-reaction rates were necessary for total nitrite nitrogen (table 5). Although these nitrite reaction rates are very large with respect to other documented studies, it should be noted that the reaction rates incorporate many processes that will vary from one study area to another. In modeling, these reaction rates are parameters that are adjusted to incorporate physical and biochemical processes through a curve-fitting procedure. In this study, nitrite-nitrogen concentrations, while important, are not as much of a concern as the ammonia and un-ionized-ammonia concentrations.

Total nitrate-nitrogen observed and computed concentrations are shown in figure 8. Only a decay rate for nitrate nitrogen is used in the model. To calibrate total nitrate nitrogen, a decay rate of 0.0 was used. A value of 0.0

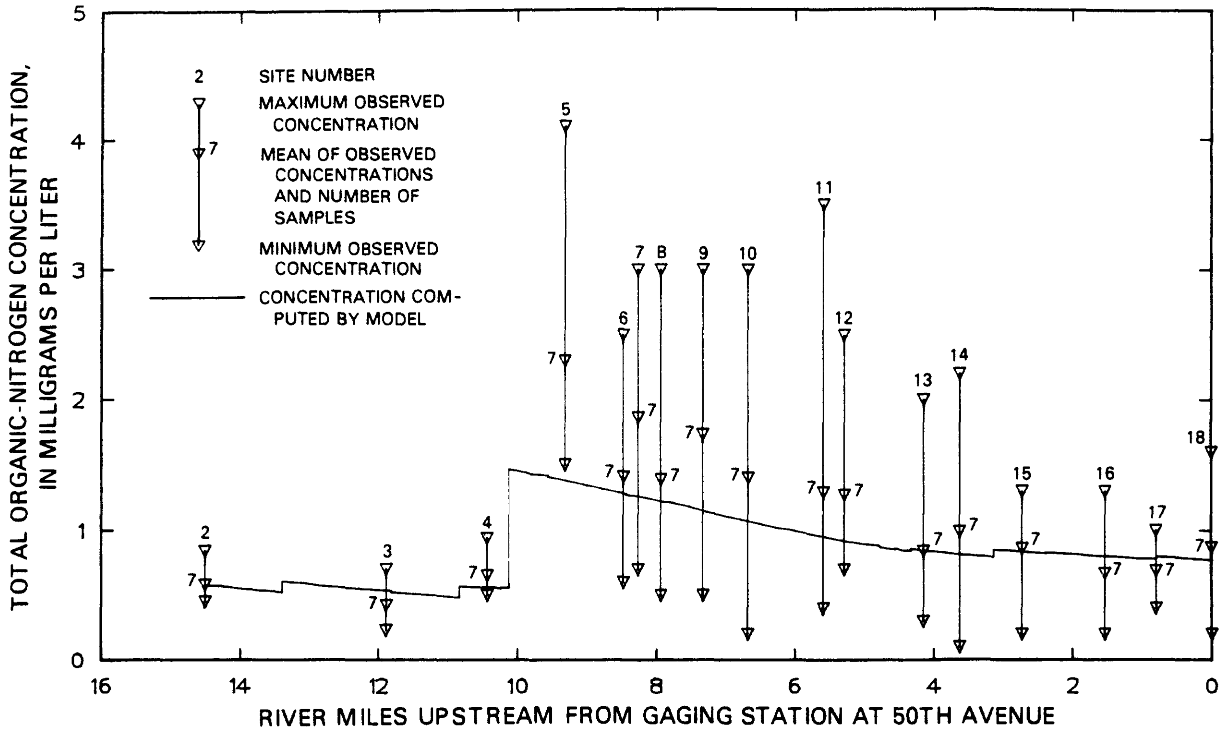

Figure 5.--Observed and model-computed total organic-nitrogen concentrations for the September 1983 calibration data.

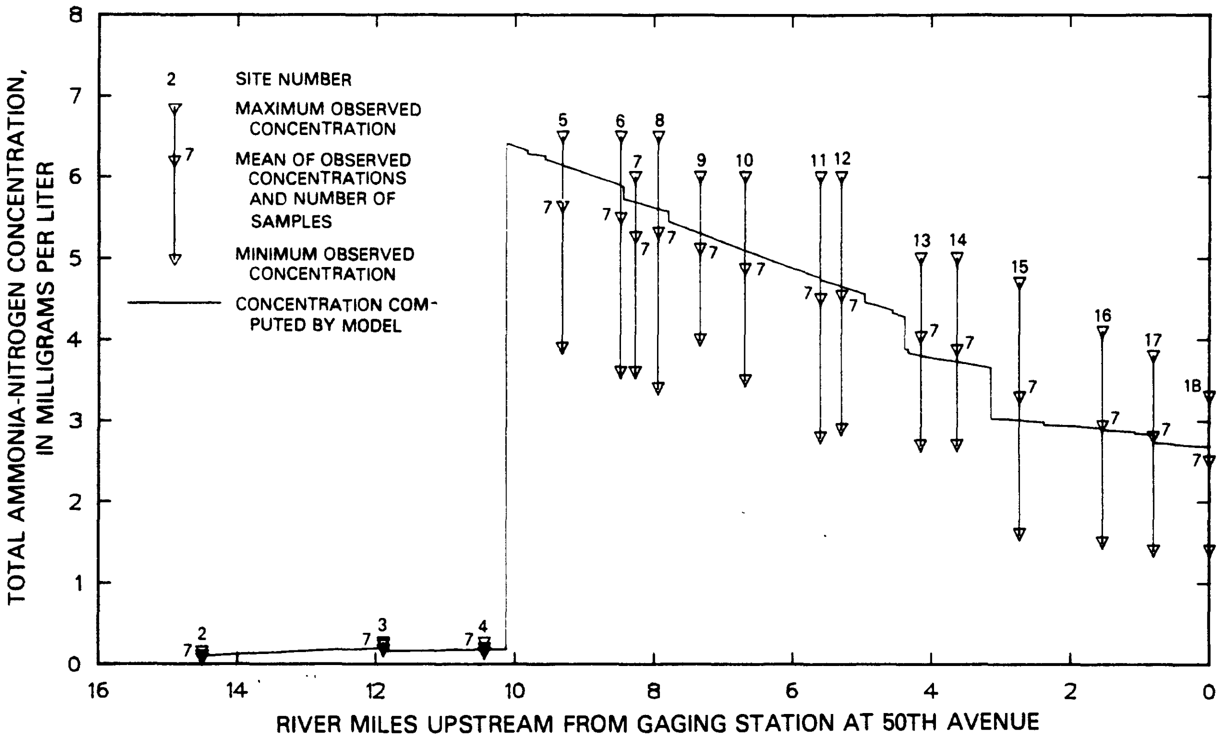

Figure 6.--Observed and model-computed total ammonia-nitrogen concentrations for the September 1983 calibration data.

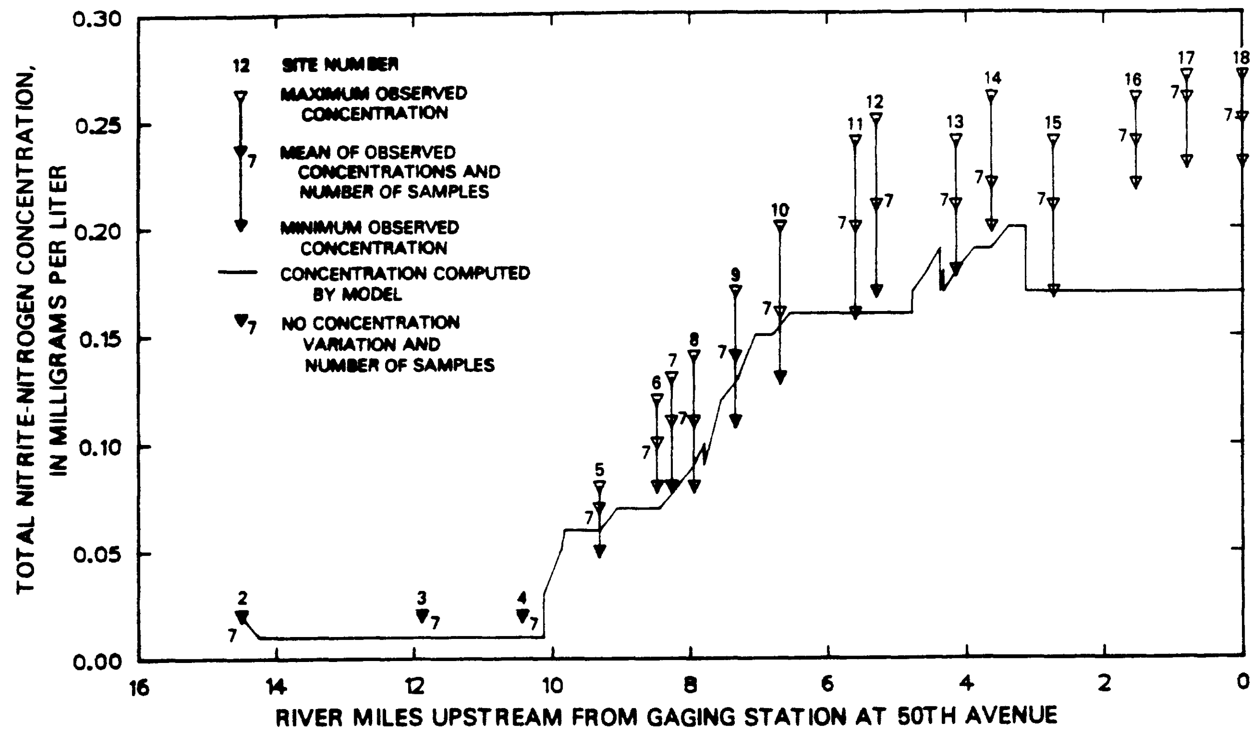

Figure 7.--Observed and model-computed total nitrite-nitrogen concentrations for the September 1983 calibration data.

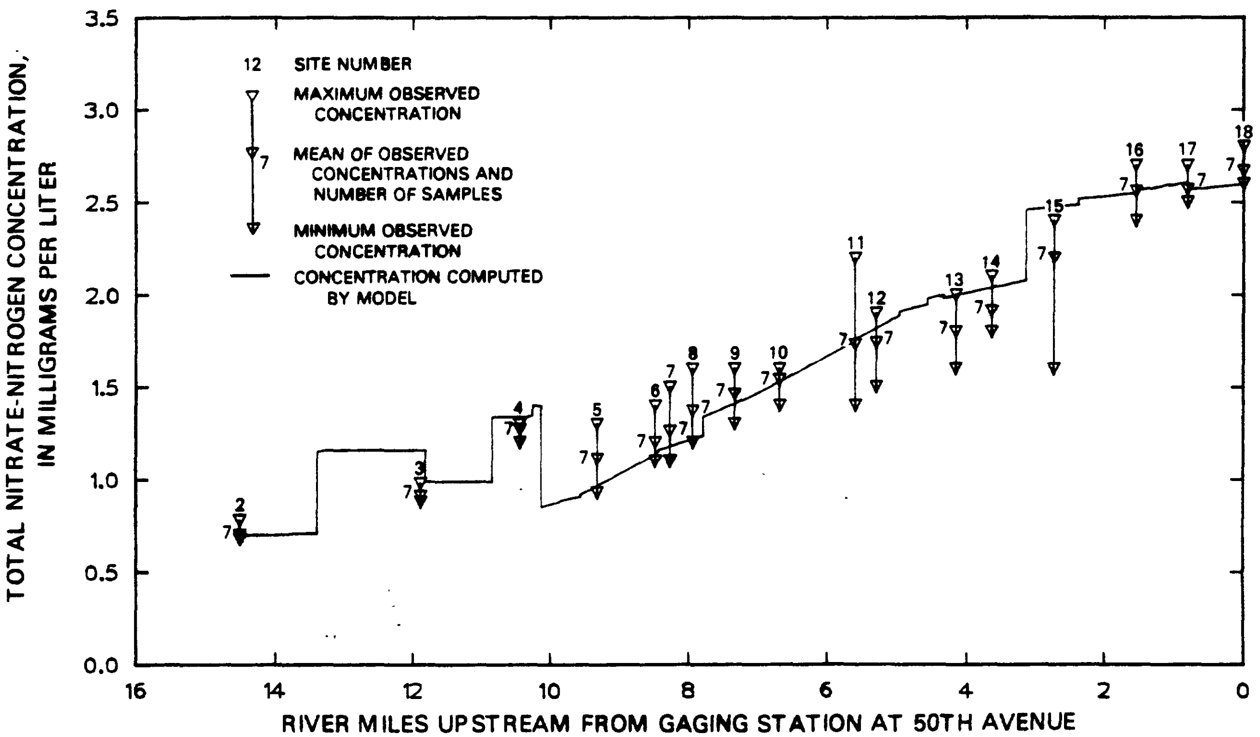

Figure 8.--Observed and model-computed total nitrate-nitrogen concentrations for the September 1983 calibration data.

for a decay rate signifies that no total nitrate nitrogen is removed from the system, and a gradual increase in nitrate concentrations is found throughout the study reach. Total nitrate nitrogen calibrated according to the specified criteria.

Observed and modeled concentrations of 5-day CBOD are shown in figure 9. The decay rate of 0.50 for 5-day CBOD was determined by plotting concentrations versus traveltime, and taking the slope of the curve (Bauer and others, 1979). The model calibrated for 5-day CBOD.

Dissolved oxygen, observed and model-computed concentrations, are shown in figure 10. The waterfalls, as discussed previously, are shown on the graph as abrupt increases in the dissolved-oxygen concentrations. According to the specified criteria, the model is calibrated for dissolved oxygen.

Dissolved-solids concentration was modeled as a conservative constituent; observed and modeled concentrations are shown in figure 11. Computed dissolved-solids concentrations are less than observed minimum concentrations in the downstream subreaches because the model-computed discharges are smaller than the observed discharges (fig. 4). Model-computed concentrations are within 20 percent of the mean of observed concentrations; trends of the computed and observed concentrations are similar. The model is considered calibrated for dissolved solids.

The model was verified, using the reaction coefficients listed in table 5 and the verification-data sets of October 1982 and January 1984. Observed and model-computed concentrations for the constituents modeled are shown in figures 12 to 18. Model-computed total organic-nitrogen concentrations were verified with the October 1982 data; however, model-computed concentration at site 5 for the January 1984 data was over 20 percent greater than the mean of the observed data (fig. 12). The decay rate for total organic nitrogen appears to be appropriate; however, observed concentrations at site 5 do not reflect the increase in organic nitrogen attributed by the model to the Bi-City WWTP effluent. This probably is due to problems in sample preservation, or problems in the analytical method used to compute total organic-nitrogen concentrations.

Observed and model-computed total ammonia-nitrogen concentrations for the verification data sets are shown in figure 13. Model-computed concentrations followed the same general trend as observed concentrations, and were within 20 percent of the mean of the observed concentrations at site 5.

Verification graphs of total nitrite nitrogen are shown in figure 14. Concentrations of total nitrite nitrogen remain small throughout the model reach. The October 1982 verification run showed similar trends in observed and model-computed concentrations. The October model-computed concentration at site 5 was 0.04 mg/L (milligrams per liter) and the mean of the observed concentrations was 0.03 mg/L. While this comparison indicated a greater than 20-percent difference, the magnitude of the concentrations is small. The verification run for January 1984 data showed that model-computed concentrations were much larger than observed concentrations. This resulted from the water-temperature adjustment made by the model to the nitrite forward-reaction coefficient. The amount that the reaction rate is decreased with decreasing water temperature is determined by an empirical equation in the model. The

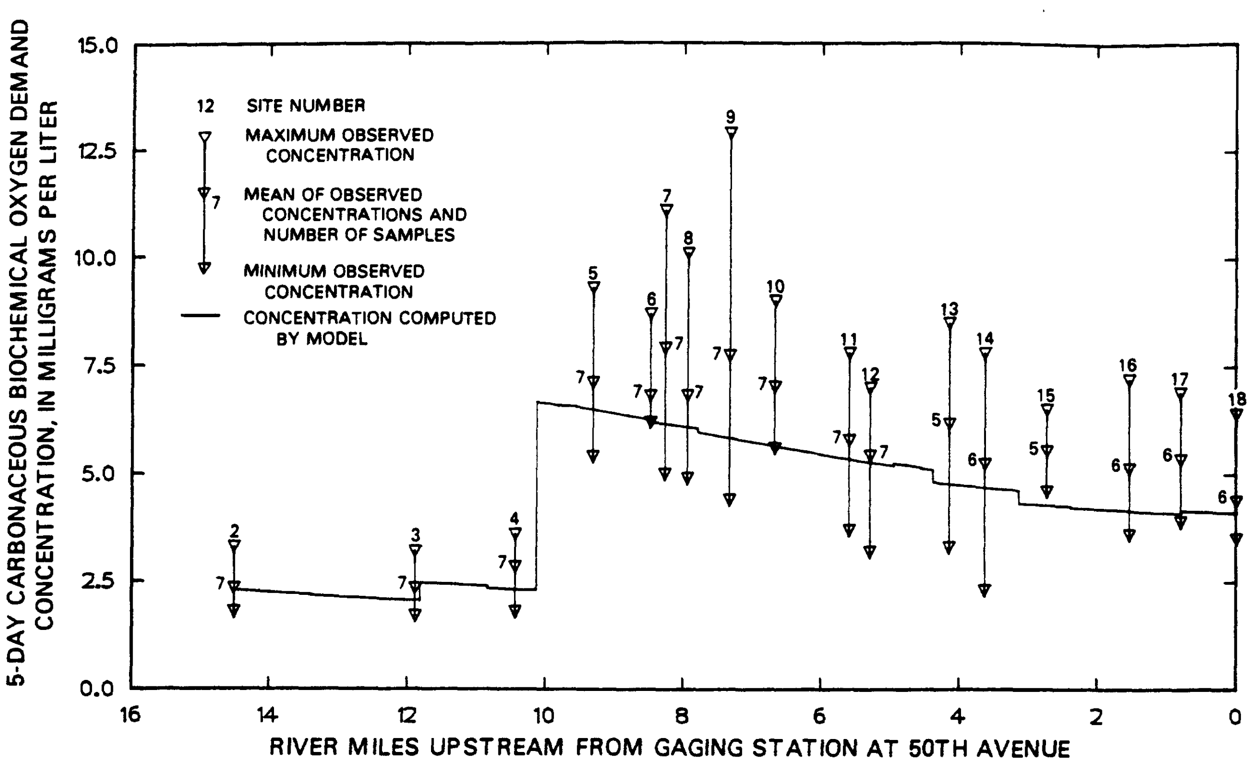

Figure 9.--Observed and model-computed 5-day carbonaceous biochemical oxygen demand for the September 1983 calibration data.

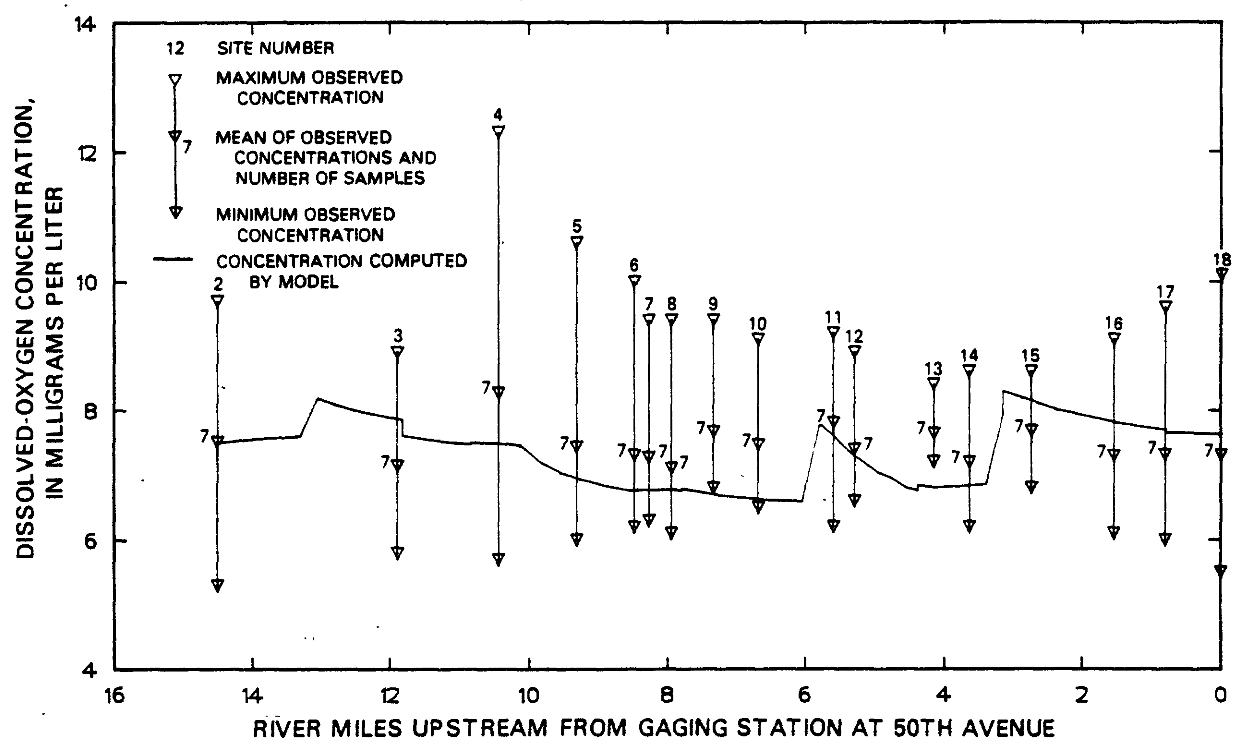

Figure 10.--Observed and model-computed dissolved-oxygen concentrations for the September 1983 calibration data.

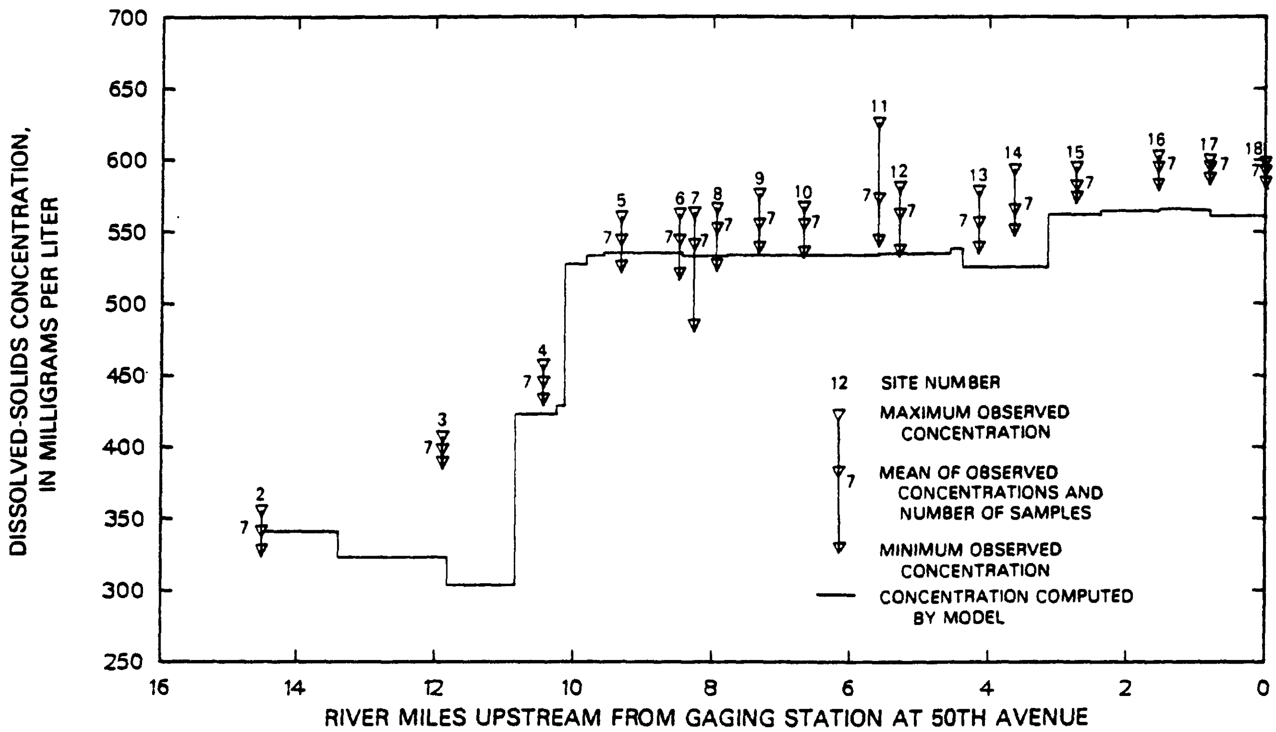

Figure 11.--Observed and model-computed dissolved-solids concentrations for the September 1983 calibration data.

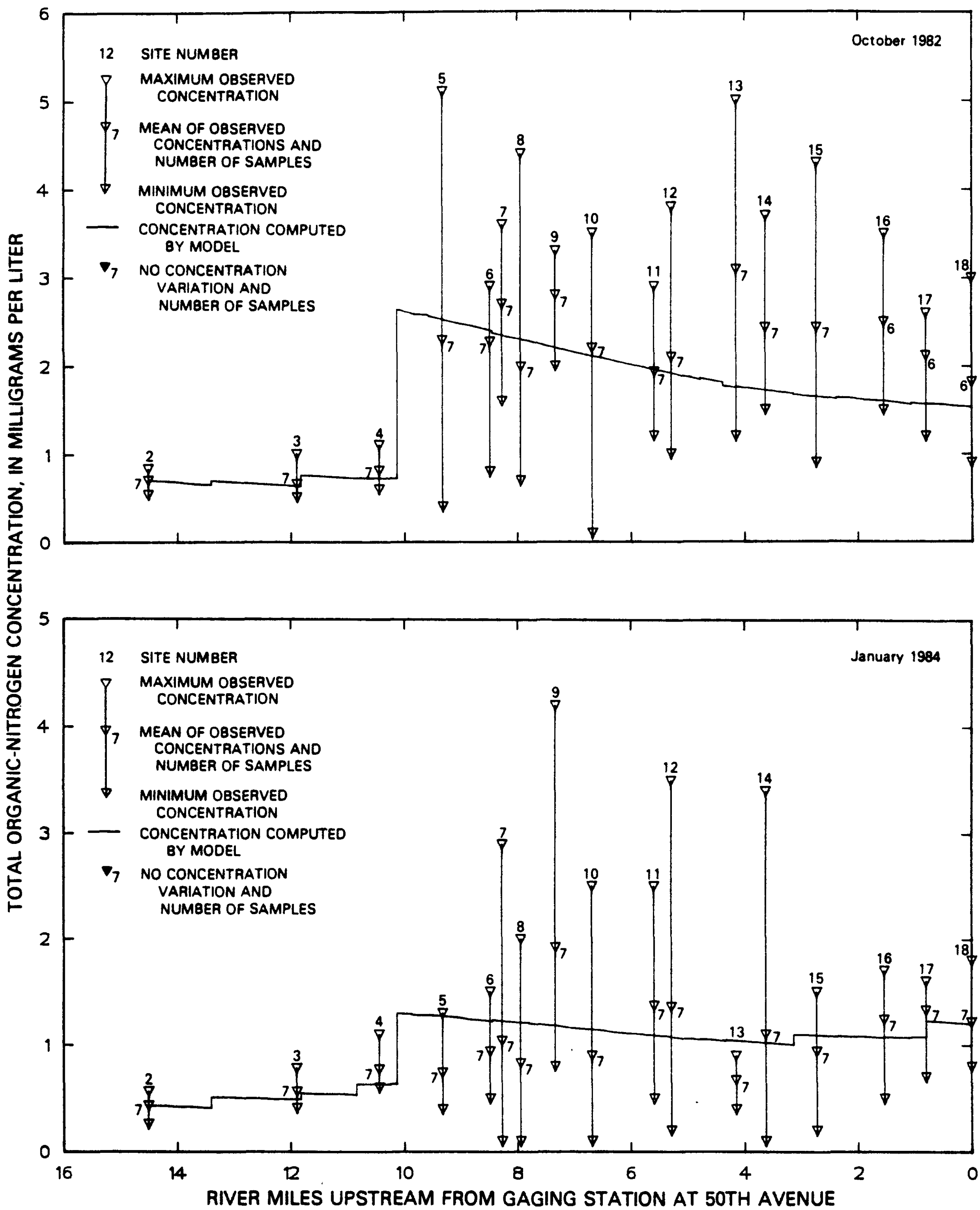

Figure 12.--Observed and model-computed total organic-nitrogen concentrations for the October 1982 and January 1984 verification data.

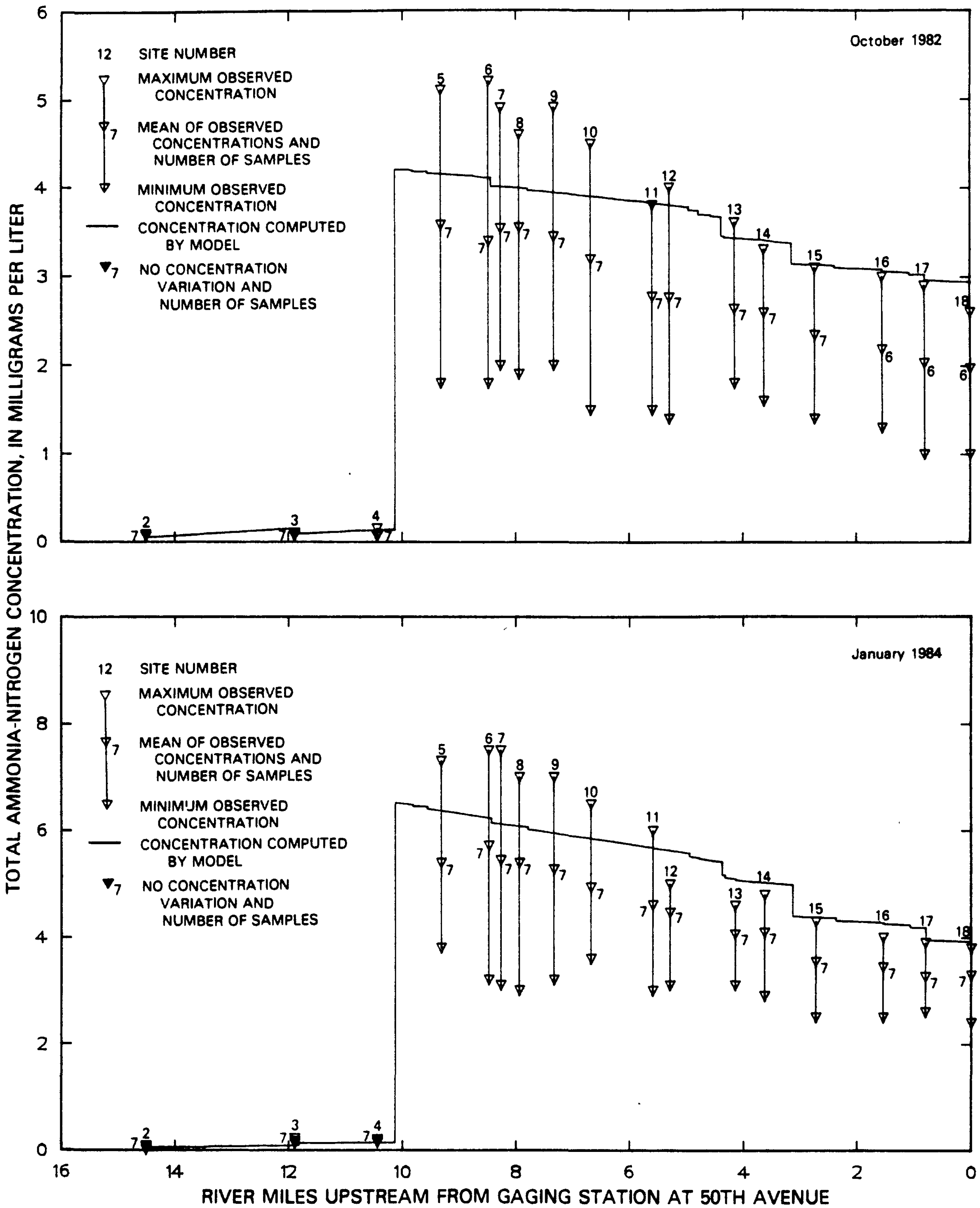

Figure 13.--Observed and model-computed total ammonia-nitrogen concentrations for the October 1982 and January 1984 verification data.

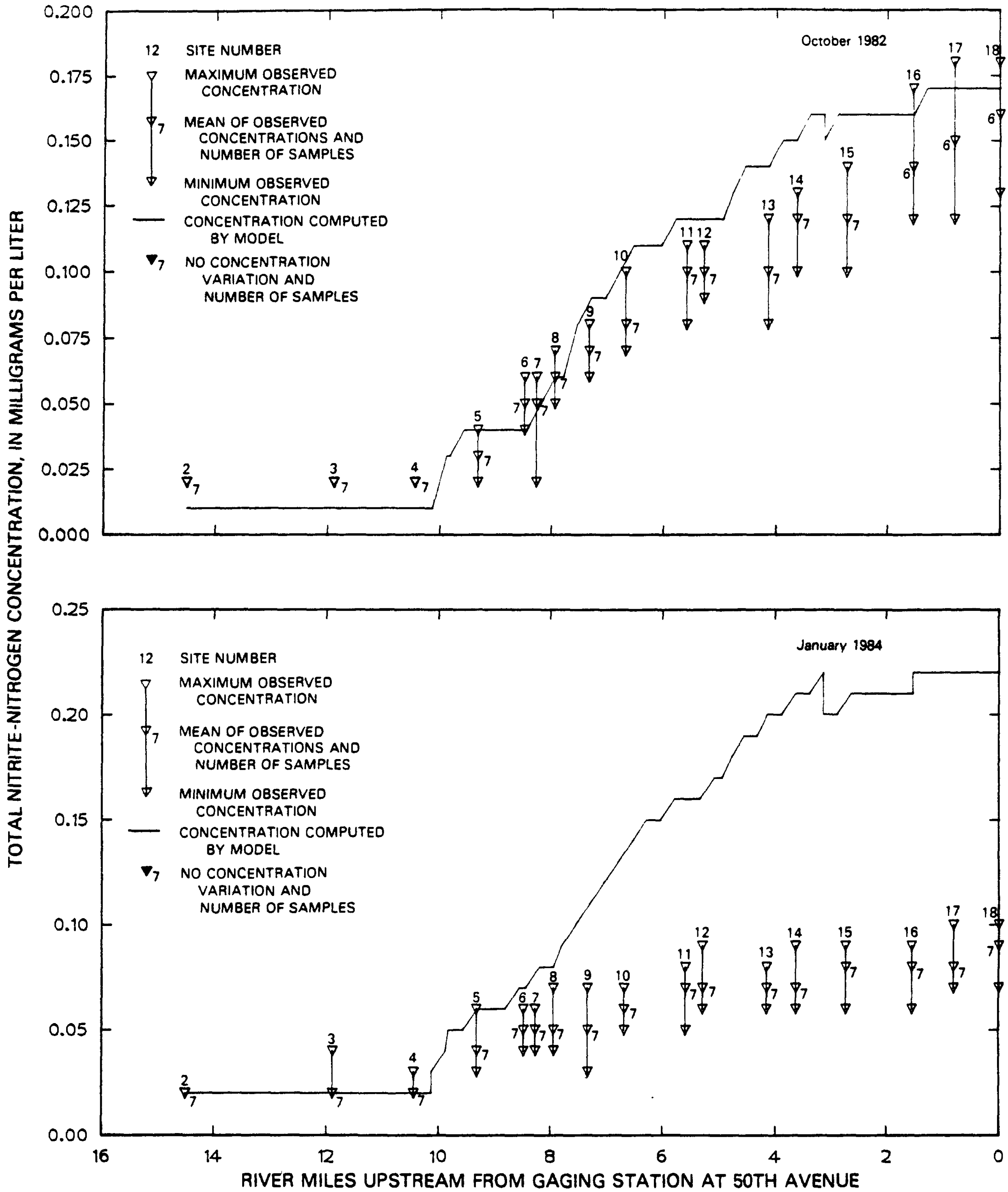

Figure 14.--Observed and model-computed total nitrite-nitrogen concentrations for the October 1982 and January 1984 verification data.

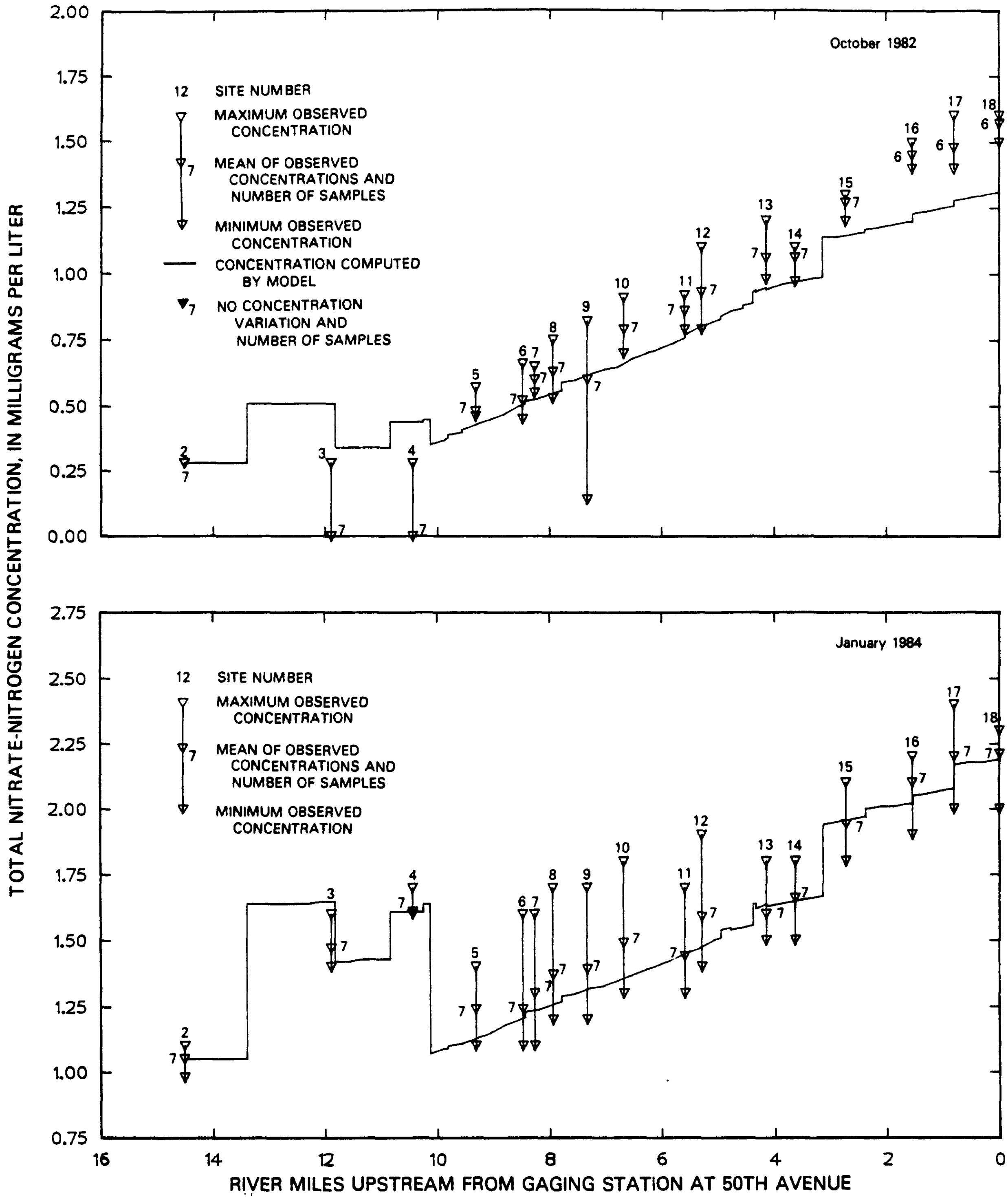

Figure 15.--Observed and model-computed total nitrate-nitrogen concentrations for the October 1982 and January 1984 verification data.

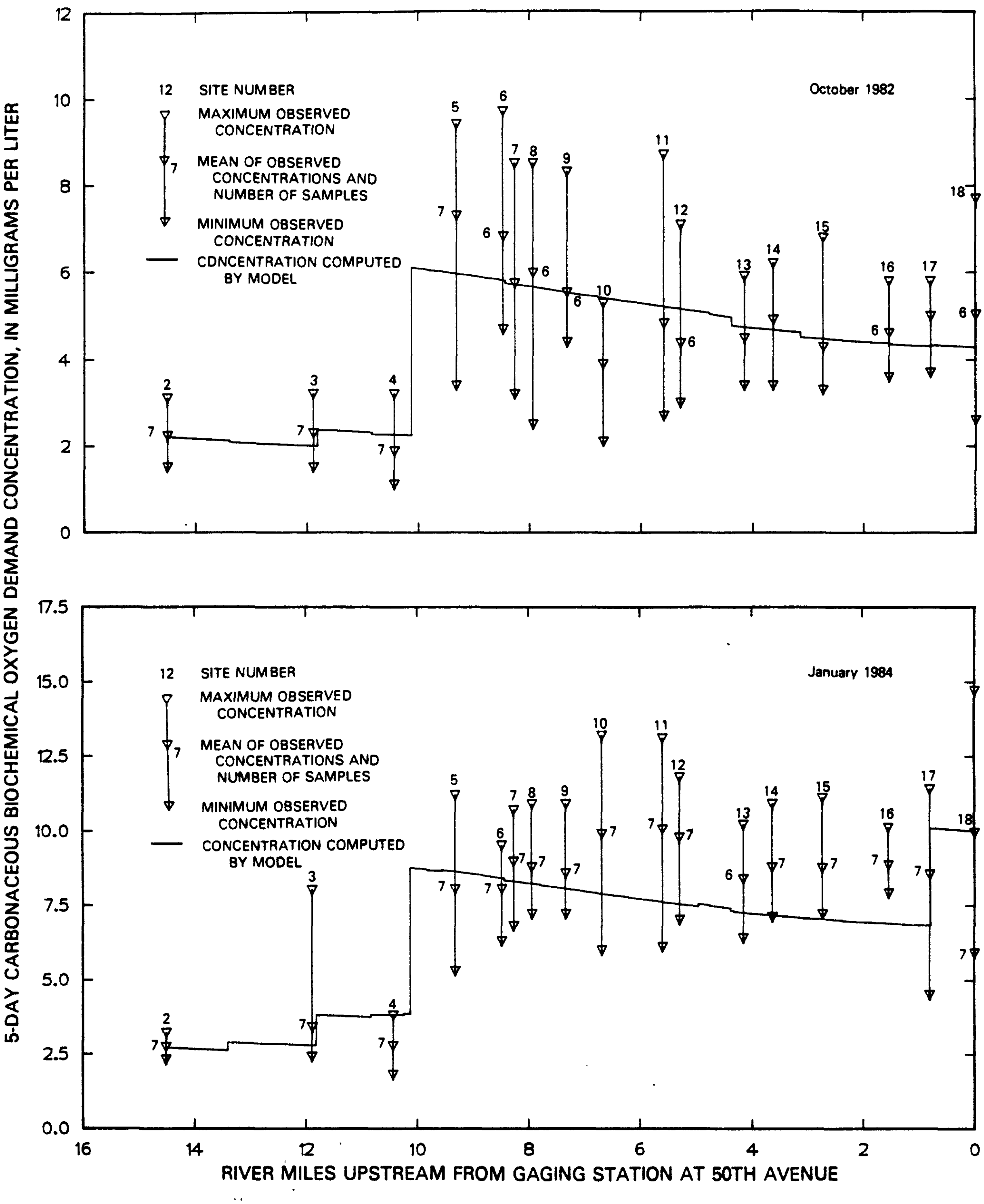

Figure 16.--Observed and model-computed 5-day carbonaceous biochemical oxygen demand for the October 1982 and January 1984 verification data.

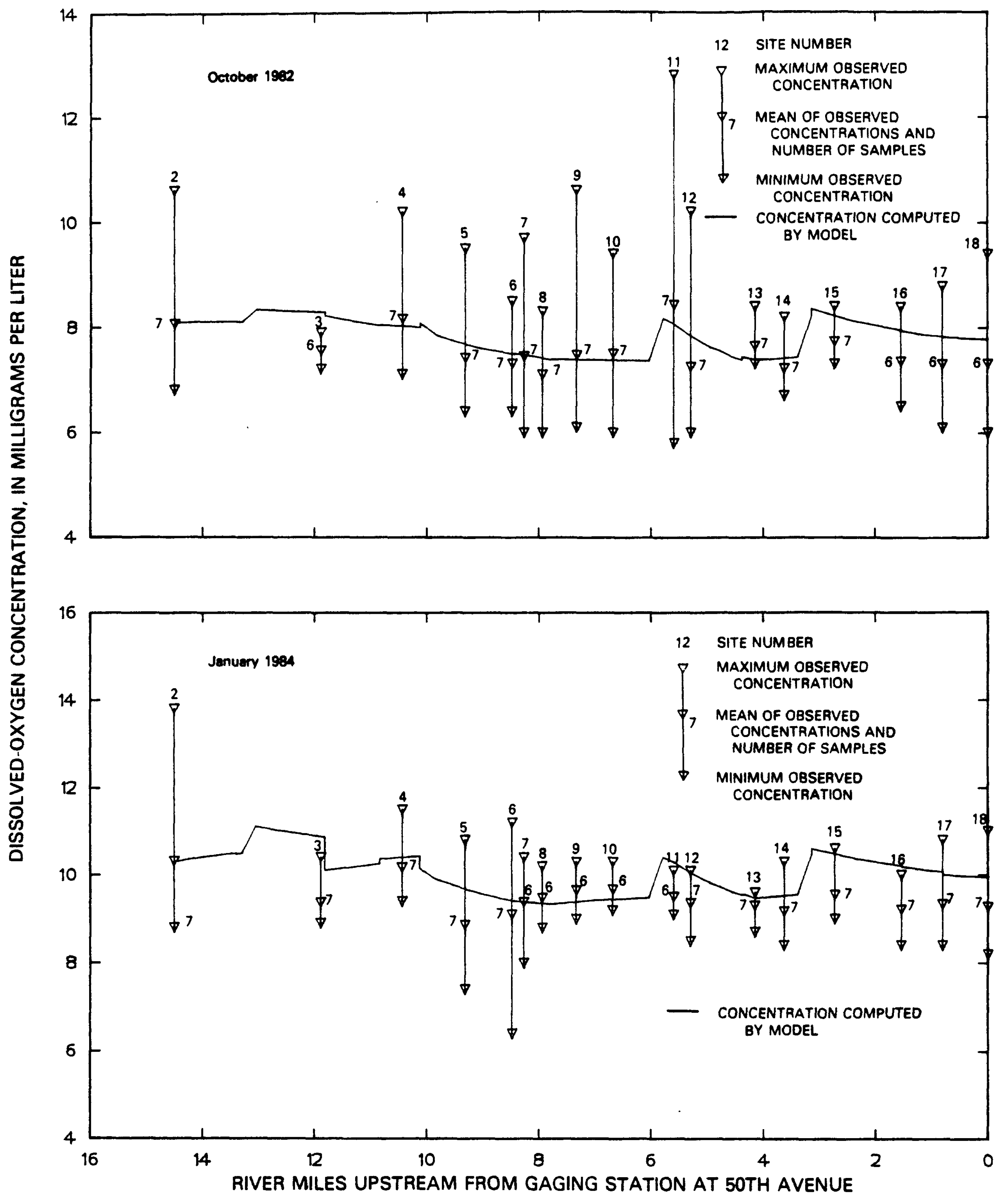

Figure 17.--Observed and model-computed dissolved-oxygen concentrations for the October 1982 and January 1984 verification data.

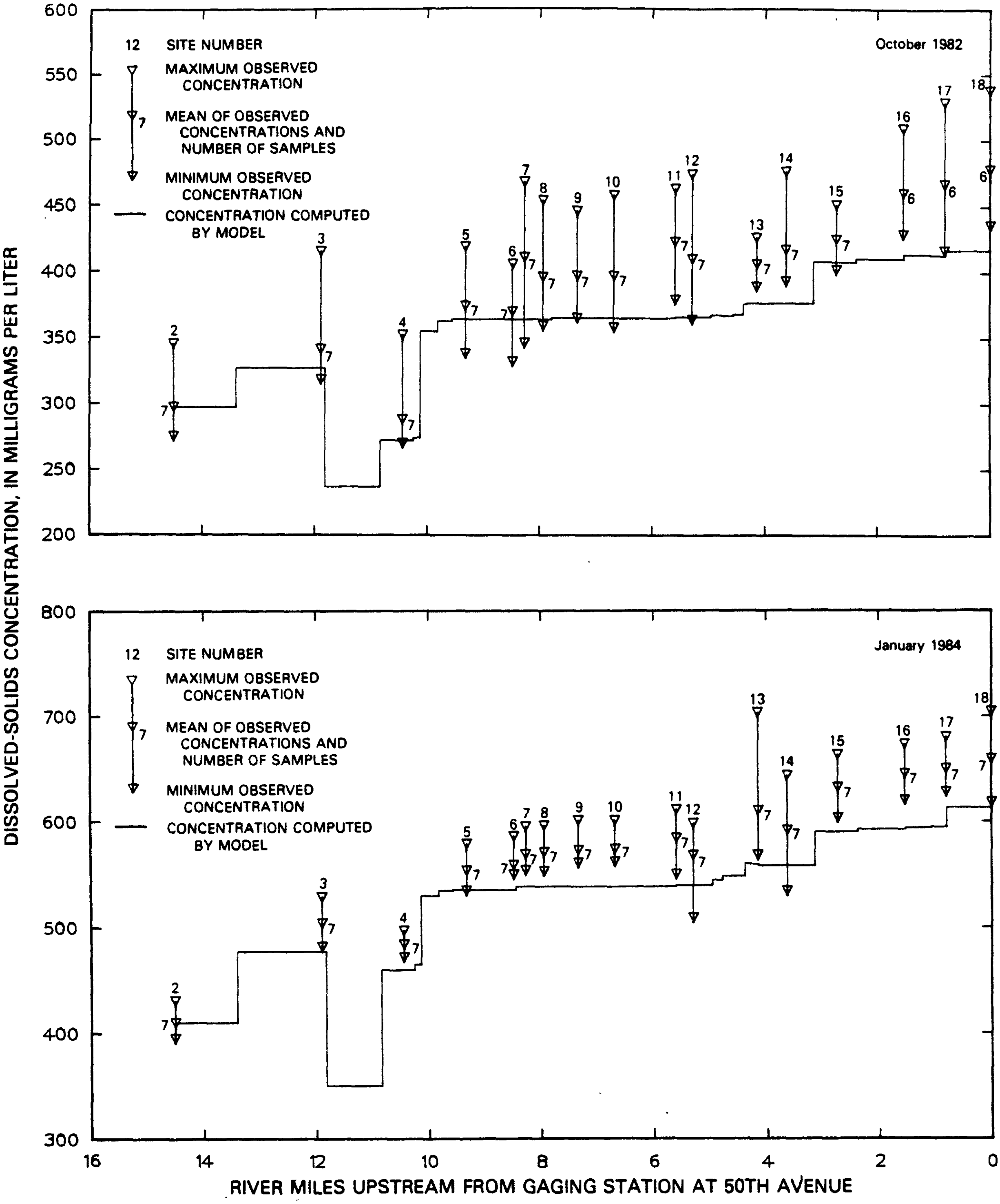

Figure 18.--Observed and model-computed dissolved-solids concentrations for the October 1982 and January 1984 verification data.

adjustment is a function of the magnitude of the reaction rate; with the large reaction rate used for total nitrite nitrogen, the amount of adjustment for the cold-water temperature was large. With water-temperature adjustment, the forward-reaction rate is decreased; this resulted in a calculated buildup of nitrogen in the nitrite form. Therefore, the model is not considered verified for total nitrite nitrogen for cold-water temperature conditions.

Observed and computed total nitrate-nitrogen concentrations for the verification model runs are shown in figure 15. The model was verified for both cold- and warm-water temperatures for total nitrate nitrogen. Verification results for 5-day CBOD are shown in figure 16; verification results for dissolved oxygen are shown in figure 17. The model was verified for both 5-day CBOD and dissolved oxygen. Observed and model-computed concentrations for dissolved solids for verification data sets are shown in figure 18. Although the model-computed concentrations sometimes are less than the minimum-observed concentrations, the computed concentrations follow the same trend and are within 20 percent of the mean of observed concentrations. The model is considered verified for dissolved solids.

Results of calibration and verification for each of the modeled constituents is given in table 6. Total nitrogen concentrations for table 6 were computed by summing concentrations of the various nitrogen species as calculated by the model. This sum then was compared to the observed total-nitrogen concentrations to check the nitrogen budget (table 6). Site SP-500 is the instream site immediately downstream of the mixing zone of the WWTP effluent. This site was used in table 6 because it represents the critical model reach below the WWTP.

UN-IONIZED AMMONIA

Methods of Computation

Several methods are available to compute un-ionized-ammonia concentrations. Un-ionized-ammonia concentrations discussed in this report were calculated using a method reported by Skarheim (1973). Skarheim's method uses temperature, pH, total ammonia, dissolved solids (DS) and the equilibrium-dissociation constants for ammonia to compute un-ionized-ammonia concentrations, and percentages of total ammonia in the un-ionized form (percent un-ionized).

Skarheim's report includes a table of pKa's for ammonia based on temperature and dissolved-solids concentrations from 0 to 30°C and 0 to 3,000 mg/L. A table of percent un-ionized-ammonia values is also given in Skarheim's (1973) report, based on the above ranges of temperature and dissolved solids, and a pH range of 6 to 9. Skarheim's pKa values are based on the dissociation constants for ammonia in aqueous solution determined by Bates and Pinching (1950).

Another method to compute un-ionized ammonia is presented in a report by Thurston, and others (1979). This report provides a table of percentages of un-ionized ammonia in aqueous solutions based on temperature, pH, and zero dissolved-solids concentrations. However, most natural systems have significant dissolved-solids concentrations. Thurston and others (1979)

Table 6.--*Results of model calibration and verification*

[mg/L, milligrams per liter; Percent difference = (observed - model computed) / observed; CBOD, carbonaceous biochemical oxygen demand]

Constituent	Mean of observed concentrations at SP-500[1] (mg/L)	Date (month-year)	Model computed concentrations at SP-500 (mg/L)	Percent difference	Similar trend	Calibration or verification accepted
			Calibration			
5-day CBOD	7.11	9/83	6.48	9	yes	yes
Total organic nitrogen	2.30	9/83	1.38	40	yes	no
Total ammonia nitrogen	5.63	9/83	6.24	-9	yes	yes
Total nitrite nitrogen	0.07	9/83	0.06	14	yes	questionable
Total nitrate nitrogen	1.11	9/83	0.97	13	yes	yes
Dissolved oxygen	7.43	9/83	6.94	7	yes	yes
Dissolved solids	544	9/83	536	1	yes	yes
Total nitrogen	9.01	9/83	8.55	5		
			Verification			
5-day CBOD	7.30	10/82	5.96	18	yes	yes
Total organic nitrogen	2.29	10/82	2.52	-10	yes	yes
Total ammonia nitrogen	3.57	10/82	4.15	-14	yes	yes
Total nitrite nitrogen	0.03	10/82	0.04	-33	yes	questionable
Total nitrate nitrogen	0.48	10/82	0.43	10	yes	yes
Dissolved oxygen	7.41	10/82	7.67	-4	yes	yes
Dissolved solids	374	10/82	364	3	yes	yes
Total nitrogen	6.37	10/82	7.14	-12		
5-day CBOD	8.00	1/84	8.62	-8	yes	yes
Total organic nitrogen	0.88	1/84	1.27	-44	yes	no
Total ammonia nitrogen	5.39	1/84	6.37	-18	yes	yes
Total nitrite nitrogen	0.04	1/84	0.06	-50	no	no
Total nitrate nitrogen	1.24	1/84	1.13	9	yes	yes
Dissolved oxygen	8.86	1/84	9.58	-8	yes	yes
Dissolved solids	554	1/84	536	3	yes	yes
Total nitrogen	7.81	1/84	8.83	-13		

[1]SP-500, South Platte River at Evans Avenue.

address this limitation by stating that, in natural systems having up to 200 to 300 mg/L dissolved solids, the reduction of percent un-ionized ammonia attributable to dissolved solids is neglible; however, for higher levels of dissolved solids, accurate percentage levels of un-ionized ammonia cannot be determined using their data.

A third way of determining un-ionized-ammonia concentrations in aqueous solutions is available by using a U.S. Geological Survey computer program called WATEQ (Plummer and others, 1976). Use of WATEQ to compute un-ionized-ammonia concentrations requires major-ion concentrations, total-ammonia concentrations, pH, temperature, and dissolved-oxygen or eH values. The WATEQ program will compute more accurate values of un-ionized-ammonia concentrations than the previously described methods, but the cost involved in collecting major-ion data for every sample collected in this study would have been prohibitive.

Accuracy obtained using Skarheim's (1973) method is easily within the level required for this study, which is apparent from a comparison of the data given in table 7. This table presents un-ionized-ammonia concentrations computed using the Skarheim, Thurston, and WATEQ methods for selected analyses of water samples collected in the study reach at the South Platte River at Littleton (SP-200, U.S. Geological Survey station 06710000). These data were collected prior to the study (not necessarily at low flow); however, they still are representative of study data collected for the study site and they also are within the range claimed by Thurston and others (1979) to be valid for their data. Selected sample observations for the South Platte River at Evans Avenue bridge (SP-500, U.S. Geological Survey station 394042104595100) also are given in table 7. Ion concentrations shown for SP-500 are estimated from regression relations with dissolved solids, developed from data collected at the Littleton station. The ionic data and the WATEQ computations shown are not intended to indicate actual concentrations, but only to provide a comparison of un-ionized-ammonia concentrations computed by the three methods for large ammonia concentrations. Percent un-ionized-ammonia concentrations calculated using Thurston's method all are greater than those calculated using Skarheim's method, and concentrations calculated using WATEQ all are less than those calculated using Skarheim's method.

A comparison of calculated ionic concentrations with actual ionic concentrations for a sample collected at the South Platte River at Denver site (SP-1400, U.S. Geological Survey station 06714000) shows that the regression relations used in table 7 are valid for a reasonable estimation of ionic concentrations from dissolved-solids concentrations for samples collected within the study reach (table 8). One analysis from SP-1400 and 24 analyses from SP-200 are the only ionic data available for the study area; these analyses are sufficient for computing the ionic concentrations needed for the un-ionized ammonia comparisons given in table 7.

Table 7.--*Comparison of percent un-ionized-ammonia concentrations calculated using three methods*

[Ionic concentrations for site SP-500 are estimated; mg/L, milligrams per liter]

Site reference code	Date (month-day-year)	Time	Temperature (°Celsius)	pH	Dissolved oxygen (mg/L)	Percent un-ionized ammonia Skarheim (1973)	Percent un-ionized ammonia Thurston (1979)	Percent un-ionized ammonia WATEQ (1976)	Total ammonia as N (mg/L)	Total nitrate as N (mg/L)
SP-200	05-01-79	1415	14.0	8.8	8.9	13.1	13.8	12.2	0.06	1.10
SP-200	06-01-79	1200	16.5	8.7	9.6	12.7	13.3	11.8	0.07	0.71
SP-200	09-06-79	1340	22.5	8.1	10.2	5.17	5.66	4.85	0.06	3.60
SP-200	01-08-80	1015	0.0	8.1	12.2	0.943	1.03	0.879	0.11	1.30
SP-200	06-19-80	1210	16.0	7.5	8.0	0.876	0.925	0.818	0.04	0.06
SP-200	05-06-81	1345	15.5	7.7	8.6	1.29	1.40	1.22	0.21	0.60
SP-500	10-08-82	0630	13.0	7.6	7.0	0.842	0.927	0.793	1.8	0.46
SP-500	03-14-83	0645	9.0	7.8	7.4	0.957	1.07	0.884	2.9	0.88
SP-500	03-14-83	1410	11.5	7.6	8.6	0.725	0.827	0.675	7.3	0.86
SP-500	09-22-83	1805	17.0	7.8	8.7	1.75	1.97	1.63	6.0	1.0
SP-500	09-23-83	0005	15.5	7.3	6.2	0.499	0.564	0.465	6.5	1.3
SP-500	01-26-84	0915	4.5	7.8	9.8	0.668	0.752	0.617	3.8	1.4

Site reference code	Date (month-day-year)	Time	Total dissolved solids (mg/L)	Calcium dissolved (mg/L)	Magnesium dissolved (mg/L)	Sodium dissolved (mg/L)	Potassium dissolved (mg/L)	Bicarbonate dissolved (mg/L)	Chloride dissolved (mg/L)	Fluoride dissolved (mg/L)	Sulfate dissolved (mg/L)
SP-200	05-01-79	1415	177	29.0	6.3	16.0	2.6	49.0	13.0	1.1	47.0
SP-200	06-01-79	1200	156	27.0	5.7	14.0	2.4	48.0	13.0	0.9	36.0
SP-200	09-06-79	1340	318	53.0	13.0	39.0	2.5	98.0	38.0	1.1	87.0
SP-200	01-08-80	1015	317	52.0	13.0	35.0	3.1	115	33.0	1.1	81.0
SP-200	06-19-80	1210	159	20.0	7.0	17.0	2.0	48.0	19.0	0.9	31.0
SP-200	05-06-81	1345	256	41.0	11.0	29.0	2.9	77.0	28.0	0.9	64.0
SP-500	10-08-82	0630	338	54.7	14.2	40.2	3.5	130	39.0	1.0	92.6
SP-500	03-14-83	0645	526	88.2	22.0	65.6	3.5	209	59.3	1.0	156
SP-500	03-14-83	1410	668	113	27.9	84.8	3.5	268	74.6	1.0	204
SP-500	09-22-83	1805	536	90.0	22.4	66.9	3.5	213	60.4	1.0	160
SP-500	09-23-83	0005	554	93.2	23.1	69.4	3.5	220	62.3	1.0	166
SP-500	01-26-84	0915	546	91.7	22.8	68.3	3.5	217	61.5	1.0	163

Table 8.--*Comparison of observed and calculated values of ionic concentrations*

[fluoride and potassium mean values were used, rather than calculated, because of poor correlation]

Constituent	Constituent concentration (milligrams per liter)		Regression equation[1]		R-squared	Difference
	Observed[2]	Calculated	Slope	Intercept		
Calcium	58.0	63.0	0.178	- 5.45	0.91	+ 8.6
Magnesium	15.0	16.0	0.042	+ 0.15	0.93	+ 6.7
Sodium	55.0	46.0	0.135	- 5.42	0.93	-16.0
Potassium	4.3	3.5	-----	------	----	-19.0
Chloride	56.0	44.0	0.108	+ 2.5	0.65	-21.0
Fluoride	0.8	1.0	-----	------	----	+25.0
Sulfate	100.0	108.0	0.339	-21.5	0.96	+ 8.0
Bicarbonate	166.0	123.0	0.342	- 8.6	0.94	-26.0

[1]Developed from 24 samples collected at station 06710000, South Platte River at Littleton, (SP-200) during the period April 4, 1979 to September 9, 1981.

[2]Observed at station 06714000, South Platte River at Denver, (SP-1400) on April 19,1972.

Computed Concentrations of Un-ionized Ammonia

Un-ionized-ammonia concentrations and percent un-ionized ammonia for each instream site during each 24-hour data-collection period are shown in figures 19 and 20. Calculated un-ionized-ammonia concentrations and the data used to make the calculations for all instream samples collected during the 24-hour data-collection efforts, are listed in the "Supplemental Information" section at the end of the report (tables 16, 17, 18, and 19). Field measurements of pH were used in all calculations, unless these data were missing; in this case lab pH was used. In those cases where measured total ammonia-nitrogen concentration was determined to be less than the detection level, one-half of the total ammonia-nitrogen concentration given was used to calculate the un-ionized-ammonia concentration and percentage. In December 1983 the laboratory detection limit for total ammonia was changed from 0.06 to 0.01 mg/L. Following the October 1982 run, and prior to the March 1983 run, the Lakewood Wastewater Treatment Plant outfall (SP-1120), located between SP-1100A (South Platte River above 8th Avenue bridge) and SP-1200 (South Platte River above 17th Avenue underpass), was eliminated as a discharge source; thus this outfall affected the total ammonia-nitrogen concentrations of the river only during the October 1982 period. The temporary stream standard for un-ionized ammonia is 0.1 mg/L.

During the October 1982 24-hour data-collection period un-ionized-ammonia concentrations downstream from the Bi-City WWTP outfall reached a maximum of 0.054 mg/L at the South Platte River at Florida Avenue (SP-600). A concentration of 0.16 mg/L at the South Platte River above 8th Avenue bridge, was calculated with lab pH and was not representative of the probable concentration of un-ionized ammonia at the time of sample collection, because lab pH values

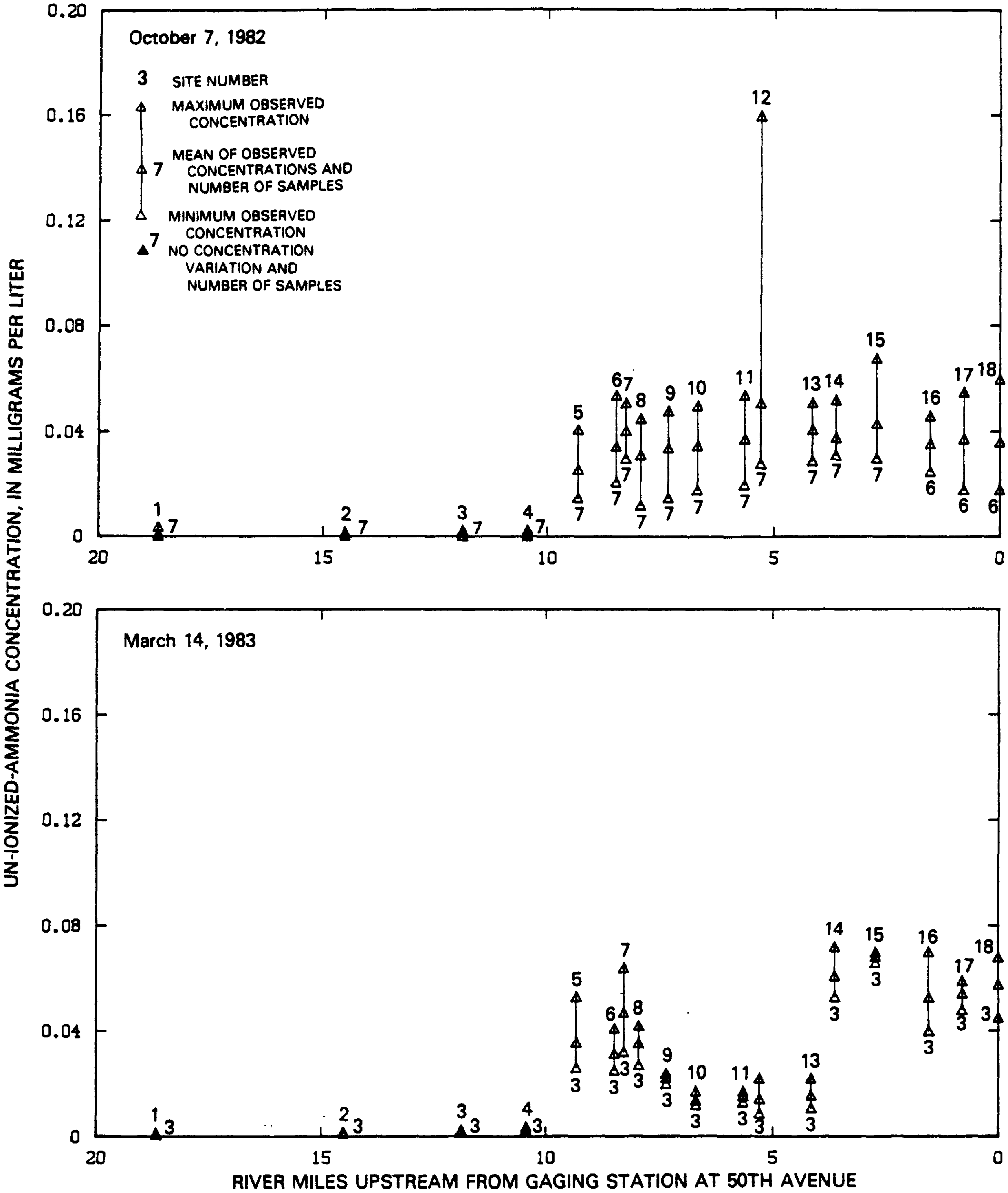

Figure 19.--Maximum, minimum, and mean un-ionized-ammonia concentrations for the South Platte River.

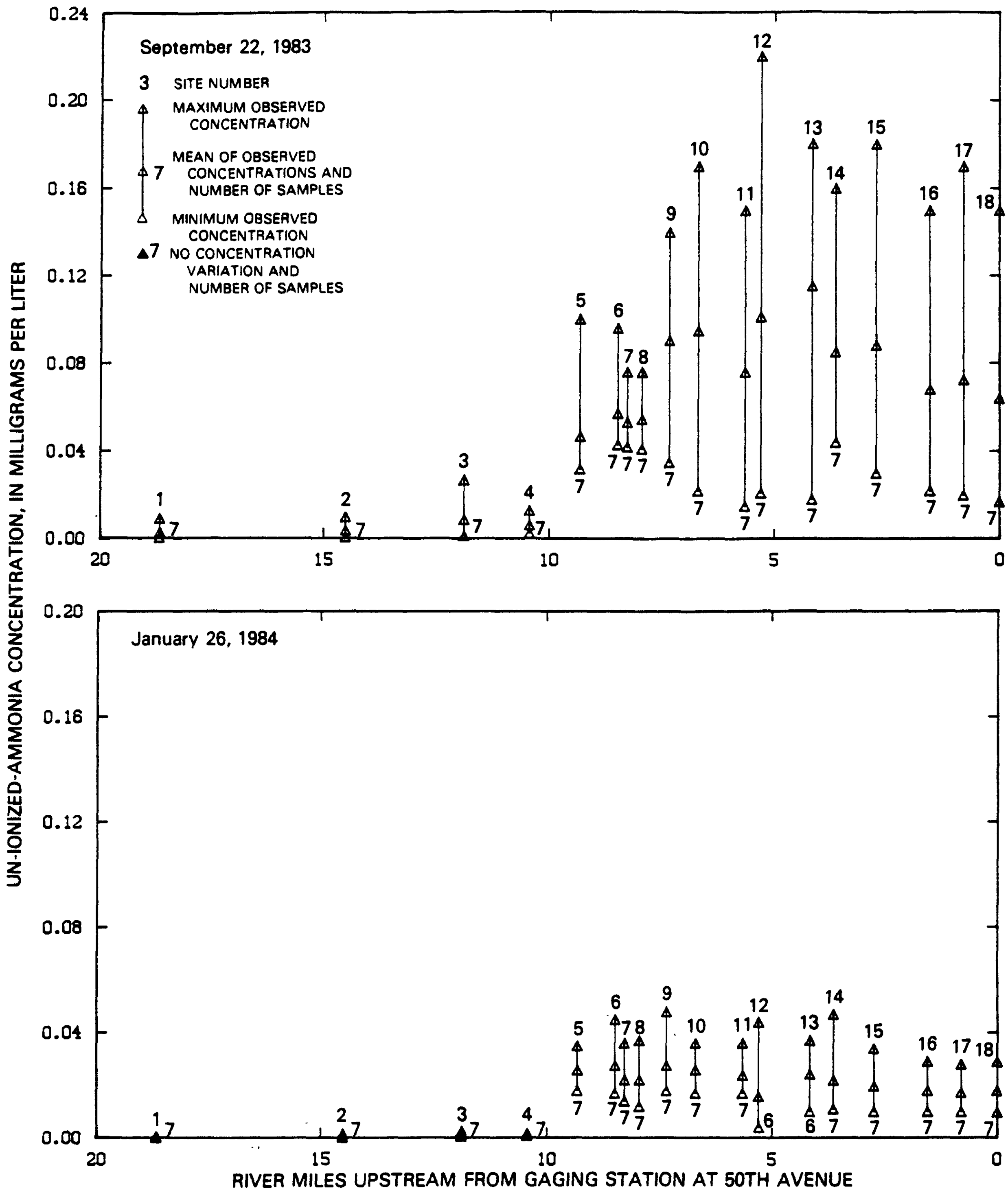

Figure 19.--Maximum, minimum, and mean un-ionized-ammonia concentrations for the South Platte River--Continued.

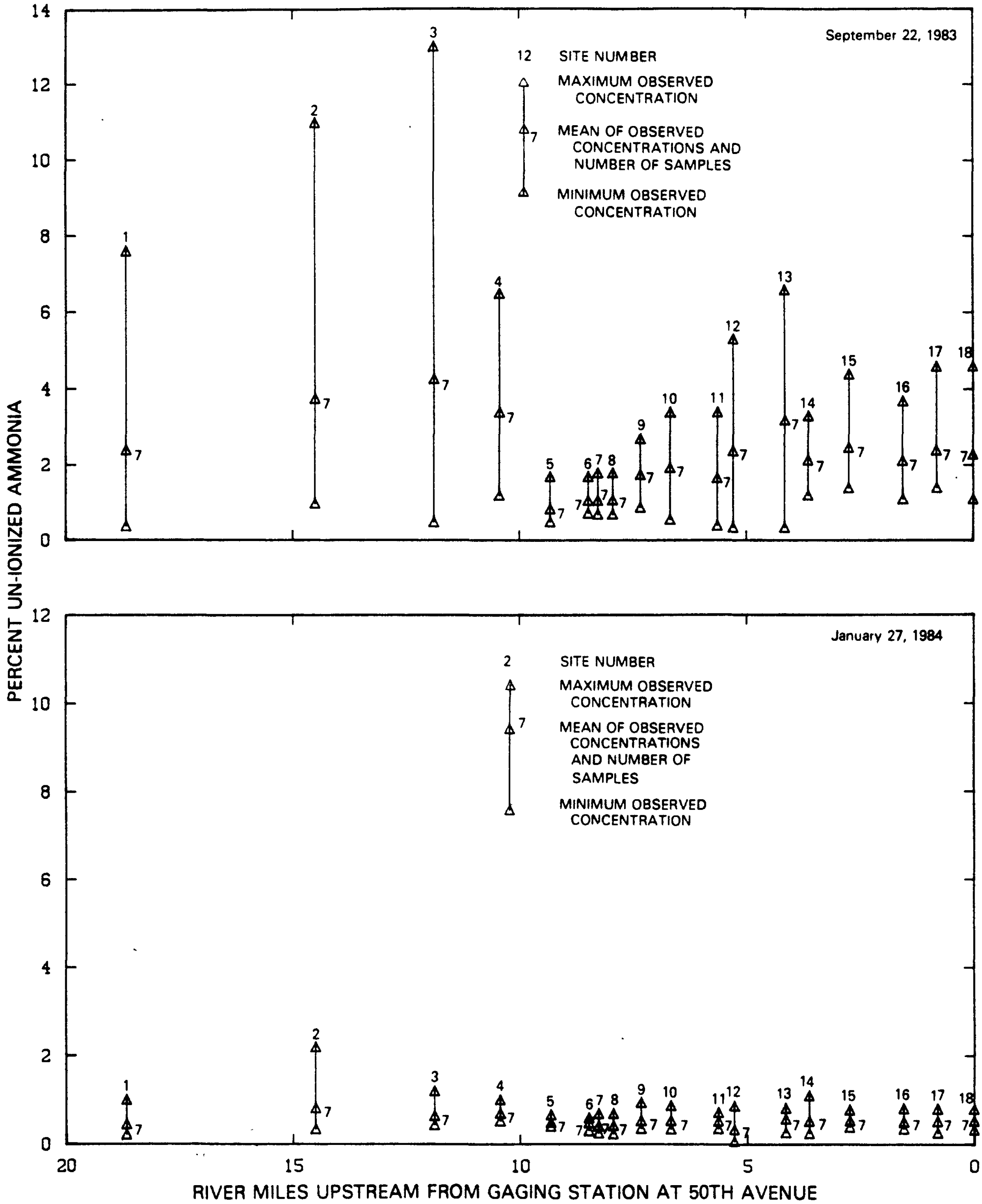

Figure 20.--Maximum, minimum, and mean percent un-ionized ammonia for the South Platte River.

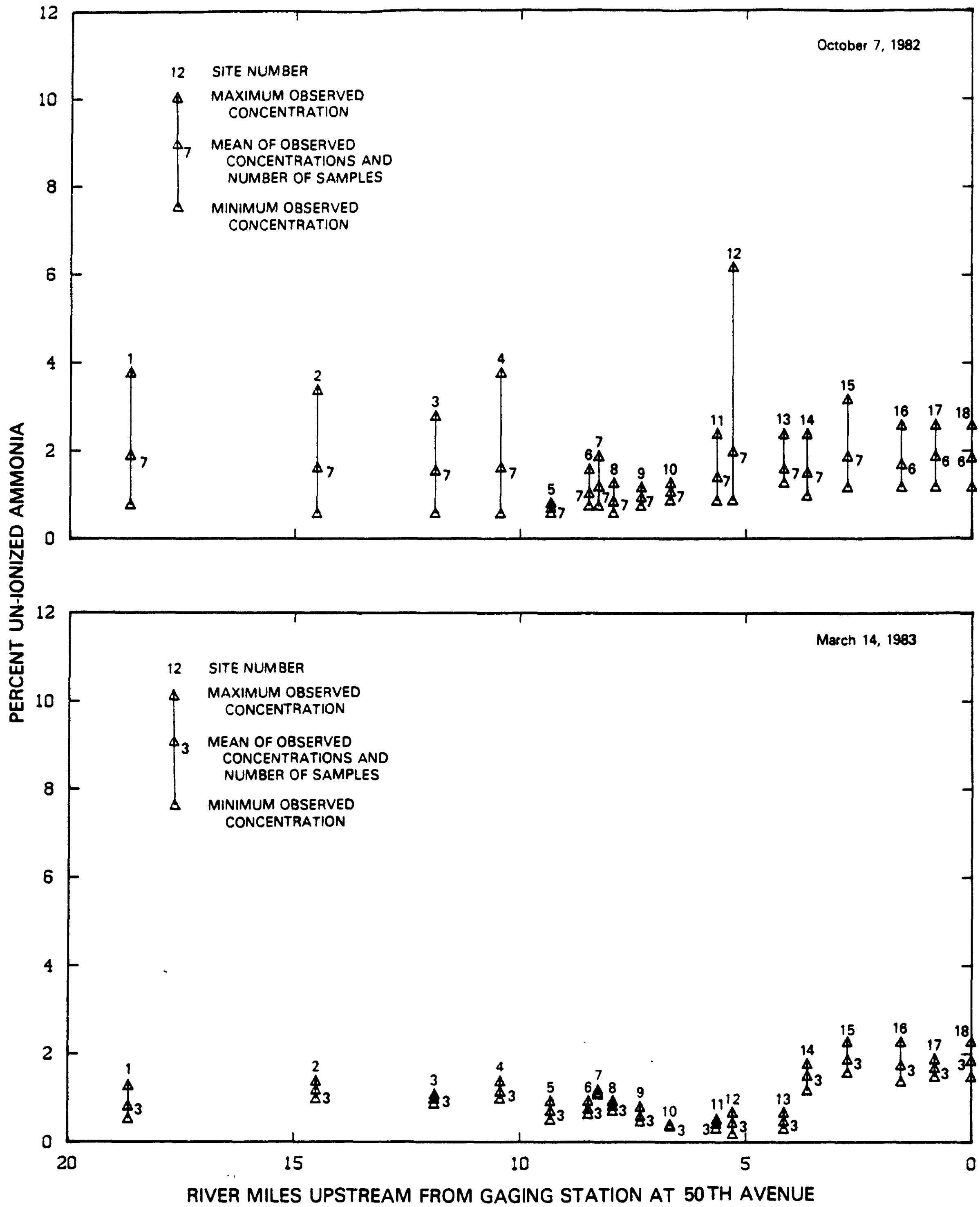

Figure 20.--Maximum, minimum, and mean percent un-ionized ammonia for the South Platte River--Continued.

were normally greater than field pH values during the October 1982 period. A higher pH will yield a larger concentration of un-ionized ammonia. A concentration of 0.068 mg/L was calculated for the site at the South Platte River at Denver (SP-1400); this site is downstream from the Lakewood Wastewater Treatment Plant outfall, which was discharging at that time.

The March 1983 24-hour data-collection period does not represent the complete diurnal cycle; field work was discontinued after approximately 12 hours because a storm created an unsteady-state flow condition. These data were not used in the model calibration or verification; however, these data were representative of the 12-hour period of data collection. The maximum concentration of un-ionized ammonia calculated during the March run was 0.072 mg/L at 1015 hours on March 14, 1983 at the South Platte River at 7th Street above Confluence Park (SP-1300).

Twenty-seven of the 146 calculated un-ionized-ammonia concentrations for the September 1983 (warm-water) period were greater than 0.10 mg/L. The maximum calculated concentration of un-ionized ammonia was 0.22 mg/L at 1940 hours on September 22, 1983 at the South Platte River above the 8th Avenue bridge (SP-1100A). During the January 1984 (cold-water) period, the maximum calculated un-ionized-ammonia concentration was 0.045 mg/L at the South Platte River at Florida Avenue (SP-600).

MODEL SIMULATIONS

The calibrated and verified model can be used to simulate how future changes in the quality and quantity of effluent from the Bi-City WWTP will affect the South Platte River. Values for the effluent quality and flow rates used in the simulations were provided by the steering committee, in agreement with the director of the Bi-City WWTP, and reflect anticipated future conditions.

7-Day, 10-Year Streamflow

Water-quality criteria guidelines are established for the streamflow condition of 7 consecutive days of low flow with a recurrence interval of 10 years (Q 7,10). The Q 7,10 for the streamflow-gaging station, South Platte River at Littleton (site 2, fig. 2) is 12.1 ft^3/s. The station is approximately 4 miles upstream from the outfall of the Bi-City WWTP. A new streamflow gaging station, South Platte River at Englewood, was installed 0.3 miles upstream from the outfall at site SP-400 (site 4, fig. 2) in December 1982. The Q 7,10 for the location of the new station will better describe the low-flow conditions for the establishment of water-quality guidelines for the Bi-City WWTP. However, a minimum of 10 years of record is necessary in order to accurately compute a Q 7,10. A Q 7,10 discharge was estimated for the Englewood station using a log-log relation between low-flow data at the new gaging station and low-flow data at the Littleton gage. From the relation and the value of 12.1 ft^3/s for Q 7,10 at the Littleton gage, the estimated Q 7,10 value for the Englewood gage is approximately 18 ft^3/s. As more data become available, a better relation between low flows at the two gages can be developed and a more accurate estimate for the Englewood Q 7,10 can be made.

Model simulations were made with a discharge of 18 ft^3/s at site SP-400 and with water-quality characteristics for the tributaries and other effluents as measured during September 1983 and January 1984. This discharge is approximately one-third of the discharge measured during the September 1983 and January 1984 data-collection periods. To achieve a discharge of 18 ft^3/s at site SP-400, all tributary flows were reduced by two-thirds. Flows of industrial effluents used in the simulations were the same as measured values. Assumed model streamflow for the warm-water (September) and cold-water (January) Q 7,10 conditions is shown in figure 21.

Because simulations were made at discharges smaller than discharges measured during the data-collection periods, adjustments were made to the physical characteristics of the model subreaches. Using the channel-geometry measurements made during the data-collection periods, stream widths were adjusted to the smaller flow conditions using the following equation:

$$\text{Width} = A \times \text{Discharge}^{B} \qquad (5)$$

where A and B are coefficients determined by drawing lines through log-log graphs of width versus discharge.

Limited data were available for the development of coefficients in equation 5, and extrapolation to lower flows was a necessary assumption for model simulations. Traveltime, depths, and reaeration rates were adjusted for the simulations using equations 1 through 3.

Concentrations of water-quality constituents for the tributaries and other inflows used in the simulations were those measured during the September 1983 and January 1984 data-collection periods. Water temperatures during the September 1983 period were about 16°C; water temperatures during the January 1984 period were about 6°C. The September and January average temperature at SP-200 (South Platte River at Littleton) is 17.5 and 3.5°C for the period 1970-1983. The September and January periods will be referred to as the warm- and cold-water conditions. The model then was run for the assumed warm- and cold-water Q 7,10 conditions. Computed concentrations for the modeled constituents for the warm- and cold-water temperature Q 7,10 conditions are shown in figures 22 and 23. Effluent discharge and constituent concentrations used were those measured during September 1983 and January 1984 for the Q 7,10 simulations shown in figures 22 and 23. Total nitrite-nitrogen concentrations are not shown in figure 23 because the model computed concentrations for total nitrite nitrogen during cold-water conditions are not verified.

Changes in Effluent Carbonaceous Biochemical Oxygen-Demand Concentrations

To simulate effects of changes in effluent CBOD concentrations on dissolved-oxygen concentrations downstream from the Bi-City WWTP plant, model runs were made with different effluent 5-day CBOD concentrations and effluent discharges. Simulations were made for both cold- and warm-water conditions. Constituent concentrations and volumes for the Bi-City WWTP effluent for each

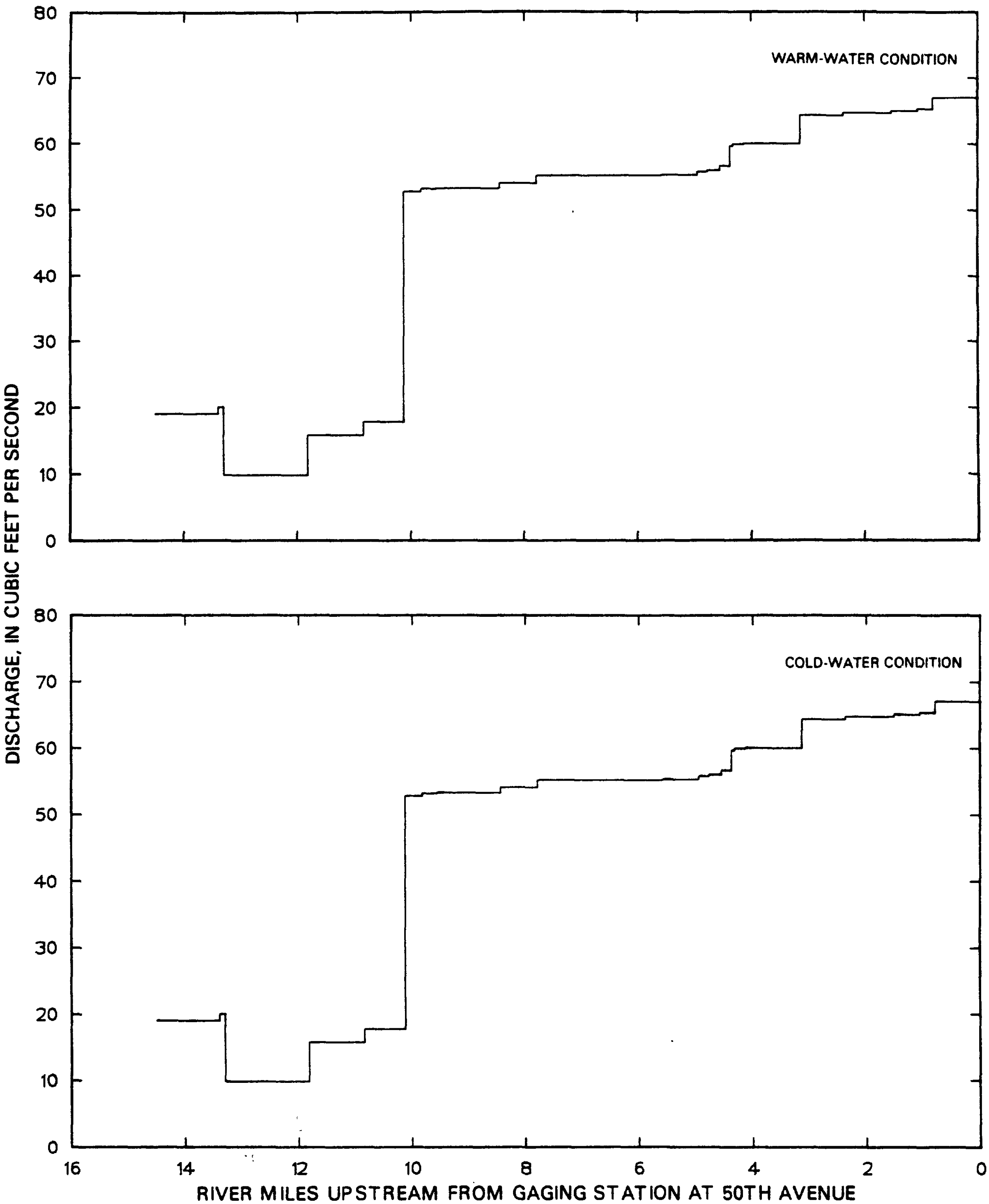

Figure 21.--Assumed model streamflow for the warm- and cold-water Q 7,10 condition.

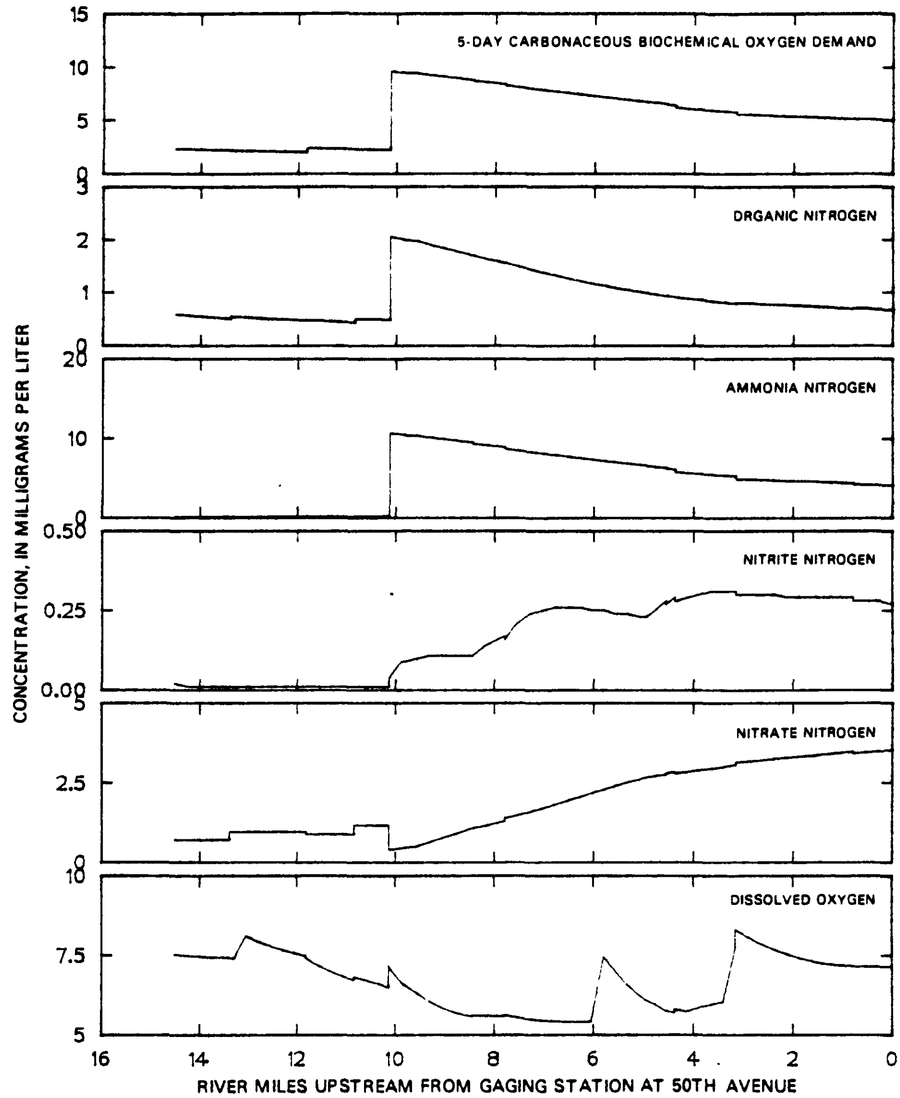

Figure 22.--Simulated concentrations for the modeled constituents for the warm-water Q 7,10 condition.

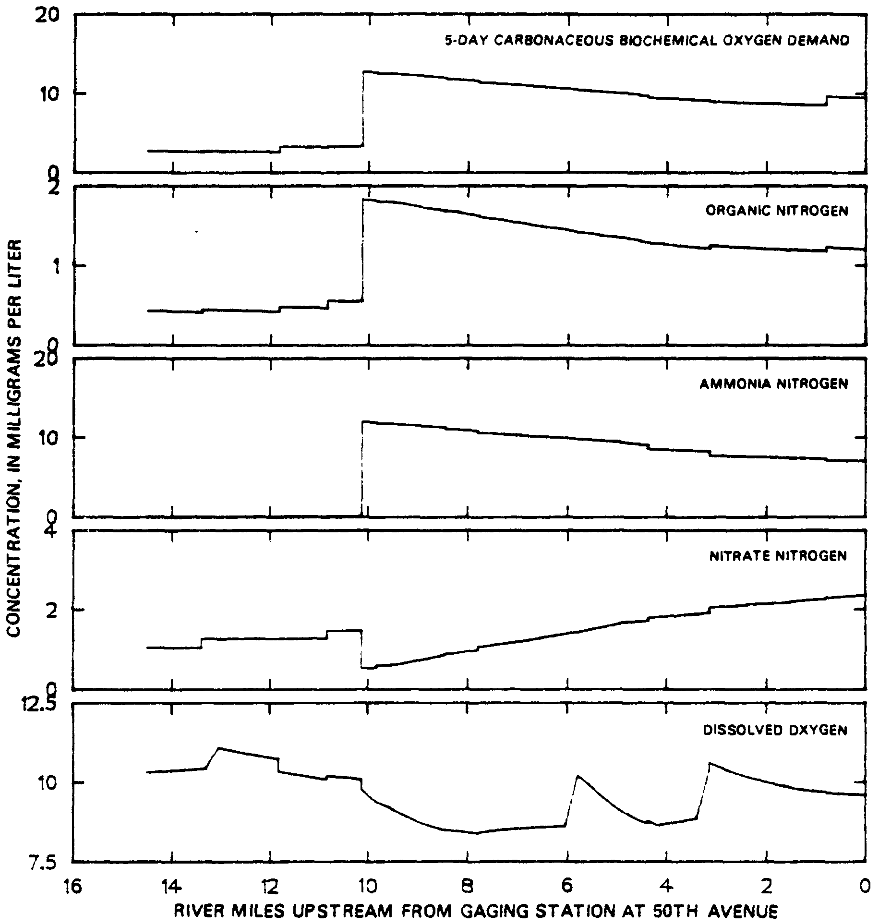

Figure 23.--Simulated concentrations for the modeled constituents for the cold-water Q 7,10 condition.

of the simulations are given in table 9. Concentrations shown in table 9 for the nitrogen species were based on values measured during the 24-hour data-collection efforts. Discharge and 5-day CBOD concentrations shown in table 9 were provided by the steering committee.

Table 9.--*Constituent concentrations for the Bi-City Wastewater Treatment Plant effluent for carbonaceous biochemical oxygen demand (CBOD) simulations*

[Mgal/d, million gallons per day; ft^3/s, cubic feet per second]

Discharge (Mgal/d)	Discharge (ft^3/s)	5-day CBOD	Total organic nitrogen	Total ammonia nitrogen	Total nitrite nitrogen	Total nitrate nitrogen
		(milligrams per liter)				
30	46.5	10	9.11	17.90	0.03	0.02
40	62.0	10	9.11	17.90	.03	.02
50	77.5	10	9.11	17.90	.03	.02
60	93.0	10	9.11	17.90	.03	.02
30	46.5	15	9.11	17.90	.03	.02
40	62.0	15	9.11	17.90	.03	.02
50	77.5	15	9.11	17.90	.03	.02
60	93.0	15	9.11	17.90	.03	.02
30	46.5	20	9.11	17.90	.03	.02
40	62.0	20	9.11	17.90	.03	.02
50	77.5	20	9.11	17.90	.03	.02
60	93.0	20	9.11	17.90	.03	.02
30	46.5	30	9.11	17.90	.03	.02
40	62.0	30	9.11	17.90	.03	.02
50	77.5	30	9.11	17.90	.03	.02
60	93.0	30	9.11	17.90	.03	.02

Simulations were made for warm- and cold-water conditions, using the values in table 9. Results of the 32 simulation model-runs are shown in figure 24. Minimum stream-reach dissolved-oxygen concentrations downstream from the Bi-City WWTP are shown as a function of effluent discharge and 5-day CBOD concentrations in figure 24. All minimum concentrations shown occurred 6.04 miles upstream from the gaging station at 50th Avenue. During the warm-water condition simulations, dissolved-oxygen concentrations were less than the standard of 5.0 mg/L for a 2.5-mile reach beginning 1.6 miles downstream from the Bi-City WWTP outfall. Decrease in dissolved-oxygen concentration of the South Platte River, as effluent 5-day CBOD concentration is increased, is shown in figure 24. For all 5-day CBOD concentrations, a slight increase in the minimum dissolved oxygen is seen as the volume of effluent is increased. This is a result of adjusting the reaeration coefficients of the South Platte River using equation 3, as more effluent is added to the system. As the reaeration coefficients are increased, they begin to offset oxygen consumption by the 5-day CBOD concentrations discharged.

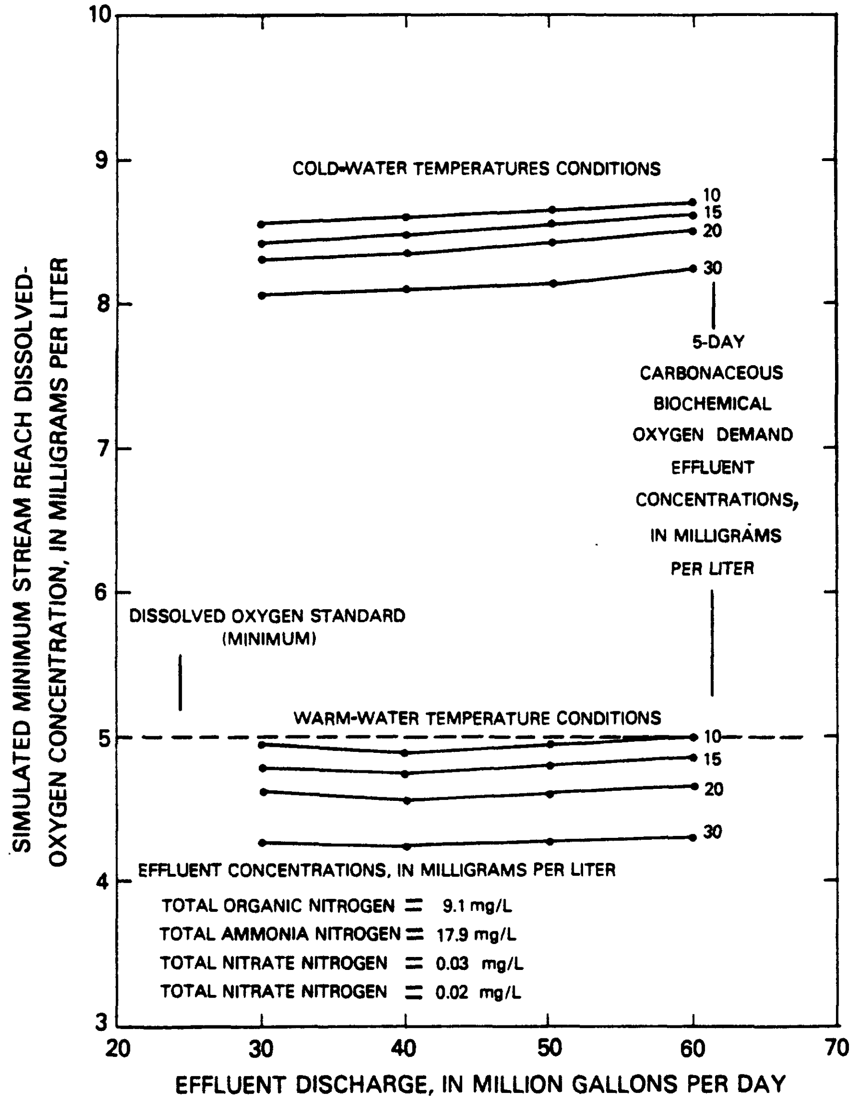

Figure 24.--Simulated minimum stream-reach dissolved-oxygen concentrations downstream from the Bi-City Wastewater Treatment Plant as a result of changes in effluent discharge and 5-day carbonaceous biochemical oxygen demand concentrations.

During the cold-water condition simulations, no dissolved-oxygen concentrations were less than the instream standard of 5.0 mg/L. The lines on figure 24 for 15 mg/L of 5-day CBOD concentrations approximate dissolved-oxygen conditions if nothing but the effluent volume increased in the future.

Simulations made for conditions given in table 9 also indicate future nitrogen levels downstream, as effluent volumes increase. Concentrations of maximum total ammonia-, total nitrite-, and total nitrate-nitrogen concentrations, as a result of changes in effluent discharge, are shown in table 10. During warm-water conditions, total nitrite-nitrogen concentrations may be greater than the standard of 0.5 mg/L when effluent volume is 40 Mgal/d. This is assuming current nitrogen-species concentration in the increased effluent discharges.

Table 10.--*Simulated maximum total ammonia-, total nitrite-, and total nitrate-nitrogen concentrations as a result of changes in effluent discharge*

[Mgal/d, million gallons per day; mg/L, milligrams per liter]

Effluent discharge (Mgal/d)	Concentration and river mile upstream from streamflow gaging station at 50th Avenue					
	total ammonia nitrogen		total nitrite nitrogen		total nitrate nitrogen	
	(mg/L)	(mile)	(mg/L)	(mile)	(mg/L)	(mile)
	Warm-water condition					
30	13.00	(10.1)	0.49	(3.1)	4.07	(0.0)
40	13.96	(10.1)	0.54	(3.1)	3.82	(0.0)
50	14.60	(10.1)	0.59	(1.1)	3.56	(0.0)
60	15.06	(10.1)	0.63	(0.8)	3.32	(0.0)
	Cold-water condition					
30	12.98	(10.1)	----	----	2.21	(0.0)
40	13.94	(10.1)	----	----	1.97	(0.0)
50	14.58	(10.1)	----	----	1.76	(0.0)
60	15.05	(10.1)	----	----	1.59	(0.0)

Decreases in the maximum concentration of total nitrate nitrogen is seen with increases in the effluent discharge in table 10; these decreases are caused by a decrease in traveltime through the model reach with the increase in discharge, which causes a reduction in the time during which nitrification can create total nitrate nitrogen. The stream standard for total nitrate nitrogen is 10.0 mg/L. This decrease in traveltime probably also is creating the change in river mileage at which the maximum total nitrite-nitrogen concentration is observed (table 10).

Changes in Effluent Nitrogen-Species Concentrations

To determine effects on the South Platte River caused by changes in the concentration levels of nitrogen species discharged by the Bi-City WWTP, simulations were made with different effluent concentrations of total ammonia nitrogen and total nitrate nitrogen. These simulations were suggested by the operator of the Bi-City WWTP and reflect different treatment alternatives available at the operational level of the treatment plant. Effluent discharge and nitrogen-species concentrations used in these simulations are listed in table 11. Simulations were run for both warm- and cold-water conditions.

Table 11.--*Constituent concentrations for the Bi-City Wastewater Treatment Plant effluent for nitrogen-species simulations*

[Mgal/d, million gallons per day; ft^3/s, cubic feet per second; CBOD, carbonaceous biochemical oxygen demand]

Discharge (Mgal/d)	Discharge (ft^3/s)	5-day CBOD	Total organic nitrogen	Total ammonia nitrogen	Total nitrite nitrogen	Total nitrate nitrogen
		(milligrams per liter)				
20	31.0	13.4	4.83	2.00	0.03	13.14
20	31.0	13.4	4.83	5.00	.03	10.14
20	31.0	13.4	4.83	10.00	.03	5.14
20	31.0	13.4	4.83	20.00	.03	0.00

Results of the simulations, using the effluent configurations in table 11, are shown in figures 25 and 26. Simulated concentrations of total ammonia, total nitrate, total nitrite, and dissolved oxygen for warm-water conditions are shown in figure 25 and for cold-water conditions in figure 26. Simulated results for total nitrite are not shown for cold-water conditions, because the model was not verified for total nitrite in cold water. As would be expected, the greater the percentage of total nitrogen in the ammonia form that is discharged, the greater the maximum total ammonia-nitrogen concentration in the South Platte River. In addition, the greater the percentage of total nitrogen in nitrate form in the effluent, the less oxygen is consumed by the nitrification process in the river downstream; thus the higher dissolved-oxygen concentrations are in the river.

Locations in the study reach at which maximum and minimum concentrations shown in figures 25 and 26 occur, vary with changes in effluent configuration. Corresponding river miles for the data shown in figures 25 and 26 are given in table 12.

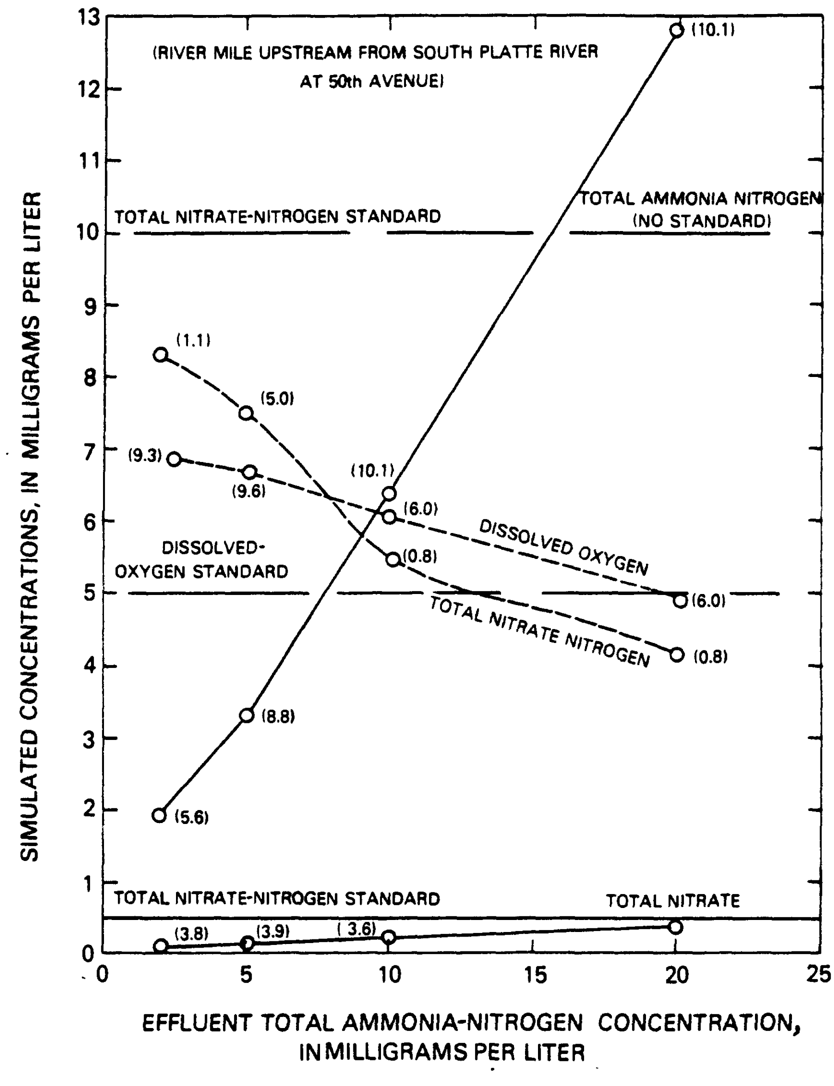

Figure 25.--Simulated warm-water condition maximum stream-reach total ammonia-, total nitrite-, and total nitrate-nitrogen concentrations, and minimum dissolved-oxygen concentrations, as a result of changes in effluent total ammonia-nitrogen concentrations. (Effluent discharge of 20 million gallons per day.)

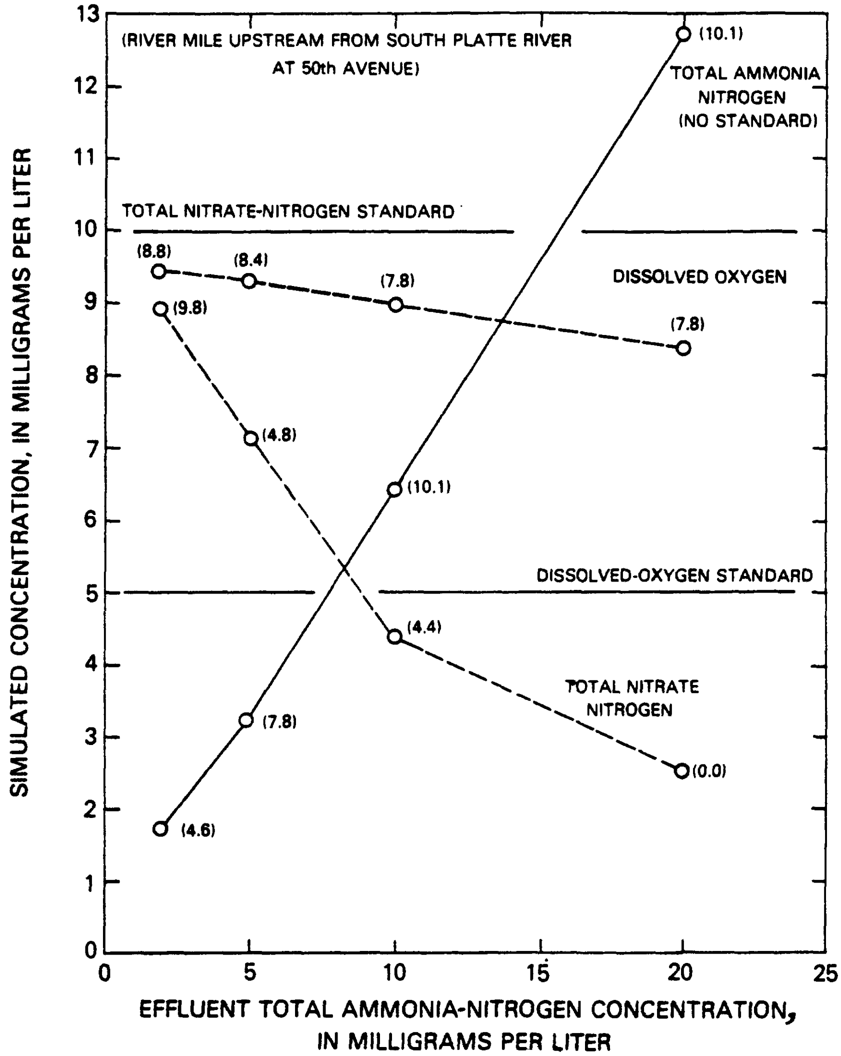

Figure 26.--Simulated cold-water condition maximum stream-reach total ammonia and total nitrate-nitrogen concentrations, and minimum dissolved-oxygen concentrations, as a result of changes in effluent total ammonia-nitrogen concentrations. (Effluent discharge of 20 million gallons per day.)

Table 12.--*Simulated maximum total ammonia-, total nitrite-, and total nitrate-nitrogen concentrations, and minimum dissolved-oxygen concentrations for the South Platte River as a result of changes in effluent total ammonia-nitrogen concentrations*

[NH_3, total ammonia; NO_3, total nitrate; mg/L, milligrams per liter]

Effluent concentration (mg/L) NH_3	Effluent concentration (mg/L) NO_3	Total ammonia nitrogen (mg/L)	Total ammonia nitrogen (miles)	Total nitrite nitrogen (mg/L)	Total nitrite nitrogen (miles)	Total nitrate nitrogen (mg/L)	Total nitrate nitrogen (miles)	Dissolved oxygen (mg/L)	Dissolved oxygen (miles)
		Concentration and river miles, at which concentration occurs, upstream from South Platte River at 50th Avenue (SP-1700)							
				Warm-water simulations					
2	13.14	1.9	(5.6-5.0)	0.1	(3.6-0.0)	8.3	(1.1)	6.9	(9.3)
5	10.14	3.3	(8.8-8.4)	0.1	(3.9-0.3)	7.6	(5.0)	6.7	(9.6-8.6)
10	5.14	6.4	(10.1)	0.2	(3.6-3.1)	5.4	(0.8)	6.1	(6.0
20	0.00	12.8	(10.1)	0.4	(3.4-3.1)	4.28	(0.8)	4.9	(6.5)
				Cold-water simulations					
2	13.14	1.8	(4.6)	Model not verified		8.9	(9.8-8.4)	9.5	(8.8-8.4)
5	10.14	3.2	(7.8)	Model not verified		7.1	(4.8)	9.3	(8.4-7.8)
10	5.14	6.4	(10.1)	Model not verified		4.4	(4.4)	9.0	(7.8)
20	0.00	12.8	(10.1)	Model not verified		2.6	(0.0)	8.47	(7.8)

Un-ionized Ammonia

The model used in this study does not simulate pH values needed to compute un-ionized-ammonia concentrations from simulated total ammonia-nitrogen concentrations. Therefore, a range in pH was used to calculate un-ionized-ammonia concentrations for the simulated conditions. The pH range was based on worst- and best-case conditions of pH depression created by effluent from the Bi-City WWTP, and on the best and worst rate of recovery of pH values. These conditions were based on data collected during the 24-hour data-collection periods, and on additional data collected by personnel of the Bi-City WWTP.

The best-case condition was the maximum-observed pH depression of 0.56 units, and the lowest rate of recovery of pH in a downstream direction of 0.04 pH units per river mile. The pH-depression value was based on data collected upstream from and downstream from the outfall of the Bi-City WWTP during the 24-hour data-collection periods. The rate of recovery was based on the minimum rate of change in pH values in a downstream direction observed during the 24-hour data-collection periods. These values are called best case, because they will produce the smallest calculated concentrations of un-ionized ammonia.

The worst-case condition was based on a pH depression of 0.10 units and a rate of recovery of 0.09 pH units per river mile. This pH depression was based on pH values measured above and below the Bi-City WWTP outfall on a weekly basis during the period, September 21, 1982, to May 6, 1984, by personnel of the Bi-City WWTP. The rate of recovery was based on the maximum rate of change in pH observed during the 24-hour data-collection periods. This condition is called the worst case, because high pH values will produce larger calculated concentrations of un-ionized ammonia.

Maximum and minimum rates of pH recovery were derived from the U.S. Geological Survey's 24-hour data-collection effort by taking the change in mean pH from site SP-500 to its maximum level downstream, then dividing by the distance in river miles between those two locations. The best- and worst-case pH values then were applied to upstream pH values measured during warm- and cold-water conditions at the Littleton gage; results are shown in table 13 for pH values at selected river miles upstream from the South Platte River at 50th Avenue.

Table 13.--*pH values at selected river miles from the South Platte River at 50th Avenue to the South Platte River at Dartmouth Avenue*

[Best-case, maximum pH depression (0.56 unit) and slowest recovery (0.04 unit per river mile); Worst-case, minimum pH depression (0.10 unit) and fastest recovery (0.09 unit per river mile)]

pH	River mile											
	10.44	9.32	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00	1.00	0.00
Warm-water condition												
Worst case	8.0	7.9	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Best case	8.0	7.4	7.5	7.5	7.6	7.6	7.6	7.7	7.7	7.7	7.8	7.8
Cold-water condition												
Worst case	7.9	7.9	7.8	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
Best case	7.9	7.3	7.4	7.4	7.4	7.5	7.5	7.5	7.6	7.6	7.6	7.7

Percent un-ionized ammonia values were computed for selected river-mile locations from the South Platte River at 50th Avenue (SP-1700) to the South Platte River at Dartmouth Avenue (SP-400), based on pH values in table 13 and on water temperatures measured during the September 1983 (warm-water condition) and January 1984 (cold-water condition) data-collection periods.

Dissolved-solids concentrations used in the calculations of percent un-ionized ammonia were simulated for Q 7,10 conditions as a conservative constituent in the model. These values ranged from 348 mg/L at SP-400 (South Platte River at Dartmouth Avenue) to about 630 mg/L at SP-1700 (South Platte River at 50th Avenue). Calculated values of percent un-ionized ammonia for selected river miles are listed in table 14.

Table 14.--*Percent un-ionized ammonia at selected river miles from the South Platte River at 50th Avenue to the South Platte River at Dartmouth Avenue*

[Best-case, maximum pH depression (0.56 unit) and slowest recovery (0.04 unit per river mile); Worst-case, minimum pH depression (0.10 unit) and fastest recovery (0.09 unit per river mile)]

pH	River mile											
	10.44	9.32	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00	1.00	0.00
	Warm-water condition											
Worst case	2.28	1.92	2.20	2.40	2.59	2.59	2.59	2.59	2.40	2.40	2.40	2.40
Best case	2.28	0.67	0.72	0.77	0.91	1.00	1.10	1.20	1.22	1.31	1.43	1.57
	Cold-water condition											
Worst case	0.66	0.72	0.82	0.90	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Best case	0.66	0.25	0.27	0.29	0.29	0.32	0.38	0.38	0.42	0.45	0.49	0.54

Percent un-ionized ammonia values given in table 14 allow for the determination of a range of un-ionized-ammonia concentrations for the groups of simulations discussed previously. Simulations made with the constituent concentrations given in table 9 were used to show differences in total ammonia-nitrogen concentrations with changes in effluent volume (table 10). Maximum calculated concentrations of un-ionized ammonia from simulated total ammonia-nitrogen concentrations for different effluent discharges are shown on figure 27. During warm-water conditions, both the best- and worst-case un-ionized-ammonia concentrations are larger than the water-quality standard of 0.1 mg/L for all effluent volumes. During cold-water conditions, it appears that for the best-case condition, un-ionized-ammonia concentrations may meet the standard for effluent volumes as large as 40 Mgal/d. As discussed previously, these simulations were made using current total ammonia-nitrogen concentrations in the effluent.

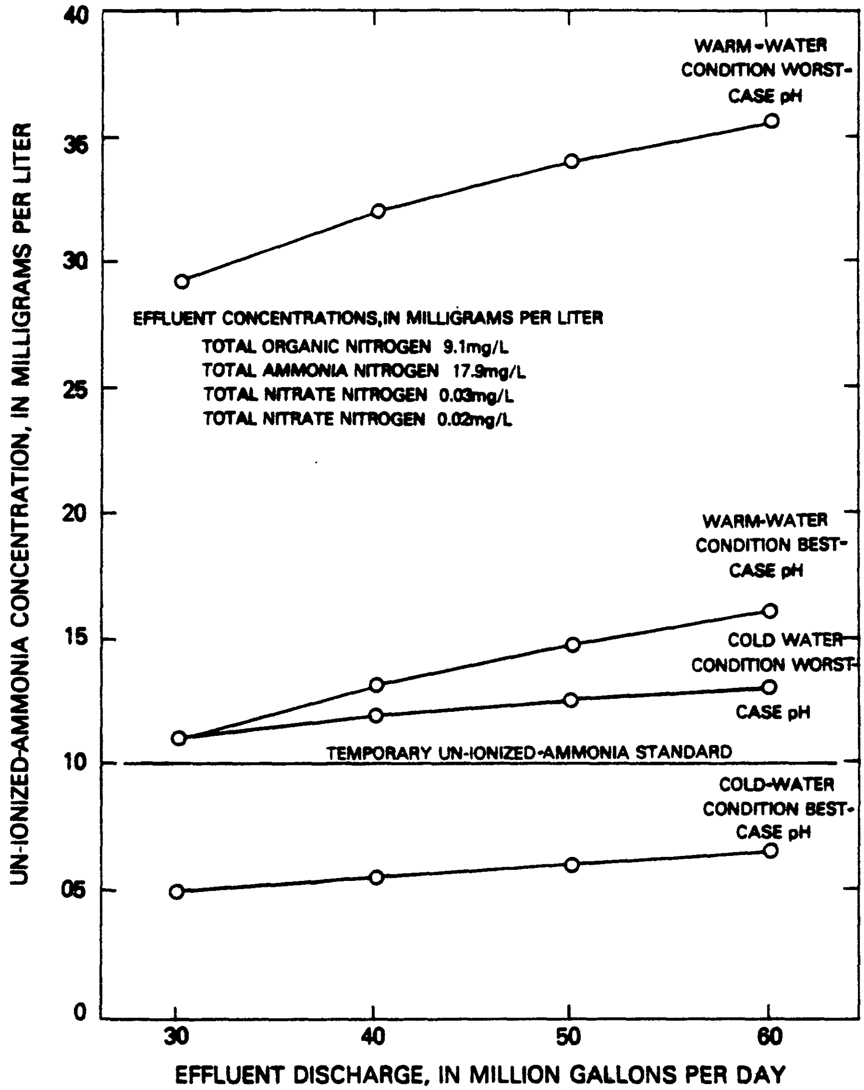

Figure 27.--Maximum calculated stream-reach un-ionized-ammonia concentrations as a result of changes in effluent discharge, pH, and water temperature.

Simulations also were made for changes in effluent total ammonia-nitrogen concentrations with current effluent discharge (table 11). These simulations represent different amounts of nitrification within the Bi-City WWTP. Maximum total ammonia-nitrogen concentrations for these simulations are given in figures 25 and 26. Maximum un-ionized-ammonia concentration ranges resulting from these simulations are shown in figure 28. For cold-water conditions, the worst-case un-ionized-ammonia concentrations are greater than the stream standard, when effluent total ammonia nitrogen is greater than 13 mg/L. Most of the range between best- and worst-case un-ionized-ammonia concentrations shown is less than the stream standard. The range of un-ionized-ammonia concentrations for the warm-water condition shows that more nitrification taking place within the plant (smaller total ammonia-nitrogen concentrations in the effluent) causes smaller un-ionized-ammonia concentrations downstream. Only a small percentage of the range between best- and worst-case un-ionized-ammonia concentrations is less than the stream standard.

MIXING ZONE

Beginning at the point where the Bi-City WWTP effluent enters the South Platte River, the effluent and the river water undergo a period of mixing. The length of river from the point of discharge downstream to the point of complete mixing is defined as the mixing zone. The downstream end of the mixing zone normally is the point at which instream water-quality guidelines must be met. Within the mixing zone, initial dilution and mixing of the effluent takes place, and standards assigned to the receiving water may not apply. During the October 1982, September 1983, and January 1984 flow-regulation periods, mixing-zone studies were completed to determine the extent of the mixing zone downstream from the Bi-City WWTP effluent.

Description of Mixing-Zone Study Reach

The mixing-zone study involved a reach of river from 0.32 miles upstream from the outfall of the Bi-City WWTP, to 0.80 miles downstream from the outfall. One upstream-measurement site was used to define background conditions of the South Platte River. Effluent from the Bi-City WWTP enters the South Platte River on the east bank 10.13 miles upstream from the South Platte River at 50th Avenue (SP-1700). The effluent enters the river in a pool with depths greater than 5 feet. This pool extends downstream for approximately 0.1 miles, where there is an abrupt change to a riffle. Depths within the riffle generally are less than 1 foot. This riffle extends approximately 0.6 miles to another pool. The pool downstream is not of the extent as the pool, where the effluent enters the river (fig. 29). Channel geometry characteristics measured during the October 1982 data collection are shown in figure 29.

Data Collection

Data collection for evaluation of the extent of the mixing zone consisted of continuously injecting a Rhodamine WT dye solution into the effluent, and subsequently measuring the dye concentrations at selected cross sections downstream. An upstream cross section also was measured for background

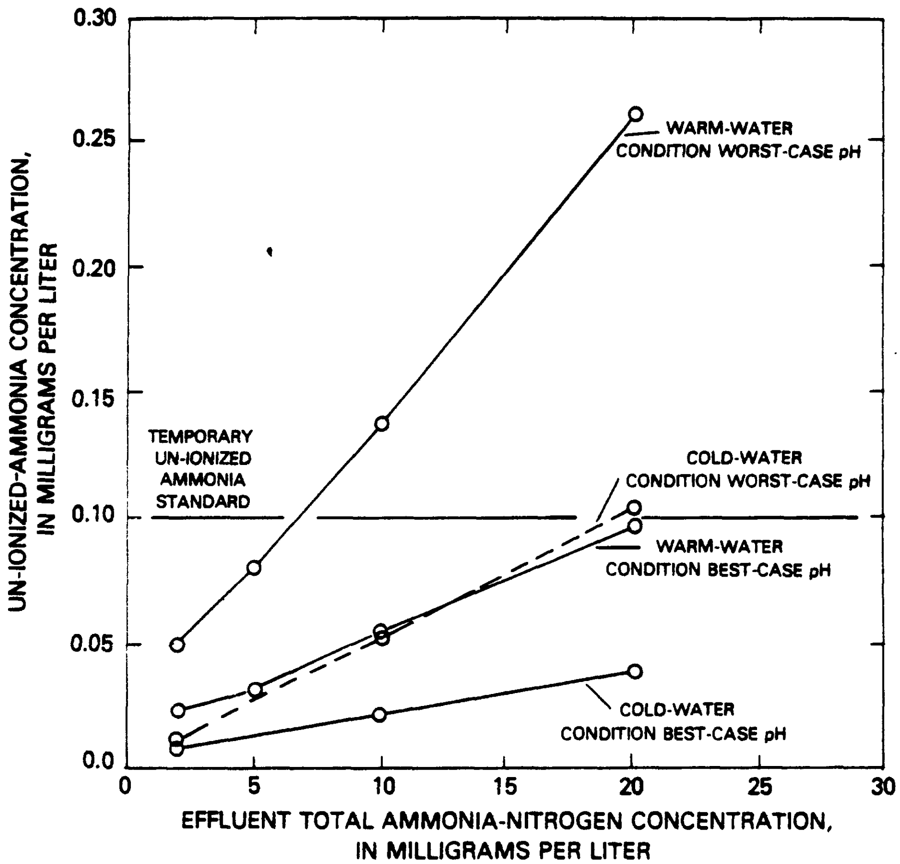

Figure 28.--Maximum calculated stream-reach un-ionized-ammonia concentrations as a result of changes in effluent total ammonia-nitrogen concentration, pH, and water temperature. (Effluent discharge of 20 million gallons per day.)

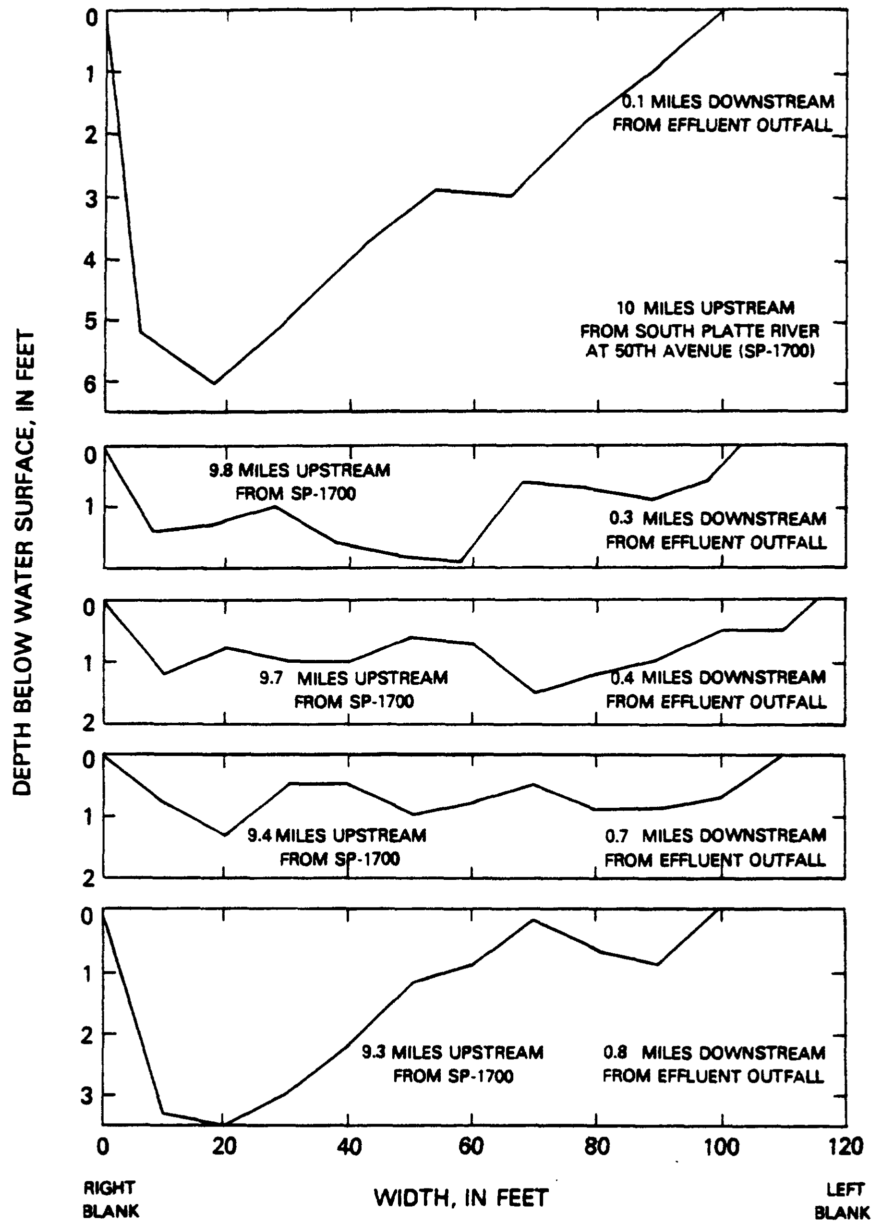

Figure 29.--Cross sections of selected mixing-zone measurement sites, October 1982.

concentrations. In addition to collection of samples for dye concentrations, field measurements of dissolved oxygen, pH, water temperature, and specific conductance were made, and samples were collected for the determination of total ammonia-nitrogen and residual-chlorine concentrations. Each cross section was divided into 8 equally spaced measurement verticals. Samples were collected and field measurements were made at mid-depth at each of the 8 verticals within the cross sections. Each vertical normally was measured at least twice during each data-collection period. Dye samples were collected and analyzed using standard fluorometric techniques (Wilson, 1968). Duplicate dye samples were taken, one for analysis in the field, and one for analysis at a common temperature in the office. All instruments used for pH and specific-conductance measurements were calibrated by using a common set of standards just prior to data collection.

Total ammonia-nitrogen samples were analyzed according to methods documented by Skougstad and others (1979) at the U.S. Geological Survey's central laboratory in Denver. Total residual-chlorine concentrations were determined onsite, using Fisher-Porter 17T2000 amperometric titrators[1]. Normal dechlorination procedures within the treatment plant were suspended during the data-collection periods. Effluent discharge was approximately 46 ft^3/s for all three data-collection periods.

During the October 1982 data-collection period, dye was injected into the effluent for approximately 3 hours. Discharge of the South Platte River upstream from the outfall was 140 ft^3/s. Six cross sections were measured downstream from the outfall and one was measured upstream from the outfall. The first cross section downstream from the outfall was located in a pool. Six-foot depths were measured in the pool, using a boat attached to a steel tagline. Because of the difficulty in launching the boat, this cross section was not measured during any of the subsequent data-collection periods.

Dye was injected for 4 hours during the September 1983 data-collection period. Five cross sections were measured downstream from the outfall and one was measured upstream from the outfall. These cross sections corresponded to those measured in October 1982, with the exception of the cross section in the pool. Discharge of the South Platte River upstream was 81 ft^3/s.

During the January 1984 data-collection period, dye was injected into the effluent for approximately 5 hours. Discharge of the South Platte River upstream from the outfall was 68 ft^3/s. Cross sections measured were at the same locations as those measured in September 1983, with one additional site located downstream from the pool, where a wading measurement was possible.

Extent of the Mixing Zone

Fully mixed conditions of the South Platte River and the effluent from the Bi-City WWTP were assumed to be present, if the difference in dye concen-

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[1]Use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

trations between any two verticals (within one cross section) was not greater than 10 percent. Dye concentrations measured during the three mixing-zone studies are shown in figures 30, 31, and 32. During the October 1982 study, a fully mixed condition was not observed at any of the cross sections. The farthest downstream cross section (0.8 mile) had a maximum difference in concentrations of 24 percent between verticals (fig. 30). As river discharge upstream from the outfall decreased, the distance required to achieve a fully mixed condition decreased (shorter mixing zone) as is shown in figures 31 and 32. The September 1983 and January 1984 studies showed a fully mixed condition 0.7 mile downstream from the outfall. The measured cross section farthest downstream was about 0.1 mile upstream from the bridge at Evans Avenue. Although the length of the mixing zone is a dynamic characteristic, it was concluded that for low-flow conditions, Evans Avenue (0.8 mile downstream from the outfall) generally would be the downstream extent of the mixing zone.

Total ammonia-nitrogen concentrations measured during the three mixing-zone studies are shown in figures 33, 34, and 35. The same type of spatial distribution of concentrations is seen in these figures as for the dye concentrations.

The influence of Harvard Gulch (0.55 river mile downstream from the outfall) diluting dye concentrations along the right bank during the September 1983 and January 1984 periods is seen in figures 31 and 32. This effect also is observed in total ammonia-nitrogen concentrations in figure 34. The change in percent difference of concentrations in the mixing zone for the three measurements is shown in figure 36. The increase in percent difference of concentrations in the total ammonia-nitrogen curve during the September 1983 period probably is the result of dilution of the sample collected near Harvard Gulch; this dilution probably created a larger percent difference in that one cross section.

Un-ionized Ammonia

Un-ionized-ammonia concentrations were computed, using Skarheim's (1973) method, for each sample collected in the mixing zone. Because the dissolved-solids (DS) concentrations necessary for the un-ionized-ammonia computations were not determined for samples collected in the mixing zone, these values were calculated, using specific conductance and a regression relation developed from data collected during the four 24-hour runs at sites SP-400 and SP-500. The regression equation is:

$$DS = (0.583 \times SC) + 21 \qquad (6)$$

where DS = dissolved-solids concentration, in milligrams per liter;
SC = specific conductance, in microsiemens per centimenter.

Equation 6 was developed from 49 observations, and has an R-squared value of 0.94. The standard error of estimate of equation 6 is 25.05.

Calculated concentrations of un-ionized ammonia in the mixing zone during the three mixing-zone measurements are shown in figures 37, 38, and 39. The Bi-City Wastewater Treatment Plant outfall is located at 0.0 mile. The data

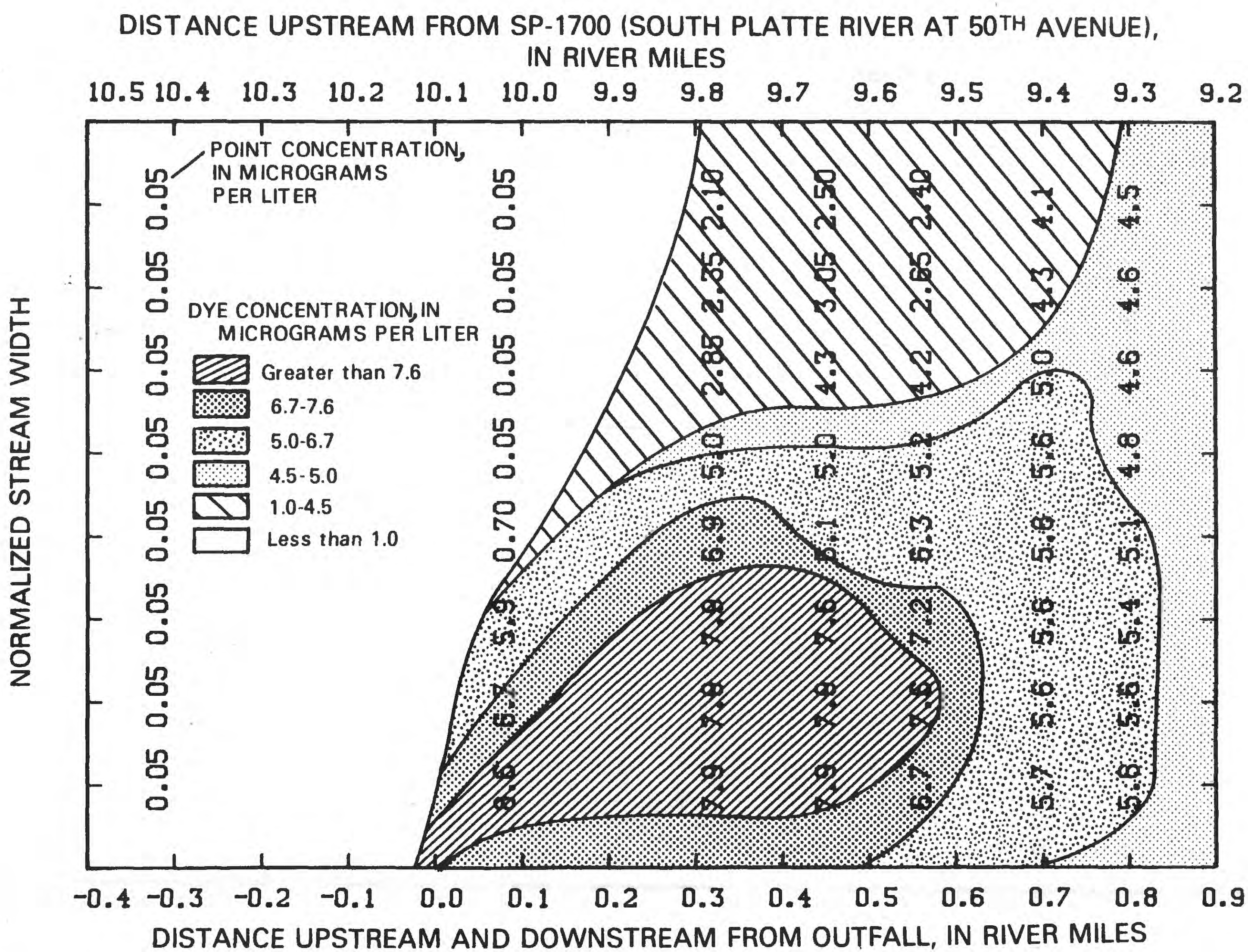

Figure 30.--Dye concentrations in mixing zone during injection of dye into effluent from Bi-City Wastewater Treatment Plant on October 6, 1982. (Discharge of the South Platte River upstream from the mixing zone was 140 cubic feet per second.)

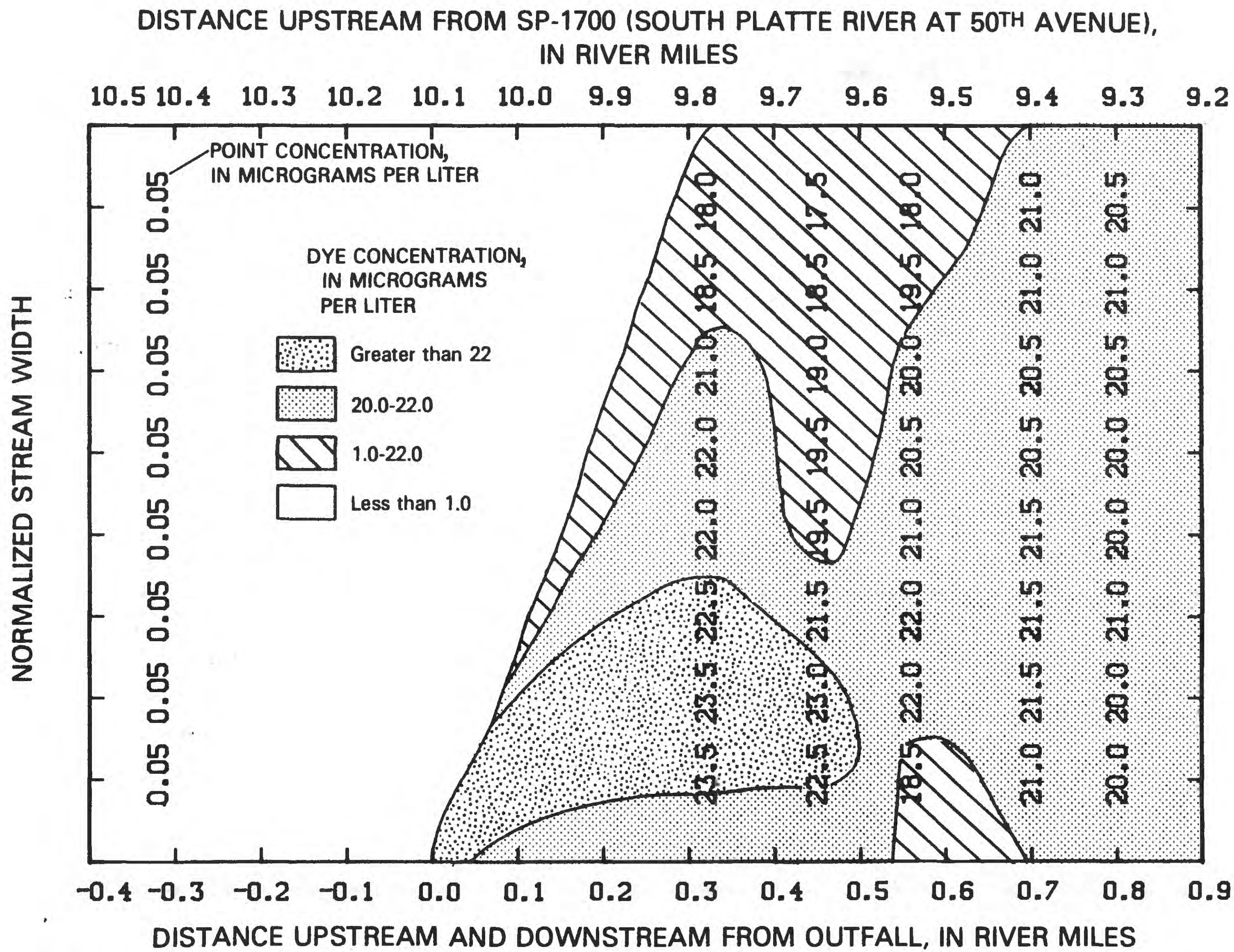

Figure 31.--Dye concentrations in mixing zone during injection of dye into effluent from Bi-City Wastewater Treatment Plant on September 21, 1983. (Discharge in the South Platte River upstream from the mixing zone was 81 cubic feet per second.)

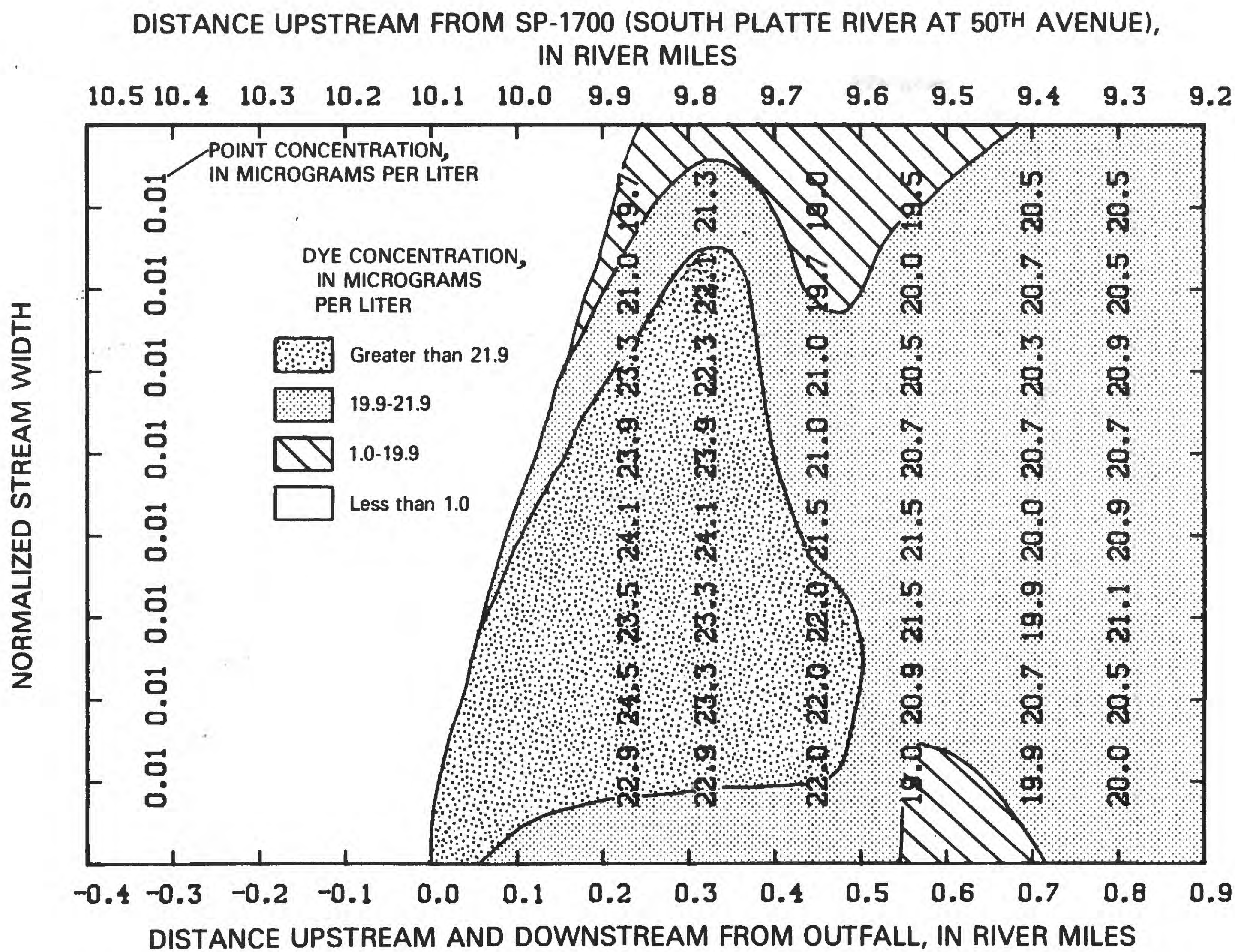

Figure 32.--Dye concentrations in mixing zone during injection of dye into effluent from Bi-City Wastewater Treatment Plant on January 25, 1984. (Discharge in the South Platte River upstream from the mixing zone was 68 cubic feet per second.)

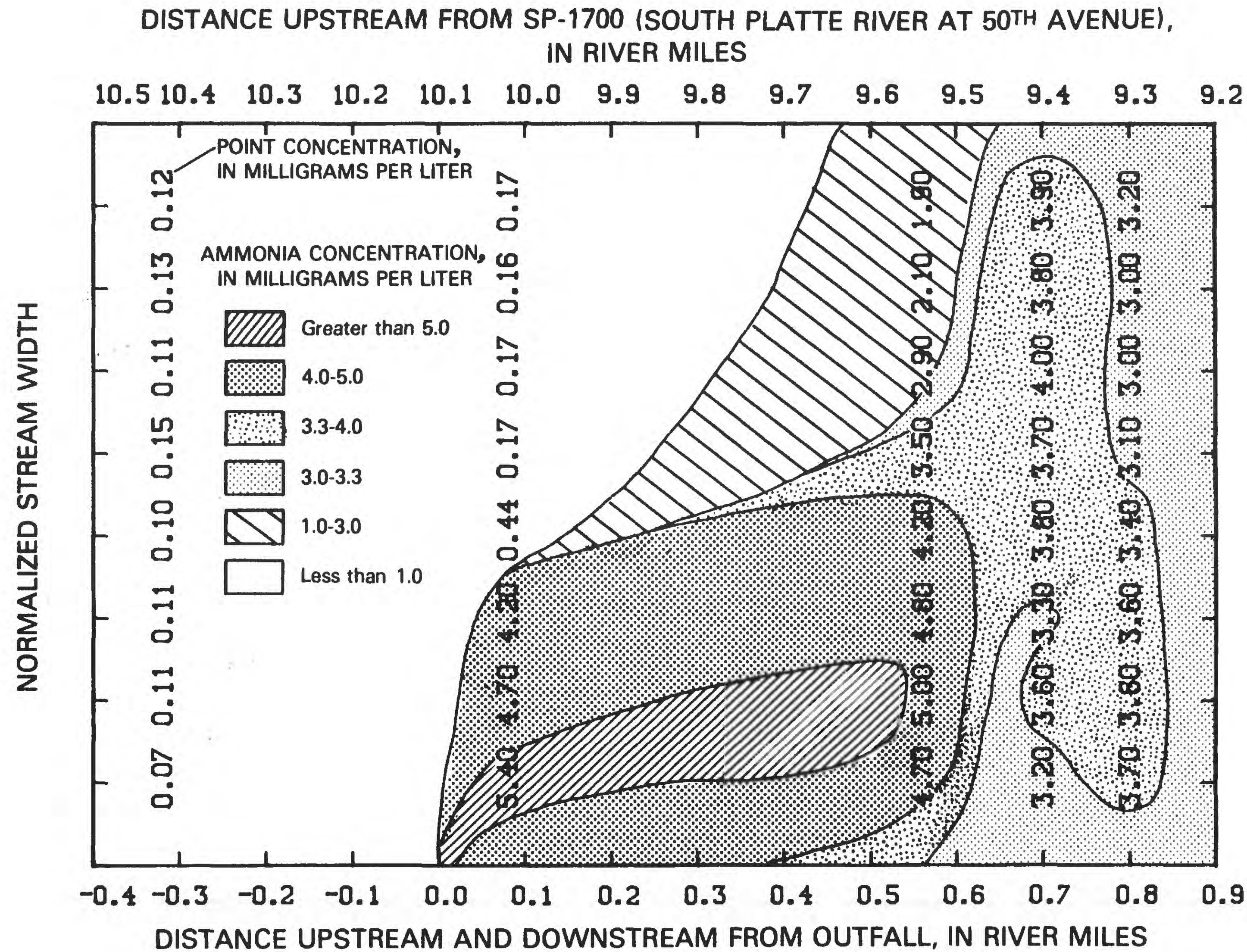

Figure 33.--Total ammonia-nitrogen concentrations in mixing zone during injection of dye into effluent from Bi-City Wastewater Treatment Plant on October 6, 1982. (Discharge of the South Platte River upstream from the mixing zone was 140 cubic feet per second.)

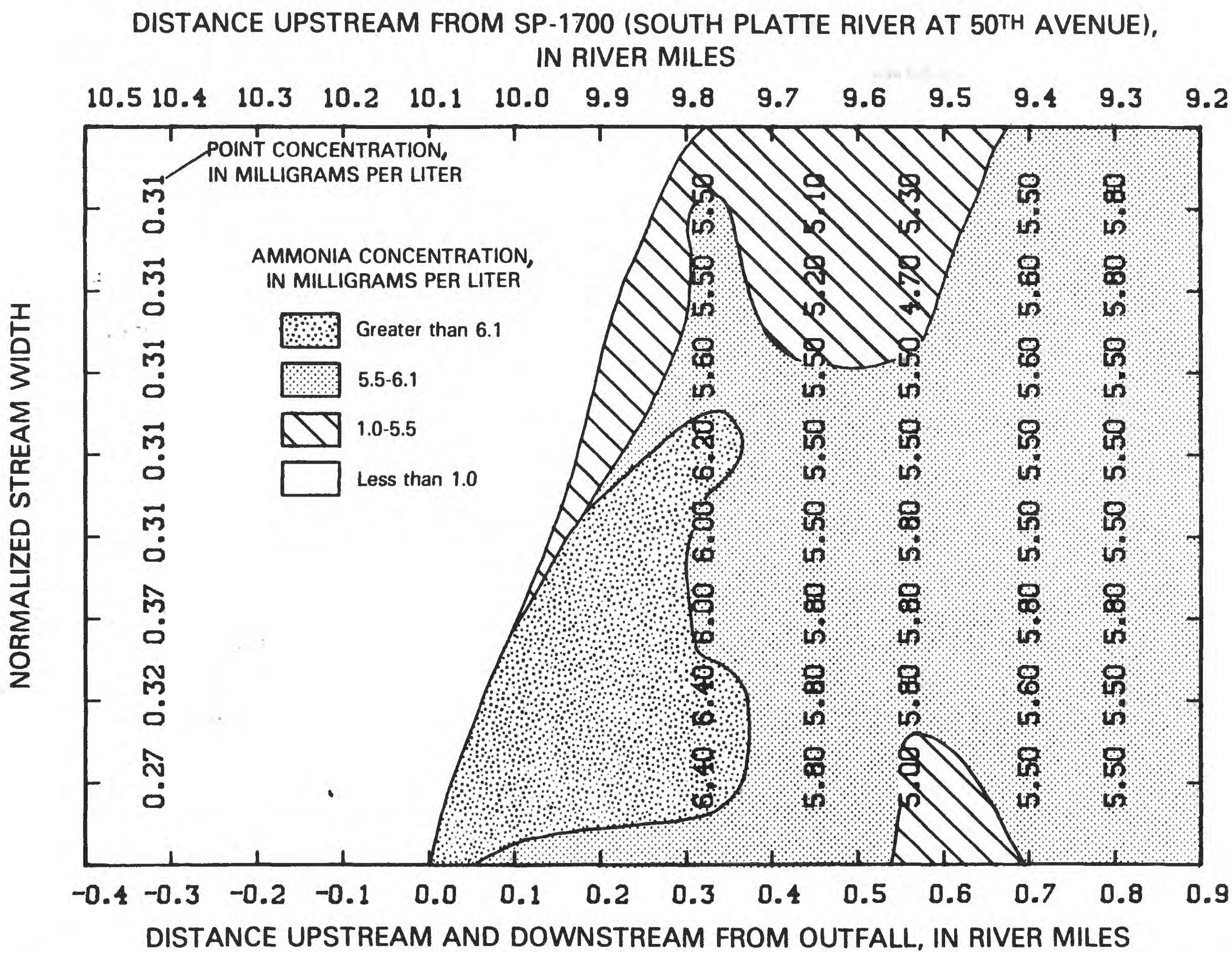

Figure 34.--Total ammonia-nitrogen concentrations in mixing zone during injection of dye into effluent from Bi-City Wastewater Treatment Plant on September 21, 1983. (Discharge in the South Platte River upstream from the mixing zone was 81 cubic feet per second.)

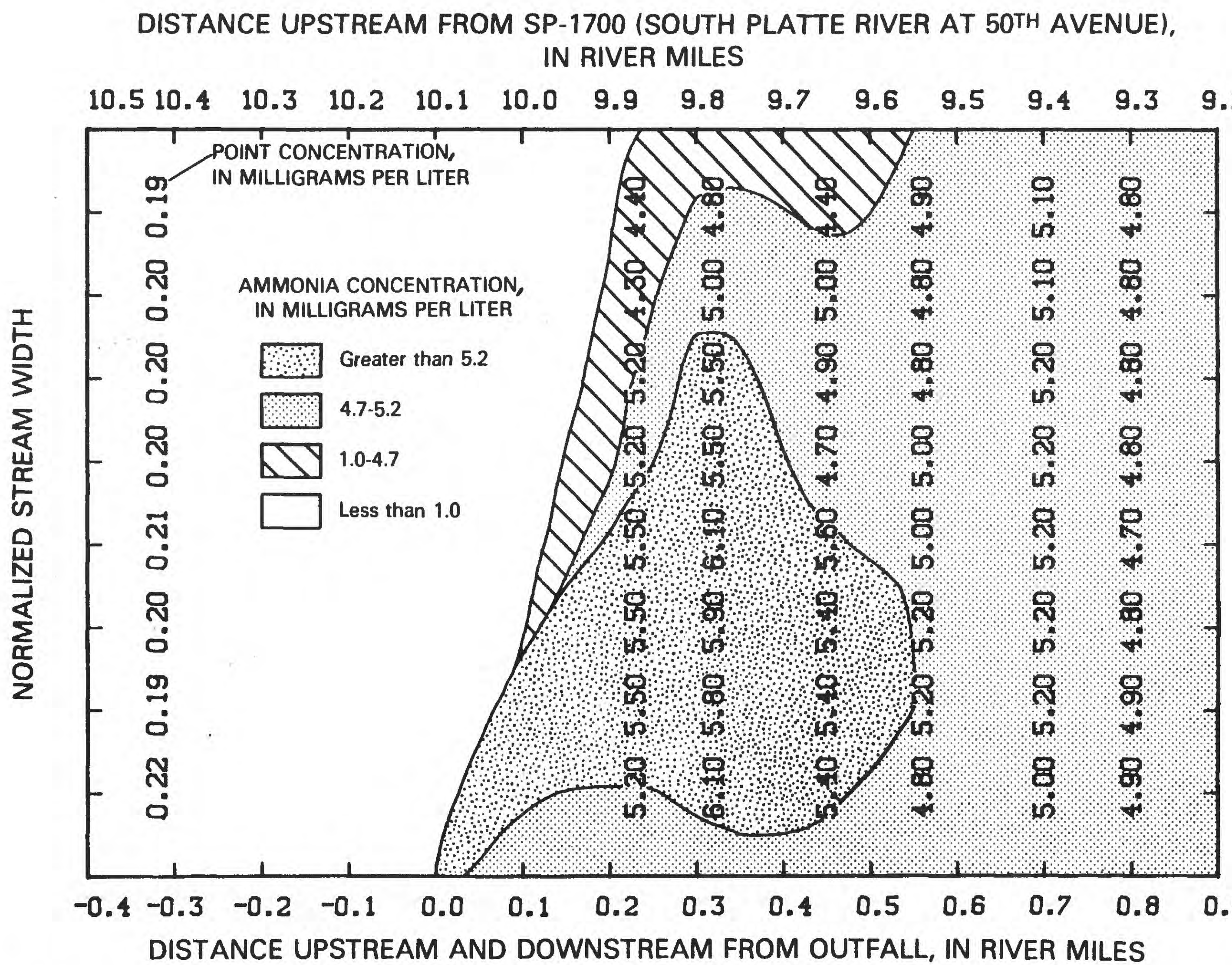

Figure 35.--Total ammonia-nitrogen concentrations in mixing zone during injection of dye into effluent from Bi-City Wastewater Treatment Plant on January 25, 1984. (Discharge in the South Platte River upstream from the mixing zone was 68 cubic feet per second.)

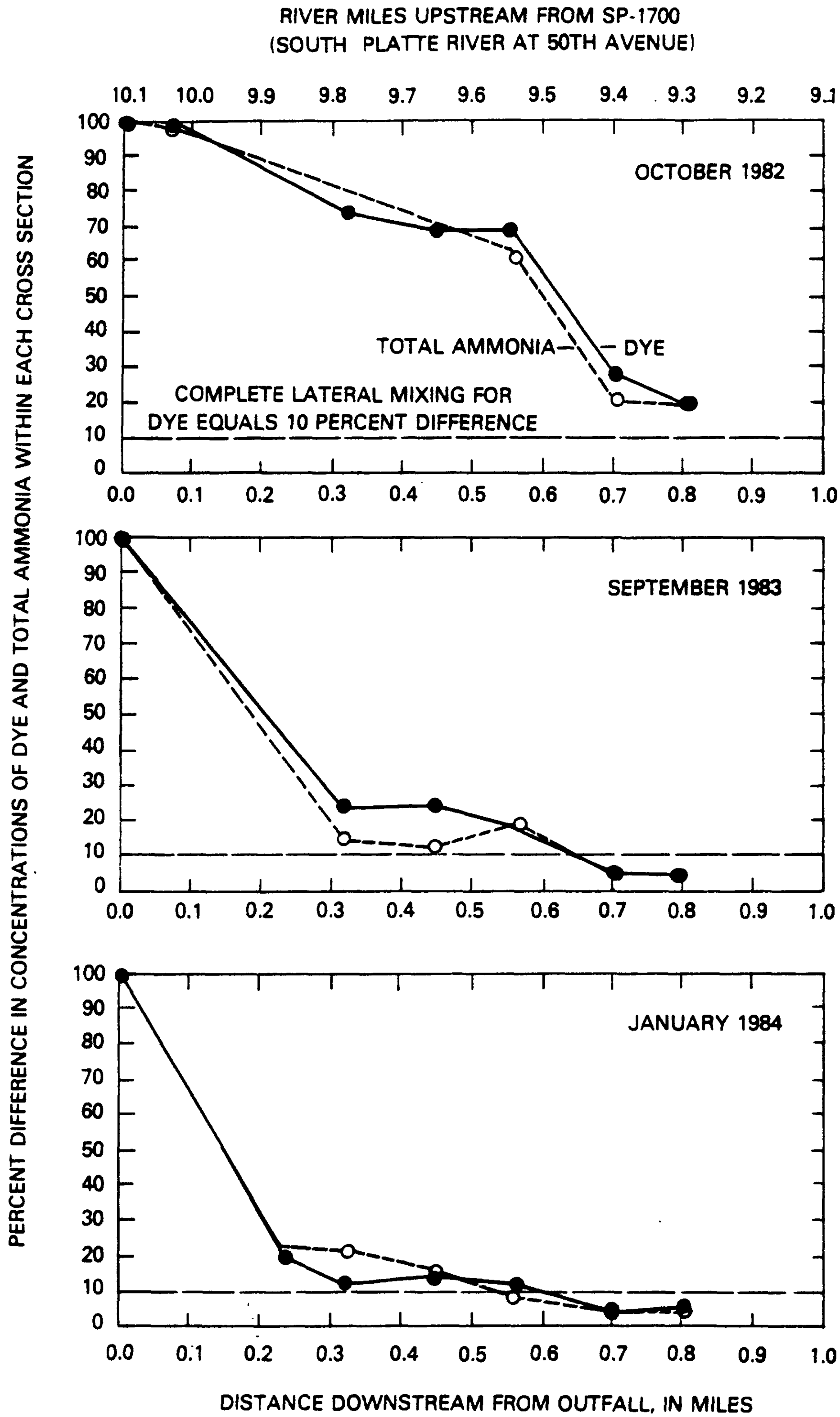

Figure 36.--Percent difference in concentrations of dye and total ammonia nitrogen within each cross section during the three mixing-zone measurements of October 1982, September 1983, and January 1984.

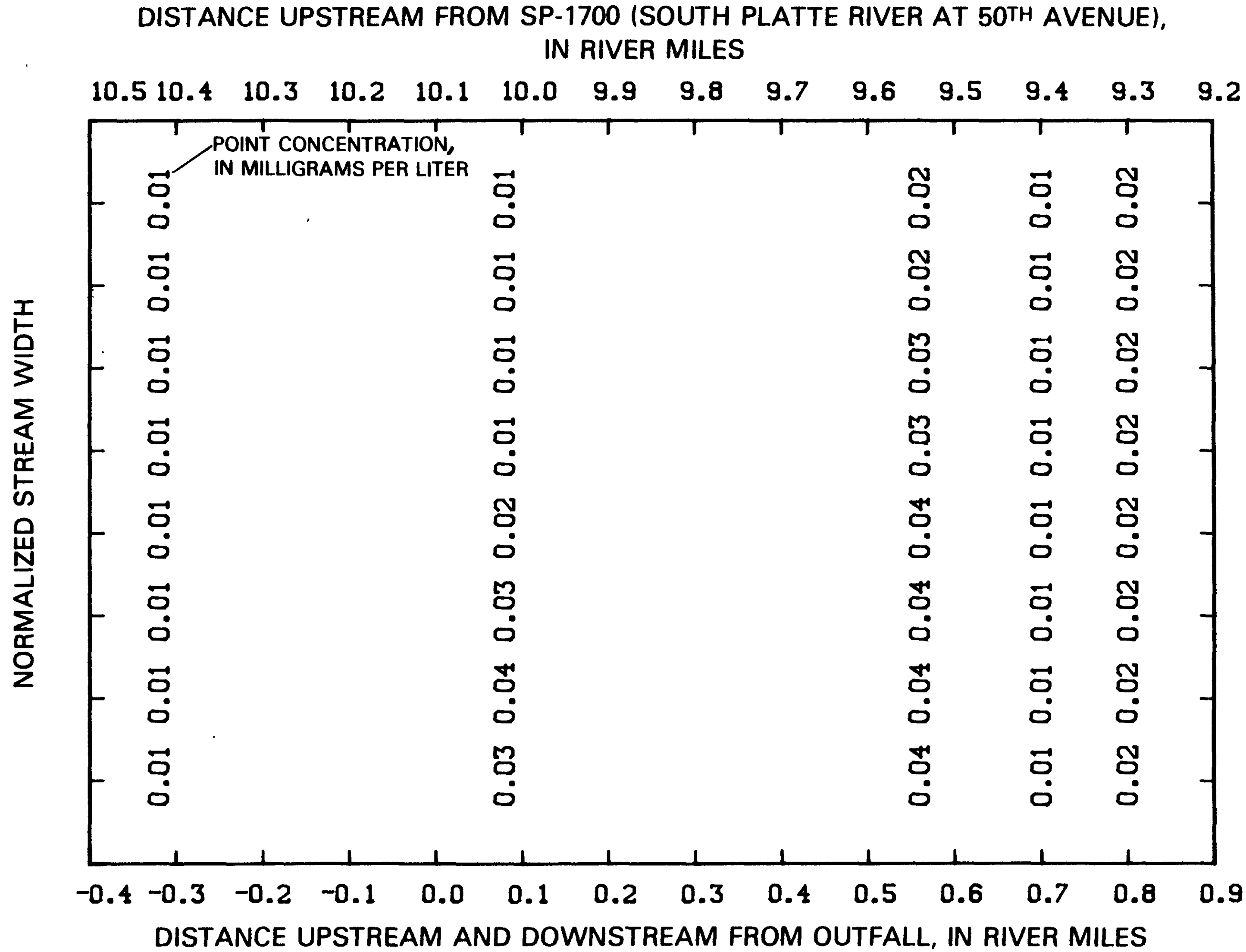

Figure 37.--Un-ionized-ammonia concentrations in mixing zone on October 6, 1982. (Discharge of the South Platte River upstream from the mixing zone was 140 cubic feet per second.)

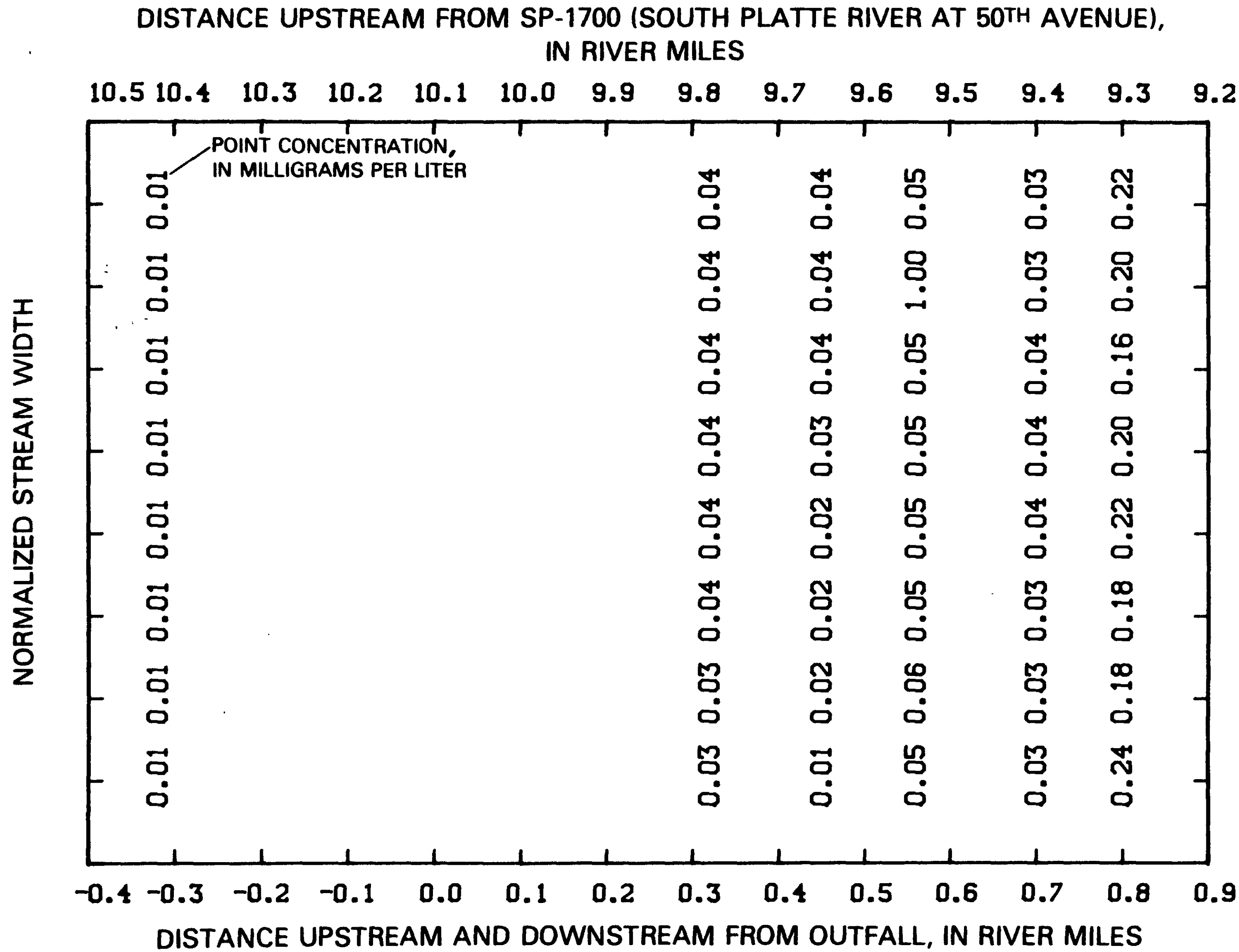

Figure 38.--Un-ionized-ammonia concentrations in mixing zone on September 21, 1983. (Discharge in the South Platte River upstream from the mixing zone was 81 cubic feet per second.)

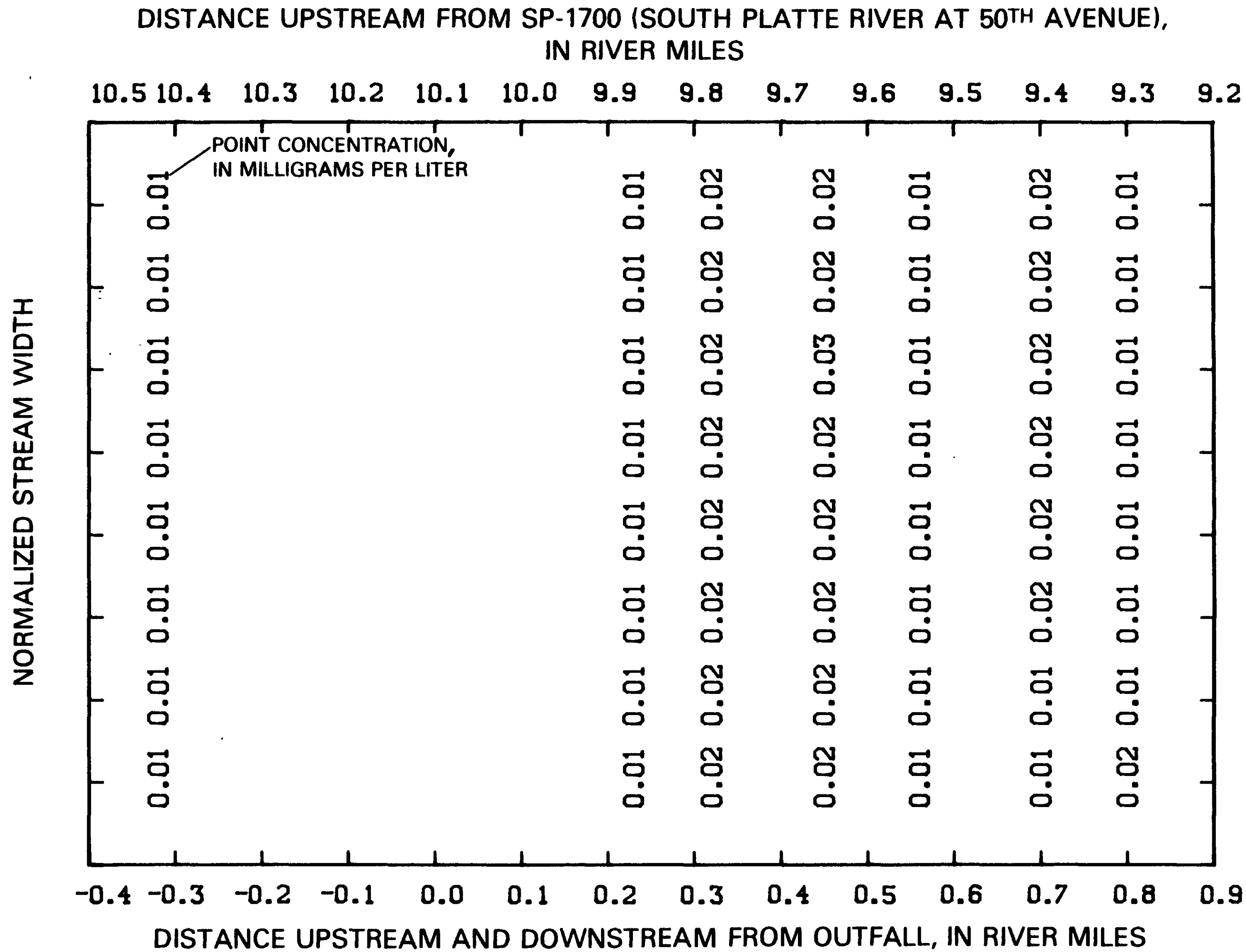

Figure 39.--Un-ionized-ammonia concentrations in mixing zone on January 25, 1984. (Discharge in the South Platte River upstream from the mixing zone was 68 cubic feet per second.)

indicate that the un-ionized-ammonia concentrations downstream from the treatment plant outfall exhibit two distinct minimums before coming to an equilibrium concentration larger than the ambient concentration. This is due primarily to a similar increase and decrease in pH downstream from the outfall. pH values for each mixing zone measurement are given in table 15. Figure 40 shows the changes in pH with distance downstream from the treatment plant outfall.

Table 15.--*Observed pH values during the three mixing-zone measurements*

Distance from outfall (miles)	Cross-section pH values at equally spaced verticals							
	A (left bank)	B	C	D	E	F	G	H (right bank)
				October 6, 1982				
[1]-0.35	7.9	7.9	7.9	8.0	7.9	7.9	7.9	7.9
0.08	7.3	7.5	7.5	8.2	8.4	8.4	8.4	8.4
0.56	7.5	7.5	7.5	7.5	7.5	7.6	7.6	7.7
0.70	6.8	6.8	6.8	7.0	7.1	7.1	7.1	7.2
0.80	7.3	7.3	7.3	7.4	7.4	7.4	7.4	7.4
				September 21,1983				
-0.32	7.1	7.7	7.8	7.8	7.9	7.8	7.8	7.8
0.32	7.1	7.2	7.3	7.4	7.4	7.4	7.4	7.4
0.45	6.8	6.8	6.9	6.9	7.1	7.1	7.2	7.4
0.56	7.2	7.6	7.5	7.5	7.5	7.5	7.5	7.6
0.70	7.2	7.2	7.2	7.3	7.3	7.3	7.3	7.2
0.80	8.2	8.0	8.0	8.1	8.1	8.0	8.1	8.2
				January 25, 1984				
-0.32	7.6	7.4	7.6	7.7	7.8	7.8	7.6	7.6
0.23	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
0.32	7.2	7.3	7.3	7.4	7.4	7.4	7.4	7.4
0.45	7.5	7.4	7.4	7.5	7.5	7.6	7.6	7.6
0.56	7.1	7.0	7.0	7.1	7.0	7.1	7.0	7.1
0.70	7.3	7.3	7.4	7.4	7.4	7.4	7.4	7.4
0.80	7.4	7.2	7.3	7.3	7.4	7.4	7.4	7.4

[1]Negative distance represents location upstream from outfall.

The first decrease in river pH was a dilution effect, because the river pH upstream of the outfall was about 8, the effluent pH was less than 7, and the effluent discharge was approximately one-half of the river discharge just upstream from the outfall (fig. 40). Farther downstream the river pH begins to increase, as the system degasses carbon dioxide (CO_2). Effluent CO_2 level has been estimated to be as much as 74 times the saturation concentration, and the CO_2 level in the river upstream from the effluent has been estimated to be at nearly 5 times saturation level (W. F. Owens, Bi-City WWTP, written commun., 1984). These estimated concentrations were 89 and 6.9 mg/L, respectively. This degassing of river and effluent water mixtures has also been verified in a related mixing study by W. F. Owens (Bi-City WWTP, written commun., 1984).

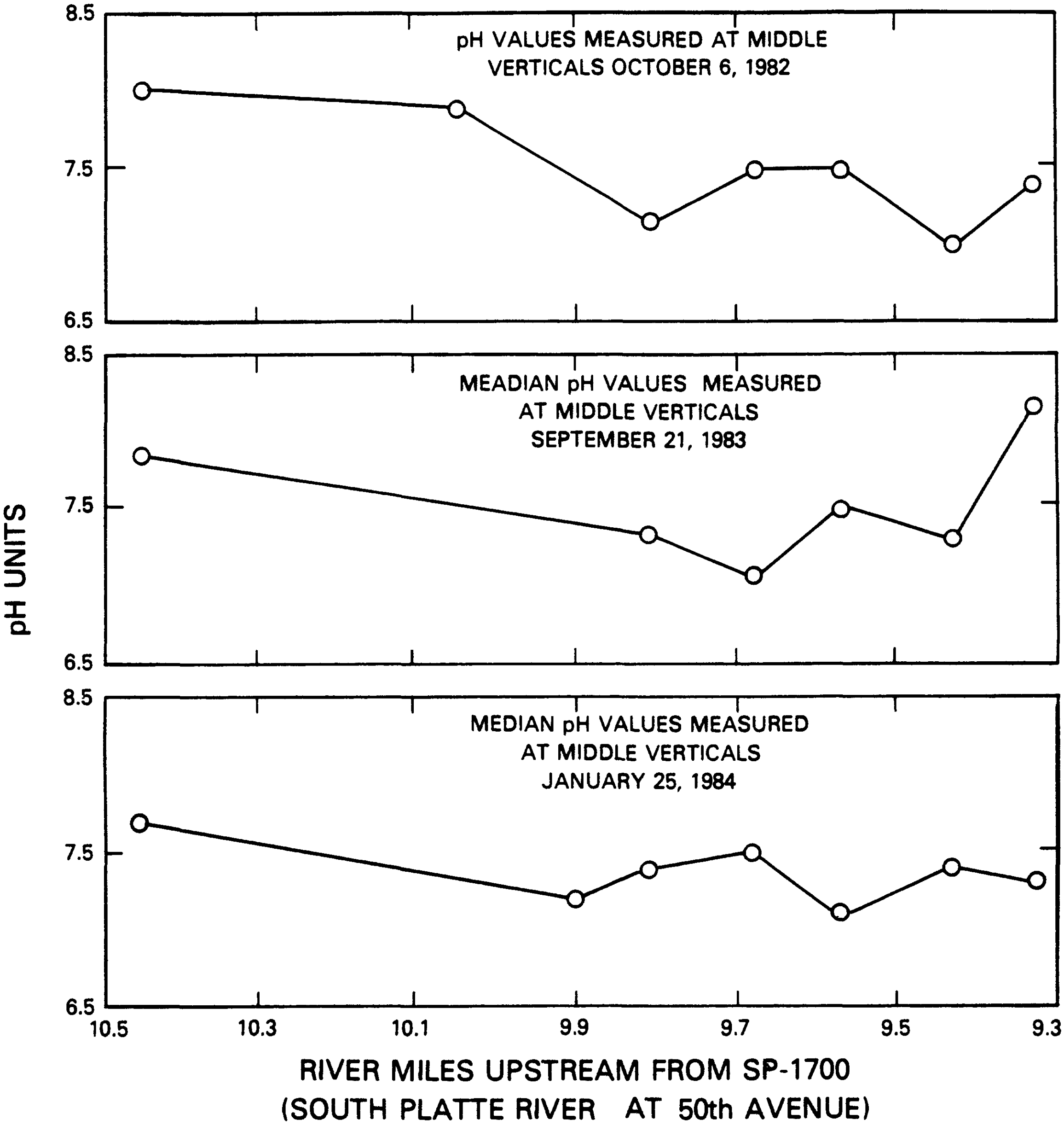

Figure 40.--pH values measured during three mixing-zone measurements.

As nitrification progresses, producing acidity, the river pH decreases again (U.S. Environmental Protection Agency, 1975). Finally, due to continued CO_2 degassing the river pH begins to increase again toward the pH levels observed upstream from the outfall. The situation described above is very specific to the mixing zone below the Bi-City WWTP and results from the treatment methodology used within the plant.

The maximum un-ionized-ammonia concentration observed was 0.42 mg/L in October 1982 and 0.24 mg/L in January 1984. Un-ionized-ammonia concentrations during the September 1983 measurement ranged from 0.16 to 0.24 mg/L at the cross section farthest downstream in the mixing zone.

Residual Chlorine

Residual-chlorine measurements were made during each of the three mixing-zone data-collection periods. Two Fisher-Porter 17T2000 amperometric titrators were used to make measurements onsite, immediately following sample collection. Samples were collected in 250-milliliter amber plastic bottles and immediately chilled. Analytical results were somewhat inconsistent and not considered entirely representative, because of fouling of the titrator probes. An unknown substance in some of the samples reacted with the copper-plated probes, turning the probes to a flat-black finish. Although these probes were cleaned several times, it was not possible to distinguish which measurements were reliable and which were not.

During the October 1982 measurements, the background concentrations observed upstream from the WWTP outfall ranged from 0.01 to 0.05 mg/L. These background concentrations indicated the problem occurred with the measurements, as no source of chlorine is known to be present at a close location upstream to account for these concentrations. Downstream concentrations ranged from 0.02 to 0.04 mg/L. No effluent samples were analyzed.

During the September 1983 measurements, the background concentrations observed ranged from 0.00 to 0.01 mg/L (the detection limit). Maximum concentrations observed downstream from the outfall were 0.06 mg/L. Effluent concentrations ranged from 0.19 to 0.40 mg/L. Background concentrations observed during the January 1984 measurements were 0.00 mg/L. Maximum concentration downstream from the outfall was 0.38 mg/L.

Given the inconsistency of the data which is more clearly seen in the data report (Spahr and others, 1984). The evidence of probe fouling during the measurements, indicates these data should be viewed only as an indication of the order of magnitude of the residual-chlorine concentrations present in the river, if de-chlorination were not taking place at the treatment plant.

SUMMARY AND CONCLUSIONS

The U.S. Geological Survey and the cities of Littleton and Englewood, Colorado, entered into an agreement to study the effects of the Bi-City WWTP effluent on the South Platte River. To study the effects of the Bi-City WWTP effluent, the U.S. Geological Survey's one-dimensional steady-state water-quality model was calibrated for a 14.5-mile reach of the South Platte River. Data used for model calibration were collected during September 1983. The model was verified for dissolved oxygen, total ammonia nitrogen, total organic nitrogen, total nitrate nitrogen, and 5-day CBOD, for both warm- and cold-water conditions using data collected during October 1982 and January 1984. Total nitrite nitrogen was verified only for warm-water temperature conditions of October 1982.

Model simulations were made using an estimated Q 7,10 (7-day, 10-year low flow) of 18 ft^3/s upstream from the Bi-City WWTP. The estimated Q 7,10 is approximately one-third of the discharge present during data collection. Flow regulation could not achieve discharges near the Q 7,10 value. The calibrated and verified model was used to indicate future water-quality conditions of the South Platte River by simulating river conditions with anticipated changes in the Bi-City WWTP effluent. Results of simulations should not be considered to be actual measurements. Simulated results are not exact, so a degree of uncertainty will be inherent.

Two major groups of simulations were made. In the first group, effluent discharge and 5-day CBOD concentrations were varied; in the second group, effluent concentrations of total nitrate nitrogen and total ammonia nitrogen were varied. The first group of simulations indicated conditions that would result, if effluent volumes were increased in the future. The second group of simulations were made to examine various levels of nitrification within the Bi-City WWTP.

Simulations for warm-water conditions made by varying the effluent discharge and 5-day CBOD concentrations indicated that dissolved-oxygen concentrations may be less than the 5.0 mg/L water-quality standard for a 2.5-mile reach beginning about 1.6 miles downstream of the outfall. When 5-day CBOD effluent concentrations increased from 20 to 30 mg/L, with an effluent discharge rate of 30 Mgal/d, the minimum simulated dissolved-oxygen concentrations downstream decreased from 4.6 to 4.3 mg/L. During cold-water condition simulations, dissolved-oxygen concentrations were much greater than the water-quality standard.

Simulations made with different amounts of total nitrogen in the nitrate and ammonia form showed that as more nitrification takes place within the Bi-City WWTP, lower total ammonia-nitrogen concentrations occur in the river. Changing the effluent total ammonia-nitrogen concentration from 20 to 5 mg/L (warm-water conditions) decreased the simulated maximum stream-reach total ammonia-nitrogen concentration from 12.8 to 3.3 mg/L and increased the simulated minimum dissolved-oxygen concentration from 4.9 to 6.7 mg/L, because dissolved-oxygen in the river was not consumed in the nitrification process. When most of the nitrogen discharged from the Bi-City WWTP is in the form of total nitrate, total nitrate concentrations in the model reach were not larger than the 10 mg/L water-quality standard.

Un-ionized-ammonia concentrations were calculated from total ammonia-nitrogen concentrations measured during the three data-collection periods. During the September 1983 data-collection period, un-ionized-ammonia concentrations were found to be larger than the temporary water-quality standard of 0.10 mg/L. Un-ionized ammonia was calculated for the various simulations, using a range of pH values. Ranges in pH were used, because the model does not simulate pH. The ranges of pH were defined on best- and worst-case criteria of maximum pH depression at the treatment plant, with a slow recovery rate of pH downstream, and a minimum pH depression at the treatment plant, with a rapid recovery rate of pH downstream. Using the range of pH values, un-ionized-ammonia concentrations calculated were found to be larger than the temporary stream standard of 0.1 mg/L during warm-water temperature conditions, unless more nitrification occurred in the Bi-City WWTP.

An evaluation of the mixing zone downstream from the outfall of the Bi-City WWTP indicated that for low-flow conditions complete mixing occurs within about 0.8 mile, approximately at the Evans Avenue bridge. Because of problems encountered in determining residual chlorine, no conclusions could be drawn regarding residual chlorine concentrations within the mixing zone.

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SUPPLEMENTAL INFORMATION

Table 16.--*Un-ionized-ammonia concentrations and related data for the South Platte River, October 7, 1982*

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-100, USGS station number 393418105022300, South Platte River near Colorado Highway 470								
10 07 82	0630	11.0	274	7.9	7.9	0.080	0.0012	1.40
10 07 82	1110	14.5	275	8.3	8.6	<0.060	0.0014	4.60
10 07 82	1530	18.5	223	8.3	7.8	<0.060	0.0018	6.20
10 07 82	1910	15.0	273	8.2	7.8	0.100	0.0038	3.80
10 07 82	2230	12.5	207	7.9	8.4	<0.060	0.0005	1.60
10 08 82	0200	13.0	198	8.0	8.5	<0.060	0.0006	2.10
10 08 82	0505	12.5	208	8.0	8.3	<0.060	0.0006	2.10
Site reference code SP-200, USGS station number 06710000, South Platte River at Littleton								
10 07 82	0730	10.0	345	7.8	7.8	0.070	0.0007	1.00
10 07 82	1145	13.0	344	8.1	8.4	0.060	0.0016	2.60
10 07 82	1610	17.0	282	8.4	8.0	<0.060	0.0020	6.80
10 07 82	1755	15.5	275	8.1	8.2	<0.060	0.0010	3.20
10 07 82	2300	14.0	281	7.8	8.6	<0.060	0.0004	1.40
10 08 82	0230	12.5	276	7.9	8.3	0.080	0.0013	1.60
10 08 82	0535	11.5	277	7.8	8.3	<0.060	0.0004	1.20
Site reference code SP-300, USGS station number 393855105004800, South Platte River above Bear Creek								
10 07 82	0815	10.0	415	7.8	7.8	0.100	0.0010	1.00
10 07 82	1240	14.5	340	8.0	8.3	0.090	0.0021	2.30
10 07 82	1640	17.0	330	8.0	8.0	0.090	0.0025	2.80
10 07 82	2020	14.5	328	7.9	8.0	0.100	0.0019	1.90
10 07 82	2320	14.0	328	7.7	8.5	0.060	0.0007	1.10
10 08 82	0255	13.0	326	7.8	7.8	0.080	0.0011	1.30
10 08 82	0600	12.0	318	7.8	8.9	<0.060	0.0004	1.20
Site reference code SP-400, USGS station number 06711565, South Platte River at Englewood								
10 07 82	0900	10.5	352	7.8	7.9	0.150	0.0016	1.10
10 07 82	1310	12.5	292	8.0	7.7	0.100	0.0020	2.00
10 07 82	1710	15.0	281	8.2	8.1	0.070	0.0027	3.80
10 07 82	2040	14.5	272	8.1	8.4	<0.060	0.0009	2.90
10 07 82	2340	14.0	270	7.9	8.2	0.070	0.0013	1.80
10 08 82	0320	12.8	276	7.9	7.5	<0.060	0.0005	1.60
10 08 82	0620	12.0	274	7.8	8.3	<0.060	0.0004	1.20

Table 16.--*Un-ionized-ammonia concentrations and related data for the South Platte River, October 7, 1982*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-500, USGS station number 394042104595100, South Platte River at Evans Avenue								
10 07 82	0930	12.0	419	7.5	7.6	3.20	0.020	0.61
10 07 82	1340	15.5	389	7.4	7.7	3.60	0.023	0.64
10 07 82	1735	16.0	383	7.5	7.4	4.00	0.033	0.84
10 07 82	2120	15.5	366	7.5	8.1	5.10	0.041	0.81
10 07 82	2355	15.5	376	7.4	7.8	4.40	0.028	0.64
10 08 82	0340	14.0	344	7.5	8.3	2.90	0.021	0.72
10 08 82	0630	13.0	338	7.6	8.3	1.80	0.015	0.84
Site reference code SP-600, USGS station number 06711590, South Platte River at Florida Avenue, at Denver								
10 07 82	1000	12.5	406	7.8	8.1	1.80	0.023	1.30
10 07 82	1430	17.0	382	7.5	8.0	3.30	0.030	0.90
10 07 82	1800	15.5	373	7.8	7.8	3.40	0.054	1.60
10 07 82	2137	14.5	368	7.6	7.9	4.50	0.042	0.94
10 08 82	0010	15.0	375	7.5	7.8	5.20	0.040	0.77
10 08 82	0405	14.0	355	7.6	8.2	3.50	0.032	0.91
10 08 82	0650	13.0	332	7.7	8.7	2.00	0.021	1.00
Site reference code SP-700, USGS station number 394128104594700, South Platte River below footbridge, below Florida Avenue								
10 07 82	0615	15.0	451	7.9	7.7	2.00	0.038	1.90
10 07 82	1215	14.3	462	7.8	8.1	3.50	0.050	1.40
10 07 82	1530	15.5	468	7.6	8.0	3.00	0.030	1.00
10 07 82	1810	15.5	392	7.7	7.3	3.10	0.039	1.30
10 07 82	2215	15.0	379	7.7	7.8	4.20	0.051	1.20
10 08 82	0050	15.0	378	7.5	8.4	4.90	0.038	0.77
10 08 82	0350	14.5	346	7.6	8.6	4.00	0.038	0.94
Site reference code SP-800, USGS station number 394141104593300, South Platte River above Mississippi Avenue								
10 07 82	0730	12.0	430	7.5	8.1	1.90	0.012	0.61
10 07 82	1250	14.5	454	7.5	7.8	3.60	0.026	0.74
10 07 82	1610	15.5	385	7.5	8.2	3.30	0.026	0.80
10 07 82	1835	15.5	387	7.7	8.0	2.90	0.037	1.30
10 07 82	2230	15.0	374	7.6	8.0	4.30	0.042	0.97
10 08 82	0115	15.0	383	7.6	8.0	4.60	0.045	0.97
10 08 82	0400	14.5	359	7.5	8.7	4.20	0.031	0.75

Table 16.--*Un-ionized-ammonia concentrations and related data for the South Platte River, October 7, 1982*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-900, USGS station number 394210104594100, South Platte River above Santa Fe overpass								
10 07 82	0830	12.0	445	7.6	8.0	2.00	0.015	0.77
10 07 82	1312	15.0	446	7.6	7.8	2.80	0.027	0.96
10 07 82	1630	15.5	390	7.5	7.5	3.10	0.025	0.80
10 07 82	1850	15.0	388	7.7	7.8	3.00	0.037	1.20
10 07 82	2250	14.5	365	7.7	8.0	4.10	0.048	1.20
10 08 82	0130	15.0	378	7.6	8.2	4.90	0.048	0.97
10 08 82	0420	14.0	365	7.6	8.5	4.20	0.038	0.90
Site reference code SP-1000, USGS station number 394241104595900, South Platte River below Alameda Avenue								
10 07 82	0930	13.5	458	7.7	7.9	2.10	0.023	1.10
10 07 82	1230	14.5	358	7.7	7.8	1.50	0.018	1.20
10 07 82	1500	16.0	458	7.6	8.3	3.10	0.032	1.00
10 07 82	1925	15.5	394	7.7	8.0	2.90	0.037	1.30
10 07 82	2335	14.0	375	7.7	7.5	3.80	0.043	1.10
10 08 82	0150	14.0	370	7.7	8.5	4.40	0.050	1.10
10 08 82	0440	14.0	363	7.6	8.1	4.50	0.041	0.90
Site reference code SP-1100, USGS station number 394321105000500, South Platte River above Vallejo Street								
10 07 82	1000	14.0	463	7.6	8.3	2.20	0.020	0.89
10 07 82	1300	15.0	461	8.0	8.5	1.50	0.036	2.40
10 07 82	1600	16.0	461	7.9	8.3	2.40	0.049	2.00
10 07 82	2030	15.5	411	7.7	7.8	2.90	0.037	1.30
10 07 82	2355	14.0	396	7.7	7.9	3.00	0.034	1.10
10 08 82	0215	14.0	379	7.8	8.4	3.80	0.054	1.40
10 08 82	0500	14.0	392	7.6	8.2	3.60	0.032	0.90
Site reference code SP-1100A, USGS station number 394345105005800, South Platte River above 8th Avenue bridge								
10 07 82	1100	15.0	474	7.7	8.3	2.30	0.028	1.20
10 07 82	1345	16.0	364	8.0	7.9	1.40	0.036	2.60
10 07 82	1645	16.0	472	---	8.4	2.60	0.16	6.20
10 07 82	2055	15.0	402	7.6	7.7	2.90	0.028	0.97
10 08 82	0020	14.0	395	7.7	8.8	3.00	0.034	1.10
10 08 82	0235	14.0	386	7.7	8.1	3.10	0.035	1.10
10 08 82	0515	14.0	380	7.6	8.6	4.00	0.036	0.90

Table 16.--*Un-ionized-ammonia concentrations and related data for the South Platte River, October 7, 1982*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-1200, USGS station number 394433105005800, South Platte River above 17th Avenue underpass								
10 07 82	0620	13.0	426	7.8	7.7	3.60	0.047	1.30
10 07 82	1010	13.0	406	7.8	7.9	3.00	0.040	1.30
10 07 82	1400	14.5	389	8.0	7.7	2.20	0.051	2.30
10 07 82	1810	15.0	403	8.0	7.8	1.80	0.043	2.40
10 07 82	2210	13.5	414	7.8	8.1	2.60	0.036	1.40
10 08 82	0120	13.0	405	7.8	8.1	2.20	0.029	1.30
10 08 82	0430	13.0	396	7.8	8.3	3.00	0.040	1.30
Site reference code SP-1300, USGS station number 394502105004700, South Platte River at 7th Street, near Confluence Park								
10 07 82	0650	12.5	427	7.7	7.7	3.30	0.033	1.00
10 07 82	1045	13.0	411	7.8	8.2	2.80	0.037	1.30
10 07 82	1435	15.0	476	8.0	8.0	2.20	0.052	2.40
10 07 82	1845	15.0	393	7.9	8.1	1.60	0.031	1.90
10 07 82	2235	14.5	423	7.8	8.6	2.80	0.041	1.50
10 08 82	0140	12.0	395	7.8	8.4	2.60	0.032	1.20
10 08 82	0500	13.5	393	7.8	8.5	2.80	0.038	1.40
Site reference code SP-1400, USGS station number 06714000, South Platte River at Denver								
10 07 82	0725	12.0	402	7.8	7.8	3.10	0.038	1.20
10 07 82	1110	13.5	441	7.9	8.0	2.70	0.046	1.70
10 07 82	1515	16.0	422	8.1	8.2	2.10	0.068	3.20
10 07 82	1910	15.0	422	8.0	8.3	1.40	0.034	2.40
10 07 82	2300	14.0	451	7.9	8.2	2.60	0.046	1.80
10 08 82	0200	14.0	421	7.8	8.6	2.10	0.030	1.40
10 08 82	0515	13.0	419	7.9	8.1	2.40	0.040	1.60
Site reference code SP-1500, USGS station number 394602104590500, South Platte River above 31st Street bridge								
10 07 82	0800	12.0	474	7.8	7.7	3.00	0.036	1.20
10 07 82	1145	14.0	452	7.8	8.0	2.50	0.035	1.40
10 07 82	1550	16.0	509	8.0	8.3	1.80	0.046	2.60
10 07 82	1950	15.0	429	7.9	8.0	1.30	0.025	1.90
10 07 82	2330	14.0	458	7.9	8.5	2.50	0.044	1.80
10 08 82	0230	13.5	439	7.8	8.4	2.00	0.027	1.40

Table 16.--*Un-ionized-ammonia concentrations and related data for the South Platte River, October 7, 1982*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-1600, USGS station number 394634104583800, South Platte River below 38th Street bridge								
10 07 82	0830	12.0	529	7.8	7.8	2.90	0.035	1.20
10 07 82	1220	14.5	442	8.0	8.2	2.40	0.055	2.30
10 07 82	1625	16.0	514	8.0	8.1	1.70	0.043	2.60
10 07 82	1815	14.5	417	7.9	7.9	1.00	0.018	1.80
10 08 82	0015	14.0	462	7.9	8.2	2.30	0.041	1.80
10 08 82	0250	13.5	439	7.9	8.3	1.90	0.032	1.70
Site reference code SP-1700, USGS station number 06714130, South Platte River at 50th Avenue, at Denver								
10 07 82	0905	12.0	538	7.8	7.7	2.60	0.031	1.20
10 07 82	1310	15.5	451	8.0	8.1	2.40	0.060	2.50
10 07 82	1650	16.5	528	8.0	8.2	1.60	0.042	2.60
10 07 82	2045	14.5	436	7.9	8.4	1.00	0.018	1.80
10 08 82	0035	14.0	464	7.9	7.8	2.30	0.041	1.80
10 08 82	0310	13.0	452	7.8	8.1	1.90	0.025	1.30

Table 17.--*Un-ionized-ammonia concentrations and related data for the South Platte River, March 14, 1983*

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-100, USGS station number 393418105022300, South Platte River near Colorado Highway 470								
03 14 83	0630	4.5	246	7.7	7.8	0.130	0.0007	0.55
03 14 83	1040	7.0	239	7.7	7.9	0.120	0.0008	0.68
03 14 83	1430	10.0	241	7.9	8.0	0.100	0.0013	1.30
03 14 83	1830	9.5	---	7.7	---	-----	------	----
Site reference code SP-200, USGS station number 06710000, South Platte River at Littleton								
03 14 83	0715	7.0	415	7.9	7.8	0.120	0.0012	1.00
03 14 83	1130	9.0	395	7.9	8.0	0.150	0.0018	1.20
03 14 83	1515	11.0	408	7.9	8.1	0.090	0.0013	1.40
03 14 83	1910	9.3	---	8.0	---	-----	------	----
Site reference code SP-300, USGS station number 393855105004800, South Platte River above Bear Creek								
03 14 83	0800	8.0	471	7.8	7.7	0.200	0.0018	0.89
03 14 83	1200	10.0	483	7.8	7.8	0.180	0.0019	1.00
03 14 83	1545	11.0	483	7.8	8.0	0.230	0.0026	1.10
03 14 83	1940	9.0	---	7.8	---	-----	------	----
Site reference code SP-400, USGS station number 06711565, South Platte River at Englewood								
03 14 83	0830	8.0	521	7.9	7.8	0.220	0.0024	1.10
03 14 83	1230	11.0	542	7.9	7.9	0.270	0.0038	1.40
03 14 83	1615	10.0	561	7.8	8.0	0.190	0.0020	1.00
Site reference code SP-500, USGS station number 394042104595100, South Platte River at Evans Avenue								
03 14 83	0645	9.0	550	7.8	7.6	2.90	0.028	0.95
03 14 83	1015	10.0	600	7.5	7.5	5.00	0.026	0.52
03 14 83	1410	11.5	688	7.6	7.6	7.30	0.053	0.72
03 14 83	1815	11.0	---	7.2	---	----	-----	----
Site reference code SP-600, USGS station number 06711590, South Platte River at Florida Avenue, at Denver								
03 14 83	0740	9.0	593	7.8	7.7	3.00	0.028	0.95
03 14 83	1050	10.0	579	7.6	7.7	3.90	0.025	0.65
03 14 83	1445	11.5	662	7.6	7.6	5.70	0.041	0.72
03 14 83	1845	11.0	---	7.6	---	----	-----	----

Table 17.--*Un-ionized-ammonia concentrations and related data for the South Platte River, March 14, 1983*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-700, USGS station number 394128104594700, South Platte River below footbridge, below Florida Avenue								
03 14 83	0830	9.0	580	7.9	7.7	2.70	0.032	1.20
03 14 83	1200	10.5	603	7.8	7.6	4.20	0.045	1.10
03 14 83	1530	11.5	670	7.8	7.6	5.60	0.064	1.10
Site reference code SP-800, USGS station number 394141104593300, South Platte River above Mississippi Avenue								
03 14 83	0900	9.0	585	7.8	7.7	2.80	0.027	0.95
03 14 83	1225	10.5	612	7.7	7.6	4.40	0.037	0.85
03 14 83	1600	11.5	651	7.6	7.6	5.80	0.042	0.73
Site reference code SP-900, USGS station number 394210104594100, South Platte River above Santa Fe overpass								
03 14 83	0615	10.0	604	7.5	7.6	4.40	0.023	0.52
03 14 83	1015	10.0	616	7.7	7.7	2.90	0.024	0.82
03 14 83	1415	12.0	598	7.4	7.7	4.10	0.020	0.48
03 14 83	1802	11.5	---	8.2	---	----	-----	----
Site reference code SP-1000, USGS station number 394241104595900, South Platte River below Alameda Avenue								
03 14 83	0715	9.5	607	7.4	7.7	4.40	0.017	0.40
03 14 83	1050	10.0	599	7.4	7.7	2.90	0.012	0.41
03 14 83	1445	12.0	598	7.3	7.7	3.30	0.012	0.38
03 14 83	1845	11.5	---	7.3	---	----	-----	----
Site reference code SP-1100, USGS station number 394321105000500, South Platte River above Vallejo Street								
03 14 83	0800	10.0	614	7.3	7.7	4.80	0.016	0.33
03 14 83	1130	10.5	611	7.5	7.8	3.20	0.017	0.54
03 14 83	1515	12.0	585	7.4	7.9	2.70	0.013	0.48
Site reference code SP-1100A, USGS station number 394345105005800, South Platte River above 8th Avenue bridge								
03 14 83	0830	10.0	614	7.1	7.7	4.30	0.0089	0.21
03 14 83	1220	11.0	583	7.6	7.8	3.10	0.022	0.70
03 14 83	1600	12.0	573	7.4	7.8	2.60	0.012	0.48

Table 17.--*Un-ionized-ammonia concentrations and related data for the South Platte River, March 14, 1983*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-1200, USGS station number 394433105005800, South Platte River above 17th Avenue underpass								
03 14 83	0915	10.0	611	7.3	7.8	4.40	0.014	0.33
03 14 83	1300	11.0	623	7.6	7.8	3.20	0.022	0.70
03 14 83	1635	11.0	618	7.4	7.9	2.40	0.011	0.44
Site reference code SP-1300, USGS station number 394502105004700, South Platte River at 7th Street, near Confluence Park								
03 14 83	0615	9.0	576	7.9	7.8	4.40	0.053	1.20
03 14 83	1015	9.5	611	8.0	7.8	4.60	0.072	1.60
03 14 83	1420	11.5	624	8.0	7.9	3.20	0.058	1.80
Site reference code SP-1400, USGS station number 06714000, South Platte River at Denver								
03 14 83	0650	8.5	597	8.1	7.9	3.80	0.069	1.80
03 14 83	1050	10.0	626	8.0	8.0	4.10	0.066	1.60
03 14 83	1455	12.0	646	8.1	7.9	3.00	0.070	2.30
Site reference code SP-1500, USGS station number 394602104590500, South Platte River above 31st Street bridge								
03 14 83	0740	8.5	606	8.0	7.8	3.30	0.048	1.40
03 14 83	1130	10.0	633	8.0	7.8	2.50	0.040	1.60
03 14 83	1540	12.0	649	8.1	7.9	3.00	0.070	2.30
Site reference code SP-1600, USGS station number 394634104583800, South Platte River below 38th Street bridge								
03 14 83	0815	9.0	610	8.0	7.8	3.20	0.048	1.50
03 14 83	1210	11.0	632	8.0	7.9	3.40	0.059	1.70
03 14 83	1605	12.0	657	8.0	7.9	3.00	0.056	1.90
Site reference code SP-1700, USGS station number 06714130, South Platte River at 50th Avenue, at Denver								
03 14 83	0850	9.0	618	8.0	7.9	3.00	0.045	1.50
03 14 83	1250	11.5	645	8.0	7.8	3.30	0.060	1.80
03 14 83	1640	11.5	659	8.1	7.8	3.00	0.068	2.30

Table 18.--*Un-ionized-ammonia concentrations and related data for the South Platte River, September 22, 1983*

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-100, USGS station number 393418105022300, South Platte River near Colorado Highway 470								
09 22 83	0630	14.0	227	7.6	7.8	0.170	0.0016	0.92
09 22 83	1035	15.5	244	8.0	7.3	0.130	0.0033	2.50
09 22 83	1430	18.5	244	8.4	7.6	0.120	0.0091	7.60
09 22 83	1840	17.0	271	7.5	7.8	0.130	0.0012	0.91
09 22 83	2145	16.0	239	7.9	7.6	0.090	0.0019	2.10
09 23 83	0110	14.5	244	7.2	7.6	0.090	0.0003	0.38
09 23 83	0335	14.5	242	8.0	7.7	0.110	0.0026	2.40
Site reference code SP-200, USGS station number 06710000, South Platte River at Littleton								
09 22 83	0720	11.5	332	8.1	7.8	0.120	0.0028	2.30
09 22 83	1120	14.0	336	8.5	8.0	0.110	0.0075	6.80
09 22 83	1510	18.0	328	8.6	8.0	0.090	0.0099	1.00
09 22 83	1920	17.0	355	8.0	8.1	0.080	0.0022	2.80
09 22 83	2215	15.0	344	7.6	7.9	0.060	0.0006	0.98
09 23 83	0145	14.0	348	7.7	7.8	0.120	0.0014	1.10
09 23 83	0415	13.0	341	7.8	7.8	0.150	0.0020	1.30
Site reference code SP-300, USGS station number 393855105004800, South Platte River above Bear Creek								
09 22 83	0805	11.5	389	8.9	7.8	0.210	0.027	3.00
09 22 83	1205	15.0	400	8.2	7.8	0.200	0.0075	3.80
09 22 83	1550	18.5	394	8.4	7.7	0.170	0.013	7.40
09 22 83	2005	17.0	396	8.0	7.8	0.230	0.0064	2.80
09 22 83	2240	15.0	399	7.3	7.7	0.250	0.0012	0.49
09 23 83	0210	13.5	400	7.7	7.8	0.260	0.0028	1.10
09 23 83	0430	13.0	407	7.8	7.8	0.260	0.0034	1.30
Site reference code SP-400, USGS station number 06711565, South Platte River at Englewood								
09 22 83	0850	10.5	457	8.6	7.9	0.200	0.013	6.50
09 22 83	1245	14.0	450	8.3	8.0	0.200	0.0087	4.30
09 22 83	1620	19.0	433	8.3	8.0	0.160	0.0099	6.20
09 22 83	2030	15.5	433	8.0	8.0	0.140	0.0035	2.50
09 22 83	2300	14.5	454	---	7.9	0.180	0.0033	1.80
09 23 83	0230	13.0	444	7.8	7.8	0.190	0.0025	1.30
09 23 83	0455	12.0	443	7.8	7.9	0.260	0.0032	1.20

Table 18.--*Un-ionized-ammonia concentrations and related data for the South Platte River, September 22, 1983*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-500, USGS station number 394042104595100, South Platte River at Evans Avenue								
09 22 83	0640	12.0	526	7.7	7.6	3.90	0.037	0.96
09 22 83	1010	13.0	543	7.6	7.5	5.50	0.045	0.82
09 22 83	1405	17.0	560	7.4	7.5	5.50	0.039	0.70
09 22 83	1805	17.0	536	7.8	7.6	6.00	0.10	1.70
09 22 83	2100	16.0	545	7.4	7.6	6.50	0.042	0.65
09 23 83	0005	15.5	554	7.3	7.5	6.50	0.032	0.50
09 23 83	0305	14.5	541	7.4	7.2	5.50	0.032	0.58
Site reference code SP-600, USGS station number 06711590, South Platte River at Florida Avenue, at Denver								
09 22 83	0720	12.5	529	7.7	7.8	4.30	0.043	1.00
09 22 83	1035	14.0	521	7.8	7.7	3.60	0.050	1.40
09 22 83	1425	17.0	562	7.5	7.6	6.00	0.053	0.88
09 22 83	1835	17.0	561	7.8	7.7	5.50	0.096	1.70
09 22 83	2125	16.0	534	7.6	7.7	6.00	0.062	1.00
09 23 83	0035	15.0	550	7.5	7.6	6.50	0.049	0.76
09 23 83	0335	14.5	554	7.5	7.6	6.50	0.048	0.73
Site reference code SP-700, USGS station number 394128104594700, South Platte River below footbridge, below Florida Avenue								
09 22 83	0750	12.5	485	7.8	7.7	4.20	0.053	1.20
09 22 83	1115	14.0	525	7.9	7.8	3.60	0.063	1.80
09 22 83	1455	17.0	561	7.7	7.6	5.50	0.076	1.40
09 22 83	1925	16.5	548	7.5	7.9	5.50	0.047	0.85
09 22 83	2215	15.5	551	7.5	7.6	6.00	0.047	0.79
09 23 83	0125	14.5	556	7.5	7.6	6.00	0.044	0.73
09 23 83	0420	14.0	563	7.5	7.6	6.00	0.042	0.70
Site reference code SP-800, USGS station number 394141104593300, South Platte River above Mississippi Avenue								
09 22 83	0810	12.0	537	7.7	7.6	4.30	0.041	0.96
09 22 83	1130	14.0	527	7.9	7.8	3.40	0.060	1.80
09 22 83	1515	17.0	564	7.7	7.6	5.50	0.076	1.40
09 22 83	1940	16.0	553	7.6	7.8	5.50	0.056	1.00
09 22 83	2245	15.5	564	7.6	7.7	6.00	0.059	0.99
09 23 83	0150	14.5	556	7.5	7.6	6.50	0.048	0.73
09 23 83	0445	14.0	566	7.5	7.7	6.00	0.042	0.70

Table 18.--*Un-ionized-ammonia concentrations and related data for the South Platte River, September 22, 1983*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-900, USGS station number 394210104594100, South Platte River above Santa Fe overpass								
09 22 83	0610	14.0	555	7.6	7.7	5.80	0.051	0.88
09 22 83	1010	14.0	542	7.6	7.8	4.00	0.035	0.89
09 22 83	1315	16.5	539	7.8	7.8	4.50	0.076	1.70
09 22 83	1816	18.5	565	7.9	7.9	5.00	0.12	2.40
09 22 83	2053	17.0	562	8.0	7.8	5.00	0.14	2.70
09 22 83	2356	16.0	548	8.0	7.7	5.50	0.14	2.50
09 23 83	0301	15.0	576	7.7	7.8	6.00	0.072	1.20
Site reference code SP-1000, USGS station number 394241104595900, South Platte River below Alameda Avenue								
09 22 83	0705	14.0	556	7.6	7.7	5.90	0.052	0.88
09 22 83	1050	14.0	551	7.4	7.8	4.00	0.022	0.56
09 22 83	1450	14.0	536	7.9	7.9	3.50	0.061	1.80
09 22 83	1843	17.0	567	8.1	7.8	4.90	0.17	3.40
09 22 83	2135	16.5	562	8.0	7.8	4.80	0.13	2.60
09 23 83	0018	15.5	550	8.0	7.7	5.00	0.12	2.40
09 23 83	0325	15.0	560	7.9	7.8	6.00	0.11	1.90
Site reference code SP-1100, USGS station number 394321105000500, South Platte River above Vallejo Street								
09 22 83	0745	14.0	560	7.4	7.6	6.00	0.034	0.56
09 22 83	1140	15.5	585	7.2	8.0	3.70	0.015	0.40
09 22 83	1530	17.0	544	7.7	7.7	2.80	0.039	1.40
09 22 83	1905	17.0	567	8.1	7.9	4.30	0.15	3.40
09 22 83	2151	16.5	626	7.9	7.7	4.50	0.094	2.10
09 23 83	0048	15.5	561	8.0	7.7	4.70	0.12	2.40
09 23 83	0358	14.5	571	7.8	7.7	5.50	0.080	1.40
Site reference code SP-1100A, USGS station number 394345105005800, South Platte River above 8th Avenue bridge								
09 22 83	0820	14.0	559	7.2	7.7	6.00	0.021	0.35
09 22 83	1215	15.0	568	7.5	7.7	4.80	0.036	0.76
09 22 83	1620	17.5	537	7.9	7.9	2.90	0.066	2.30
09 22 83	1940	17.0	561	8.3	7.9	4.10	0.22	5.30
09 22 83	2226	16.5	581	8.0	7.7	4.50	0.12	2.60
09 23 83	0116	15.0	564	8.3	7.7	4.50	0.21	4.60
09 23 83	0500	14.5	565	7.5	7.8	5.00	0.036	0.73

Table 18.--*Un-ionized-ammonia concentrations and related data for the South Platte River, September 22, 1983*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-1200, USGS station number 394433105005800, South Platte River above 17th Avenue underpass								
09 22 83	0900	14.0	540	7.2	7.9	5.00	0.018	0.35
09 22 83	1200	16.0	550	8.0	7.9	5.00	0.13	2.50
09 22 83	1540	16.0	561	8.0	7.9	4.70	0.12	2.50
09 22 83	2008	17.0	539	8.4	8.1	2.70	0.18	6.60
09 22 83	2257	16.0	545	8.3	7.9	3.10	0.15	5.00
09 23 83	0205	15.0	578	8.3	7.9	3.90	0.18	4.60
09 23 83	0433	15.0	576	7.5	7.9	3.80	0.029	0.76
Site reference code SP-1300, USGS station number 394502105004700, South Platte River at 7th Street, near Confluence Park								
09 22 83	0620	13.5	561	7.9	7.8	4.10	0.069	1.70
09 22 83	1005	14.5	562	8.0	7.9	4.80	0.11	2.30
09 22 83	1410	16.5	558	8.1	7.9	5.00	0.16	3.30
09 22 83	1745	17.0	576	8.0	8.0	3.90	0.11	2.70
09 22 83	2050	17.0	557	7.9	8.0	2.70	0.059	2.20
09 22 83	2350	15.5	551	7.8	7.9	2.80	0.044	1.60
09 23 83	0305	15.0	593	7.7	7.8	3.80	0.045	1.20
Site reference code SP-1400, USGS station number 06714000, South Platte River at Denver								
09 22 83	0700	13.0	581	---	7.9	3.20	0.052	1.60
09 22 83	1040	13.5	574	8.2	7.7	4.70	0.16	3.30
09 22 83	1450	17.5	583	8.2	8.0	4.00	0.18	4.40
09 22 83	1820	17.0	583	8.0	8.1	3.80	0.10	2.70
09 22 83	2120	16.0	579	7.9	7.9	2.70	0.055	2.00
09 23 83	0020	15.0	577	7.9	7.9	1.60	0.030	1.90
09 23 83	0325	14.0	595	7.8	7.9	3.00	0.042	1.40
Site reference code SP-1500, USGS station number 394602104590500, South Platte River above 31st Street bridge								
09 22 83	0745	13.0	602	8.0	7.9	2.90	0.059	2.00
09 22 83	1130	14.5	596	8.1	7.9	3.40	0.096	2.80
09 22 83	1530	18.0	584	8.1	8.0	4.10	0.15	3.70
09 22 83	1850	17.0	603	7.9	7.9	3.70	0.081	2.20
09 22 83	2155	16.0	600	7.8	7.9	2.50	0.040	1.60
09 23 83	0045	15.0	583	7.8	7.9	1.50	0.022	1.50
09 23 83	0350	14.0	598	7.7	7.9	2.50	0.028	1.10

Table 18.--*Un-ionized-ammonia concentrations and related data for the South Platte River, September 22, 1983*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-1600, USGS station number 394634104583800, South Platte River below 38th Street bridge								
09 22 83	0815	13.0	596	8.0	7.9	2.70	0.055	2.00
09 22 83	1200	15.0	596	8.2	8.0	3.10	0.11	3.70
09 22 83	1605	18.0	587	8.2	8.0	3.80	0.17	4.60
09 22 83	1910	16.5	595	7.9	8.0	3.60	0.076	2.10
09 22 83	2215	16.0	597	7.8	7.8	2.70	0.044	1.60
09 23 83	0105	14.5	591	7.8	7.9	1.40	0.020	1.40
09 23 83	0405	14.0	600	7.8	8.0	2.30	0.032	1.40
Site reference code SP-1700, USGS station number 06714130, South Platte River at 50th Avenue, at Denver								
09 22 83	0840	13.0	598	---	7.9	2.50	0.040	1.60
09 22 83	1245	16.0	596	8.2	7.9	3.00	0.12	4.00
09 22 83	1640	18.0	586	8.2	8.1	3.30	0.15	4.60
09 22 83	1935	16.5	591	7.9	7.9	3.30	0.069	2.10
09 22 83	2240	15.5	598	7.7	7.9	2.50	0.031	1.20
09 23 83	0130	14.5	584	7.8	7.9	1.40	0.020	1.40
09 23 83	0425	14.0	591	7.7	7.9	1.50	0.017	1.10

Table 19.--*Un-ionized-ammonia concentrations and related data for the South Platte River, January 26, 1984*

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-100, USGS station number 393418105022300, South Platte River near Colorado Highway 470								
01 26 84	0645	4.0	243	7.6	7.6	0.060	0.0002	0.42
01 26 84	1030	4.0	250	8.0	7.8	0.050	0.0005	1.00
01 26 84	1415	4.5	238	7.7	7.7	<0.010	0.0000	0.55
01 26 84	1845	5.0	234	7.6	7.6	<0.010	0.0000	0.46
01 26 84	2335	5.0	244	7.7	7.7	<0.010	0.0000	0.57
01 27 84	0220	4.0	248	7.8	7.6	<0.010	0.0000	0.66
01 27 84	0555	4.0	252	7.8	7.7	0.060	0.0004	0.66
Site reference code SP-200, USGS station number 06710000, South Platte River at Littleton								
01 26 84	0730	2.0	419	7.8	7.8	0.040	0.0002	0.55
01 26 84	1110	3.0	404	8.0	7.8	0.060	0.0006	0.95
01 26 84	1515	5.0	395	8.3	7.9	0.070	0.0015	2.20
01 26 84	2005	3.5	398	7.8	7.8	0.040	0.0002	0.63
01 27 84	0010	2.0	400	7.9	7.7	<0.010	0.0000	0.70
01 27 84	0300	1.5	431	7.8	7.6	0.050	0.0003	0.53
01 27 84	0630	1.0	420	7.8	7.6	0.080	0.0004	0.51
Site reference code SP-300, USGS station number 393855105004800, South Platte River above Bear Creek								
01 26 84	0800	3.0	503	7.8	7.6	0.180	0.0011	0.59
01 26 84	1150	4.0	509	7.8	7.7	0.180	0.0012	0.64
01 26 84	1545	6.0	529	8.0	7.5	0.220	0.0026	1.20
01 26 84	2035	4.0	482	7.8	7.5	0.170	0.0011	0.64
01 27 84	0040	2.5	496	7.8	7.6	0.140	0.0008	0.57
01 27 84	0325	2.5	503	7.7	7.5	0.120	0.0005	0.45
01 27 84	0650	2.0	506	7.7	7.6	0.190	0.0008	0.44
Site reference code SP-400, USGS station number 06711565, South Platte River at Englewood								
01 26 84	0840	2.0	490	7.9	7.6	0.180	0.0012	0.69
01 26 84	1235	3.0	480	8.0	7.7	0.170	0.0016	0.94
01 26 84	1615	4.0	488	8.0	7.6	0.170	0.0017	1.00
01 26 84	2115	2.0	487	7.8	7.6	0.160	0.0009	0.55
01 27 84	0105	2.0	497	7.8	7.6	0.200	0.0011	0.55
01 27 84	0400	1.5	472	7.8	7.6	0.140	0.0007	0.53
01 27 84	0720	1.0	474	7.9	7.6	0.190	0.0012	0.64

Table 19.--*Un-ionized-ammonia concentrations and related data for the South Platte River, January 26, 1984*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-500, USGS station number 394042104595100, South Platte River at Evans Avenue								
01 26 84	0915	4.5	546	7.8	7.4	3.80	0.025	0.67
01 26 84	1300	7.0	574	7.5	7.2	5.70	0.023	0.41
01 26 84	1645	7.0	579	7.6	7.3	5.50	0.028	0.51
01 26 84	2150	6.0	535	7.6	7.3	7.30	0.035	0.48
01 27 84	0125	6.0	558	7.6	7.4	7.00	0.033	0.48
01 27 84	0435	5.0	543	7.6	7.3	4.10	0.018	0.44
01 27 84	0740	5.0	546	7.6	7.4	4.30	0.019	0.44
Site reference code SP-600, USGS station number 06711590, South Platte River at Florida Avenue, at Denver								
01 26 84	0620	5.5	586	7.6	7.3	4.80	0.022	0.46
01 26 84	1000	5.0	557	7.7	7.4	3.20	0.018	0.55
01 26 84	1355	7.0	556	7.6	7.2	5.50	0.028	0.52
01 26 84	1817	6.5	550	7.4	7.4	5.50	0.017	0.31
01 26 84	2117	6.2	550	7.6	7.4	6.50	0.031	0.48
01 27 84	0017	6.0	555	7.7	7.2	7.50	0.045	0.60
01 27 84	0314	5.5	560	7.6	7.3	7.00	0.032	0.46
Site reference code SP-700, USGS station number 394128104594700, South Platte River below footbridge, below Florida Avenue								
01 26 84	0705	5.0	595	7.5	7.3	4.60	0.016	0.35
01 26 84	1030	5.0	554	7.8	7.4	3.10	0.022	0.69
01 26 84	1430	7.0	568	7.3	7.3	5.40	0.014	0.26
01 26 84	1845	6.0	582	7.5	7.4	5.00	0.019	0.38
01 26 84	2133	6.2	559	7.4	7.3	6.00	0.018	0.30
01 27 84	0037	6.0	561	7.6	7.3	7.50	0.036	0.48
01 27 84	0337	5.5	563	7.6	7.3	6.50	0.030	0.46
Site reference code SP-800, USGS station number 394141104593300, South Platte River above Mississippi Avenue								
01 26 84	0725	2.0	596	7.5	7.3	4.40	0.012	0.27
01 26 84	1100	5.0	553	7.8	7.4	3.00	0.021	0.69
01 26 84	1455	7.0	568	7.4	7.3	5.40	0.018	0.32
01 26 84	1902	6.5	588	7.5	7.4	5.50	0.022	0.39
01 26 84	2155	6.0	563	7.6	7.5	5.90	0.028	0.48
01 27 84	0105	6.0	568	---	7.3	7.00	0.017	0.24
01 27 84	0355	5.5	562	7.7	7.3	6.50	0.037	0.57

Table 19.--*Un-ionized-ammonia concentrations and related data for the South Platte River, January 26, 1984*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-900, USGS station number 394210104594100, South Platte River above Santa Fe overpass								
01 26 84	0755	3.0	601	7.6	7.2	4.90	0.018	0.37
01 26 84	1100	6.0	563	7.9	7.5	3.20	0.030	0.94
01 26 84	1525	6.0	572	7.5	7.4	4.80	0.018	0.38
01 26 84	1925	5.5	573	7.5	7.3	5.00	0.018	0.36
01 26 84	2228	5.0	579	7.6	7.5	5.50	0.024	0.44
01 27 84	0131	5.5	564	7.7	7.5	6.50	0.037	0.57
01 27 84	0428	5.0	561	7.8	7.3	7.00	0.048	0.69
Site reference code SP-1000, USGS station number 394241104595900, South Platte River below Alameda Avenue								
01 26 84	0830	5.0	601	7.5	7.3	5.00	0.017	0.35
01 26 84	1220	5.0	577	7.9	7.4	3.60	0.031	0.87
01 26 84	1550	6.0	565	7.7	7.4	3.60	0.022	0.60
01 26 84	1952	6.0	562	7.5	7.4	4.90	0.018	0.38
01 26 84	2252	5.5	583	7.6	7.3	5.00	0.023	0.46
01 27 84	0153	6.0	570	7.7	7.5	6.00	0.036	0.60
01 27 84	0445	4.5	562	7.7	7.3	6.50	0.034	0.53
Site reference code SP-1100, USGS station number 394321105000500, South Platte River above Vallejo Street								
01 26 84	0850	6.0	592	7.5	7.2	5.00	0.019	0.38
01 26 84	1315	7.0	611	7.7	7.3	4.00	0.026	0.64
01 26 84	1630	7.0	592	7.7	7.2	3.00	0.019	0.65
01 26 84	2026	5.5	550	7.5	7.2	4.60	0.017	0.36
01 26 84	2326	6.2	583	7.6	7.3	4.70	0.023	0.48
01 27 84	0228	5.5	591	7.8	7.3	5.00	0.036	0.72
01 27 84	0503	5.5	568	7.6	7.2	6.00	0.027	0.46
Site reference code SP-1100A, USGS station number 394345105005800, South Platte River above 8th Avenue bridge								
01 26 84	0625	5.0	588	7.9	7.3	5.00	0.044	0.87
01 26 84	1015	5.0		7.6	7.3	5.00	0.0000	
01 26 84	1400	7.0	588	7.7	7.4	4.30	0.028	0.65
01 26 84	1830	6.5	536	7.0	7.5	3.10	0.0039	0.12
01 26 84	2040	6.0	580	7.2	7.3	4.30	0.0082	0.19
01 26 84	2300	5.0	598	7.1	7.2	4.60	0.0064	0.14
01 27 84	0325	4.0	509	6.9	7.4	5.00	0.0041	0.08

Table 19.--*Un-ionized-ammonia concentrations and related data for the South Platte River, January 26, 1984*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-1200, USGS station number 394433105005800, South Platte River above 17th Avenue underpass								
01 26 84	0710	6.0	637	7.8	7.4	4.40	0.033	0.75
01 26 84	1105	13.0	703	7.6	7.0	4.60	0.037	0.81
01 26 84	1430	10.0	568	7.7	7.4	4.50	0.037	0.82
01 26 84	1825	8.0		7.8	7.5	3.90	0.0000	
01 26 84	2115	5.0	576	7.7	7.5	3.10	0.017	0.55
01 27 84	0010	5.0	582	7.4	7.5	3.60	0.010	0.28
01 27 84	0300	5.0	595	7.4	7.4	4.30	0.012	0.28
Site reference code SP-1300, USGS station number 394502105004700, South Platte River at 7th Street, near Confluence Park								
01 26 84	0735	5.0	643	7.5	7.4	4.70	0.016	0.35
01 26 84	1125	5.0	628	8.0	7.3	4.30	0.047	1.10
01 26 84	1445	6.0	534	7.7	7.4	4.80	0.029	0.60
01 26 84	1855	5.0	559	7.7	7.4	4.60	0.025	0.55
01 26 84	2145	5.0	596	7.6	7.5	2.90	0.013	0.44
01 27 84	0030	4.5	573	7.6	7.4	3.10	0.013	0.42
01 27 84	0320	4.5	602	7.4	7.4	4.20	0.011	0.26
Site reference code SP-1400, USGS station number 06714000, South Platte River at Denver								
01 26 84	0800	5.0	663	7.6	7.3	4.00	0.017	0.44
01 26 84	1155	5.0	658	7.8	7.4	3.80	0.026	0.69
01 26 84	1510	6.5	603	7.8	7.5	4.30	0.034	0.78
01 26 84	1915	5.0	642	7.7	7.4	4.00	0.022	0.55
01 26 84	2210	5.0	637	7.7	7.5	2.80	0.015	0.55
01 27 84	0045	4.0	613	7.6	7.5	2.50	0.010	0.40
01 27 84	0335	4.0	610	7.6	7.4	3.40	0.014	0.40
Site reference code SP-1500, USGS station number 394602104590500, South Platte River above 31st Street bridge								
01 26 84	0820	5.5	673	7.5	7.4	3.90	0.014	0.36
01 26 84	1220	7.0	673	7.8	7.5	3.60	0.029	0.81
01 26 84	1545	7.0	628	7.7	7.4	3.90	0.025	0.64
01 26 84	1950	5.0	645	7.7	7.4	4.00	0.022	0.55
01 26 84	2230	5.0	645	7.6	7.4	3.40	0.015	0.44
01 27 84	0110	4.5	628	7.6	7.5	2.50	0.010	0.42
01 27 84	0400	4.0	620	7.6	7.5	2.80	0.011	0.40

Table 19.--*Un-ionized-ammonia concentrations and related data for the South Platte River, January 26, 1984*--Continued

Date Month-Day-Year	Time	Temperature (degrees Celsius)	Dissolved solids (milligrams per liter)	Field pH (standard units)	Lab pH (standard units)	Nitrogen ammonia (milligrams per liter)	Un-ionized ammonia (milligrams per liter)	Percent un-ionized ammonia
Site reference code SP-1600, USGS station number 394634104583800, South Platte River below 38th Street bridge								
01 26 84	0840	5.0	673	7.4	7.4	3.90	0.011	0.27
01 26 84	1240	7.0	680	7.8	7.5	3.50	0.028	0.80
01 26 84	1615	6.5	657	7.8	7.4	3.30	0.026	0.78
01 26 84	2010	4.0	628	7.8	7.4	3.80	0.024	0.64
01 26 84	2050	4.0	648	7.6	7.4	3.10	0.012	0.40
01 27 84	0125	4.0	639	7.6	7.5	2.60	0.010	0.40
01 27 84	0410	4.0	628	7.6	7.4	2.60	0.010	0.40
Site reference code SP-1700, USGS station number 06714130, South Platte River at 50th Avenue, at Denver								
01 26 84	0905	5.0	704	7.5	7.4	3.80	0.013	0.34
01 26 84	1310	7.0	682	7.8	7.4	3.60	0.029	0.80
01 26 84	1700	6.5	670	7.8	7.3	3.40	0.026	0.78
01 26 84	2030	5.0	637	7.7	7.3	3.50	0.019	0.55
01 26 84	2310	4.0	649	7.7	7.3	3.60	0.018	0.50
01 27 84	0140	4.0	650	7.6	7.4	2.70	0.011	0.40
01 27 84	0430	4.0	618	7.6	7.5	2.40	0.0097	0.40