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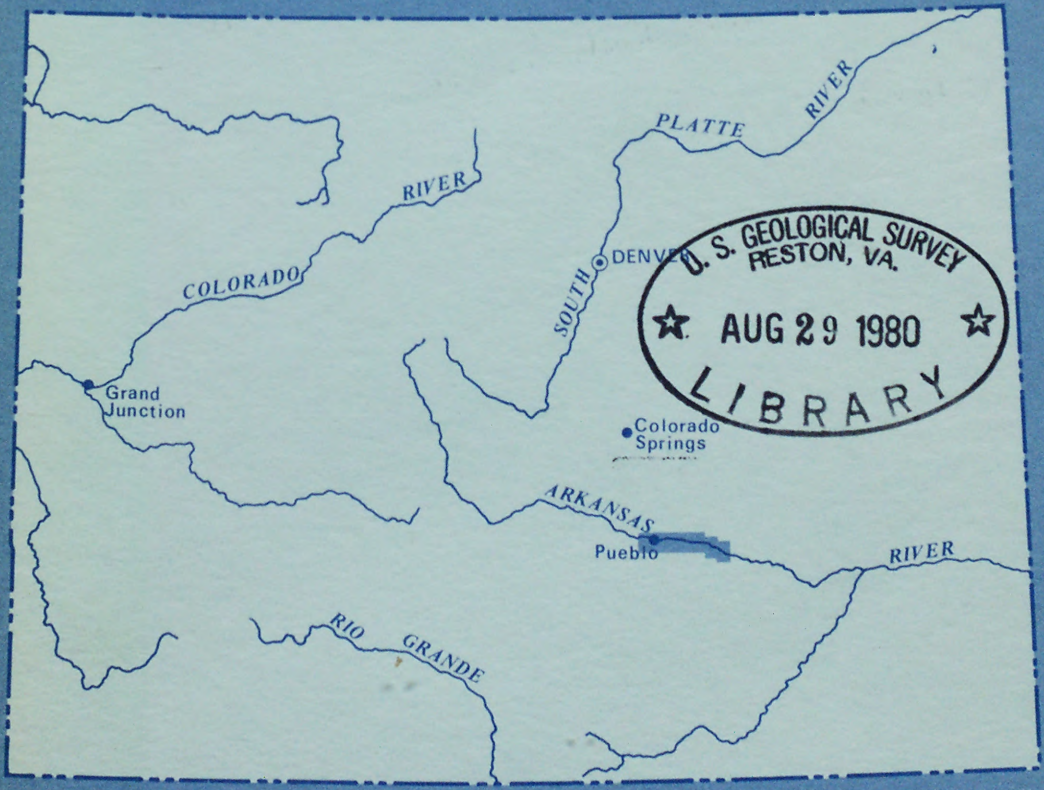
CALIBRATION AND POTENTIAL USES OF A DIGITAL WATER-QUALITY MODEL FOR THE ARKANSAS RIVER IN PUEBLO COUNTY, COLORADO

U.S. GEOLOGICAL SURVEY



Water-Resources Investigations 80-38

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UNITED STATES DEPARTMENT OF THE INTERIOR

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METRIC CONVERSION FACTORS

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

Multiply inch-pound unit	*By*	*To obtain metric unit*
foot (ft)	0.3048	meter
foot per second	0.3048	meter per second
foot per second per second	0.3048	meter per second per second
square foot	0.09290	square meter
mile	1.609	kilometer
cubic foot per second	0.02832	cubic meter per second

CALIBRATION AND POTENTIAL USES OF A DIGITAL WATER-QUALITY MODEL FOR THE ARKANSAS RIVER IN PUEBLO COUNTY, COLORADO

By Kimball E. Goddard

ABSTRACT

To assist the Pueblo Area Council of Governments in meeting their commitments under Section 208 of Public Law 92-500, the U.S. Geological Survey conducted a 1-year study to calibrate and demonstrate the use of a steady-state water-quality model for a 42-mile reach of the Arkansas River in Pueblo County, Colo. The digital model used in the study was developed by the U.S. Geological Survey.

The model was calibrated using hydraulic and water-quality data collected during April 1 to 2 and October 13 to 15, 1976. The reaction-rate coefficients, except those for coliform bacteria, were determined during the calibration of the model by a procedure of curve-fitting in which the reaction-rate coefficients resulting in the best match of calculated and measured water-quality values were considered to be the optimum values. The coefficients thus determined are: Carbonaceous biochemical oxygen demand, 1.0 day^{-1}; total organic nitrogen, 0.2 day^{-1}; total ammonia 1.0 day^{-1}; total nitrite, 4.0 days^{-1}; total nitrate, 1.0 day^{-1}; and total orthophosphate, 0.6 day^{-1}. The constituents that had the largest deviations between calculated and measured values were total ammonia and coliform bacteria. Based on the calibration, the model is capable of accurately predicting concentrations of carbonaceous biochemical oxygen demand, total organic nitrogen, total nitrite, and total orthophosphate; predicted concentrations of total ammonia, total nitrate, and dissolved oxygen will be somewhat less accurate. Additional data are needed to determine the model's capability to predict concentrations of coliform bacteria.

Traveltime and reaeration data were collected during October 19 to 21, 1976. The reaeration rates ranged from 5.04 to 12.1 days^{-1}.

Potential uses of the model were demonstrated by simulating the effects of different wastewater discharges on streamflow quality, using water-quality and stream-discharge data provided by the Pueblo Area Council of Governments. Selected results for carbonaceous biochemical oxygen demand and total ammonia from three simulations illustrate the capability of the model.

Based on water-quality data collected during April and October 1976, concentrations of nonionized ammonia exceeded the State standard of 0.02 milligram per liter in a reach of the Arkansas River downstream from the outfalls of the Pueblo wastewater-treatment plant and the CF & I Steel Corp. plant during periods of low discharge.

INTRODUCTION

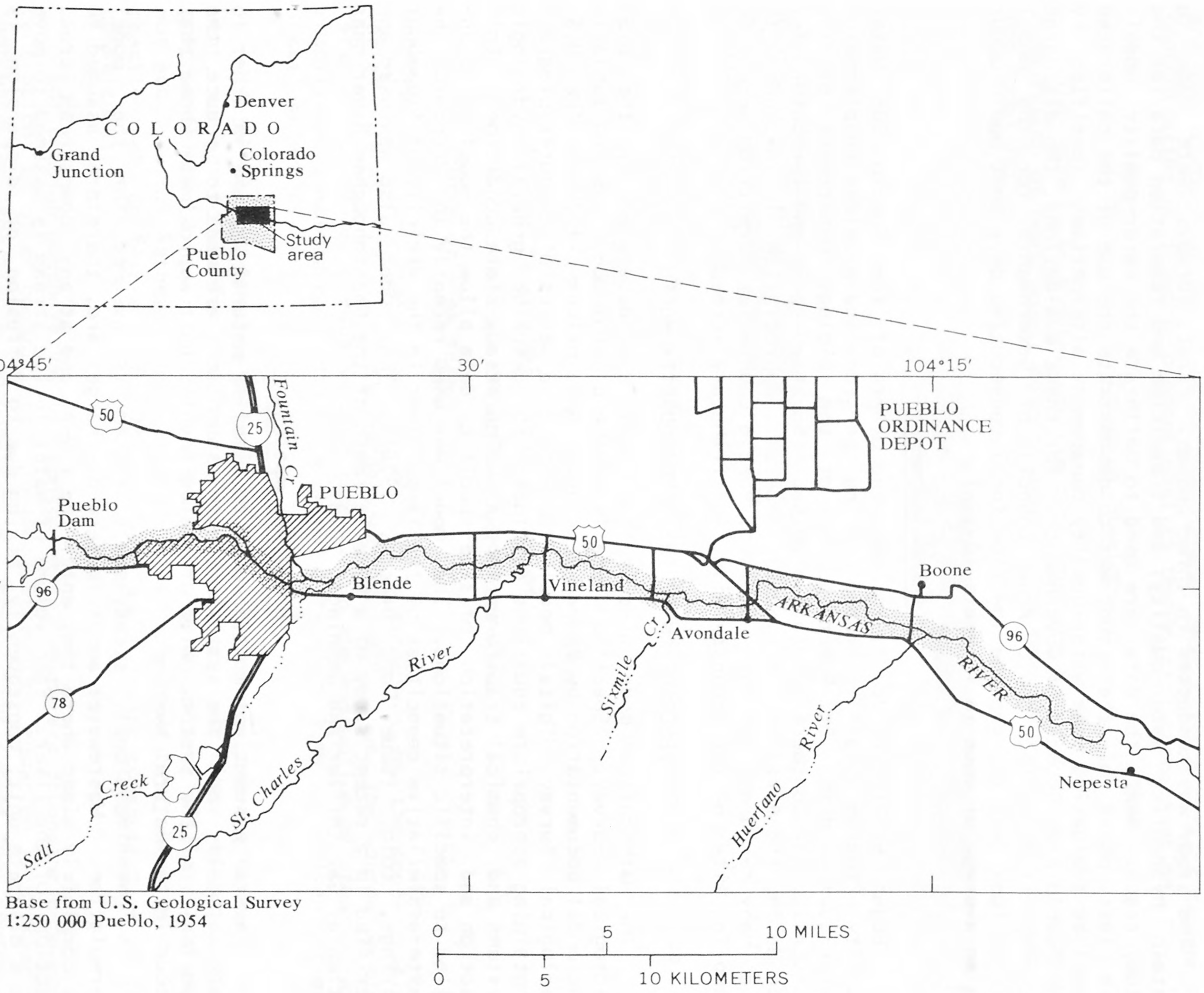
Pueblo County is located on the plains of eastern Colorado about 20 miles east of the Front Range of the Southern Rocky Mountains. The Arkansas River originates along the Continental Divide in central Colorado and flows through a mountainous section of Colorado for about 150 miles before entering the eastern plains and Pueblo County. Upstream from Pueblo County, the quality of the Arkansas River is suitable for all forms of recreation and propagation of game fish. However, in traversing Pueblo County, the quality of the Arkansas River is affected by waste disposal from agricultural, residential, and industrial sources. Two major sources of wastewater effluent, the Pueblo Wastewater Treatment Plant and the CF & I Steel Corp. plant, are located in the city of Pueblo. Water-quality problems that exist downstream from Pueblo include excessive concentrations of carbonaceous biochemical oxygen demand (CBOD) and the various nitrogen species.

To assist areas such as Pueblo County in reducing pollution of streams, the U.S. Congress passed Public Law 92-500 (Federal Water Pollution Control Act as amended in 1972). Section 208 of Public Law 92-500 provides for grants to local areas to be administered through a local planning agency. The local planning agency is to use the grants to develop and implement water-pollution controls to meet the goal of reducing pollution of streams by 1983 to conditions that are suitable for recreation and fish propagation. The Pueblo Area Council of Governments has the responsibility for coordination of studies dictated by Section 208 of Public Law 92-500 in Pueblo County.

Objectives

In order to fulfill the guidelines for implementing Section 208 of Public Law 92-500, the Pueblo Area Council of Governments requested that the U.S. Geological Survey conduct a 1-year investigation to develop the means to predict the environmental effects of planning alternatives as related to water quality in the Arkansas River.

The objectives of the investigation were to calibrate and demonstrate the use of a steady-state water-quality model in a 42-mile reach of the Arkansas River between Pueblo Dam and the stream-gaging station near Nepesta (fig. 1). The calibrated model will be used by the Pueblo Area Council of Governments to predict effects on water quality in the Arkansas River resulting from hypothetical management alternatives. Because of time constraints and monetary considerations the water-quality model was not verified for the stream reach. A second ongoing water-quality modeling study of the stream reach, however, will serve to verify the model.



Base from U.S. Geological Survey
1:250 000 Pueblo, 1954

Figure 1.-- Location of study area (study reach shaded).

Approach

The study was conducted in three phases. First, surveys were made to obtain hydraulic, water-quality, and traveltime and reaeration data for the study reach. Next, the data were used to calibrate the water-quality model. The last phase of the study was to demonstrate the use of the calibrated model by evaluating some water-quality management alternatives specified by the Pueblo Area Council of Governments. For these evaluations, the discharge rate specified by the Pueblo Area Council of Governments for the model simulations was the average low flow for 7 consecutive days that would occur on an average of once in 10 years ($Q_{7,10}$).

Acknowledgments

Eugene H. Fisher, Joe R. Foreman, and others of the Pueblo 208 Water Quality Program Staff assisted during the study and provided supplemental water-quality data. Dr. Robert Gordon of the Biology Department of the University of Southern Colorado provided laboratory space and incubators for use during the April data-collection program. Appreciation is extended to the many residents and land owners of Pueblo County for permitting access to sampling sites on the Arkansas River and tributary streams.

DESCRIPTION OF THE WATER-QUALITY MODEL

The mathematical model used in this study was developed by the U.S. Geological Survey. Specific details of the digital model are available in the model documentation by Bauer, Jennings, and Miller (1979). The U.S. Geological Survey digital model consists of a series of computer programs containing appropriate equations developed to describe general hydrologic systems and chemical transformations assuming steady-state conditions. Collection and interpretation of site-specific data allow the model to be applied to specific situations. The model was used recently to determine the waste-assimilative capacities of the Yampa River in the vicinity of Steamboat Springs, Colo. (Bauer and others, 1978). The model also was used and verified in a recent study of a 67-mile reach of the Chattahoochee River near Atlanta, Ga. (Miller and Jennings, 1978).

Model Assumptions

Several assumptions must be made to simplify natural systems in order to mathematically model the systems. These assumptions are made to reduce the complexity of the system, while providing results that approximate those that occur in the natural system.

A one-dimensional, steady-state system is assumed for the model formulation. Wastewater and tributary discharges are, therefore, assumed to be completely mixed where they enter the river, and at any downstream cross section of the river. Each volume of water in the stream is assumed to move as a discrete unit; consequently, mixing due to diffusion or dispersion is considered negligible. In application of the model, the river is divided into a number of subreaches, generally defined by the locations of wastewater or tributary inflow sites or outflow sites. Within these subreaches, discharge is held constant in the model.

Another assumption relates to the kinetics of biological reactions, reaeration, and settling processes that are modeled. First-order kinetics are used throughout the equation development; that is, the rate of change of concentration is directly proportional to the initial concentration.

Equation Development

The model is a deterministic type and uses a mass-balance equation for computation of constituent concentration. The mass-balance equation used in the model is:

$$\underbrace{\frac{\partial C}{\partial t}}_{\text{Rate of change of the conservative or nonconservative concentration with time}} = -\frac{1}{A}\underbrace{\frac{\partial (QC)}{\partial X}}_{\text{Rate of change of the conservative mass flow rate in the direction } X} \pm \underbrace{\Sigma S}_{\text{Source or sink terms in the system}} \tag{1}$$

where C = conservative or nonconservative concentration, in milligrams per liter;

t = time, in hours;

A = river cross-sectional area, in square feet;

Q = discharge, in cubic feet per second;

X = river downstream direction coordinate; and

S = source or sink term.

If the constituent to be modeled is conservative, the concentration varies only as a result of discharge variation (ΔQ); thus, the source or sink term in equation 1 equals zero ($\Sigma S=0$). In the assumption of steady-state conditions, computed concentrations do not vary with time at given stream locations or $\partial C/\partial t=0$.

If the constituent to be modeled is a simple nonconservative constituent, subject to chemical and biological reactions but not dependent upon concentrations of other variables, the source or sink term in equation 1 does not equal zero. Rather, the source or sink term equals KrC where Kr is the reaction-rate coefficient for the variable and C is the concentration of the constituent.

For coupled nonconservative constituents, which are dependent upon concentrations of other constituents in the system, the equation is similar to that used for the simple nonconservative constituent except that source or sink term contains other components. One of the links in a coupled system is the results from preceding reactions.

Equation 1 is used to calculate concentrations of conservative constituents such as total nitrogen, simple nonconservative constituents such as CBOD and coliform bacteria (Mahloch, 1973), as well as coupled nonconservative constituents such as nitrate and orthophosphate (Thomann, 1972). Computation of dissolved-oxygen concentration is based on a modified formulation of Streeter and Phelps (1925).

Application of Equation

A study reach is divided into subreaches on the basis of changes in hydraulic variables such as discharge or changes of the model parameters. Model parameters are herein defined as elements of a mathematical model used to describe a hydrologic condition or define a reaction rate or other process-describing characteristic. The model parameters remain constant during computations for a particular subreach. A value is computed for each constituent at the upstream end of each subreach by mass-balance calculations.

DATA REQUIRED FOR THE MODEL

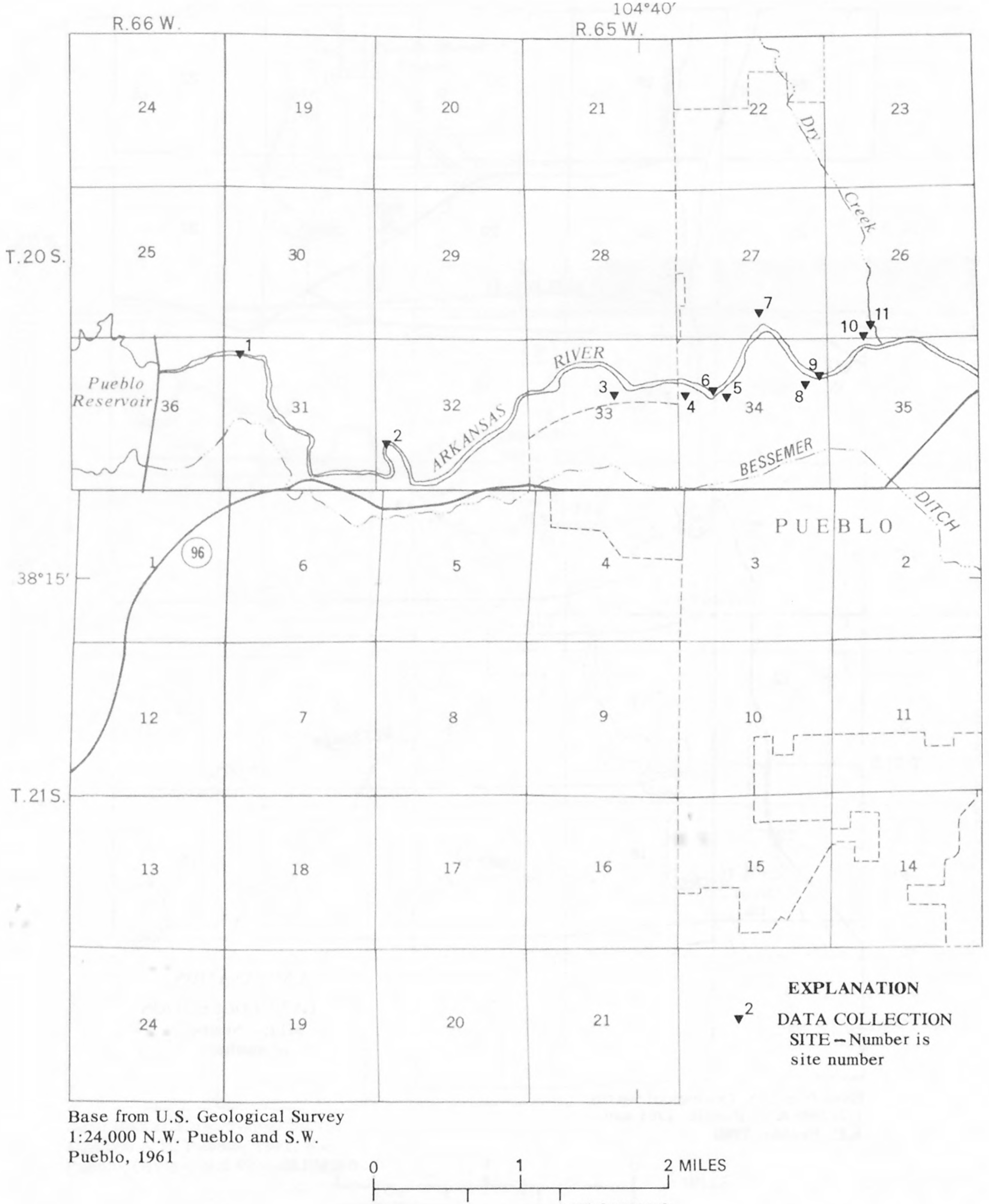
Intensive surveys were conducted during April and October 1976 to obtain the hydraulic and water-quality data required for calibrating the model. The April survey was conducted during a 24-hour period on April 1 to 2 when the initial upstream discharge was 115 cubic feet per second. The October survey was conducted during a 48-hour period on October 13 to 15 when the initial upstream discharge was 400 cubic feet per second. A traveltime survey using fluorescent dye was made during October 19 to 21, 1976, to determine mean stream-velocity characteristics of the study reach. During the same period, a survey was made to calculate reaeration-rate constants for the study reach using fluorescent dye and ethylene gas.

Data were collected at 38 sites along the 42-mile study reach: 23 sites on the Arkansas River, 6 sites at the mouths of drainage ditches or pipes, 5 sites on tributaries, and 4 sites where wastewater is discharged. The sites are located on figure 2 and are described in table 1.

Hydraulic Data

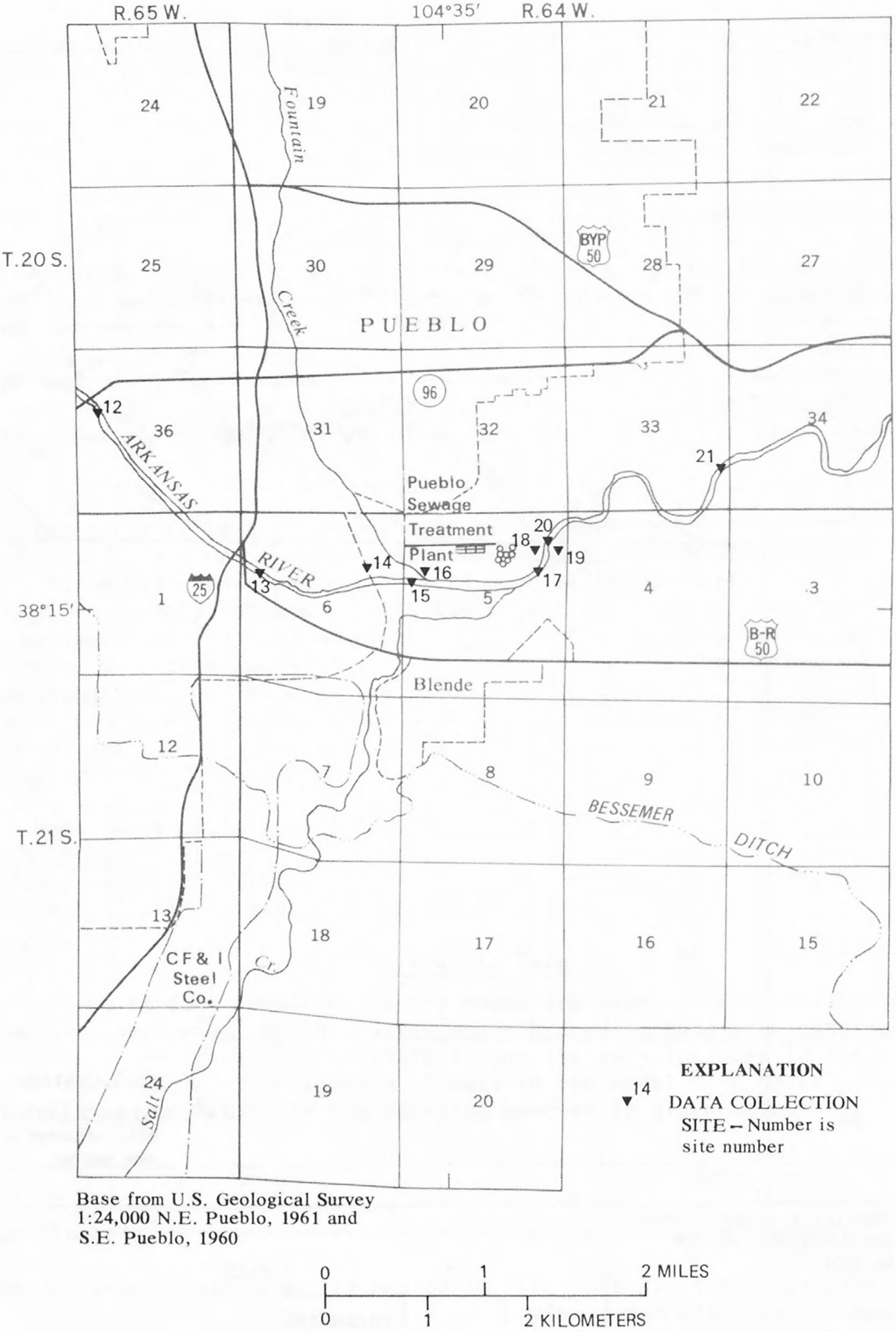
Hydraulic data required for the model are mean stream discharge, mean velocity, and mean depth. Sites where hydraulic data were obtained during the surveys are identified in table 1, and the data included in tables 2 and 3 in the section "Application of data in the model." A description of how hydraulic data are used in the modeling process is given below.

Data	Data use
Mean discharge-------------------------	Define discharge changes.
Mean cross-sectional velocity and depth	Estimate K_2, the reaeration coefficient, and estimate the mean velocity of each subreach.



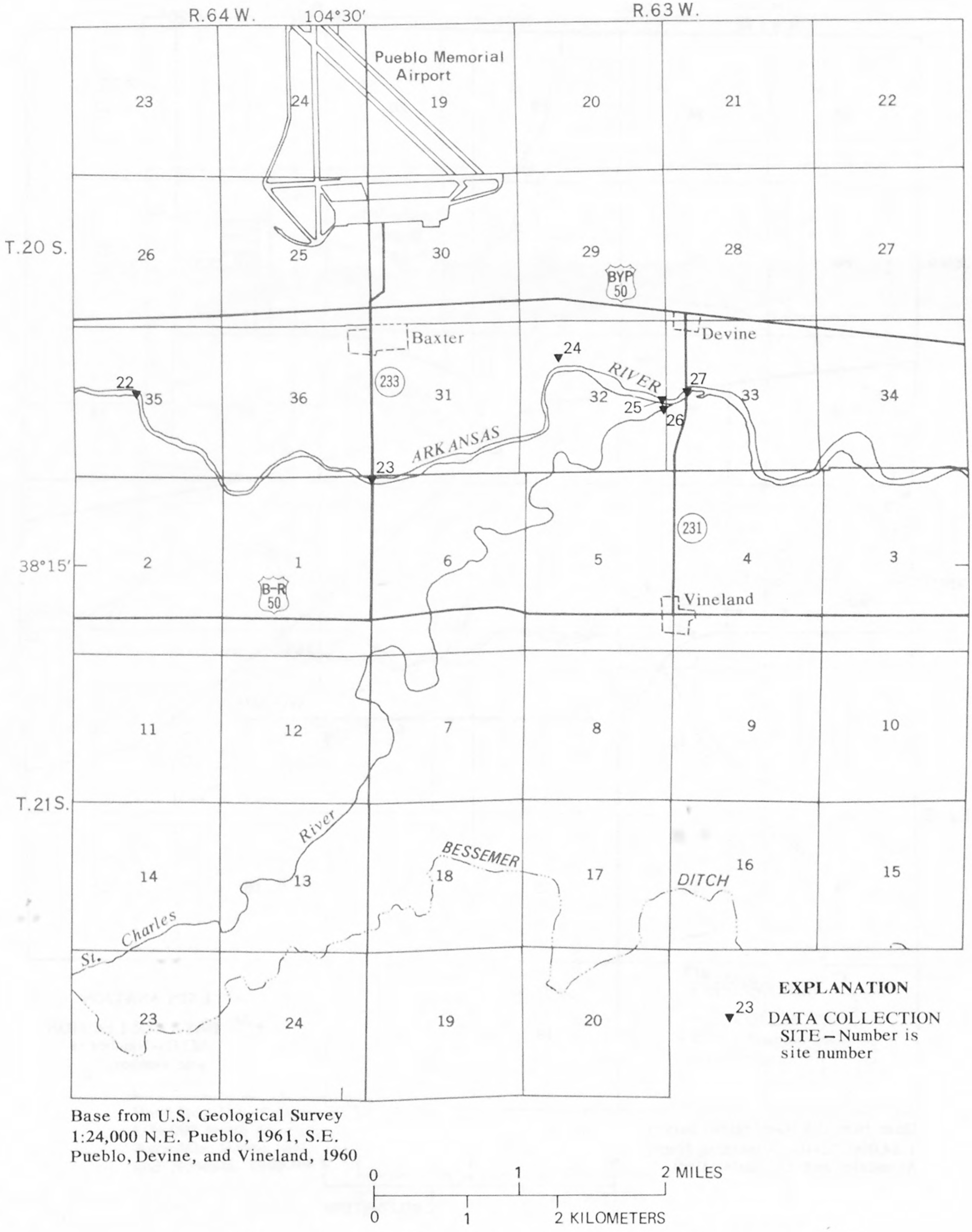
Base from U.S. Geological Survey
1:24,000 N.W. Pueblo and S.W.
Pueblo, 1961

Figure 2. -- Location of data-collection sites.



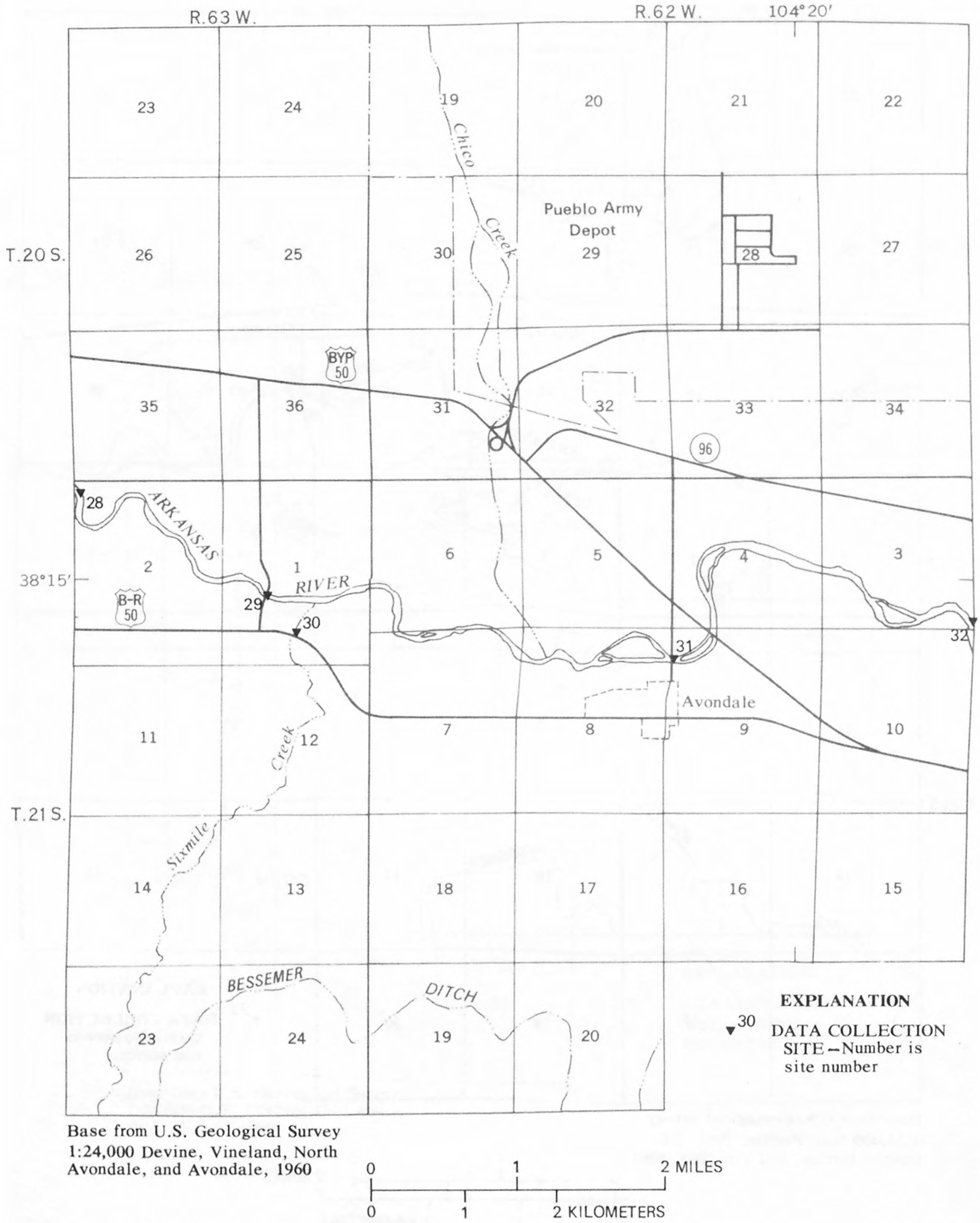
Base from U.S. Geological Survey
1:24,000 N.E. Pueblo, 1961 and
S.E. Pueblo, 1960

Figure 2. --Location of data-collection sites--Continued.



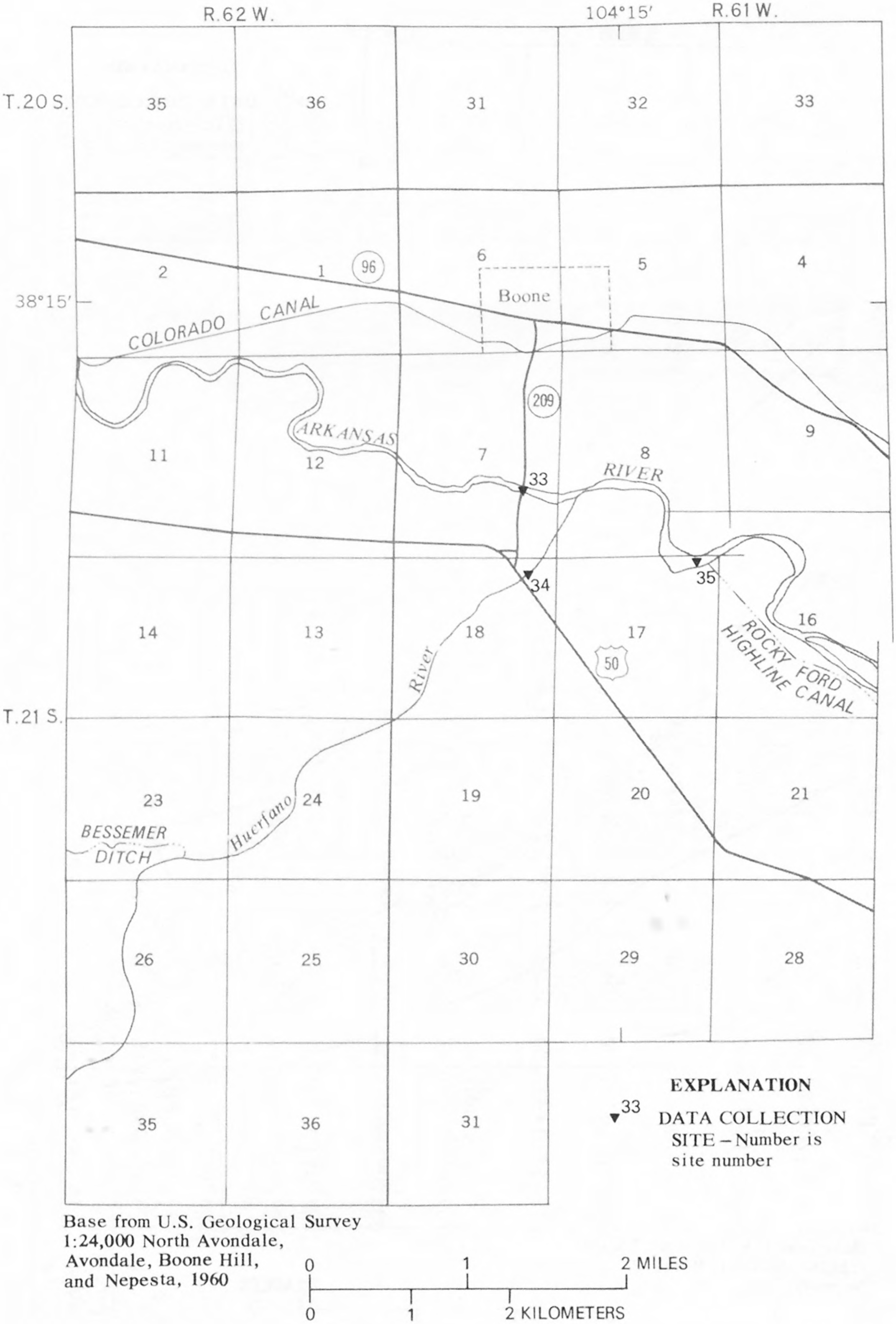
Base from U.S. Geological Survey
1:24,000 N.E. Pueblo, 1961, S.E.
Pueblo, Devine, and Vineland, 1960

Figure 2. -- Location of data-collection sites -- Continued.



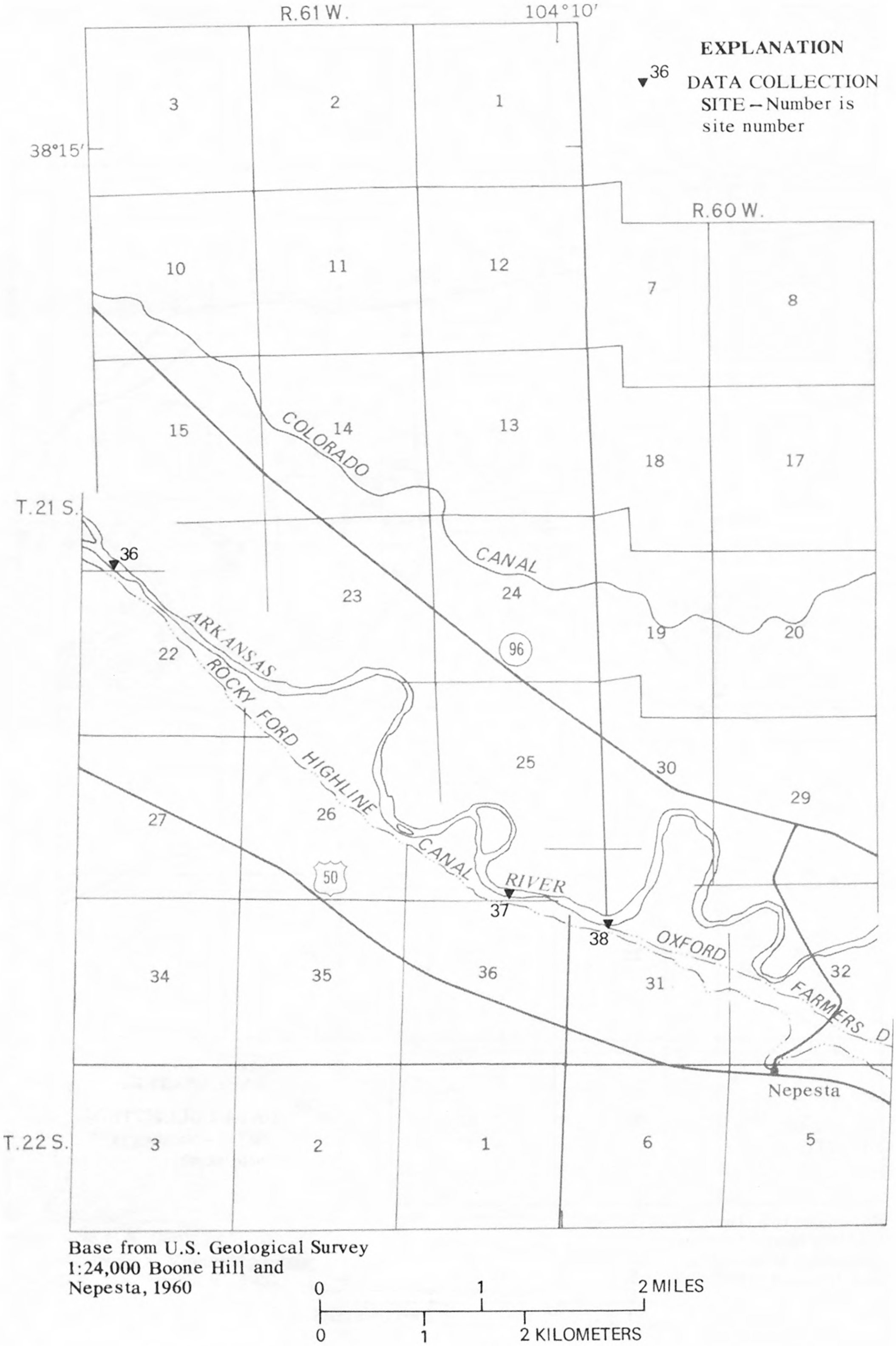
Base from U.S. Geological Survey
1:24,000 Devine, Vineland, North
Avondale, and Avondale, 1960

Figure 2.--Location of data-collection sites--Continued.



Base from U.S. Geological Survey 1:24,000 North Avondale, Avondale, Boone Hill, and Nepesta, 1960

Figure 2.--Location of data-collection sites--Continued.



Base from U.S. Geological Survey
1:24,000 Boone Hill and
Nepesta, 1960

Figure 2. -- Location of data-collection sites -- Continued.

Table 1.--*Description of data-collection sites, data types, and collection periods*

Site number[1]	Site identifier[2]	Site type[3]	River mile[4]	Name	Data type[5]	Collection period
1	381617104430600 (07099400)	M	42	Arkansas River above Pueblo--	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
2	381544104414400	M	40.1	Arkansas River near Goodnight.	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
3	381604104400500	D	38	Goodnight drain at mouth-----	Q,QW	Oct. 13-15
4	381604104394200	D	37.5	Pueblo Blvd. storm drain at mouth.	Q,QW	Oct. 13-15
5	381603104392200	D	37.3	City Park Drain Number One at mouth.	Q,QW	Oct. 13-15
6	381602104392600 (07099500)	M	37.2	Arkansas River near Pueblo---	Q,CG,QW Q,CG,QW Q,CG,DGI	April 1-2 Oct. 13-15 Oct. 19
7	381623104390500	D	36.7	Northside Water Works sluice at mouth.	Q,QW Q,QW	April 1-2 Oct. 13-15
8	381608104383800	D	36.2	City Park Drain Number Two at mouth.	Q,QW	Oct. 13-15
9	381624104383500	M	36.2	Arkansas River near southside water works.	Q,CG,DG	Oct. 19
10	381621104382000	D	35.9	Northside waterworks drain at mouth.	Q,QW Q,QW	April 1-2 Oct. 13-15
11	381628104381700	T	35.7	Dry Creek at mouth----------	Q,QW Q,QW	April 1-2 Oct. 13-15
12	381607104372500	M	34.9	Arkansas River at 4th street bridge.	Q,CG,QW Q,CG,QW Q,CG,DG	April 1-2 Oct. 13-15 Oct. 19

Table 1.--*Description of data-collection sites, data types, and collection periods*--Continued

Site number[1]	Site identifier[2]	Site type[3]	River mile[4]	Name	Data type[5]	Collection period
13	381607104372500	M	33.5	Arkansas River at Santa Fe Avenue bridge.	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
[6]14	381508104354400	W	32.8	Southern Colorado Power outfall.	Q,QW Q,QW	April 1-2 Oct. 13-15
15	381510104350900	M	32.5	Arkansas River near Colorado Highway 227 bridge.	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
16	381515104351900	T	32.3	Fountain Creek at mouth------	Q,QW Q,QW	April 1-2 Oct. 13-15
17	381520104342000	M	31.4	Arkansas River above Pueblo Wastewater Treatment Plant outfall.	Q,CG,DG	Oct. 19
18	381522104342100	W	31.3	Pueblo wastewater treatment outfall.	Q,QW Q,QW	April 1-2 Oct. 13-15
[7]19	381522104341800	T,W	31.2	Salt Creek at mouth---------	Q,QW Q,QW	April 1-2 Oct. 13-15
20	381523104341600	M	31.2	Arkansas River at Salt Creek-	Q,CG,DGI	Oct. 20
21	381547104330800	M	29.8	Arkansas River at 23rd Lane--	Q,CG,QW Q,CG,QW Q,CG,DG	April 1-2 Oct. 13-15 Oct. 20
22	381601104313000	M	27.9	Arkansas River at 28th Lane--	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
23	381530104294600	M	25.8	Arkansas River at Colorado Highway 233 bridge.	Q,CG,QW Q,CG,QW Q,CG,DG	April 1-2 Oct. 13-15 Oct. 20

Table 1.--*Description of data-collection sites, data types, and collection periods*--Continued

Site number[1]	Site identifier[2]	Site type[3]	River mile[4]	Name	Data type[5]	Collection period
24	381609104282600	W	24.2	Meadowbrook wastewater treatment-plant outfall.	Q,QW Q,QW	April 1-2 Oct. 13-15
25	381600104272600	M	23.3	Arkansas River above St. Charles River.	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
26	381556104273300	T	23.2	St. Charles River at mouth---	Q,QW Q,QW	April 1-2 Oct. 13-15
27	381613104272600	M	23.1	Arkansas River at Colorado Highway 231 bridge.	Q,CG,DG	Oct. 20
28	381532104252100	M	20.5	Arkansas River at 40th Lane--	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
29	381453104235500 (07109500)	M	18.5	Arkansas River near Avondale-	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
30	381440104234200	T	18.1	Sixmile Creek at mouth-------	Q,QW Q,QW	April 1-2 Oct. 13-15
31	381432104205500	M	15.3	Arkansas River at Avondale---	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
32	381443104184200	M	12.4	Arkansas River at Colorado Canal headgate.	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15
33	381401104153700	M	7.8	Arkansas River at Boone------	Q,CG,DGI	Oct. 21
34	381332104153900	T	7.4	Huerfano River near mouth----	Q,QW Q,QW	April 1-2 Oct. 13-15
35	381338104142400	M	6.7	Arkansas River at Rocky Ford Highland Canal headgate.	Q,CG,QW Q,CG,QW	April 1-2 Oct. 13-15

Table 1.--*Description of data-collection sites, data types, and collection periods*--Continued

Site number[1]	Site identifier[2]	Site type[3]	River mile[4]	Name	Data type[5]	Collection period
36	381247104125900	M	4.0	Arkansas River below Rocky Ford Highland Canal headgate.	Q,CG,DG	Oct. 21
37	381103104102200 (07117000)	M	0	Arkansas River near Nepesta--	Q,CG,QW Q,CG,QW Q,CG	April 1-2 Oct. 13-15 Oct. 21
38	381054104094100	M	-0.7	Arkansas River at Oxford Farmers Canal headgate.	DG	Oct. 21

[1] Site number refers to number on figure 2 and in all tables.

[2] Latitude (first six digits), longitude (next seven digits), and sequence code (last two digits); U.S. Geological Survey station number given in parenthesis for established gaging stations.

[3] M=main channel of Arkansas River; D=drainage ditch or pipe; T=natural tributary; W=wastewater discharge.

[4] River miles upstream from the gaging station, Arkansas River near Nepesta.

[5] Q=discharge; CG=channel cross-sections; QW=water quality; DGI=dye and gas-tracer injection; DG=dye and gas-tracer concentration.

[6] Discharge of cooling water from Southern Colorado Power's electrical generating facility, at Pueblo. Flows through Runyon Lake upstream from site.

[7] Wastewater from CF & I Steel Corp. is discharged to Salt Creek.

Water-Quality Data

During the April and October surveys, measurements of water temperature, specific conductance, pH, and dissolved-oxygen (DO) concentration were made at 31 sites. Water samples also were collected at the 31 sites for analysis of 5-day carbonaceous biochemical oxygen demand ($CBOD_5$), total Kjeldahl nitrogen, total ammonia, total nitrite, total nitrate, total phosphorus, total orthophosphate, and total- and fecal-coliform bacteria. At sites where the discharge of wastes was suspected to have the greatest impact on water quality of the Arkansas River, such as Salt Creek (site 19), the sampling frequency ranged from 1.5 to 3 hours for at least 24 hours. At the other sites, the sampling frequency ranged from 4 to 6 hours for at least 24 hours. Water-quality data collected during the study are listed in the Supplemental Information section (pages 65 to 81). Uses of water-quality data in the model are described below.

Data	Data use
Water temperature--------	Calculate DO saturation values, make adjustments of rate constants, and determine nonionized ammonia concentrations.
pH----------------------	Determine nonionized-ammonia concentrations.
DO----------------------	Determine DO concentrations of the inflows and help define the DO profile for the Arkansas River.
$CBOD_5$ concentrations-----	Determine $CBOD_5$ concentrations of the inflows at selected locations on the Arkansas River.
Nitrogen and phosphorus species concentrations.	Determine nitrogen and phosphorus concentrations of the inflows and at selected locations along the Arkansas River.
Total- and fecal-coliform bacteria concentrations.	Determine total- and fecal-coliform concentrations of the inflows and at selected locations along the Arkansas River.

Traveltime and Reaeration Data

During the traveltime and reaeration data-collection survey, the study reach was divided into three subreaches because of variations in channel characteristics, such as cross-sectional configuration, depth, streambed materials, and streambed gradient. Subreach 1 consisted of sites 1 to 19, subreach 2 consisted of sites 20 to 32, and subreach 3 consisted of sites 33 to 38 (fig. 2). Fluorescent dye (rhodamine-WT) and ethylene gas were injected at site 6 in subreach 1, at site 20 in subreach 2, and at site 33 in subreach 3. Dye and gas samples were collected at sites 9 and 17 in subreach 1, at sites 21, 23, and 27 in subreach 2, and at sites 36 and 38 in subreach 3. Traveltime and reaeration data for subreach 1 were affected by sluicing of water at a diversion dam in the subreach.

Uses of traveltime and reaeration data in the model are listed below.

Data	Data use
Dye concentrations---------	Refine mean-reach velocity and traveltime estimates.
Tracer-gas concentrations--	Determine K_2, the reaeration coefficient.

APPLICATION OF DATA IN THE MODEL

Hydraulic Data

The accuracy of the model application is dependent on the detail with which the physical hydrology of the study reach is defined. Hydraulic data that are critical in the model calibration are river discharge, traveltime, and reaeration rate. These factors greatly affect a river's ability to assimilate wastes. Discharge is usually the dominant factor in the assimilative capacity of a river. Traveltime is the time element involved in the self-purification processes such as biochemical oxidation and nitrification. The reaeration rate, or the rate at which atmospheric oxygen dissolves in a stream, is critical in determining DO concentrations as well as affecting all oxygen-consuming processes.

Discharge

The complexity of most river systems limits the capability for modeling seasonal water-quality changes. However, in many river systems, there exists a particular period during which most water-quality variables reach critically large or small values (Hines and others, 1975). In the Arkansas River, as in most river systems, this period occurs at the time when discharge is minimal. Periods of minimal discharge are likely to produce the largest instream concentrations of waste-related constituents due to reduced dilution capacity. The Arkansas River in Pueblo County has two periods of minimal discharge each year--one in the spring, March to early May, before melting of snow in the mountains begins; and one in the fall, mid-August to mid-October, after melting of snow has ceased. The two intensive surveys were planned to correspond to the minimal-discharge periods.

Discharge profiles are calculated by the model by addition of the various wastewater and tributary discharges to and subtraction of the diversions from the initial upstream discharge. Model-computed discharge profiles of the Arkansas River and measured discharge values for the April and October surveys are shown in figure 3.

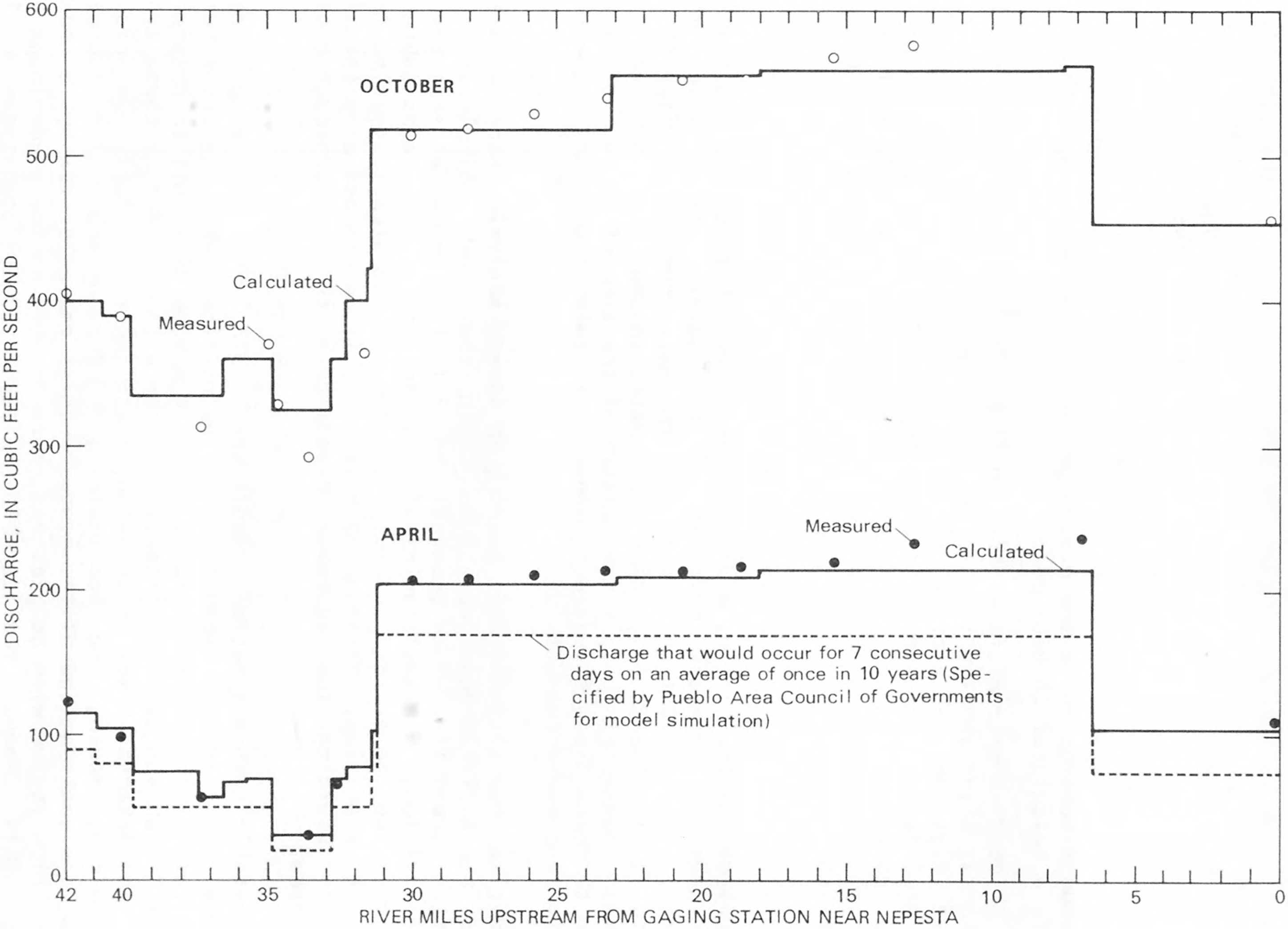


Figure 3.--Model-generated discharge profiles and discharge measurements, April and October 1976, and hypothetical profile of minimal discharge that would occur for 7 consecutive days on an average of once in 10 years.

Discharge was determined for the initial upstream point as well as for each wastewater and tributary inflow and diversion outflow. Because approximate steady-state discharge conditions existed, one or two discharge measurements were sufficient to quantify discharge except at the outfalls of the two wastewater-treatment plants. Municipal wastewater-treatment plants are subject to unequal inflow during the 24-hour cycle. Due to this unequal inflow, a diurnal cycle of discharge occurs at the wastewater-treatment plants in the study reach. Numerous measurements were made at these sites to assure accurate discharge data. The discharge-measurement data used in the model are given in table 2. Measured discharge, as shown in table 2, is an instantaneous discharge while the discharge used in the model, also shown in table 2, is a calculated 24-hour mean.

The third discharge profile shown in figure 3 is a hypothetical profile of the Arkansas River showing the minimal discharge that would occur for 7 consecutive days on an average of once in 10 years. This hypothetical discharge profile was computed for the Pueblo Area Council of Governments by a private contractor (Dumeyer, 1975). Discharge shown in this profile was used in predictive model simulations as specified by the Pueblo Area Council of Governments.

Traveltime

In considering traveltime, a distinction is made between the translation of a flood wave and the mass movement of the water. Flood waves move approximately 1.5 to 2.0 times faster than the mass movement of water (Bauer and others, 1979), particularly where large water volumes are involved. It is the mass movement that is the measure of the time of passage of wastes from reach to reach along the stream channel. In this discussion, traveltime pertains to this mass movement.

Traveltime has a significant bearing on stream analysis, because wastes introduced into a stream move downstream with the flow. Simultaneously, these wastes are affected by chemical and biological processes that change their concentrations. In application of data in the model, mean-subreach velocity must be determined because the model calculates traveltime from mean-subreach velocities. Mean-subreach velocity is determined at a specific discharge by dividing the subreach discharge by the mean-subreach cross-sectional area.

Unacceptable errors sometimes result when using the discharge versus area method to calculate mean-subreach velocities. When the river being studied is variable in cross-sectional area, it may be difficult to determine an accurate mean-subreach cross-sectional area with only two or three cross sections. The Arkansas River in the study reach varies greatly in cross-sectional width, depth, and bed material. For low and medium discharge conditions, the upstream end of the study reach is characterized by a pool-and-riffle flow regime with cobbles and coarse gravel as the predominant bed materials. This channel configuration alters slowly downstream. The downstream end of the study reach for all discharge conditions is characterized by a regular-gradient shifting-sand channel. Typical cross sections and bottom material along the study reach are shown in figure 4.

Table 2.--*Measured discharges for the April and October 1976 surveys and discharges used in the model*

Site number	Site type	River mile	April 1976 survey				October 1976 survey			
			Date	Time	Measured discharge	Discharge used in model	Date	Time	Measured discharge	Discharge used in model
					cubic feet per second				cubic feet per second	
1	Initial Arkansas River.	42.0	1	1020	121	115.0	13	0900	404	400
							14	0800	401	
--	Diversion------	41.0				[1]10.0				[2]10.0
--	Diversion------	39.8				[2]30.0				[2]55.0
3	Drainage-------	38.0				[3].1	13	1030	.06	.1
4	Drainage-------	37.5				[3].5	13	1100		.5
--	Diversion------	37.4				[2]18.0				[2]0
5	Drainage-------	37.3				[3].6	13	1135	.58	.6
7	Drainage-------	36.7				[2]10.0				[2]25
8	Drainage-------	36.2				[3]1.0	13	1305	.98	1.0
10	Drainage-------	35.9	2	1810	1.85	1.8	13	1345	.45	.4
11	Tributary------	35.7	2	1830	.10	.10	13	1415	0	.1
--	Diversion------	34.8				[1]40.0				[1]35.0
14	Wastewater-----	32.8	2	1235	38.6	39.0	13	1650	34.1	34
16	Tributary------	32.3	2	1340	6.54	6.5	13	1745	41.2	40.0
							14	1230	8.48	
18	Wastewater-----	31.3	1	2055	[5]27.9	24.7	13	0740	[5]13.2	20.1
			1	2315	24.8		13	0920	24.6	
			2	0130	23.2		13	1105	25.4	
			2	0605	17.0		13	1220	27.5	
			2	0835	22.8		13	1330	26.1	
			2	1130	33.3		13	1430	23.8	
			2	1440	28.6		13	1630	23.2	
			2	1740	25.5		13	1750	22.0	
							13	1845	21.7	
							13	1945	22.3	
							13	2125	23.5	
							13	2310	23.2	
							14	0200	17.8	
							14	0430	13.9	
							14	0800	15.2	
							14	1005	26.1	
							14	1350	24.1	

Table 2.--*Measured discharges for the April and October 1976 surveys and discharges used in the model*--Continued

Site number	Site type	River mile	April 1976 survey				October 1976 survey			
			Date	Time	Measured discharge (cubic feet per second)	Discharge used in model (cubic feet per second)	Date	Time	Measured discharge (cubic feet per second)	Discharge used in model (cubic feet per second)
19	Wastewater-----	31.2	2	1515	105	103	14	1535	92.6	93.0
			2	1640	101					
24	Wastewater-----	24.2	2	1340	.17	.1	13	1103	.03	.1
26	Tributary------	23.2	2	1200	4.75	4.8	13	1155	39.2	39.0
30	Tributary------	18.1	2	1130	2.91	2.9	13	1420	4.65	4.6
34	Tributary------	7.4	2	1045	.93	.9	13	1707	2.79	2.8
--	Diversion------	6.5				[4]110.0				[4]110.0

[1] Information from Public Service Company of Colorado.

[2] Information from Pueblo Board of Water Works.

[3] Estimated from October survey.

[4] Information from Colorado Department of Natural Resources, Office of the State Engineer.

[5] Discharge determined using calibrated flume.

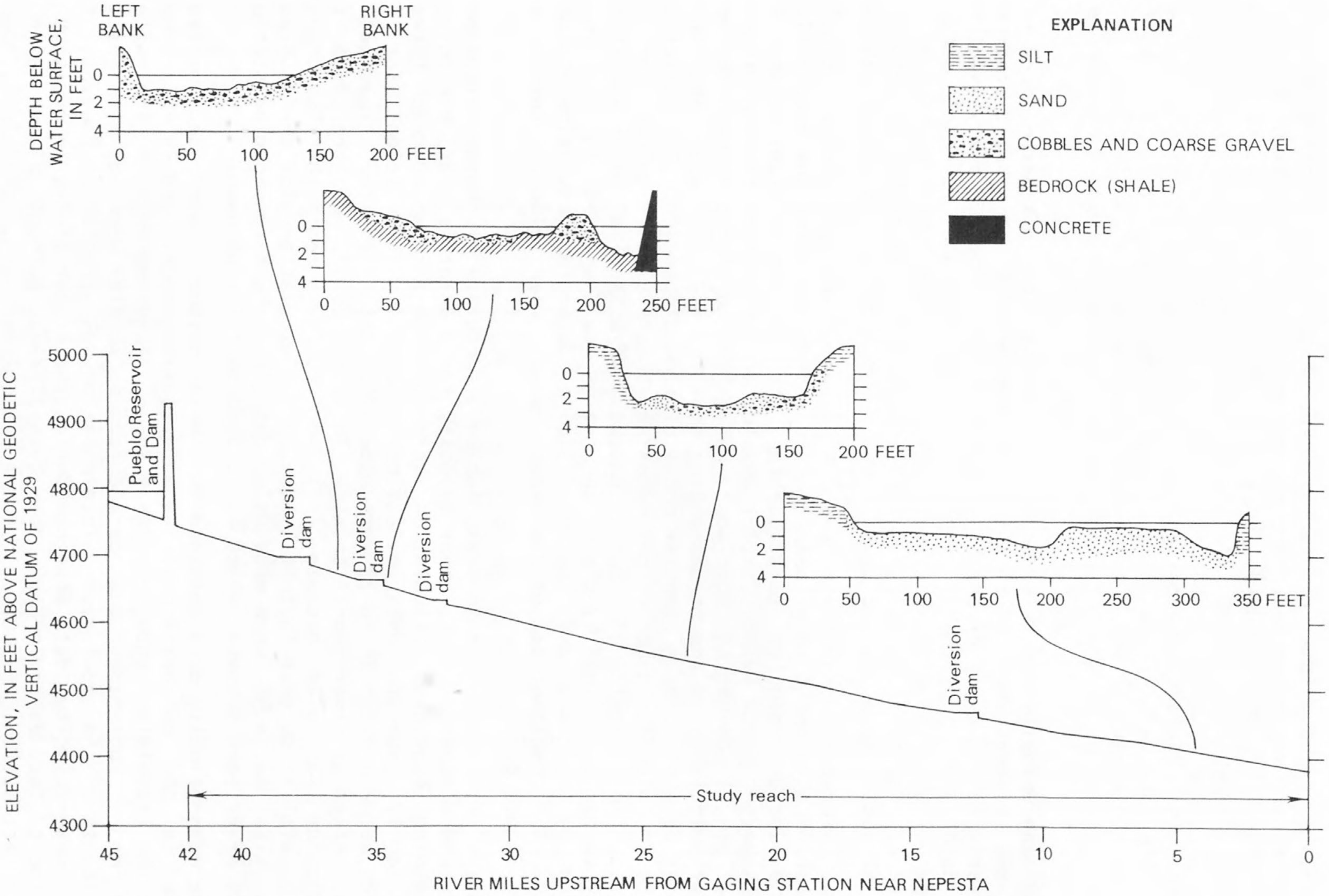


Figure 4.--Slope profile, selected cross sections, and bed material, Arkansas River study reach.

To help improve the traveltime determinations, a tracer study using rhodamine-WT dye was conducted. The procedure involved injecting dye into the Arkansas River and measuring the time necessary for the dye to reach and pass downstream points. Three dye studies were conducted so that traveltime for the various stream reach types found in the model reach could be evaluated. The resultant dye-passage curves are shown in figures 5, 6, and 7. The time interval between the centroids of the dye-passage curves was the method used to measure traveltime between sampling points. Traveltime of the dye and calculated mean velocities of the dye in the study subreaches are listed in table 3.

The mean velocity determined only applies for the discharge occurring during the tracer run. Estimation of mean velocity at other discharges, particularly at the $Q_{7,10}$ discharge, requires a more rigorous analysis of the tracer data plus additional streamflow data. The goal is development of discharge versus mean-velocity curves. The procedure for development of these relationships is briefly discussed below and is described in detail in reports by Bauer, Rathbun, and Lowham (1979) and McQuivey and Keefer (1976).

The procedure involves use of known discharge versus velocity relationships at a point in or near the study reach to determine hypothetical discharge versus velocity relationships for the entire study reach. The known discharge versus velocity relationships are calculated from information obtained at stream-gaging stations. Ratios are developed between the mean and shear velocities at the stream-gaging station and the mean and shear velocities determined by a computer model of flow dispersion. The ratios are then used to calculate hypothetical mean- and shear-velocity values for the study reach for a series of index discharges. Hypothetical mean- and shear-velocity values determined by use of the ratios are then used in the model developed by McQuivey and Keefer (1976) to determine traveltime and mean velocity. The resultant set of discharge versus mean-velocity curves are shown in figure 8.

Sufficient information for calculation of accurate discharge versus mean velocity and discharge versus shear velocity for a point is available only at stream-gaging stations. Calculations were not made for the subreach between sites 9 to 17, due to data-collection problems. Calculations for the subreach between sites 21 to 27 were made using data from the stream-gaging station, Arkansas River near Avondale. This station is not located in the subreach, but was used because it is located in a reach that has channel geometry similar to that in this subreach. Calculations for the subreach between sites 36 to 38 were made using data from the stream-gaging station, Arkansas River near Nepesta, which is located in this subreach.

The mean-velocity data obtained by these methods were used wherever possible in the calibration of the water-quality model used in this study. Because the traveltime-study subreaches do not always match with the water-quality model subreaches and because tracer studies were not made for the entire length of the model reach, interpolation was necessary. However, the use of mean-velocity data obtained during the tracer study, in addition to mean-velocity data determined by the channel-area method, allows a more accurate estimation of subreach mean velocities and, therefore, model-calibrated traveltimes.

Table 3.--*Geometry of selected subreaches of the Arkansas River, and traveltime and velocity data collected in the subreaches during October 1976*

Subreach as defined by site numbers indicated	Geometry				Traveltime data		Velocity data			
	Decrease in elevation of water surface through subreach (feet)	Length of subreach (feet)	Slope of subreach	Mean depth of water in subreach (feet)	Traveltime of peak concentration of dye cloud through subreach (minutes)	Traveltime of centroid of dye cloud through subreach (minutes)	Mean velocity of peak concentration of dye (feet per second)	Mean velocity of centroid of dye cloud (feet per second)	Shear velocity (feet per second)	Mean velocity of peak times slope of subreach (feet per second)
9-17	50	25,344	0.00197	1.70	210	182	2.01	2.32	0.33	0.00396
21-23	35	21,120	.00166	2.02	205	161	1.64	2.19	.33	.00272
23-27	25	13,200	.00189	1.70	95	90	2.29	2.44	.32	.00433
21-27	60	34,320	.00175	1.70	300	252	1.9	2.3	.31	.00333
36-38	37	24,820	.00149	1.11	230	240	1.8	1.72	.23	.00268

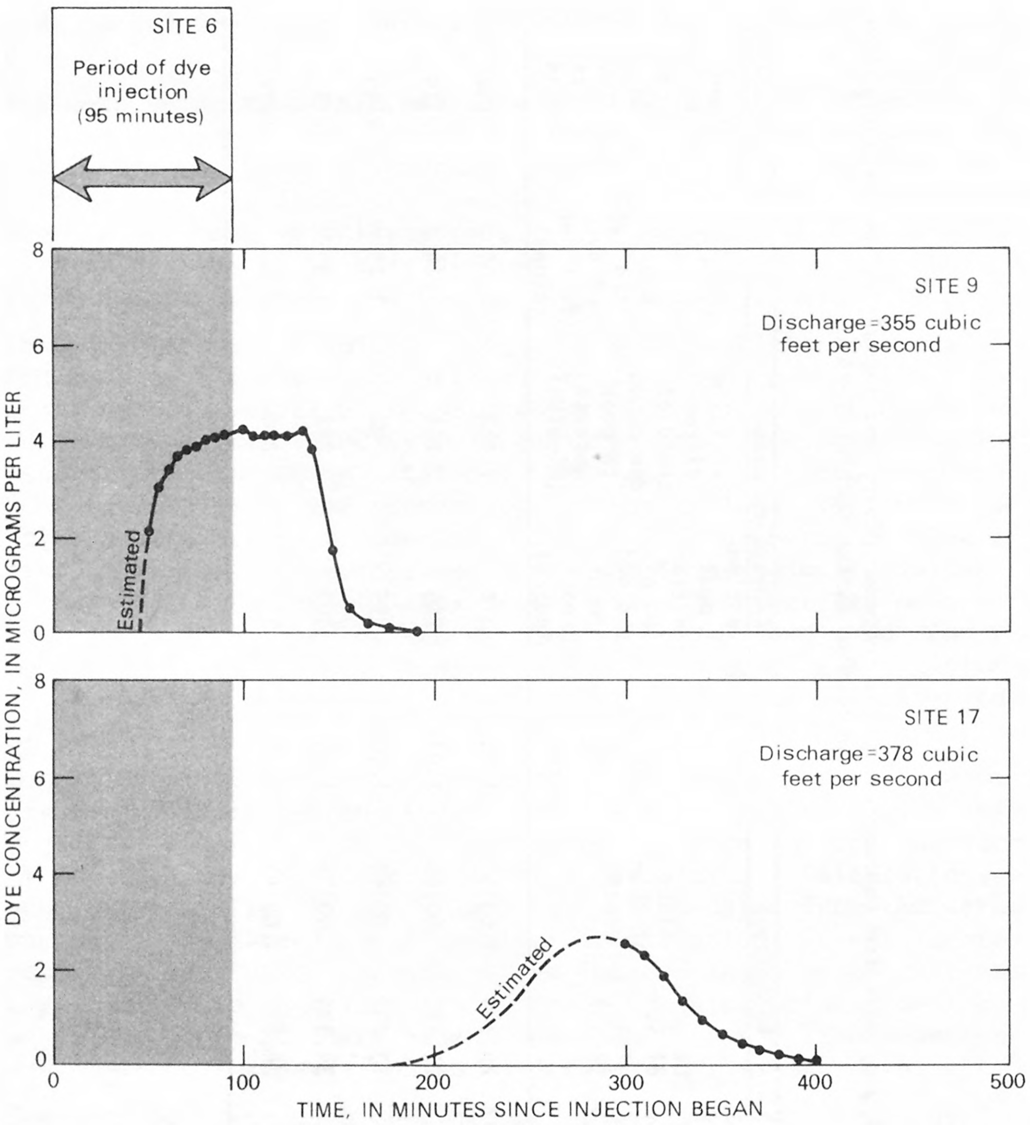


Figure 5.--Dye concentration versus time curves, Arkansas River, sites 9 (river mile 36.2) and 17 (river mile 31.4), October 1976.

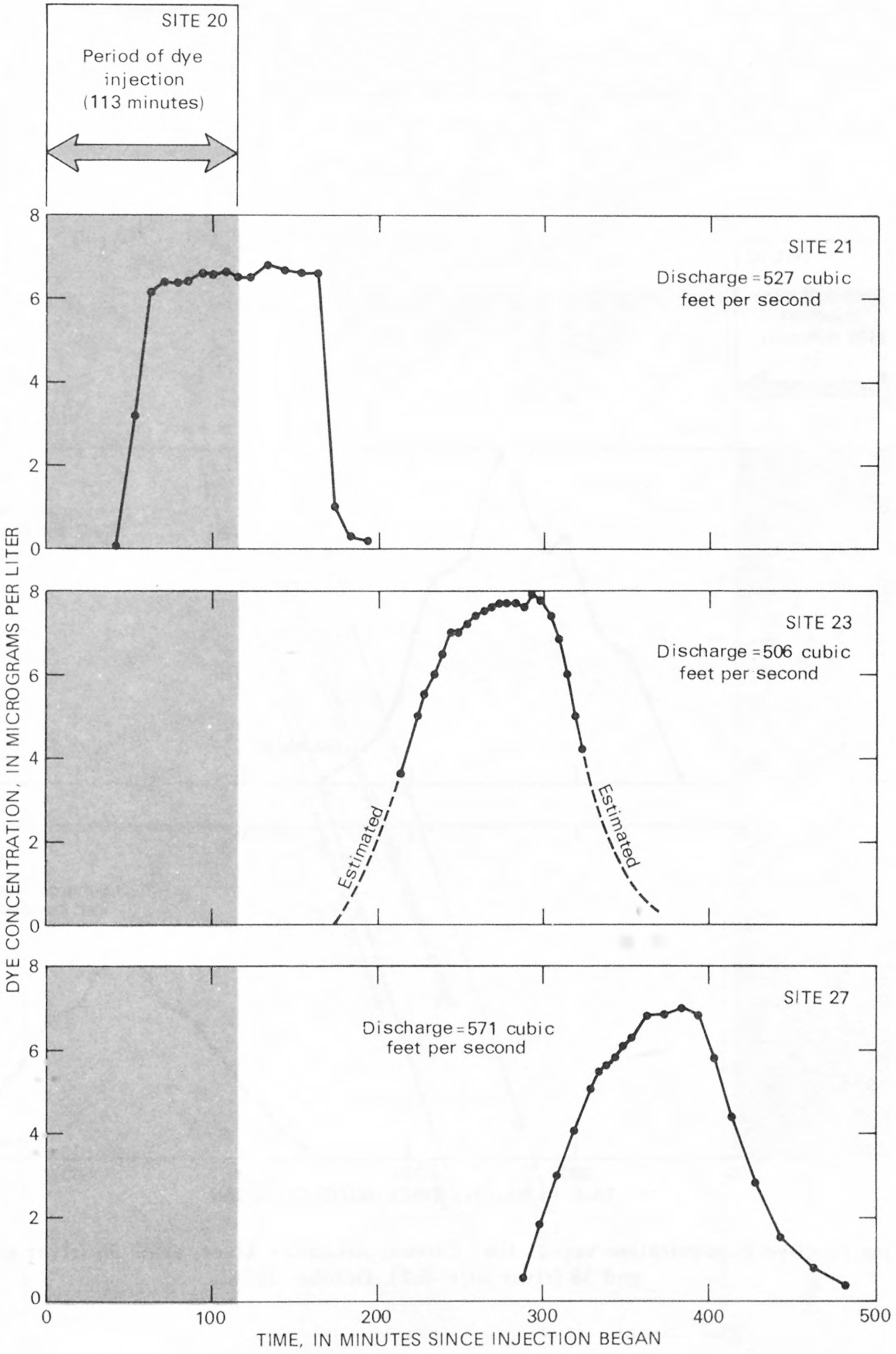


Figure 6.--Dye concentration versus time curves, Arkansas River, sites 21 (river mile 29.8), 23 (river mile 25.8), and 27 (river mile 23.1), October 1976.

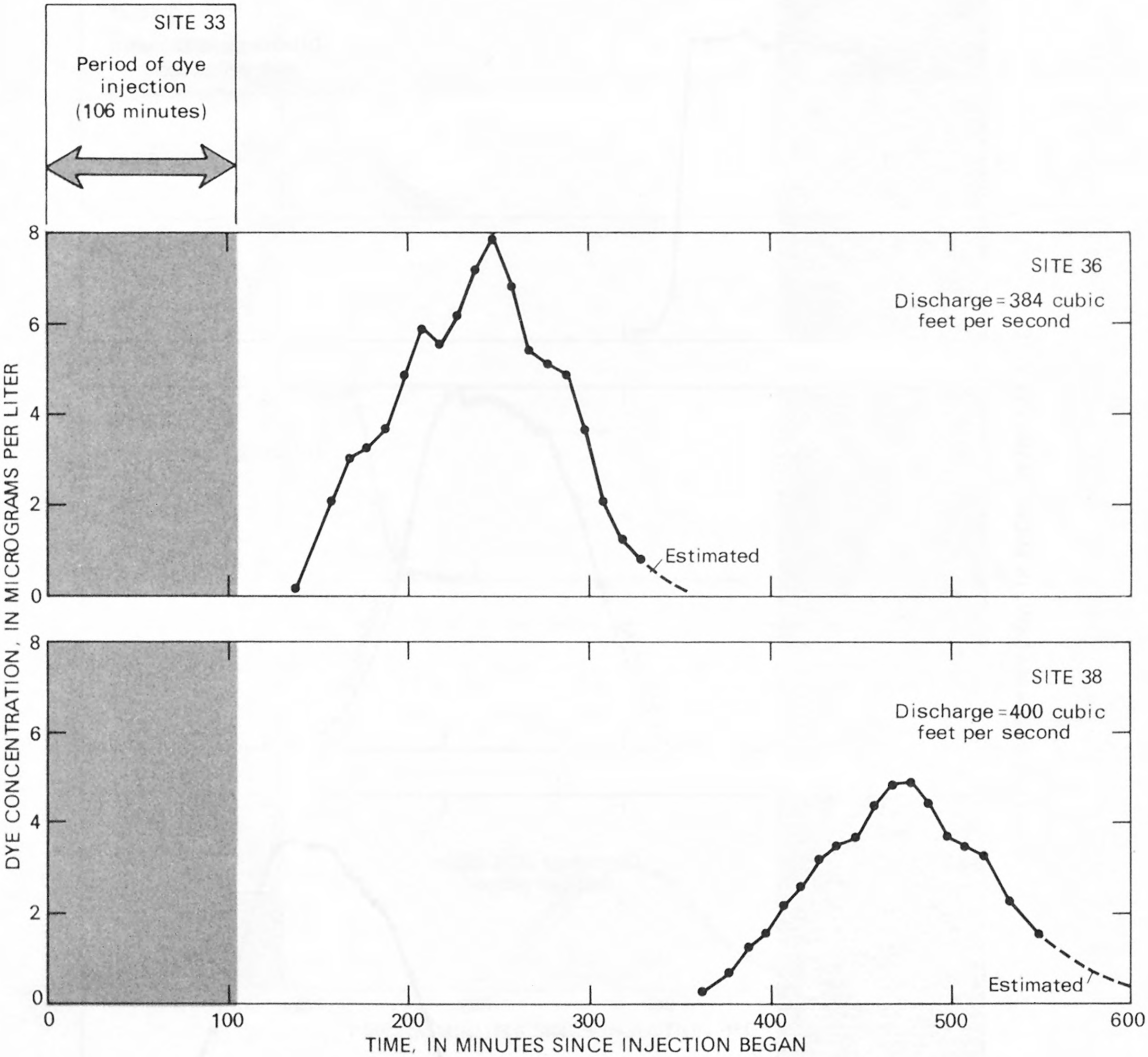


Figure 7.--Dye concentration versus time curves, Arkansas River, sites 36 (river mile 4.0) and 38 (river mile -0.7), October 1976.

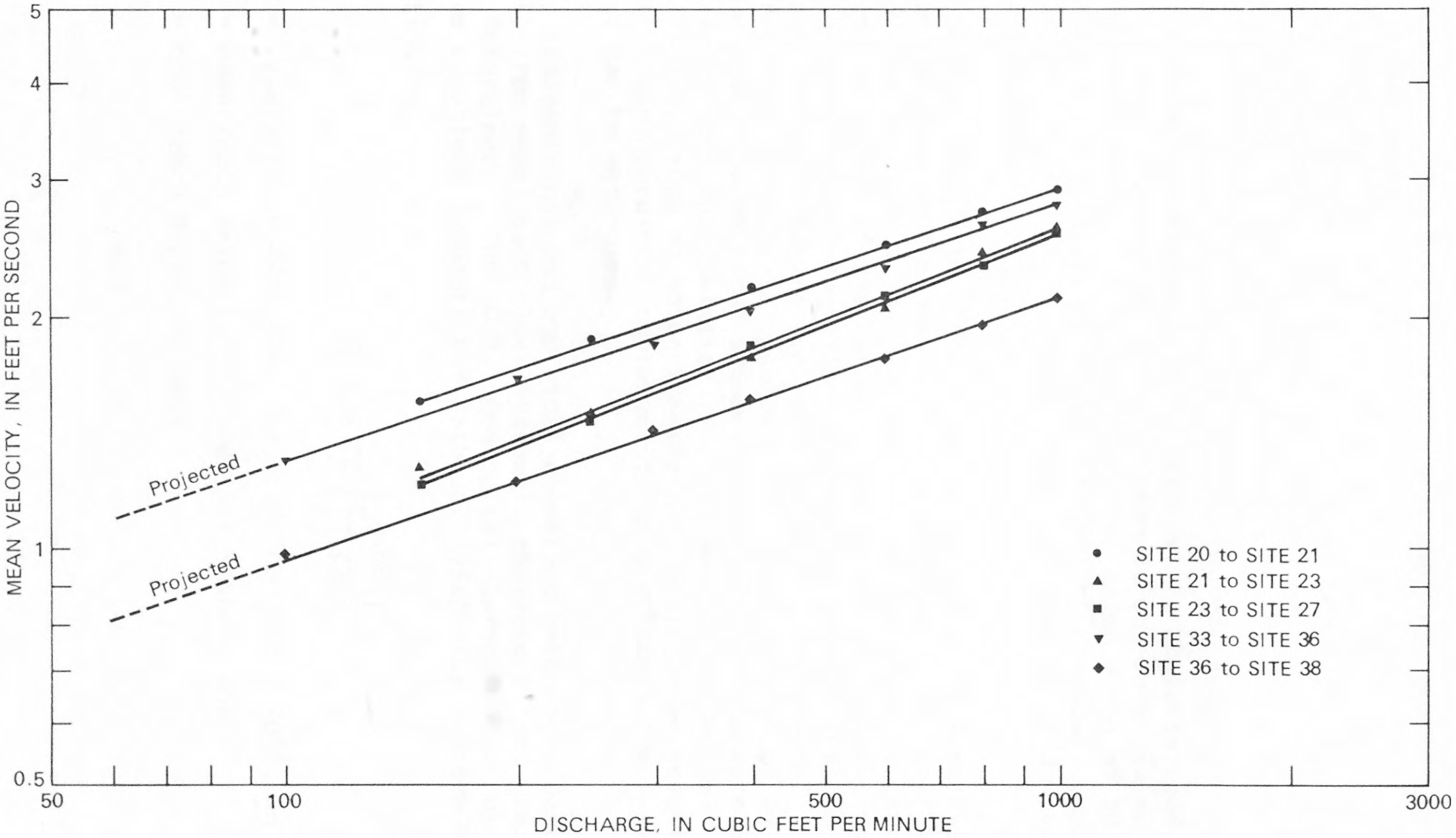


Figure 8.--Calculated mean-velocity curves for the Arkansas River, using the index-discharge stations, Arkansas River near Avondale and Arkansas River near Nepesta.

Reaeration

A stream has a natural capacity for purifying itself by oxidizing biodegradable wastes. The oxygen required to complete the reactions is obtained from the stream water, which normally contains some DO. The amount of DO that is present in the stream is dependent primarily upon two factors: DO contained in the stream water and any DO added from tributaries along the course; and reaeration, the physical absorption of oxygen from the atmosphere. Reaeration is the primary mechanism by which a stream replaces oxygen consumed in biodegradation of organic wastes.

The reaeration process in a stream is characterized by its surface reaeration rate. Knowledge of the reaeration rate (also known as the reaeration coefficient, K_2) is necessary for calculation of DO concentrations which, in turn, is a critical factor in many biochemical reactions. Hence. determination of K_2 is necessary for calibration of a waste-assimilative water-quality model.

The rate at which atmospheric oxygen dissolves in a stream is variable. Reaeration depends on the amount of DO present: If the water is supersaturated with DO, reaeration is negative; if the water is saturated with DO, reaeration is zero; if the water contains no DO, reaeration is maximum. Between these extremes, reaeration is directly proportional to the DO deficit (difference between saturation and concentration present). Although the magnitude of the DO deficit regulates the total amount of DO that can enter the stream under the physical process of reaeration, the rate at which atmospheric oxygen goes into solution is dependent upon physical and hydrologic characteristics, such as water temperature, depth, mean velocity, and stream slope. If these hydrologic characteristics are known, the reaeration coefficient, K_2, can be estimated.

Many semiempirical and empirical equations have been developed for predicting K_2 from mean-reach river hydraulic characteristics that can be measured or determined. The U.S. Geological Survey model uses one of these predictive equations (Bennett and Rathbun, 1972) for determination of K_2. The equation is:

$$K_2 = 8.76 \frac{(\bar{U}^{0.607})}{(H^{1.689})} , \tag{2}$$

where K_2 = reaeration coefficient, base 10 log units, 20°C, in days^{-1};

$\bar{U}$ = mean-reach velocity, in feet per second; and

H = mean-reach depth, in feet.

The reaeration coefficient (K_2) is temperature corrected by the equation:

$$K_{2(t)} = K_2(1.021^{(t20)}) \ , \tag{3}$$

where t = stream water temperature, in degrees Celsius.

In order to improve the K_2 estimations used in the water-quality model, a modified gas-tracer study for direct determination of K_2 was conducted simultaneously with the dye-tracer study. The technique used for this study is a modification of the original technique developed by Tsivoglou (1967). The modified gas-tracer technique is described briefly below. More detailed explanations of the technique have been given by Rathbun, Schultz, and Stephen (1975) and Rathbun and Grant (1978).

The procedure involved a simultaneous injection of two tracers at selected points on the Arkansas River. The tracers were a fluorescent dye (rhodamine WT), which enabled detection of the location of the tracers in the river and which also was used as a conservative tracer to define dispersion effects; and the inert gas (ethylene), which was used for determination of K_E, the ethylene desorption coefficient. The ethylene desorption coefficient measured the gas-transfer capacity of the Arkansas River and can be directly related to the reaeration coefficient using a constant determined in the laboratory.

As noted by Bauer, Rathbun, and Lowham (1979) there are three assumptions inherent in the tracer technique as presented by Tsivoglou (1967). These are as follow: First, it is assumed that the ratio of the desorption coefficient for the tracer gas to the absorption coefficient for oxygen is independent of mixing conditions, temperature, and the presence of pollutants for the range of ambient conditions occurring in streams; second, it is assumed that the fluorescent-dye tracer is conservative; and finally, it is assumed that the tracer gas undergoes the same dispersion and dilution as the conservative tracer and is lost from the stream only by desorption to the atmosphere through the water surface.

The basic equation for determination of the ethylene desorption coefficient using the peak method is:

$$K_E = \frac{1}{t_d - t_u} \ ln \ \frac{C_{EU}/C_{DU}}{C_{ED}/C_{DD}} \quad , \tag{4}$$

where K_E = ethylene desorption coefficient;

C_{EU}, C_{ED} = peak concentration of ethylene gas at the upstream and downstream ends of the subreach, in micrograms per liter;

C_{DU}, C_{DD} = peak concentration of dye at the upstream and downstream ends of the subreach, in micrograms per liter;

t_d, t_u = time of the peak concentrations at the upstream and downstream ends of the subreach, in hours; and

ln = natural logarithm, base e.

The use of this equation assumes that the dye is conservative and there is no flow accrual. However, experimental evidence at the present time tends to indicate a loss of dye due to absorption on bottom and suspended sediments or photochemical decay (Rathbun and Grant, 1978). Also, in some of the subreaches studied, there was an increase in discharge which reduced the tracer concentrations. To correct equation 4 for loss of dye and flow accrual, a corrective factor J must be computed as follows:

$$Q_1A_1 = Q_2A_2J_2 = Q_3A_3J_3 = Q_nA_nJ_n \quad , \tag{5}$$

where Q = discharge, in cubic feet per second;

A = area under the dye curve, in micrograms per liter-minutes; and

J = corrective factor.

therefore,

$$J_2 = \frac{Q_1A_1}{Q_2A_2} \text{ or, } J_n = \frac{Q_1A_1}{Q_nA_n} \quad .$$

Equation 4 then becomes, for the subreach between cross sections 2 and 3:

$$K_E = \frac{1}{t_3-t_2} \quad ln \frac{C_{E_2}/C_{D_2}}{C_{E_3}/C_{D_3}J_3} , \tag{6}$$

and similarly for each subreach downstream.

The peak method has the advantage of needing only the peak gas concentration rather than a complete definition of the gas concentration versus time curve. The ethylene versus time curves determined during the gas-tracer study are shown in figures 9, 10, and 11. Peak values, as indicated in these figures, were used to calculate the reaeration coefficients listed in table 4. The reaeration coefficient was not determined for the subreach between sites 21 and 23 because the tracers were not fully mixed at site 21. The uneven mixing at site 21 is indicated by a higher peak concentration of dye at site 23 (fig. 6).

For stream reaches where enough samples were collected to define the complete curves of tracer-gas concentration versus time, the reaeration coefficient can be computed from the areas under the curve.

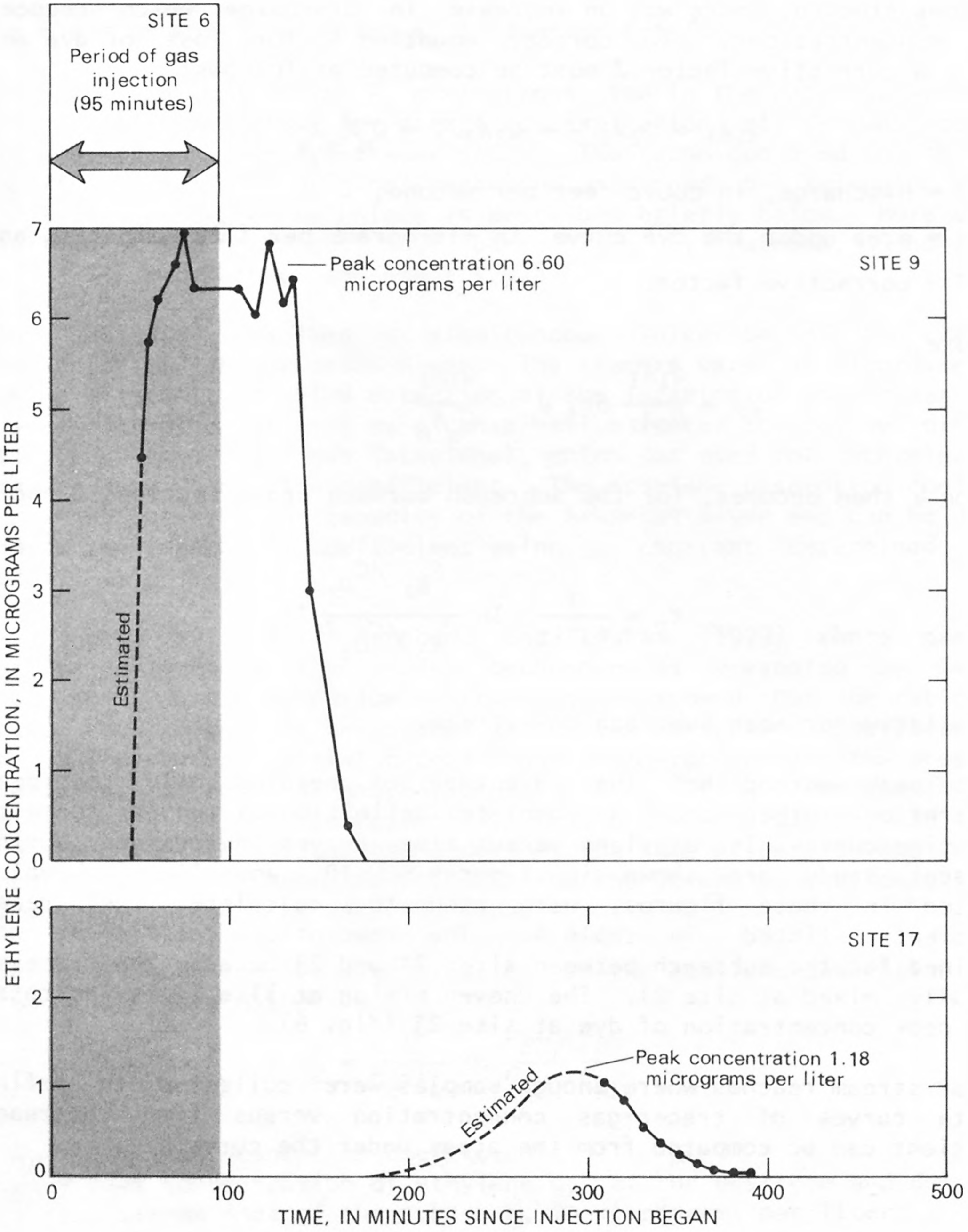


Figure 9. -- Ethylene concentration versus time curves, Arkansas River, sites 9 (river mile 36.2) and 17 (river mile 31.4), October 1976.

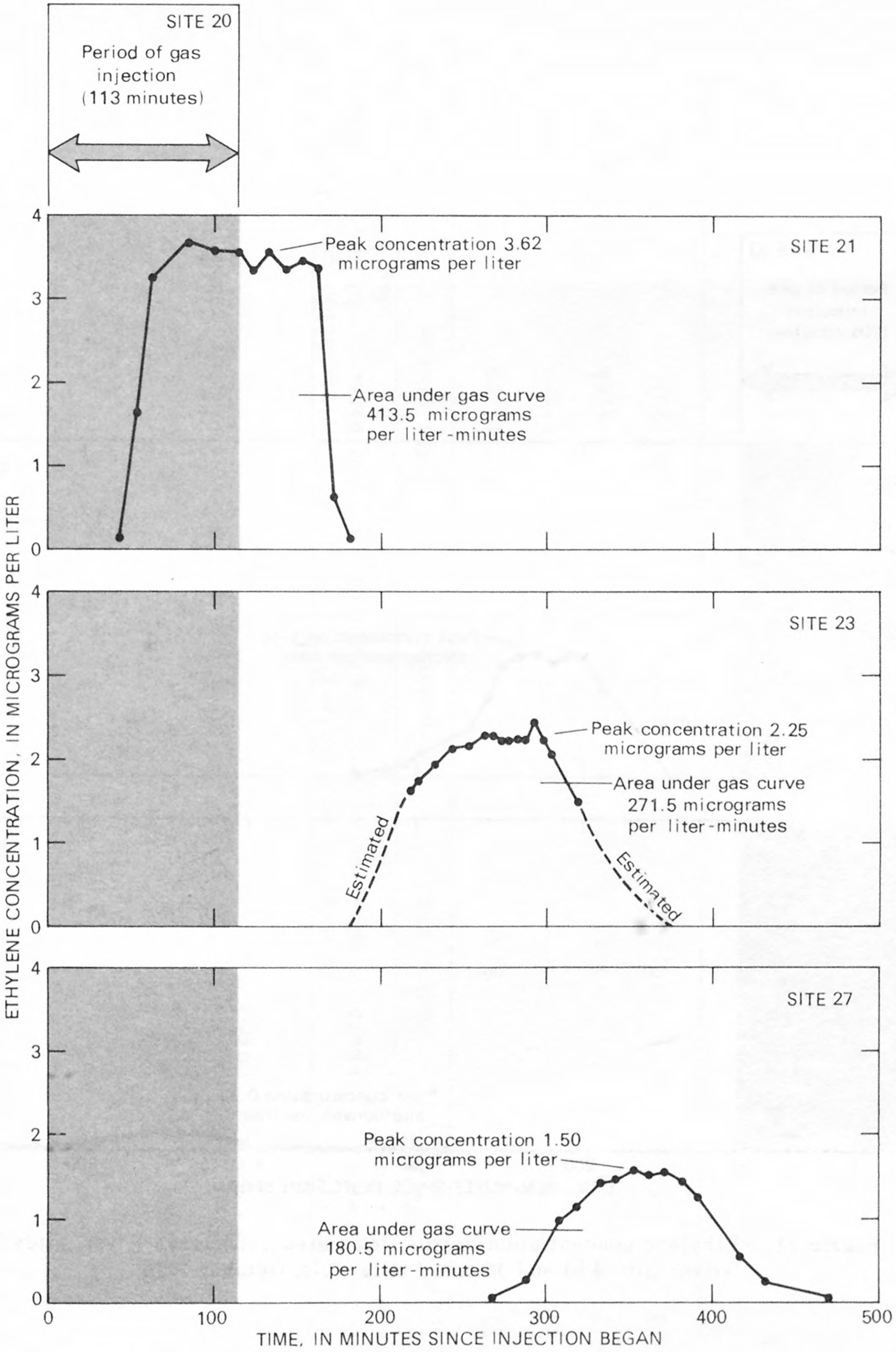


Figure 10. -- Ethylene concentration versus time curves, Arkansas River, sites 21 (river mile 29.8), 23 (river mile 25.8), and 27 (river mile 23.1), October 1976.

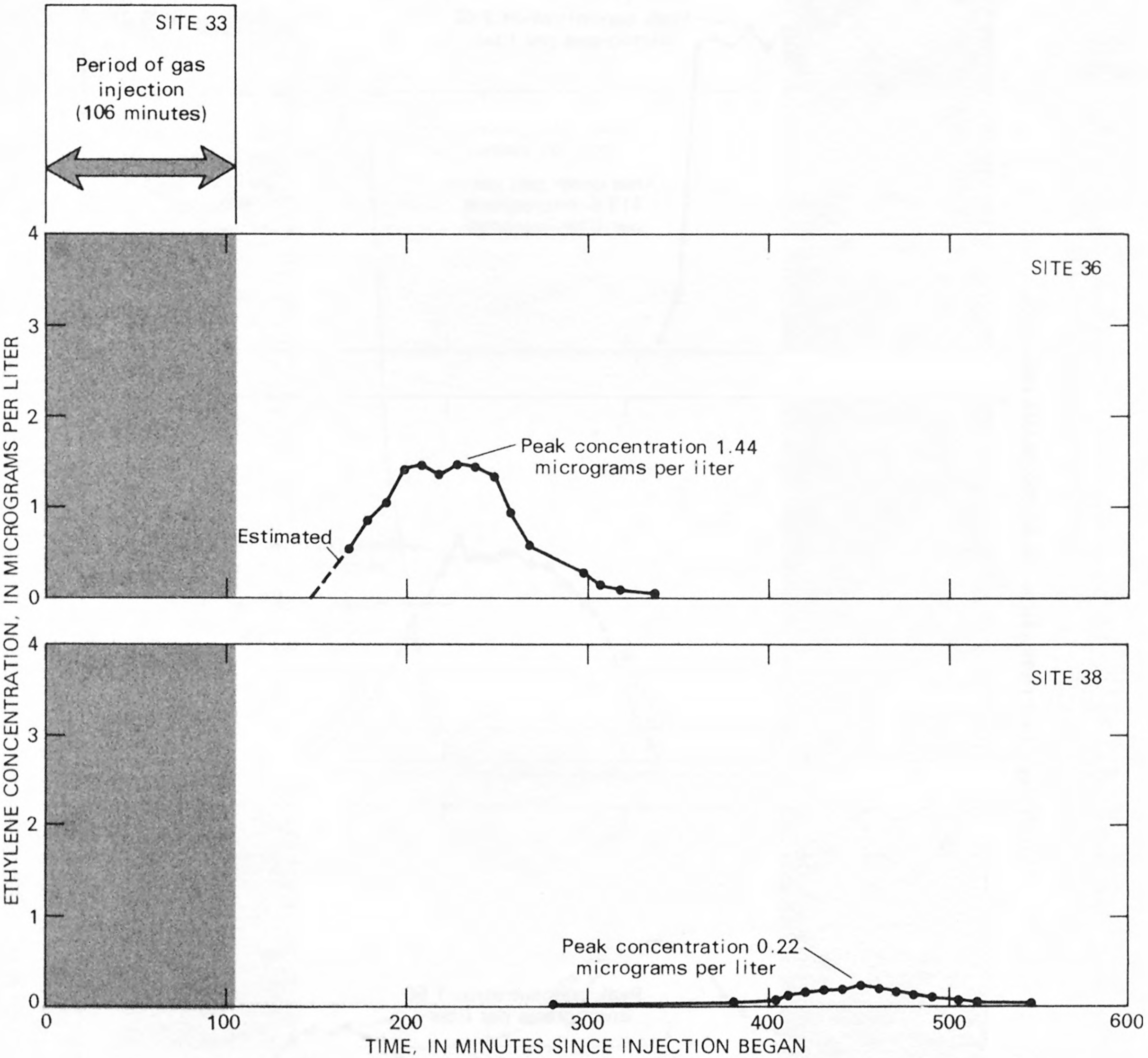


Figure 11.--Ethylene concentration versus time curves, Arkansas River, sites 36 (river mile 4.0) and 38 (river mile -0.7), October 1976.

Table 4.--*Reaeration coefficients for ethylene determined using area and peak computation methods, selected subreaches of the Arkansas River, October 1976*

Subreach as defined by site numbers indicated	Water temperature (degrees Celsius)	Reaeration coefficient based on measured water temperatures (day^{-1})		Reaeration coefficient adjusted to 20 degrees Celsius (day^{-1})	
		Peak method	Area method	Peak method	Area method
9-17	12	9.33	----	11.29	----
21-23	14	-----	----	-----	----
23-27	14	4.37	5.01	5.04	5.78
36-38	14	10.5	----	12.1	----

The basic equation using the area method is:

$$K_E = \frac{1}{t_d - t_u} \, ln \left(\frac{A_U}{A_D} \right) , \qquad (7)$$

where K_E = ethylene-desorption coefficient;

A_U, A_D = area under the tracer-gas concentration versus time curve at the upstream and downstream ends of the subreach; and

t_d, t_u = time of the centroids of the gas-tracer mass at the upstream downstream ends of the subreach, in hours.

To correct for flow accrual, equation 7 becomes:

$$K_E = \frac{1}{t_d - t_u} \, ln \left(\frac{A_U Q_U}{A_D Q_D} \right) , \qquad (8)$$

where Q_U, Q_D = discharge at the upstream and downstream ends of the subreach, in cubic feet per second.

The area procedure has the advantage that it is not dependent upon dye concentrations and, therefore, the nonconservative nature of the dye is not important. However, the only sites at which the area under the ethylene versus time curves could be determined with sufficient accuracy to apply the area method were sites 23 and 27 (figs. 9, 10, and 11). The leading edge of the ethylene cloud was missed at site 17, the ethylene was not fully mixed at site 21, and sluicing from the Rocky Ford Highline Canal created problems with the area data at sites 36 and 38. The areas under the ethylene curves, as indicated in figure 10, were used in application of the area method for the subreach between sites 23 and 27.

The ethylene tracer-gas desorption coefficient computed by the peak or area methods described above is converted to a reaeration coefficient (as shown in table 4) with the relation:

$$K_2 = RK_E \quad , \qquad (9)$$

where R = the ratio of absorption coefficient for oxygen to the desorption coefficient for the tracer gas, as determined in the laboratory. From laboratory studies by Rathbun, Stephens, Schultz, and Tai (1978) the R-value relationship for ethylene was determined to be 1.15.

A comparison of the K_2 values analytically determined with K_2 values determined from various predictive equations also was made for the Arkansas River. These comparisons give a measure of the degree of uncertainty present in the predictive equations. The equations with the least amount of error would be the most applicable to any future studies of the Arkansas River.

To compare the various equation results, it was first necessary to calculate various hydraulic and energy-dissipation properties for the river subreaches being studied. The hydraulic and energy-dissipation properties used in the equation computations are given in table 3. The data presented in table 3 were determined from measured channel cross sections, topographic maps, and the dye-traveltime data. River-surface slope and shear velocity are used in calculations involving energy-dissipation equations. Shear velocity (U_*) is often called friction velocity as it relates to boundary friction in streamflow and is defined as:

$$U_* = \sqrt{GRS_o} \ , \tag{10}$$

where U_* = shear velocity;

G = gravitational constant (32 feet per second per second);

R = hydraulic radius (cross-sectional area divided by cross-sectional width), in feet; and

S_o = slope of energy gradient (commonly water-surface slope), dimensionless.

The equations selected for comparison analysis are not listed in this report but may be obtained from the referenced reports or from a report on the reaeration characteristics of the Yampa River by Bauer, Rathbun, and Lowham (1979).

A summary of the comparisons of the averages of the measured reaeration coefficients and the reaeration coefficients predicted with the equations is given in tables 5 and 6. A listing of the individual errors of estimate is given in table 7. The error of estimate (EOE) is defined as:

$$EOE = (K_2\text{pred}-K_2\text{mes})/K_2\text{mes} \ , \tag{11}$$

where K_2pred = reaeration coefficient determined by equation; and

K_2mes = reaeration coefficient determined by measurement.

Because the individual errors can either be negative or positive, the average absolute error of estimate also is presented in table 7. Results of the error analysis indicate that the equations developed by Parkhurst and Pomeroy (1972) and by Dobbins (1965) gave the smallest errors for the energy-dissipation equations and that the equations developed by Langbein and Durum (1967) and by Padden and Gloyna (1971) gave the smallest errors for the velocity-depth equations. Due to the greater ease of obtaining the data necessary for use of the velocity-depth equations, the equations by Langbein and Durum (1967) or Padden and Gloyna (1971) are the most applicable for use in future studies of reaeration in the Arkansas River.

Table 5.--*Comparison between reaeration coefficients determined using measured data (October 1976) and those determined using energy-dissipation equations, selected subreaches of the Arkansas River*

Subreach as defined by site numbers indicated	Reaeration coefficients (day^{-1}), base e units									
	Determined using measured data	Determined using energy-dissipation equations								
		Lau (1972)	Krenkel and Orlob (1963)	Parkhurst and Pomeroy (1972)	Tsivoglou and Neal (1976)	Cadwallader and McDonnell (1969)	Bennett and Rathbun (1972)	Thackston and Krenkel (1969)	Churchill, Elmore, and Buckingham (1962)	Dobbins (1965)
9-17	9.33	10.8	14.3	6.89	15.3	10.3	10.1	6.06	6.14	7.69
23-27	[1]4.69	7.98	15.9	7.51	17.7	11.3	11.1	6.32	9.48	7.80
36-38	10.5	7.35	16.9	9.60	10.8	13.6	17.1	6.93	22.4	10.1

[1] Average value determined from peak- and area-computation methods.

Table 6.--*Comparison between reaeration coefficients determined using measured data (October 1976) and those determined using velocity-depth equations, selected subreaches of the Arkansas River*

Subreach as defined by site numbers indicated	Reaeration coefficients (days^{-1}), base e units										
	Determined using measured data	Determined using velocity-depth equations									
		Churchill, Elmore, and Buckingham (1962)	Langbein and Durum (1967)	Owens, Edwards, and Gibbs[1] (1964)	Owens, Edwards, and Gibbs[2] (1964)	Isaacs and Gaudy (1968)	Negulescu and Rojanski (1969)	Bennett and Rathbun (1972)	O'Connor and Dobbins (1958)	Padden and Gloyna (1971)	Bansal (1973)
9-17	9.33	7.74	6.23	12.6	10.7	6.45	10.4	10.4	6.85	5.29	2.78
23-27	[3]4.69	9.22	7.45	14.6	12.3	7.71	12.2	11.8	7.67	6.09	3.17
36-38	10.5	14.9	10.32	25.8	23.0	11.5	14.3	1.0	12.9	8.06	4.97

[1] Equation 1.

[2] Equation 2.

[3] Average value determined from peak- and area-computation methods.

Table 7.--*Error analysis of reaeration coefficients*

[Based on comparisons presented in tables 5 and 6 between reaeration coefficients determined using measured data (October 1976) and those determined using energy-dissipation and velocity-depth equations for selected subreaches of the Arkansas River]

Energy dissipation

Equation used	Error of estimate for subreach as defined by sites;			Average error of estimate (absolute value)
	9-17	23-27	36-38	
Lau (1972)---------	0.16	0.70	-0.30	0.39
Krenkel and Orlob (1963).	.53	2.3	.61	1.1
Parkhurst and Pomeroy (1972).	-.26	.60	-.09	.32
Tsivoglou and Neal 1976).	.64	2.8	.03	1.2
Cadwallader and McDonnell (1969).	.10	1.4	.30	.6
Bennett and Rathbun (1972).	.08	1.4	.63	.7
Thackston and Krenkel (1969).	-.35	.35	-.34	.35
Churchill, Elmore, and Buckingham (1962).	-.34	1.0	1.1	.81
Dobbins (1965)-----	-.18	.66	-.04	.29

Velocity and depth

Equation used	Error of estimate for subreach as defined by sites;			Average error of estimate (absolute value)
	9-17	23-27	36-38	
Churchill, Elmore, and Buckingham (1962).	-0.17	0.97	0.42	0.52
Langbein and Durum (1967).	-.33	.59	-.02	.31
Owens, Edwards, and Gibbs[1] (1964).	.35	2.1	1.5	1.8
Owens, Edwards, and Gibbs[2] (1964).	.15	1.6	1.2	.98
Isaacs and Gaudy (1968).	-.31	.64	.10	.35
Negulescu and Rojanski (1969).	.11	1.6	.36	.69
Bennett and Rathbun (1972).	.11	1.5	1.0	.87
O'Connor and Dobbins (1958)	-.27	.64	.23	.38
Padden and Gloyna (1971).	-.43	.30	-.23	.32
Bansal (1973)------	-.70	-.32	-.53	.52

[1] Equation 1.

[2] Equation 2.

The velocity-depth equations with the smallest error results are:

Langbein and Durum (1967)

$$K_2 = 3.3\left(\frac{\bar{U}}{\bar{H}^{1.33}}\right) \quad \text{and} \qquad (12)$$

Padden and Gloyna (1971)

$$K_2 = 2.98\left(\frac{\bar{U}}{\bar{H}^{1.5}}\right)0.703 \qquad (13)$$

where K_2 = reaeration coefficient, base 10 log units, 20°C, in days^{-1};

$\bar{U}$ = mean-reach velocity, in feet per second; and

$\bar{H}$ = mean-reach depth, in feet.

The reaeration coefficient for the model analysis was computed using a velocity-depth equation described by Bennett and Rathbun (1972). The comparison of the reaeration coefficient computed by this predictive equation with the measured reaeration coefficient indicated an average error of estimate of 0.87 (table 7). Because the reaeration-coefficient analysis was completed after the model analysis, no attempt was made to use equations other than the equation of Bennett and Rathbun (1972). The amount of error resulting from the use of the reaeration equation of Bennett and Rathbun (1972) on the model analysis is not known.

Water-Quality Data

The hydraulic data previously discussed determine how a stream system routes flow through the model reach. The next step in application of data in the model is determination of the chemical quality of all the point-source discharges to the Arkansas River in the model reach. For the purpose of this modeling effort, the initial upstream flow as well as all discharges flowing into the Arkansas River model reach are considered point sources of inflow. Inflows include effluents from wastewater-treatment plants and industrial complexes as well as discharge from natural streams.

The water-quality data needed for the model are concentrations of constituents that are common in organic wastes: DO, CBOD, total organic nitrogen, total ammonia, total nitrite, total nitrate, total orthophosphate, total phosphorus, and total- and fecal-coliform bacteria. Samples were collected at each inflow site to determine the chemical and biological quality. At the initial upstream point, nine samples were collected in April and four samples were collected in October. Data for each constituent from analyses of these samples were averaged to determine the initial river quality. At sites other than wastewater-discharge sites, which had no diurnal variation, as many as 5 samples were collected; at wastewater-discharge sites, which had diurnal variation, as many as 11 samples were collected. Data from analyses of these samples were averaged to determine the average composition of the discharges flowing into the river. When discharge variation was significant; discharge-weighted averages were used in the model; when discharge variation was negligible, simple averages were used in the model. The chemical and biological data used in the model are given in table 8. All of the chemical and biological data collected are given in the Supplemental Information section at the end of the report.

Sites 3, 4, 5, and 8 were sampled only in October. Because inflow from these sites, resulting mainly from ground-water discharge, remains virtually constant in quantity and quality throughout the year, it was assumed that concentrations of the constituents measured would be the same in April as they were in October.

CALIBRATION OF THE MODEL

The U.S. Geological Survey model was calibrated for the study reach by determining reaction-rate coefficients for the data (the role of reaction-rate coefficients in the model equation has been previously discussed; see page 5). Reaction rates describe the speed at which reactions occur and are based on the chemical and biological rates of oxidation and removal of the organic material. Reaction-rate coefficients were determined for CBOD, total organic nitrogen, total ammonia, total nitrite, total nitrate, total orthophosphate, and fecal-coliform bacteria.

Reaction-rate coefficients for a particular stream reach can be estimated by a procedure of curve fitting. Numerous computer runs are made and the values of the various coefficients adjusted so that the model result (for a particular set of data) is acceptably close to the quality of the water in the stream as determined by the water-quality analyses. The reaction-rate coefficients resulting in the best match of calculated and actual quality are considered to be the optimum values.

The range within which the reaction-rate coefficients can be varied also is important. Reaction-rate coefficients beyond the range of reasonable possibility would seriously affect the credibility of the calibration. The acceptable range of reaction-rate coefficients was determined by a review of the literature on water-quality modeling.

The model-generated data and the measured data for $CBOD_5$ for the April and October surveys are shown in figure 12. The $CBOD_5$ values between river miles 23 and 31 as measured in April and October are not shown in figure 12 because of data-collection problems. The $CBOD_5$ values for this section of the Arkansas River were estimated, based on the trend of downstream CBOD concentrations. The reaction-rate coefficient used in both instances was 1.0 day^{-1}.

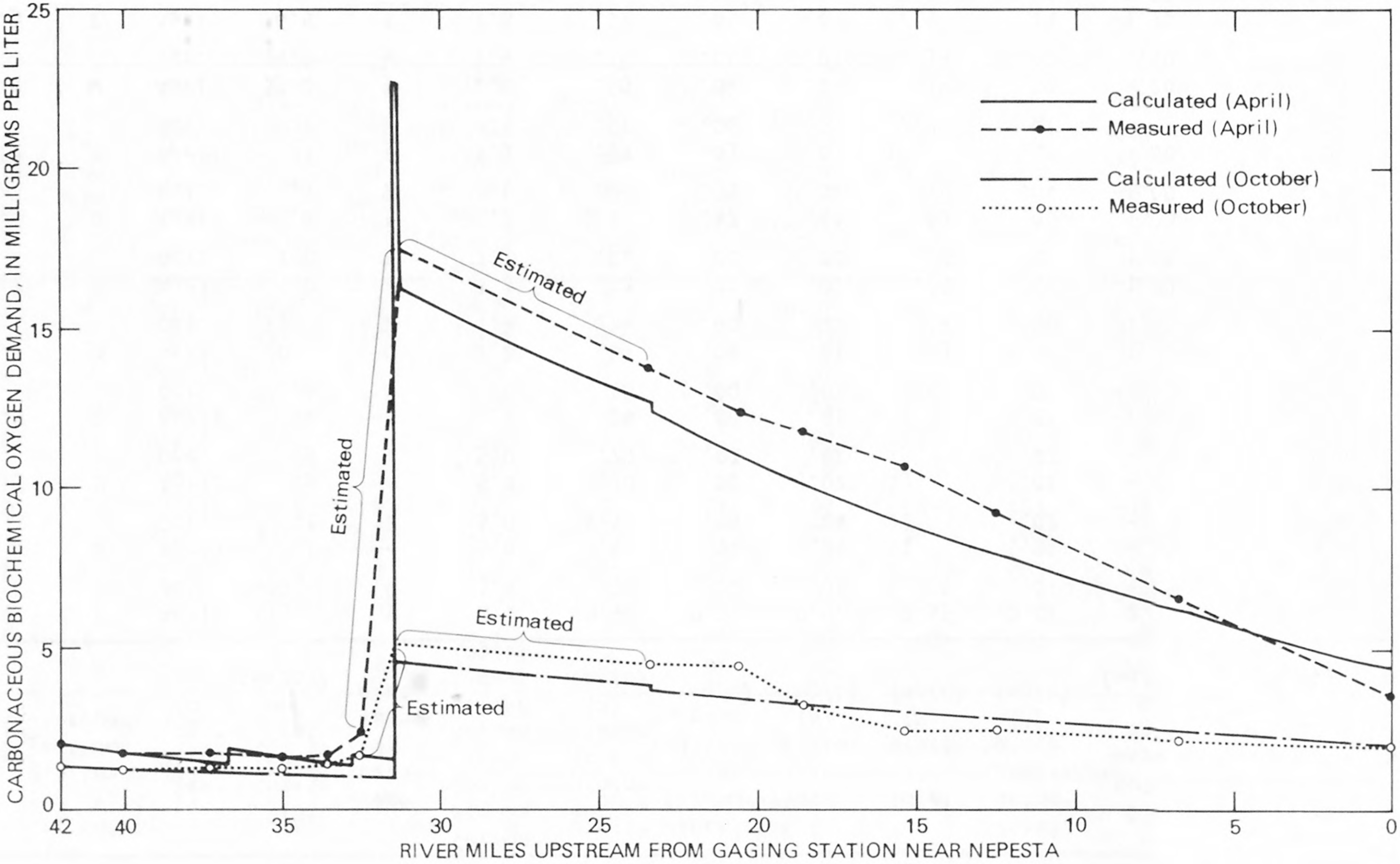


Figure 12.--Model-calculated and measured concentrations of carbonaceous biochemical oxygen demand (5-day), Arkansas River study reach, April and October 1976.

Table 8.--*Water-quality data used in the model*

[mg/L=milligram per liter; mL=milliliter]

Site number[1]	River mile[2]	Inflow type[3]	Sampling period	Discharge (cubic feet per second)	Number of samples	Carbonaceous biochemical oxygen demand (5-day) (mg/L)	Total organic nitrogen (N) (mg/L)	Total ammonia nitrogen (mg/L)	Total nitrite (N) (mg/L)	Total nitrate (N) (mg/L)	Total orthophosphate (P) (mg/L)	Dissolved oxygen deficit (mg/L)[4]	Total-coliform bacteria (colonies per 100 mL)	Fecal-coliform bacteria (colonies per 100 mL)
1	42	I	April	115	9	2.0	0.44	0.06	0.02	0.55	0.01	2.1	2	0
			Oct.	400	4	1.4	.36	.00	.01	.59	.01	-.25	20	8
3	38	D	April	.1	--	5.0	1.4	.04	.04	12	.02	-.75	480	250
			Oct.	.1	2	5.0	1.4	.04	.04	12	.02	-.75	480	250
4	37.5	D	April	.5	--	5.0	.70	.02	.02	19	.02	-.80	600	0
			Oct.	.5	2	5.0	.70	.02	.02	19	.02	-.80	600	0
5	37.3	D	April	.6	--	.4	.26	.00	.01	4.4	.02	-1.40	1,500	630
			Oct.	.6	2	.4	.26	.00	.01	4.4	.02	-1.40	1,500	630
7	36.7	D	April	10	[5]0	2.8	.44	.04	.01	.53	.00	-1.50	26	5
			Oct.	25	2	1.4	.24	.00	.02	.24	.00	-1.80	22	7
8	36.2	D	April	1.0	--	1.1	.22	.02	.02	.88	.01	-1.20	300	55
			Oct.	1.0	2	1.1	.22	.02	.02	.88	.01	-1.20	300	55
10	35.9	D	April	1.8	3	.7	1.6	.47	.01	.60	.00	.00	0	0
			Oct.	.4	2	1.4	.06	.98	.02	.45	.04	-1.00	0	0
11	35.7	T	April	.1	3	1.2	.83	.03	.03	11	.00	-.60	28	43
			Oct.	.1	4	.1	.51	.06	.01	7.7	.01	-----	55	10
14	32.8	W	April	39.0	3	2.0	.50	.04	.01	.74	.00	-.20	19	16
			Oct.	34.0	4	1.4	.18	.01	.01	.39	.00	-.50	13	11
16	32.3	T	April	6.5	5	1.8	.72	.05	.03	2.5	.19	-1.70	53	2
			Oct.	40.0	4	1.2	1.5	.01	.01	3.0	.40	-1.70	1,400	180

Table 8.--*Water-quality data used in the model*--Continued

Site number[1]	River mile[2]	Inflow type[3]	Sampling period	Discharge (cubic feet per second)	Number of samples	Carbonaceous biochemical oxygen demand (5-day) (mg/L)	Total organic nitrogen (N) (mg/L)	Total ammonia nitrogen (mg/L)	Total nitrite (N) (mg/L)	Total nitrate (N) (mg/L)	Total orthophosphate (P) (mg/L)	Dissolved oxygen deficit (mg/L)[4]	Total-coliform bacteria (colonies per 100 mL)	Fecal-coliform bacteria (colonies per 100 mL)
18	31.3	W	April	24.7	9	89.2	9.3	15	0.01	0.02	5.2	2.20	[6]1,000,000	[6]200,000
			Oct.	20.1	10	74.8	.0	20	.09	.13	5.9	3.10	70	5
19	31.2	W	April	103	4	9.9	1.0	3.4	.28	.68	.03	.40	180	270
			Oct.	93	11	4.5	.71	3.5	.48	.92	.03	1.10	210	73
24	24.2	W	April	.4	5	30.0	4.3	9.2	.66	.97	7.1	.80	180	0
			Oct.	.1	4	43.0	.0	20	.38	1.1	10	1.10	0	0
26	23.2	T	April	4.8	5	2.2	1.1	.03	.02	.65	.01	-.40	70	75
			Oct.	39	4	1.6	.61	.01	.01	.44	.06	.70	460	190
30	18.1	T	April	2.9	3	1.1	.82	.03	.04	7.2	.02	.90	66	52
			Oct.	4.6	4	1.4	.82	.01	.01	4.9	.02	-.90	2,170	800
34	7.4	T	April	.9	3	1.1	.54	.03	.00	.08	.01	.50	7	1
			Oct.	2.8	4	1.6	.51	.01	.00	.11	.01	.10	780	260

[1] Refer to table 1 and figure 2.

[2] River miles upstream from gaging station 07117000 Arkansas River near Nepesta.

[3] I=initial Arkansas River; D=drainage ditch or pipe; T=natural tributary; and W=wastewater effluent.

[4] Negative deficit is supersaturation (concentration greater than saturation).

[5] Chemical and biological data estimated from Arkansas River samples.

[6] Estimated.

The reaction-rate coefficient for CBOD of 0.1^{-1}, as referred to in much of the literature, is much too small for the Arkansas River in Pueblo County. Because the reaction rate for CBOD is determined by a complex biological process, it was not unexpected that large variations were determined. According to Velz (1970), the reaction-rate coefficient for CBOD in streams where biological extraction is occurring ranges from 0.3 to 1.1 days^{-1} or more, depending on opportunity for contact between the biological mass and the water. A shallow stream with a large roughness coefficient and attached growth favors greater rates of biological extraction. The Arkansas River has such characteristics in the reach between river miles 15 and 35 where the bottom is covered with a mat of biological growth. Considering this, a reaction-rate coefficient for CBOD of 1.0 day^{-1} is not unreasonable.

The reaction-rate coefficient of 1.0 day^{-1} results in an acceptable fit between calculated and measured $CBOD_5$ concentrations for the two different flow periods. Also, according to Velz (1970), the rate of biological extraction that is determined for a particular stream appears to vary only slightly with the seasons of the year. It is reasonable to expect a reaction-rate coefficient for $CBOD_5$ of 1.0 day^{-1} will result in accurate predictions of CBOD concentrations in the Arkansas River in Pueblo County.

These CBOD reactions are the result of reduction of carbonaceous matter by a heterotrophic group of organisms. Simultaneously, nitrogenous matter is converted to oxidized nitrogen compounds. Nitrification is a series of associated biologically controlled reactions by which simple amino compounds (organic nitrogen) and ammonia are converted to nitrite and then to nitrate. The oxidation of ammonia to nitrite is caused by bacteria of the genus *Nitrosomonas* while the oxidation of nitrite to nitrate is caused by bacteria of the genus *Nitrobacter*. These organisms generally are restricted in numbers by the available food supply and they are sensitive to environmental conditions such as DO concentration and water temperature. The rate of nitrification is controlled mainly by the respective populations of these bacteria.

Model-generated data and measured data for total organic nitrogen for the April and October surveys are shown in figure 13. The term organic nitrogen as used in this report includes all nitrogen in the trinegative state except for ammonia. The coefficient used was 0.2 day^{-1}.

The calculated concentration of total organic nitrogen (fig. 13) was greater than the measured concentration for April and was less than the measured concentration for October. These differences are thought to be due to problems in determining the concentrations of total organic nitrogen present in the effluent from the wastewater-treatment plant in Pueblo. The method of determining total organic nitrogen is by subtracting values of total ammonia from values of total Kjeldahl nitrogen. This method can result in greater than the normal laboratory error, particularly when the concentrations of total ammonia and total Kjeldahl nitrogen are large, such as in effluent from wastewater-treatment plants. However, the slope of the model-generated data and the measured data match within data variation, indicating the rate coefficient of 0.2 day^{-1} is acceptable.

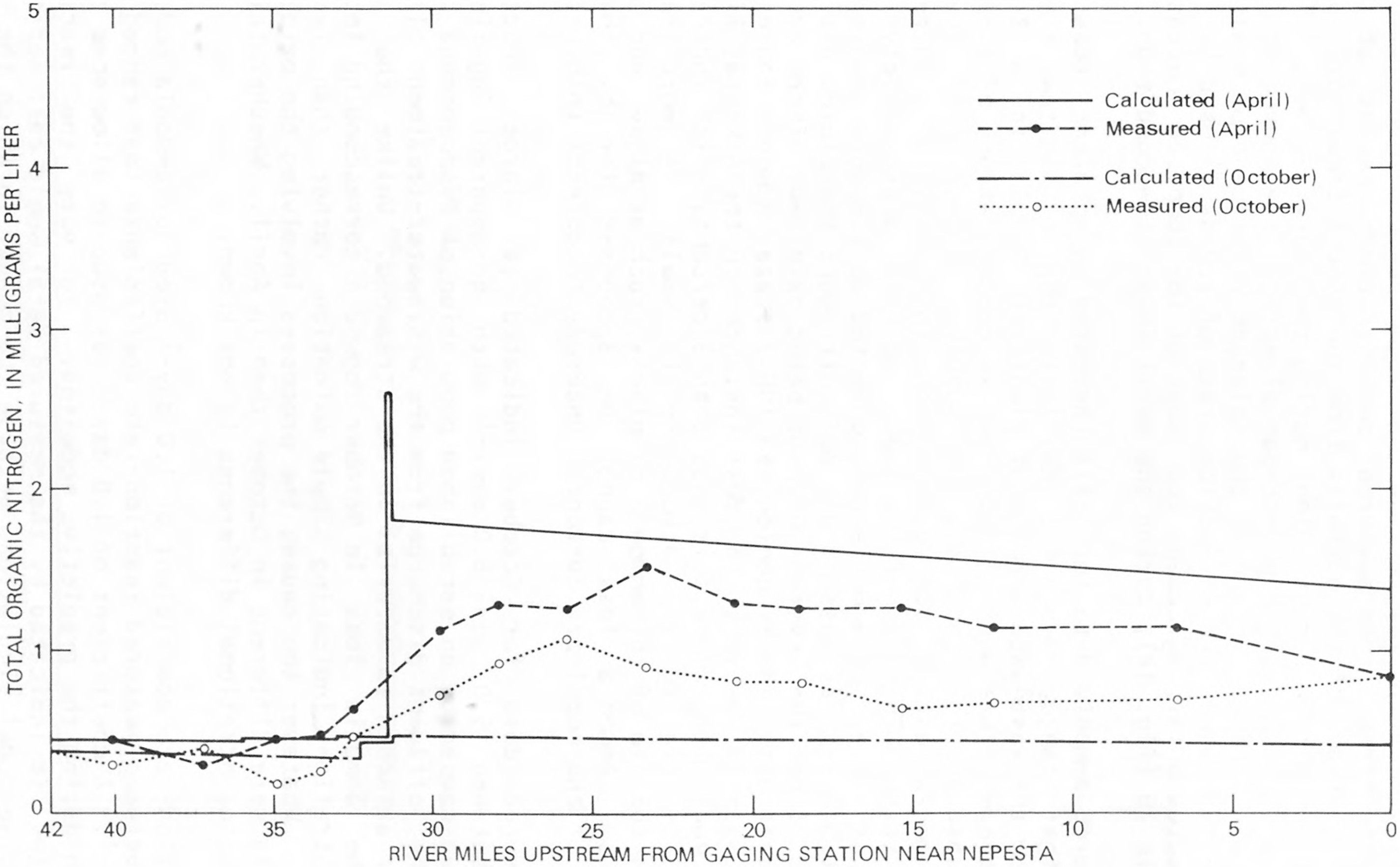


Figure 13.--Model-calculated and measured concentrations of total organic nitrogen, Arkansas River study reach, April and October 1976.

The model-generated data and measured data for total ammonia for the April and October surveys are shown in figure 14. The reaction-rate coefficient used was 1.0 day^{-1}. The model-generated total ammonia concentrations were larger than measured concentrations, except at the sites immediately downstream of the outfalls from the CF & I Steel Corp. plant and the Pueblo wastewater-treatment plant during the April survey. The rapid disappearance of ammonia in the downstream direction is a phenomenon observed on many Colorado streams surveyed by the Colorado Department of Health (Bauer and others, 1978). The average reaction rate of 1.0 day^{-1} used in the model analysis indicates a fair agreement for most of the computed concentrations, mile 32 to mile 20 (fig. 14), during the April lower flow condition.

The measured ammonia data for April indicated an apparent reaction-rate coefficient that ranged from 0.3 day^{-1} in the first few river miles downstream from the wastewater-treatment plant at Pueblo to a 2.0 days^{-1} further downstream. This would be expected as concentrations of *Nitrosomonas* bacteria increase due to an abundant food supply. However, if the entire amount of ammonia lost was due to oxidation, there would be a corresponding increase in nitrate. This is not the case because approximately 3.6 mg/L (milligrams per liter) of ammonia was converted to 2.9 mg/L of nitrite plus nitrate as nitrogen--a net loss of 0.7 mg/L nitrogen; therefore, nitrogen was being removed from the system without being oxidized. There are several possible explanations. In its nonionized (NH_3) state, ammonia can escape as a gas from water; however, in most instances in the Arkansas River, the percentage of nonionized ammonia is less than 5 percent, which indicates that the loss of ammonia to the atmosphere is small. A more reasonable explanation is the use of the ammonia by plants, such as algae and attached bottom plants. Ammonia loss cannot be accounted for by the model. Modifications of the model are currently underway to correct this problem.

The measured data for October indicated a large reaction-rate coefficient--between 5.0 and 8.0 days^{-1} with no apparent lag time. This could have been caused by an established population of *Nitrosomonas* bacteria, either in the effluent discharge from the wastewater-treatment plant, from Salt Creek, or attached to material in the streambed. Unlike the situation in April, the ammonia loss in October showed a corresponding increase in nitrate concentration, indicating simple oxidation rather than removal by other means. Whatever the cause, the processes involving the oxidation and loss of ammonia were different in October than in April. Whether this is a seasonal or a concentrational difference is not known.

The reaction-rate coefficient of 1.0 day^{-1} used for ammonia modeling was a compromise between measured reaction-rate coefficients that ranged from 0.3 and 8.0 days^{-1}. A coefficient of 1.0 day^{-1} was used to allow some basis for interpretation during the predictive modeling. To vary the reaction-rate coefficient (as is indicated by the measured data) would cast serious doubt on any predictive model simulations because the manner in which the reaction-rate coefficient varies in the downstream direction with season and concentration is unknown. Also, the model-generated curves were not plotted

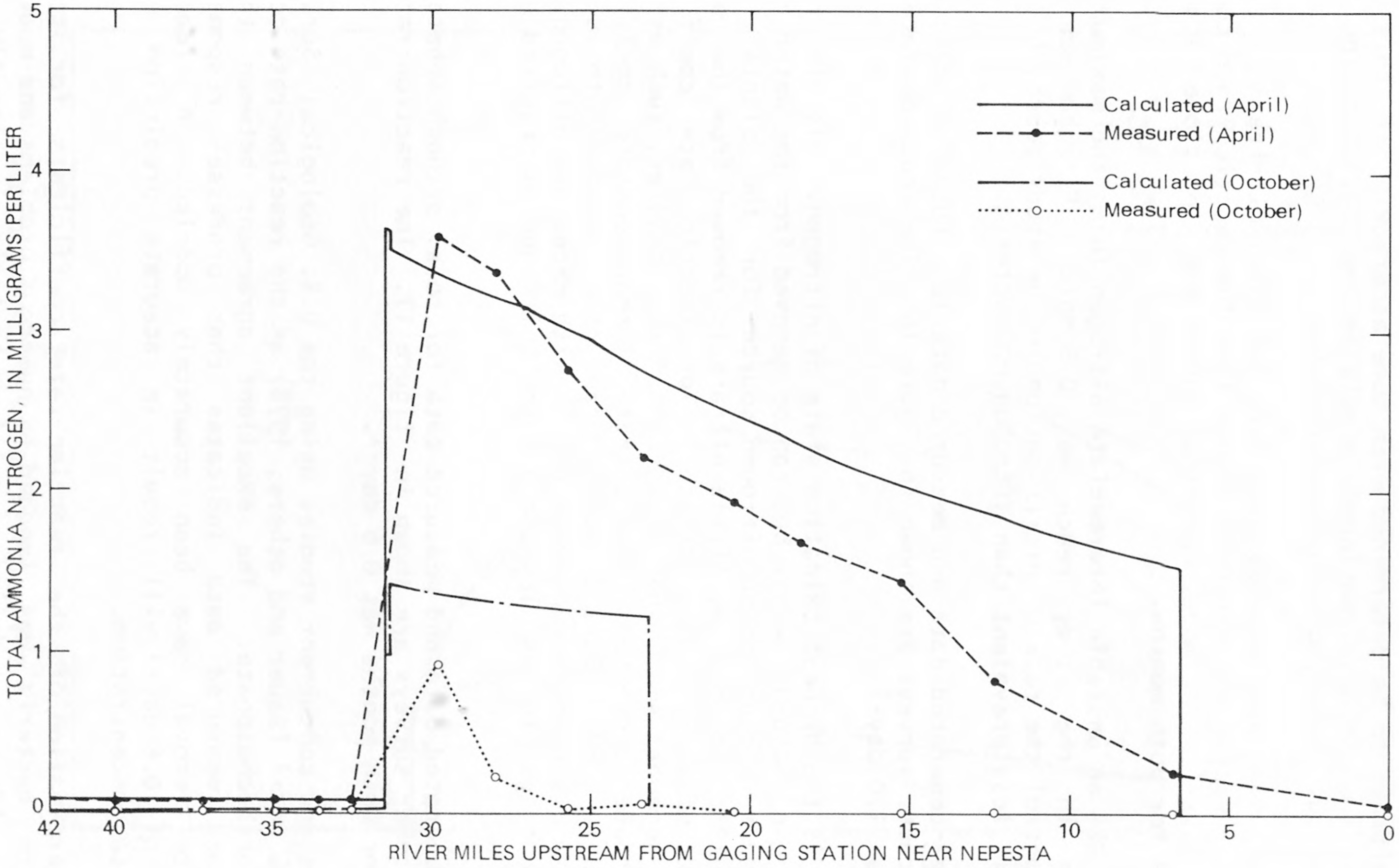


Figure 14. -- Model-calculated and measured concentrations of total ammonia nitrogen, Arkansas River study reach, April and October 1976.

when the measured ammonia concentration approached or reached zero (fig. 14). In other words, the model stopped oxidating ammonia at the point indicated in figure 14. This was done to enable the reaction-rate coefficients for nitrite and nitrate to be determined with more accuracy. If this was not done, the model would have continued to oxidize ammonia, when, in fact, this was not occurring, thereby giving false results.

Model-generated data and measured data for total nitrite for the April and October surveys are shown in figure 15. The reaction-rate coefficient used was 4.0 days^{-1}. The model-generated curves are in close accord with measured data for both months.

Nitrite is an unstable intermediate nitrogen form; the maximum observed concentration in the study reach was 0.6 mg/L. *Nitrosomonas* bacteria apparently control the rate of nitrification in the study reach, because they are relatively less prevalent than *Nitrobacter* bacteria.

The model-generated data and measured data for total nitrate for the April and October surveys are shown in figure 16. The reaction-rate coefficient used was 1.0 day^{-1}.

Nitrate is the highest oxidation state of nitrogen. It is reasonably conservative in natural water but can be removed from the water by plants. However, ammonia is a preferred nitrogen source for the plants, and when there is sufficient ammonia, little nitrate is removed from the water, even during periods of active plant growth. The reaction-rate coefficient of 1.0 day^{-1} is somewhat small when compared to other studies, such as the Yampa River study (Bauer and others, 1978), where a reaction-rate coefficient of 1.7 days^{-1} was used. During April, when active plant growth is expected, sufficient ammonia exists to provide plants with necessary nitrogen. During October, plant growth is slowed and little nitrogen is required by aquatic plants.

Model-generated data and measured data for total orthophosphate for the April and October surveys are shown in figure 17. The reaction-rate coefficient used for both months was 0.6 day^{-1}.

Previous and concurrent studies using the U.S. Geological Survey model have used 0.6 day^{-1} (Bauer and others, 1978) as the reaction-rate coefficient for total orthophosphate. The excellent agreement between the model-generated and measured data indicates that processes responsible for orthophosphate removal have been accurately modeled. A reaction-rate coefficient of 0.6 day^{-1} will result in accurate prediction of total orthophosphate concentration.

The determination of the reaction-rate coefficients for total- and fecal-coliform bacteria was impeded by numerous problems and model results were limited. Adequate modeling of coliform bacteria is largely dependent upon accurate data. Data-collection problems resulted in the discarding of the coliform-bacteria data collected during the April survey.

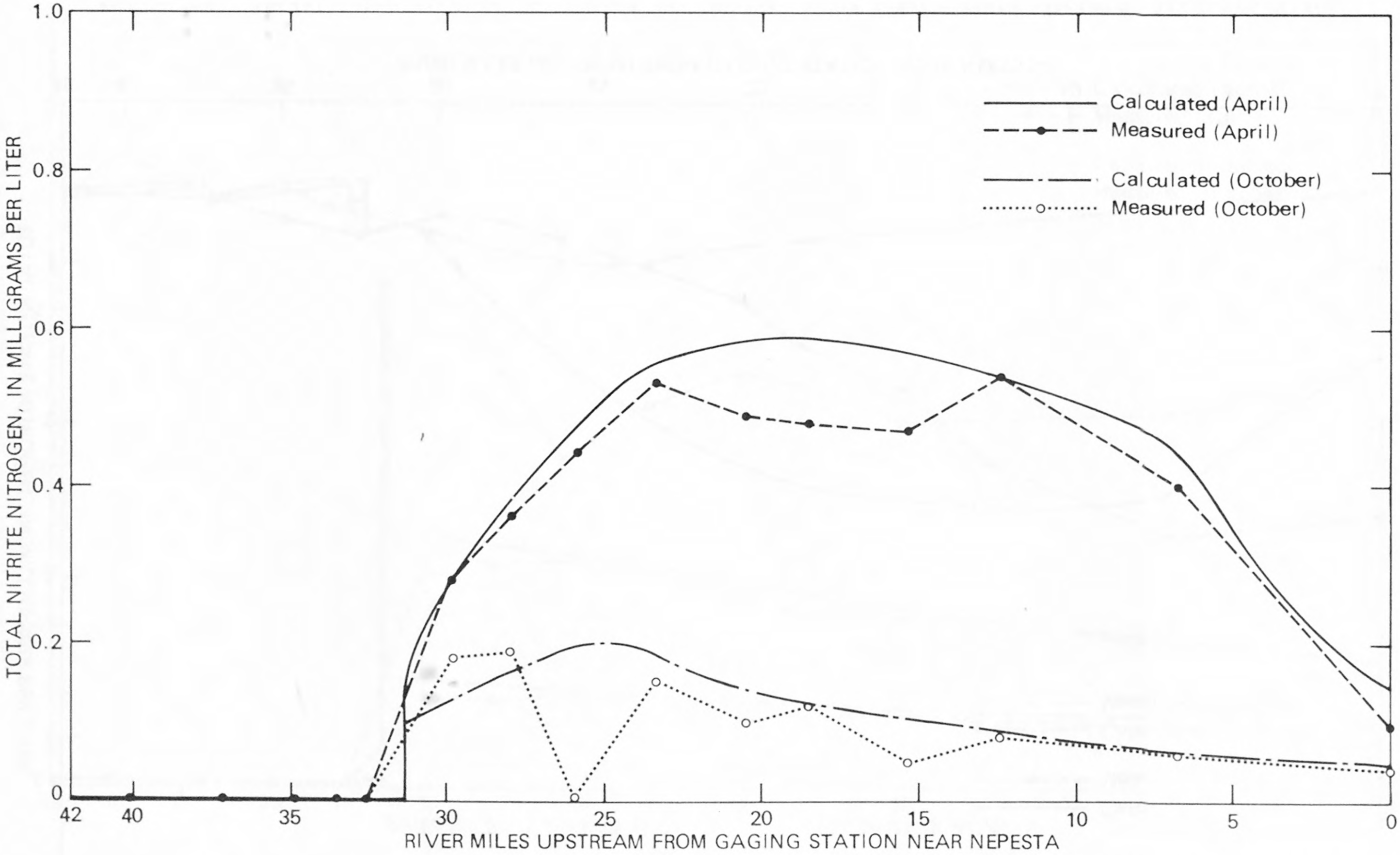


Figure 15.--Model-calculated and measured concentrations of total nitrite nitrogen, Arkansas River study reach, April and October 1976.

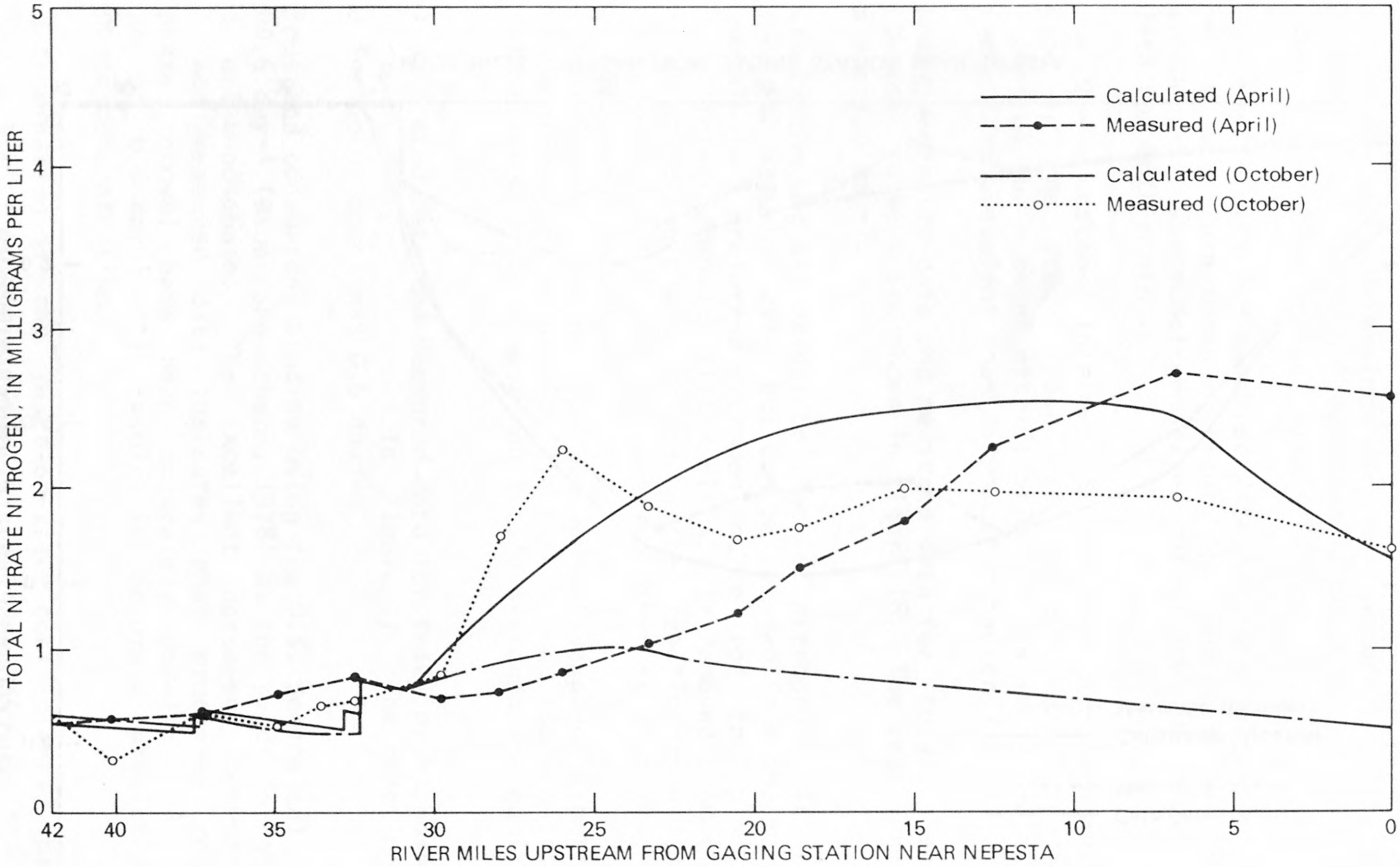


Figure 16.--Model-calculated and measured concentrations of total nitrate nitrogen, Arkansas River study reach, April and October 1976.

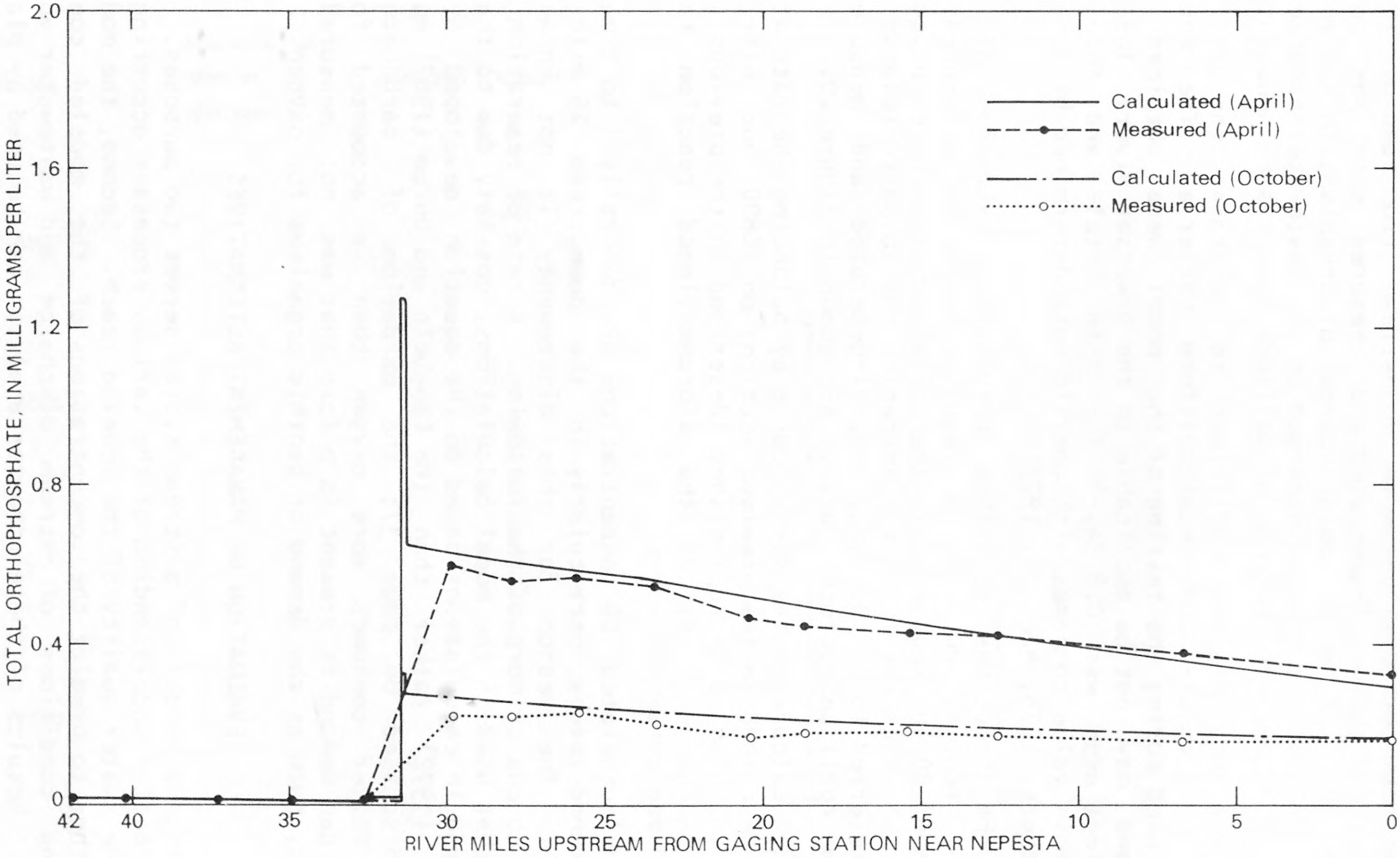


Figure 17.--Model-calculated and measured concentrations of total orthophosphate, Arkansas River study reach, April and October 1976.

Model-generated data and measured data for concentrations of total- and fecal-coliform bacteria for the October survey are shown in figures 18 and 19. The model-generated data has no relationship to the measured concentrations of coliform bacteria downstream from Pueblo. The lack of correlation between the model-generated and measured data was possibly a result of a lack of major point sources of organisms in the model reach (chlorinated effluent was being discharged by the wastewater-treatment plant at Pueblo), and large contributions of coliform bacteria by nonpoint sources.

The October data were not sufficient to determine the reaction-rate coefficients for total- and fecal-coliform bacteria. The reaction-rate coefficients used during the testing of the model were obtained from the literature and may not be applicable to the Arkansas River. The reaction-rate coefficient used was 0.8 day^{-1} for both total- and fecal-coliform bacteria. This value compares with coefficients determined by other studies (Bauer and others, 1978; Mahloch, 1973).

Two of the processes described previously, oxidation of CBOD and nitrification, require DO. As a result, there is a decrease in the concentration of DO in reaches of the river where these processes are significant. A decrease in DO concentration due to waste-related oxidation is commonly referred to as DO sag. Model-generated and measured DO-sag curves for the April and October surveys are shown in figure 20.

The model calculates the DO-sag curve by balancing the rate at which DO is consumed (described in the previous sections on CBOD and nitrification) with rate at which DO is replenished (described in the previous section on reaeration). A change in any of the aforementioned reaction rates will affect the DO-sag curve.

The model-generated DO concentrations are generally 1 to 2 mg/L larger than the measured values, particularly in the downstream 25 miles of the study reach. The reason for this discrepancy is not known but is attributable to one or more of the following: A rate of reaeration which is less than that used in the model calculations, possibly due to the inherent errors involved in calculations based on the equation developed by Bennett and Rathbun (1972) rather than the Langbein and Durum (1967) equation as previously discussed on page 37; the oxidation of carbonaceous and nitrogenous matter consumes more oxygen than is accounted for; or a dissolved-oxygen demand is present in a form that was not measured in the field surveys, such as the demand of benthic organisms for oxygen.

EVALUATION OF MANAGEMENT ALTERNATIVES

Developing a model of a stream system serves two purposes. First, it results in a better understanding of the various processes occurring in and affecting the water quality of the modeled reach. Second, the model can be used as a method to predict the concentrations of the modeled constituents under varying conditions of stream discharge and wastewater volumes and compositions. Results of these computer analyses can be used by planners for evaluating the impact of management alternatives on water quality in the stream system.

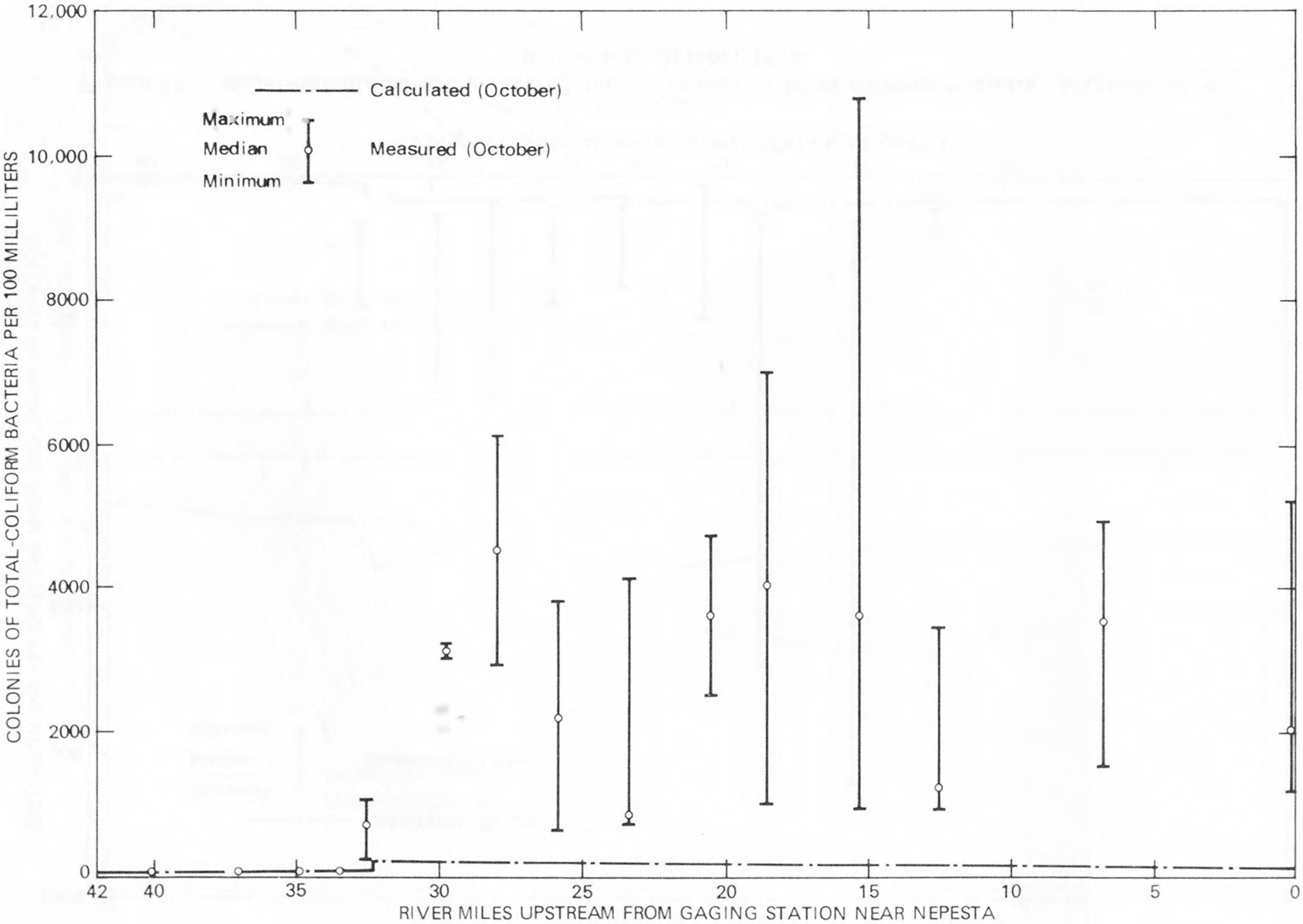


Figure 18.--Model-calculated and measured concentrations of total-coliform bacteria, Arkansas River study reach, October 1976.

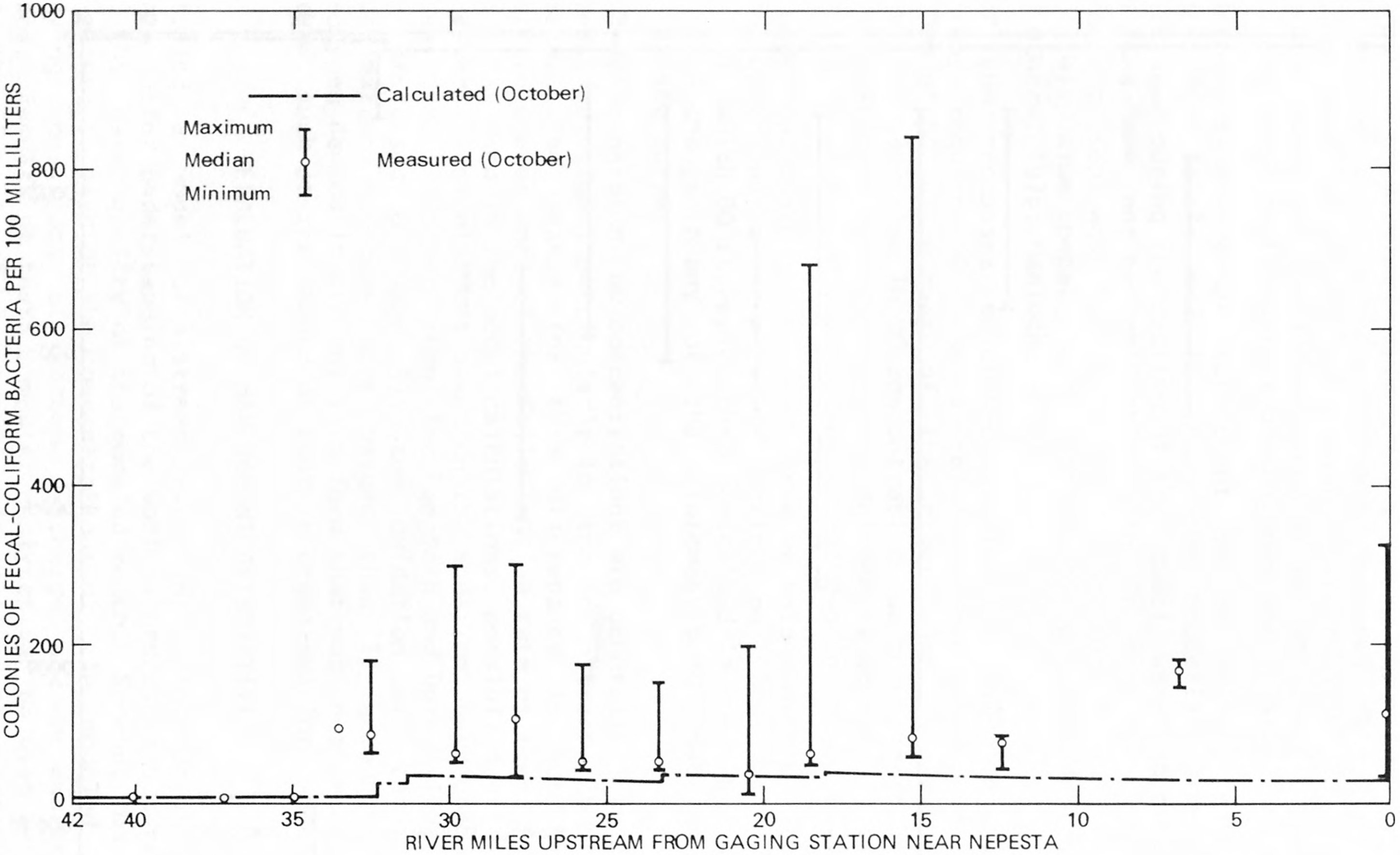


Figure 19.--Model-calculated and measured concentrations of fecal-coliform bacteria, Arkansas River study reach, October 1976.

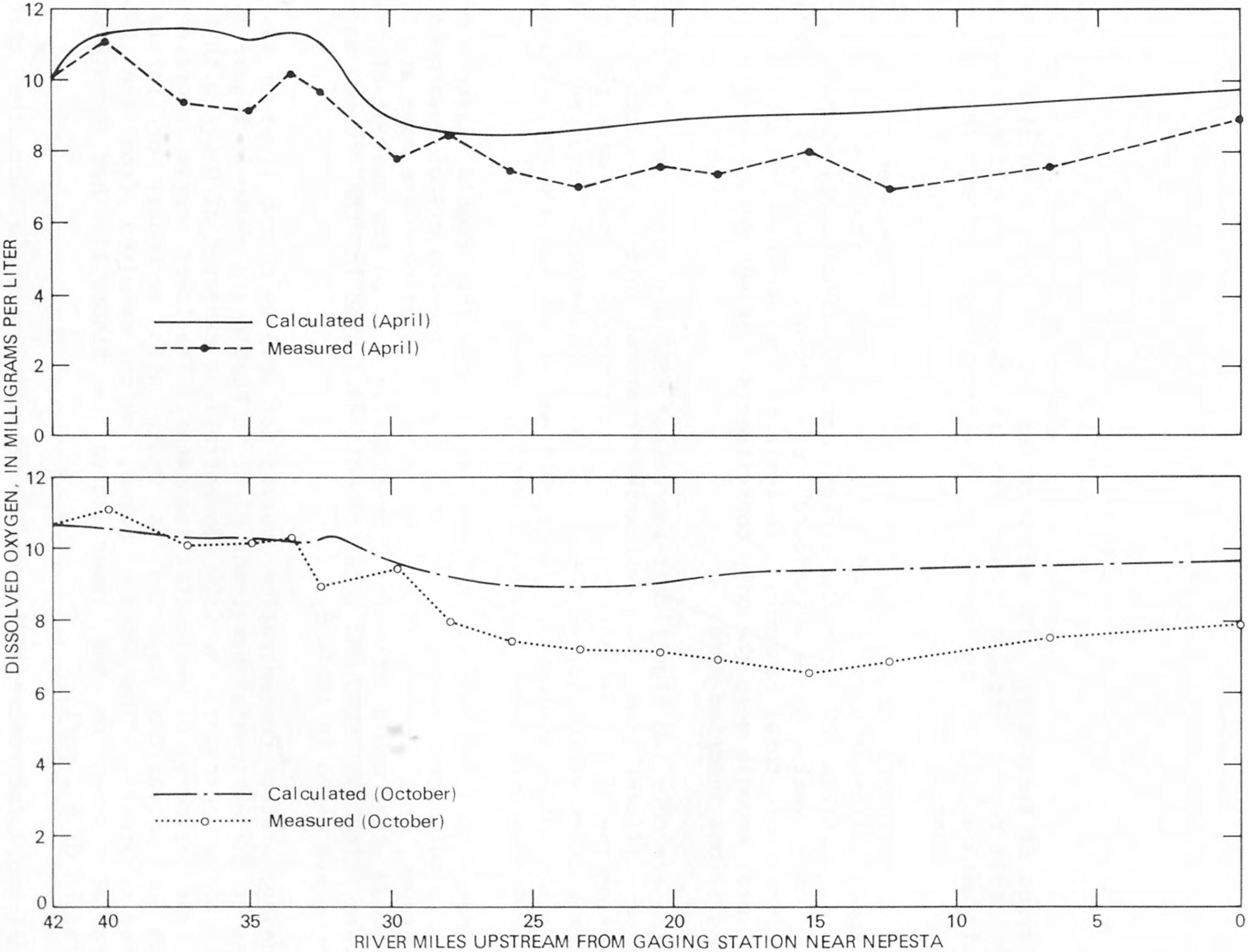


Figure 20.--Model-calculated and measured concentrations of dissolved oxygen, Arkansas River study reach, April and October 1976.

Model Simulations

During calibration of the model presented in this report, U.S. Geological Survey personnel worked closely with representatives of the Pueblo Area Council of Governments in order that the results and limitations of the model would be fully understood. Based on data provided by the Pueblo Area Council of Governments, more than 20 model simulations were made to demonstrate the use of the model using the specified $Q_{7,10}$ discharge and various combinations of sources of wastewater, types of wastewater treatment, and chemical and biological composition of wastewater that would result from the various types of treatment. The selected results of three simulations presented in this report include those results based on present wastewater-treatment methods and on optimum wastewater-treatment methods that could possibly be in use by 1983.

The constituents of greatest interest to planners when considering waste-disposal alternatives are CBOD and total ammonia. CBOD is important because it requires DO from the stream, and CBOD concentrations have been used for many years as a "standard" of organic pollution. Large concentrations of total ammonia are toxic to fish and other aquatic life. CBOD and total ammonia were the only constituents varied during the three model simulations reported here.

There are only two significant sources of CBOD and total ammonia in the model reach--effluent from the wastewater-treatment plant at Pueblo and effluent from the CF & I Steel Corp. plant (Salt Creek). These were the only wastewater sources varied during the three model simulations reported here. Data for the other sources were kept constant at the average concentration determined during both the April and October surveys.

Discharge data for both the Arkansas River and the Pueblo wastewater-treatment plant were supplied by the Pueblo Area Council of Governments (J. R. Foreman, oral commun., 1977). The model simulations were made at the minimum flow that would occur for 7 consecutive days on the average of once in 10 years (fig. 3). CBOD and total ammonia data used in the three model simulations are given in table 9.

Model-generated concentration curves for CBOD using two types of waste treatment at the wastewater-treatment plant in Pueblo are shown in figure 21. The upper curve represents the CBOD concentrations expected at $Q_{7,10}$ with the present type (primary) of wastewater treatment. The lower curve represents the CBOD concentrations expected at $Q_{7,10}$ with secondary or tertiary wastewater treatment. The DO-sag curve, which resulted from the CBOD concentrations shown on the lower curve in figure 21, had a minimum concentration of 6.2 mg/L.

Model-generated concentration curves for total ammonia for the three types of wastewater treatment are shown in figure 22. The upper curve represents the total ammonia concentrations expected at $Q_{7,10}$ using the present type (primary) of wastewater treatment. The middle curve represents

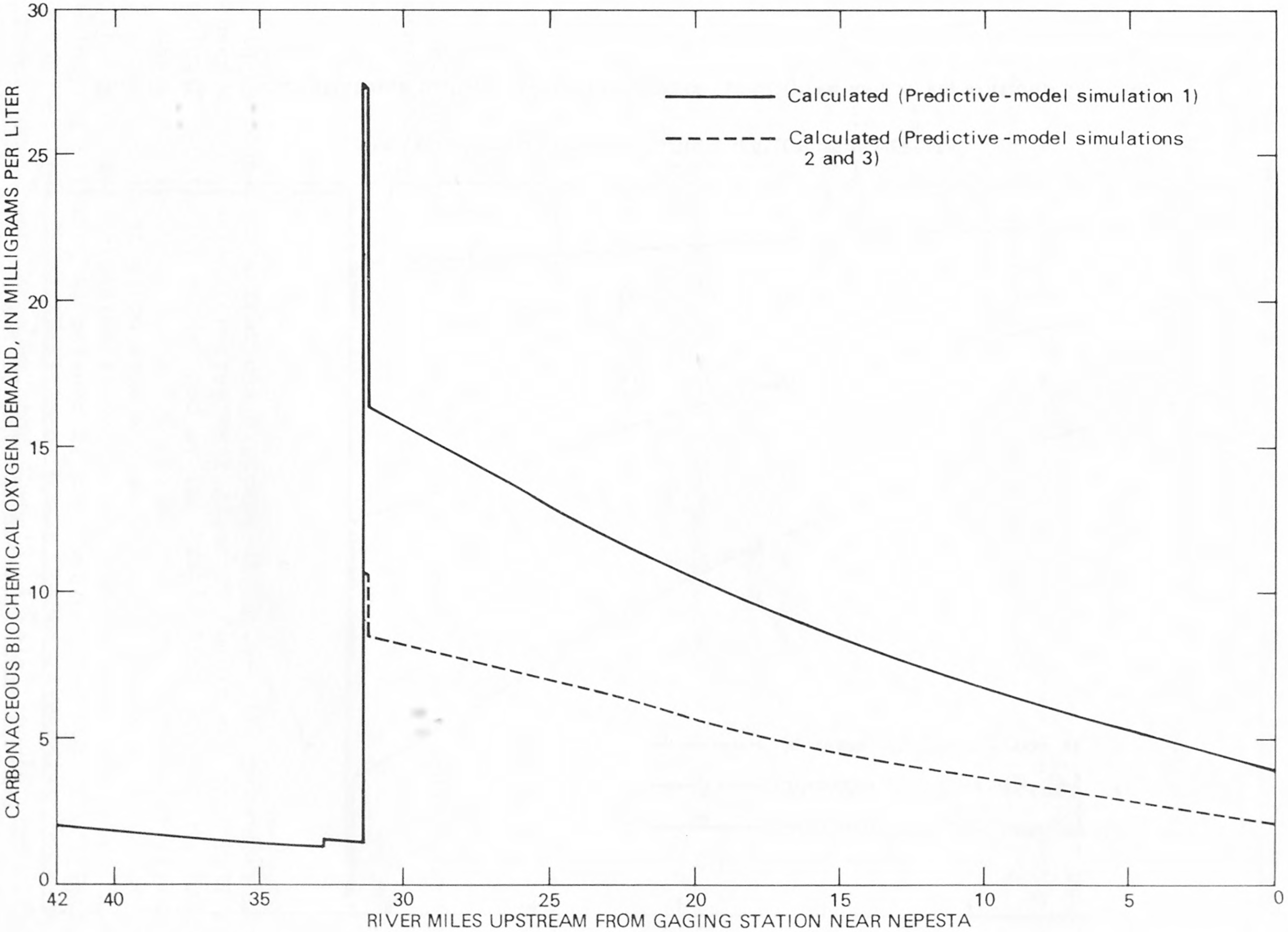


Figure 21.--Concentrations of carbonaceous biochemical oxygen demand (5-day), predictive-model simulations 1, 2, and 3.

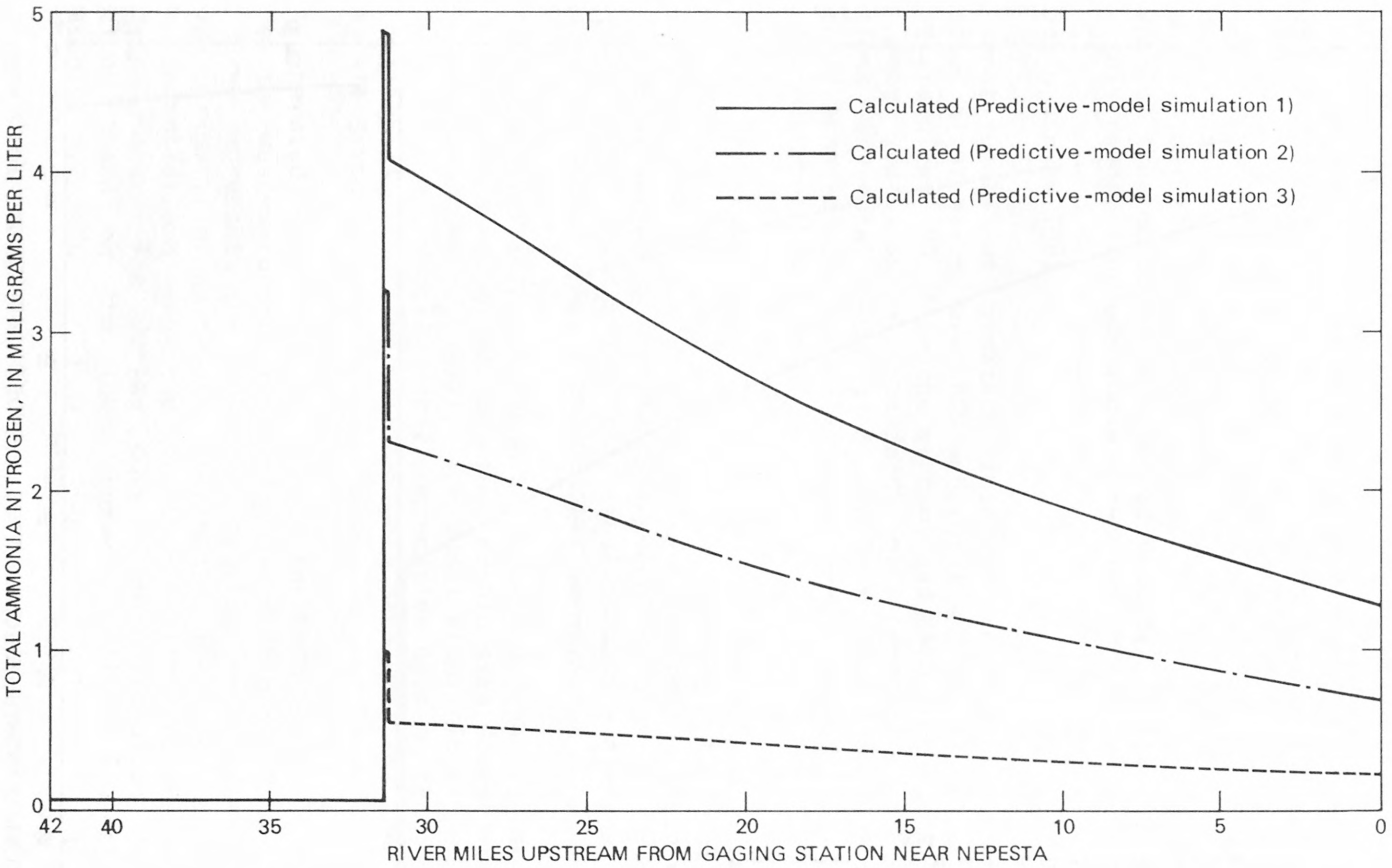


Figure 22. -- Concentrations of total ammonia nitrogen, predictive-model simulations 1, 2, and 3.

Table 9.--*Discharge, types of treatment of wastewater, and chemical quality of wastewater used in the predictive model simulations*

[mg/L=milligram per liter]

Model simulation number	Wastewater source[1]	Discharge[2] (cubic feet per second)	Treatment	Carbonaceous biochemical oxygen demand (5 day) (mg/L)	Total ammonia nitrogen (N) (mg/L)
1---	Pueblo wastewater treatment plant.	25	Present---------	82.0	15.0
	CF & I Steel Corp. plant.	95	Present---------	7.2	3.4
2---	Pueblo wastewater treatment plant.	25	Secondary treatment.[3]	30.0	10.0
	CF & I Steel Corp. plant.	95	Best practical technology.[3]	7.2	1.5
3---	Pueblo wastewater treatment plant.	25	Tertiary treatment.[3]	30.0	3.0
	CF & I Steel Corp. plant.	95	Best available technology.[3]	7.2	.16

[1] Pueblo wastewater treatment plant is site number 18; CF & I Steel Corp. plant is site number 19.

[2] Discharge specified by Pueblo Area Council of Governments.

[3] CBOD and total ammonia concentrations specified by Pueblo Area Council of Governments.

the total ammonia concentrations expected at $Q_{7,10}$ if secondary treatment were used at the wastewater-treatment plant at Pueblo and the "best practical technology" treatment, as defined by the Pueblo Area Council of Governments, were used at the CF & I Steel Corp. plant. The lower curve represents the total ammonia concentration expected at $Q_{7,10}$ if tertiary treatment were used at the wastewater-treatment plant at Pueblo and the "best available technology" treatment, as defined by the Pueblo Area Council of Governments, were used at the CF & I Steel Corp. plant. Ammonia-removal processes, which the model does not account for, would likely reduce the calculated concentrations of total ammonia so that the curves represent the maximum concentrations that could be expected.

Nonionized Ammonia

The water-quality model predicts concentrations of total ammonia; however, the water-quality standard for streams in Colorado is for nonionized ammonia. The stream standard for nonionized ammonia is equal to or less than 0.02 mg/L (Colorado Department of Health, 1978). Persons using the water-quality model to evaluate management alternatives need to consider nonionized ammonia in developing management alternatives. Nonionized ammonia can be calculated from total ammonia (Willingham, 1976), given water temperature and pH. The percentage of total ammonia that would exist as nonionized ammonia for ranges of water temperature and pH commonly occurring in the study reach of the Arkansas River is listed in table 10. Maximum concentrations of total ammonia and calculated concentrations of nonionized ammonia determined for each Arkansas River site sampled during the April and October surveys are presented in table 11. The standard of 0.02 mg/L for nonionized ammonia was exceeded at six sampling sites downstream from the outfalls of the Pueblo wastewater-treatment plant and the CF & I Steel Corp. plant during the April survey.

Table 10.--*Percentages of nonionized ammonia nitrogen in ammonia-water solutions at various pH and water-temperature values (after Willingham, 1976)*

pH (units)	Water temperature, in degrees Celsius						
	0	5	10	15	20	25	30
9.0	7.67	11.1	15.7	21.5	28.4	36.3	44.6
8.5	2.55	3.80	5.56	7.97	11.2	15.3	20.3
8.0	.820	1.23	1.83	2.67	3.82	5.38	7.46
7.5	.261	.394	.586	.859	1.24	1.77	2.48
7.0	.083	.125	.186	.273	.396	.566	.799
6.5	.026	.040	.059	.086	.125	.180	.254
6.0	.008	.013	.019	.027	.040	.057	.080

Studies by Skarheim (1973) showed the percentage of total ammonia that exists as nonionized ammonia also is a function of dissolved-solids concentration. The effect of increased dissolved solids is to reduce the percentage of nonionized ammonia. A sample of water with a pH of 8.0, temperature of 15.0°C and a dissolved-solids concentration of 1,000 mg/L will have 2.67 percent of the total ammonia as nonionized ammonia using the data from Willingham (1976), which disregards dissolved solids; and 2.28 percent using data from Skarheim (1973), which considers the effects of dissolved solids. Because dissolved-solids concentrations were not determined during the study, the effect on the percentage of total ammonia existing as nonionized ammonia was not considered in calculating concentrations shown in table 11.

If assumptions are made regarding possible water temperature and pH values, the concentration of nonionized ammonia may be determined from the total ammonia curves shown in figure 22 by the use of tables found in Willingham (1976) or Skarheim (1973).

Table 11.--*Maximum total ammonia concentrations and respective calculated concentrations of nonionized ammonia at main-stem Arkansas River sites during April and October 1976 surveys*

[°C=degree Celsius; mg/L=milligram per liter]

Site number	Site name	Date	Time	pH (units)	Water temperature (°C)	Total ammonia (mg/L)	Non-ionized ammonia (mg/L)
1	Arkansas River above Pueblo---	April 2	0310	7.5	6.0	0.10	0.00
		October 12	1533	8.2	13.0	.00	.00
2	Arkansas River near Goodnight-	April 1	1515	8.3	11.0	.04	.00
		October 12	1510	8.6	15.0	.00	.00
6	Arkansas River near Pueblo----	April 1	1630	8.5	14.0	.04	.00
		October 12	1320	8.9	16.0	.00	.00
12	Arkansas River at 4th Street Bridge.	April 1	1650	8.2	14.0	.10	.00
		October 12	1235	8.9	15.0	.00	.00
13	Arkansas River at Santa Fe Avenue Bridge.	April 2	1000	8.4	10.0	.09	.00
		April 1	1545	8.1	16.0	.00	.00
15	Arkansas River near Colorado Highway 227 Bridge.	April 2	0115	8.3	14.0	.04	.00
		October 12	0815	7.8	12.0	.00	.00
21	Arkansas River at 23rd Lane---	April 1	2130	7.8	15.0	4.5	.08
		October 14	0133	8.3	13.5	.38	.02
23	Arkansas River at Colorado Highway 233 Bridge.	April 1	2300	7.6	14.5	3.7	.04
		October 13	1438	8.2	17.5	.00	.00
25	Arkansas River above St. Charles River.	April 2	0230	7.8	13.5	3.1	.14
		October 14	0100	8.2	18.0	.00	.00
28	Arkansas River at 40th Lane---	April 2	1700	7.9	14.5	2.7	.06
		October 13	1410	8.0	17.0	.00	.00
29	Arkansas River near Avondale--	April 2	0115	7.9	14.5	2.5	.05
		October 13	0310	8.1	14.0	.00	.00
31	Arkansas River at Avondale----	April 2	0945	8.0	13.0	2.4	.07
		October 13	0910	7.4	13.0	.00	.00
32	Arkansas River at Colorado Canal Headgate.	April 2	1345	7.7	15.0	.70	.01
		October 13	0945	7.7	13.0	.00	.00
35	Arkansas River at Rocky Ford Highline Canal Headgate-----	April 2	1052	7.7	14.0	.61	.01
		October 13	1040	8.0	14.0	.00	.00
37	Arkansas River near Nepesta---	April 2	1928	8.3	12.0	.11	.00
		October 13	1720	8.4	18.0	.00	.00

SUMMARY

Section 208 of Public Law 92-500 stipulates that local governmental agencies develop and implement water-pollution controls to eliminate pollution of the Nation's rivers and streams by 1983. To assist the Pueblo Area Council of Governments in evaluating alternative plans for controlling pollution in the Arkansas River, the U.S. Geological Survey calibrated and demonstrated potential uses of a predictive water-quality model for a 42-mile reach of the river in Pueblo County. Based on the calibration, the model is capable of accurately predicting concentrations of carbonaceous biochemical oxygen demand, total organic nitrogen, total nitrite, and total orthophosphate; predicted concentrations of total ammonia, total nitrate, and dissolved oxygen will be somewhat less accurate. Additional data are needed to determine the model's capability to predict concentrations of coliform bacteria.

Data needed to calibrate the model were collected during April and October 1976. During the calibration of the model, the following reaction-rate coefficients were determined: Carbonaceous biochemical oxygen demand, 1.0 day^{-1}; total organic nitrogen, 0.2 day^{-1}; total ammonia, 1.0 day^{-1}; total nitrite, 4.0 days^{-1}; total nitrate, 1.0 day^{-1}; and total orthophosphate, 0.6 day^{-1}. The reaeration-rate coefficients for total- and fecal-coliform bacteria could not be determined because of data-collection problems and large concentrations of bacteria from nonpoint sources. The reaeration-rate coefficients determined during the calibration of the model ranged from 5.04 to 12.1 days^{-1}.

After calibration, potential uses of the model were demonstrated by simulating the effects of different wastewater discharges on streamflow quality, using water-quality and stream-discharge data provided by the Pueblo Area Council of Governments for various pollution-control alternatives. More than 20 simulations were made using various combinations of the data. Selected results for carbonaceous biochemical oxygen demand and total ammonia from three simulations illustrate the capability of the model.

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SUPPLEMENTAL INFORMATION

Table 12.--*Selected physical data and laboratory analyses of nutrients, bacteria, and biochemical oxygen demand of streamflow*

EXPLANATION OF HEADING INFORMATION

UNITS:

DEG C = Degrees Celsius
MG/L = Milligrams per liter
MICROMHOS = Micromhos per centimeter at 25° Celsius
COL. PER 100 ML= Colonies per 100 milliliters

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)	DISSOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJELDAHL NITROGEN (N) (MG/L)
1	07099400	76-04-01	1500	7.0	650	10.2	7.0	0.49
		76-04-01	1800	6.5	650	10.8	8.0	.39
		76-04-01	2100	7.0	750	9.6	7.4	.41
		76-04-02	0002	7.0	600	10.0	7.8	.59
		76-04-02	0310	6.0	650	9.9	7.5	.67
		76-04-02	0635	6.0	650	10.0	8.3	.59
		76-04-02	0925	6.5	625	10.8	8.4	.30
		76-04-02	1245	7.0	650	10.8	8.4	.40
		76-04-02	1515	7.0	650	10.8	8.4	.38
		76-10-12	1533	14.0	550	12.1	8.2	.41
		76-10-12	2140	13.0	540	8.8	7.9	.32
		76-10-13	0434	11.5	550	11.6	8.2	.27
		76-10-13	0940	13.0	545	10.2	8.4	.45
2	381544104414400	76-04-01	1515	11.0	650	11.0	8.3	.41
		76-04-01	2120	6.0	650	8.6	7.9	.39
		76-04-02	0345	5.5	650	9.8	8.1	.31
		76-04-02	0945	7.0	650	11.2	8.5	.83
		76-04-02	1310	9.0	625	11.6	8.5	.39
		76-04-02	1545	9.0	625	11.6	8.5	1.0
		76-10-12	1510	15.0	545	14.5	8.6	.27
		76-10-12	2100	13.0	560	8.1	8.0	.18
		76-10-13	0408	11.5	560	10.8	8.1	.39
		76-10-13	0910	13.0	540	10.8	8.5	.32
3	381604104400500	76-10-12	1347	15.0	2900	10.2	7.7	1.5
		76-10-13	0215	10.5	2900	9.1	7.7	1.3
4	381604104394200	76-10-12	1335	16.0	2000	8.8	8.1	.71
		76-10-13	0200	13.0	2200	10.0	8.0	.73
5	381603104392200	76-10-12	1315	16.0	1200	9.1	8.0	.25
		76-10-13	0128	14.0	1110	10.8	8.1	.26
6	07099500	76-04-01	1630	14.0	650	9.0	8.5	.46
		76-04-01	1935	12.0	650	9.2	7.2	.59
		76-04-02	0110	7.0	700	7.8	8.0	.17
		76-04-02	0510	5.0	650	10.0	8.1	.47
		76-04-02	0745	5.0	650	10.3	8.3	.47
		76-04-02	1650	11.0	600	10.2	8.5	.21
		76-10-12	1320	16.0	535	10.8	8.9	.37
		76-10-12	1950	15.0	560	8.9	8.5	.52
		76-10-13	0123	12.5	540	11.5	8.1	.42
		76-10-13	0820	12.0	540	9.2	---	.24
7	381623104390500	76-10-12	1415	16.0	545	9.7	9.0	.12

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITROGEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)	TOTAL COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)
0.08	0.01	0.52	1.0	0.03	0.00	2	0	1.7
.04	.02	.55	.96	.02	.01	---	---	2.0
.08	.02	.53	.96	.03	.00	---	---	---
.04	.02	.52	1.1	.03	.01	---	---	2.3
.10	.02	.51	1.2	.05	.06	0	0	---
.05	.01	.54	1.1	.02	.00	---	---	2.3
.08	.01	.55	.86	.00	.00	---	---	2.1
.02	.01	.64	1.1	.00	.01	---	---	1.8
.05	.02	.56	.96	.01	.01	2	0	2.0
.00	.01	.54	.96	.02	.01	530	8	1.8
.01	.01	.52	.85	.02	.01	---	---	1.8
.00	.01	.54	.82	.02	.01	---	---	2.2
.00	.01	.77	1.2	.02	.01	20	8	1.8
.04	.01	.50	.92	.02	.00	1	0	1.8
.04	.02	.52	.93	.02	.00	------	---	
.04	.02	.52	.85	.02	.01	0	0	2.0
.03	.01	.60	.99	.00	.01	---	---	1.7
.04	.01	.54	.94	.01	.00	---	---	1.6
.03	.01	.51	1.5	.01	.00	1	0	1.7
.00	.02	.18	.47	.01	.01	12	16	1.6
.01	.01	.43	.62	.03	.01	---	---	.75
.00	.01	.34	.74	.02	.01	---	---	1.1
.00	.02	.27	.61	.01	.01	25	6	1.1
.02	.04	10	12	.05	.01	220	205	5.0
.06	.04	13	14	.06	.02	740	290	---
.02	.02	17	18	.00	.01	600	0	3.9
.01	.01	21	22	.02	.03	600	0	6.2
.00	.01	4.2	4.5	.02	.01	2000	860	.8
.00	.01	4.5	4.8	.04	.04	920	400	.1
.04	.01	.57	1.0	.03	.01	27	23	1.5
.02	.01	.57	1.2	.02	.00	---	---	1.9
.04	.02	.71	.90	.02	.00	---	---	2.0
.04	.01	.60	1.1	.03	.07	12	16	1.8
.03	.01	.64	1.1	.00	.00	---	---	1.8
.02	.01	.59	.81	.00	.00	29	27	1.7
.00	.02	1.2	1.6	.01	.01	15	4	1.6
.00	.02	.22	.76	.02	.00	---	---	1.4
.01	.01	.61	1.0	.01	.02	---	---	1.2
.00	.02	.40	.66	.01	.01	40	3	1.2
.00	.02	.25	.39	.02	.00	18	8	1.6

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)	DISSOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJELDAHL NITROGEN (N) (MG/L)
		76-10-13	0305	11.5	570	11.5	8.0	0.36
8	381608104383800	76-10-12	1300	15.0	1040	9.6	8.1	.25
		76-10-13	0105	14.5	1080	10.0	7.9	.24
10	381621104382000	76-04-01	1535	10.0	700	9.0	7.8	1.1
		76-04-02	0420	7.0	750	9.8	7.9	.98
		76-04-02	1625	9.0	700	9.8	8.0	4.2
		76-10-12	1435	16.0	600	8.9	7.9	1.6
		76-10-13	0323	11.5	570	10.6	7.9	.48
11	361628104381700	76-04-01	1545	14.0	2100	8.8	7.8	.90
		76-04-02	0445	8.0	2200	8.2	7.6	.81
		76-04-02	1610	13.0	2100	11.6	8.0	.88
		76-10-12	1448	18.0	1450	7.3	7.3	.50
		76-10-12	2020	17.0	1500	6.3	7.4	.60
		76-10-13	0338	14.0	1550	8.6	7.5	.58
		76-10-13	0840	16.5	1500	8.4	7.4	.60
12	381607104372500	76-04-01	1650	14.0	750	9.4	8.2	.46
		76-04-01	1955	12.0	590	9.2	7.5	.39
		76-04-01	2230	9.0	850	7.0	7.8	.38
		76-04-02	0130	10.0	900	6.8	---	.49
		76-04-02	0535	7.0	700	8.0	8.1	.51
		76-04-02	0830	6.5	800	8.5	8.2	.57
		76-04-02	1430	11.0	750	10.6	8.3	.76
		76-04-02	1715	11.0	800	10.8	8.4	.49
		76-10-12	1235	15.0	545	13.4	8.8	.17
		76-10-12	1840	15.5	540	9.3	8.9	.32
		76-10-13	0038	12.0	520	9.3	8.1	.08
		76-10-13	0755	12.0	590	8.6	8.0	.08
13	381516104362200	76-04-01	1545	16.0	815	10.2	8.1	.46
		76-04-01	2200	12.0	850	8.0	8.3	.39
		76-04-02	0445	8.5	960	8.8	8.0	.69
		76-04-02	1000	10.0	906	12.0	8.4	.98
		76-04-02	1540	12.0	1110	12.0	8.5	.46
		76-10-12	1050	14.0	630	---	8.6	.15
		76-10-12	1735	16.0	600	10.4	9.0	.24
		76-10-12	2350	12.0	660	9.3	8.2	.29
		76-10-13	0710	11.0	650	8.2	7.8	.30
		76-10-13	1120	15.0	650	13.2	8.7	.29
14	381508104354400	76-04-01	1430	17.0	710	7.8	---	.40
		76-04-02	0350	16.0	810	8.9	8.3	.85
		76-04-02	1510	17.0	825	9.3	8.4	.38

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITROGEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)	TOTAL COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)
0.00	0.02	0.24	0.62	0.01	0.00	26	5	1.4
.00	.01	.85	1.1	.01	.01	500	80	.9
.05	.03	.90	1.2	.04	.01	110	30	1.3
.47	.01	.58	1.7	.05	.01	0	0	.6
.47	.01	.61	1.6	.04	.00	0	0	.8
.48	.01	.60	4.8	.02	.00	100	10	.6
1.5	.02	.45	2.1	.03	.04	0	0	1.8
.45	.01	.45	.94	.02	.04	0	0	1.0
.03	.03	11	12	.03	.00	26	25	1.0
.04	.04	11	12	.04	.01	20	82	1.4
.02	.03	12	13	.01	.00	38	21	---
.14	.01	7.3	7.8	.00	.01	110	20	0
.00	.01	7.8	8.4	.00	.00	---	---	.1
.03	.01	7.7	8.3	.01	.01	---	---	.2
.08	.01	8.0	8.6	.00	.01	0	0	0
.10	.01	.74	1.2	.05	.04	400	420	1.7
.08	.02	.70	1.1	.03	.00	---	---	1.8
.09	.02	.72	1.1	.02	.00	---	---	---
.04	.02	.75	1.3	.10	.00	---	---	1.6
.08	.02	.74	1.3	.02	.02	62	54	1.7
.08	.01	.77	1.4	.00	.00	---	---	1.8
.09	.02	.72	1.5	.04	.00	---	---	1.3
.05	.02	.75	1.3	.05	.00	72	5	1.8
.00	.01	.27	.45	.01	.00	48	8	1.4
.01	.01	.46	.79	.01	.01	---	---	2.8
.02	.01	.75	.84	.02	.01	---	---	1.2
.00	.01	.56	.65	.01	.01	20	8	1.0
.00	.02	.98	1.5	.02	.00	20	34	1.2
.04	.02	1.5	1.9	.03	.02	---	---	---
.10	.02	1.6	2.3	.02	.00	55	72	1.8
.09	.02	1.6	2.6	.02	.05	---	---	---
.09	.02	1.4	1.9	.04	.00	57	39	1.8
.00	.02	.65	.82	.01	.00	33	94	1.1
.00	.01	.56	.81	.00	.00	---	---	1.7
.00	.02	.74	1.1	.02	.00	---	---	1.6
.01	.02	.72	1.0	.01	.00	---	---	0
.00	.02	.58	.89	.01	.00	---	1750	1.4
.03	.02	.74	1.2	.02	.00	6	1	1.8
.04	.01	.76	1.6	.06	.00	0	6	2.0
.05	.01	.73	1.1	.01	.01	57	39	2.2

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPER-ATURE (DEG C)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	DIS-SOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)
		76-10-12	1125	19.0	580	---	8.6	0.17
		76-10-12	1715	19.0	600	9.4	8.5	.30
		76-10-13	0013	18.0	575	10.7	8.6	.18
		76-10-13	0730	18.0	590	8.0	8.6	.10
15	381510104350900	76-04-01	1645	16.5	790	8.7	8.4	1.2
		76-04-01	1930	12.0	810	12.1	8.4	.58
		76-04-01	2230	15.0	820	8.3	8.3	1.1
		76-04-02	0115	14.0	800	9.1	8.3	.86
		76-04-02	0510	13.0	850	8.4	8.2	.86
		76-04-02	0740	13.0	850	8.8	8.2	.59
		76-04-02	1030	14.0	794	9.9	8.4	.47
		76-04-02	1340	15.5	860	10.8	8.4	3.8
		76-04-02	1625	16.0	740	10.6	8.5	.21
		76-10-13	0815	12.0	745	8.3	7.8	.36
		76-10-13	1005	12.5	760	8.9	8.0	.48
		76-10-13	1315	16.0	755	10.3	8.4	.45
		76-10-13	1525	17.5	780	10.0	8.7	.61
		76-10-13	1730	17.5	750	10.1	8.7	.41
		76-10-13	2040	15.0	690	7.9	8.5	.43
		76-10-13	2250	14.0	730	7.6	8.3	.55
		76-10-14	0130	13.5	680	7.8	8.4	.29
		76-10-14	0340	12.0	690	---	8.4	.36
		76-10-14	0700	12.0	612	5.7	8.4	.71
		76-10-14	0945	14.0	662	9.8	8.5	.41
16	381515104351900	76-04-01	1630	17.0	2200	9.9	8.7	.87
		76-04-01	2230	9.5	2020	9.1	8.2	.55
		76-04-02	0540	7.0	2200	9.8	8.3	.96
		76-04-02	1045	13.0	2140	12.1	8.7	.68
		76-04-02	1640	13.5	2400	11.4	8.8	.80
		76-10-12	1030	13.0	1700	---	8.3	2.0
		76-10-12	1800	17.0	1700	7.5	8.3	1.9
		76-10-12	2320	12.5	1700	8.7	8.4	1.1
		76-10-13	0645	9.0	1700	9.0	8.3	.83
18	381522104342100	76-04-01	1715	16.0	2500	---	7.3	37
		76-04-01	2015	14.0	2500	---	7.5	37
		76-04-01	2315	15.0	2000	4.6	7.7	28
		76-04-02	0145	14.0	2000	5.7	7.5	31
		76-04-02	0605	14.0	2000	5.6	7.5	31
		76-04-02	0835	14.0	1900	5.9	7.5	24
		76-04-02	1130	15.0	1890	6.8	7.5	23

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITROGEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)	TOTAL COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)
0.00	0.01	0.40	0.58	0.01	0.00	16	10	1.5
.01	.01	.40	.71	.01	.00	---	---	1.6
.01	.01	.41	.60	.01	.00	---	---	1.2
.00	.01	.36	.47	.01	.00	10	12	1.4
.05	.01	.76	2.0	.08	.05	6	3	1.5
.02	.01	.76	1.4	.04	.01	---	---	4.8
.04	.01	.84	2.0	.16	.01	---	---	2.0
.09	.01	.81	1.7	.05	.08	---	---	2.8
.05	.01	.91	1.8	.03	.00	---	---	2.2
.03	.02	.93	1.5	.00	.00	---	---	1.9
.04	.02	.91	1.4	.00	.00	---	---	2.0
.05	.02	.86	4.7	.01	.00	---	---	2.2
.05	.02	.82	1.1	.01	.02	47	26	2.1
.00	.01	.65	1.0	.10	.02	900	66	1.4
.00	.01	.75	1.2	.13	.04	700	84	1.6
.01	.01	.71	1.2	.13	.04	---	---	2.0
.00	.01	.42	1.0	.14	.01	11000	1100	2.3
.00	.01	.56	.98	.13	.02	---	---	2.0
.01	.01	.73	1.2	.14	.05	---	---	2.0
.02	.01	.78	1.3	.15	.05	---	---	2.1
.00	.01	.78	1.1	.11	.04	220	106	1.6
.01	.01	.78	1.2	.11	.04	---	---	1.6
.00	.01	.10	.82	.06	.01	1040	180	1.6
.00	.01	.60	1.0	.07	.01	300	62	1.6
.03	.01	2.2	3.1	.26	.17	90	1	1.9
.02	.06	2.7	3.4	.25	.20	---	---	1.8
.02	.05	2.9	3.9	.25	.20	8	4	1.9
.08	.02	2.4	3.1	.25	.20	---	---	1.9
.10	.01	2.4	3.2	.24	.18	60	2	1.6
.01	.01	2.8	4.8	.69	.38	1000	150	1.0
.00	.01	2.8	4.7	.95	.40	---	---	2.0
.01	.01	3.1	4.2	.91	.44	---	---	1.6
.00	.01	3.1	3.9	.81	.39	---	---	1.3
21	.01	.00	37	7.3	6.5	---	---	88
18	.01	.00	37	7.8	6.5	---	---	90
16	.01	.00	28	8.8	6.4	---	---	97
8.4	.01	.00	31	7.9	6.3	---	---	96
16	.02	.02	31	6.7	5.6	---	---	89
14	.01	.08	24	6.2	5.3	---	---	65
12	.01	.03	23	5.0	4.0	---	---	90

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)	DISSOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJELDAHL NITROGEN (N) (MG/L)
		76-04-02	1440	15.0	2200	6.1	7.6	21
		76-04-02	1740	15.0	2500	5.6	7.6	21
		76-10-13	0800	16.0	2100	6.9	7.1	18
		76-10-13	0945	18.0	2130	6.7	7.5	19
		76-10-13	1300	19.5	2240	6.8	7.6	21
		76-10-13	1500	21.0	2210	6.7	7.6	21
		76-10-13	1705	20.5	2250	6.4	7.7	19
		76-10-13	2030	20.5	1800	6.5	7.8	19
		76-10-13	2230	20.0	2120	6.3	7.6	18
		76-10-14	0045	20.0	1750	6.6	8.0	16
		76-10-14	0710	19.0	1770	7.6	7.9	18
		76-10-14	0955	19.0	2000	6.4	7.9	17
19	381522104341800	76-04-01	1730	18.0	650	---	8.3	4.1
		76-04-01	2330	18.0	680	6.8	7.6	4.7
		76-04-02	0615	17.0	700	7.3	8.3	4.7
		76-04-02	1720	17.5	690	7.4	8.4	3.9
		76-10-13	0845	---	660	6.3	8.3	3.8
		76-10-13	1025	---	655	6.8	8.3	3.9
		76-10-13	1345	20.5	670	7.0	8.3	3.9
		76-10-13	1555	20.5	670	6.7	8.4	4.7
		76-10-13	1715	---	650	6.6	8.3	4.6
		76-10-13	2105	20.0	680	6.7	8.5	4.9
		76-10-13	2340	20.0	660	6.2	8.3	4.3
		76-10-14	0145	19.5	650	6.3	8.4	4.0
		76-10-14	0350	18.0	650	6.5	8.4	4.0
		76-10-14	0720	21.0	555	6.6	8.4	3.9
		76-10-14	1010	21.5	550	6.8	8.3	4.0
21	381547104330800	76-04-01	1447	21.5	850	9.3	8.5	4.9
		76-04-01	1800	17.0	875	7.6	8.0	4.2
		76-04-01	2130	15.0	875	9.4	7.8	4.6
		76-04-02	0100	14.0	875	9.4	7.7	5.0
		76-04-02	0305	13.5	900	4.7	7.5	4.4
		76-04-02	0610	13.0	870	6.0	8.0	4.4
		76-04-02	0910	14.5	860	8.5	8.3	4.0
		76-04-02	1500	16.5	920	9.0	8.4	4.4
		76-10-13	1335	17.0	800	10.6	8.4	2.0
		76-10-13	2010	15.5	760	11.8	8.7	2.0
		76-10-14	0133	13.5	750	7.6	8.3	1.8
		76-10-14	0400	13.0	725	7.7	8.2	1.1
		76-10-14	0700	12.0	720	---	8.0	1.2

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITRO- GEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITRO- GEN (N) (MG/L)	TOTAL PHOS- PHORUS (P) (MG/L)	TOTAL ORTHO PHOS- PHORUS (P) (MG/L)	TOTAL COLI- FORM (COL. PER 100 ML)	FECAL COLI- FORM (COL. PER 100 ML)	BIO- CHEM- ICAL OXYGEN DEMAND 5 DAY (MG/L)
19	0.01	0.02	21	6.1	5.0	---	---	92
18	.01	.00	21	6.6	5.7	---	---	93
19	.09	.21	18	8.3	6.3	0	0	46
20	.15	.18	19	7.6	6.2	110	0	82
22	.15	.16	21	6.1	5.1	---	---	49
22	.10	.15	21	6.3	5.3	80	0	75
20	.12	.06	19	6.7	5.7	100	0	60
19	.01	.00	19	7.1	6.3	---	---	58
19	.01	.00	18	7.7	6.1	---	---	81
18	.06	.13	16	7.5	5.9	0	0	59
18	.09	.24	18	7.6	6.2	20	5	50
18	.09	.22	17	6.9	6.1	100	4	44
3.0	.26	.69	5.1	.11	.05	---	---	9.0
4.1	.27	.67	5.6	.09	.02	---	---	12
3.6	.24	.67	5.6	.11	.03	---	---	10
2.7	.33	.67	4.9	.06	.02	---	---	8.4
3.3	.31	.89	5.0	.07	.02	180	50	4.5
3.2	.32	.88	5.1	.06	.03	310	20	3.0
3.7	.28	.92	5.1	.06	.03	---	---	4.5
3.9	.29	.91	5.9	.06	.01	180	143	5.0
4.0	.30	.90	5.8	.06	.03	153	103	4.5
3.6	.66	.94	6.5	.26	.01	---	---	4.5
3.6	.53	.97	5.8	.06	.01	---	---	4.8
3.3	.72	.88	5.6	.10	.13	180	60	4.6
3.2	.57	.93	5.5	.08	.06	---	---	5.4
3.3	.52	.98	5.4	.06	.05	13000	90	4.6
3.1	.75	.95	5.7	.09	.00	---	---	5.1
3.7	.21	.68	5.8	.79	.55	---	---	---
4.2	.20	.59	5.0	.84	.62	---	---	---
4.5	.19	.57	5.4	.91	.68	---	---	---
3.9	.17	.56	5.7	.80	.61	---	---	---
3.7	.32	.62	5.3	.86	.65	---	---	---
3.0	.27	.83	5.5	.64	.46	---	---	---
2.7	.34	.76	5.1	.61	.44	---	---	---
3.3	.40	.80	5.6	.72	.52	---	---	---
1.3	.25	.75	3.0	.43	.27	3000	300	7.5
1.1	.21	.79	3.0	.46	.28	---	---	8.9
.38	.20	1.0	3.0	.45	.21	3200	55	7.8
.70	.09	.88	2.1	.30	.19	---	---	7.8
.64	.09	.91	2.2	.31	.18	---	---	---

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)	DISSOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJELDAHL NITROGEN (N) (MG/L)
		76-10-14	0900	12.5	750	8.1	8.0	1.2
		76-10-14	1708	19.0	760	11.0	8.7	1.9
22	381601104313000	76-04-01	1510	19.0	850	10.4	8.5	4.7
		76-04-01	1845	15.0	860	10.3	8.0	4.4
		76-04-01	2230	15.0	900	8.2	7.6	2.9
		76-04-02	0130	14.0	900	8.4	7.7	5.0
		76-04-02	0340	13.0	900	4.4	7.8	4.2
		76-04-02	0635	12.5	880	6.2	8.0	3.4
		76-04-02	0940	14.5	780	8.6	8.4	4.1
		76-04-02	1235	16.5	810	9.4	8.2	4.4
		76-04-02	1515	17.0	920	10.4	8.3	4.3
		76-10-13	1415	18.0	770	9.1	8.3	1.5
		76-10-13	1740	18.0	750	11.6	8.6	1.3
		76-10-13	2240	15.5	720	7.5	8.6	1.2
		76-10-14	0100	14.0	740	6.8	8.3	1.3
		76-10-14	0430	13.0	700	7.1	8.0	1.0
		76-10-14	0635	13.0	700	6.8	7.9	.73
		76-10-14	0840	13.0	710	6.4	8.0	.93
23	381530104294600	76-04-01	1535	20.5	825	9.2	8.4	4.6
		76-04-01	1930	14.0	900	9.4	7.8	4.8
		76-04-01	2300	14.5	940	6.6	7.6	4.9
		76-04-02	0200	14.0	925	6.6	7.5	5.0
		76-04-02	0405	12.0	950	4.0	7.7	2.3
		76-04-02	0700	12.5	930	4.4	7.8	3.4
		76-04-02	1005	14.0	900	7.7	8.2	3.8
		76-04-02	1250	16.5	900	9.4	8.1	3.5
		76-04-02	1535	17.0	960	9.3	8.2	2.0
		76-10-13	1438	17.5	790	8.1	8.2	1.1
		76-10-13	1810	17.5	750	---	8.5	1.1
		76-10-13	2313	15.0	740	5.5	8.6	1.2
		76-10-14	0025	14.5	750	5.8	8.4	1.3
		76-10-14	0243	14.0	775	---	8.3	1.3
		76-10-14	0555	13.0	725	---	7.6	.77
		76-10-14	0810	12.0	710	5.5	8.1	.81
24	381609104282600	76-04-01	1500	15.5	1300	8.2	7.9	17
		76-04-01	2300	16.5	1270	7.7	7.8	16
		76-04-02	0430	14.0	1200	8.2	8.0	15
		76-04-02	0945	15.0	1300	7.9	8.1	9.8
		76-04-02	1530	15.5	1300	7.7	7.9	9.8
		76-10-13	1508	20.0	1360	5.8	7.7	19

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITRO-GEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITRO-GEN (N) (MG/L)	TOTAL PHOS-PHORUS (P) (MG/L)	TOTAL ORTHO PHOS-PHORUS (P) (MG/L)	TOTAL COLI-FORM (COL. PER 100 ML)	FECAL COLI-FORM (COL. PER 100 ML)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)
0.79	0.10	0.86	2.2	0.32	0.18	---	50	7.5
1.3	.21	.72	2.8	.46	.28	---	---	9.2
3.3	.34	.76	5.8	.82	.54	---	---	---
4.1	.30	.65	5.4	.88	.65	---	---	---
4.2	.27	.60	3.8	.92	.67	---	---	---
4.2	.25	.59	5.8	.91	.67	---	---	---
3.9	.31	.62	5.1	.84	.66	---	---	---
2.3	.30	.80	4.5	.68	.51	---	---	---
2.6	.50	.80	5.4	.52	.39	---	---	---
2.9	.52	.78	5.7	.80	.62	---	---	---
2.9	.48	.72	5.5	.70	.52	---	---	---
1.0	.47	1.2	3.2	.37	.27	6100	300	9.0
.46	.77	1.2	3.3	.41	.30	---	---	9.0
.00	.01	1.5	2.7	.35	.17	---	---	8.8
.07	.05	2.5	3.8	.41	.26	---	---	8.0
.00	.00	2.2	3.2	.29	.18	---	---	8.0
.00	.00	1.6	2.3	.26	.16	2900	105	5.0
.01	.00	1.8	2.7	.29	.18	---	30	7.8
2.8	.44	.96	6.0	.77	.56	---	---	---
3.5	.42	.78	6.0	.74	.52	---	---	---
3.7	.34	.66	5.9	.83	.61	---	---	---
.03	.31	.66	6.0	1.0	.71	---	---	---
2.8	.38	.82	3.5	.82	.64	---	---	---
2.5	.35	.95	4.7	.77	.55	---	---	---
2.5	.56	.84	5.2	.52	.38	---	---	---
2.2	.56	1.0	5.1	.61	.44	---	---	---
2.1	.64	.96	3.6	.71	.56	---	---	---
.00	.00	2.3	3.4	.40	.23	640	40	7.8
.00	.02	2.8	3.9	.35	.23	---	---	7.0
.01	.00	2.6	3.8	.37	.24	---	---	7.5
.00	.00	2.2	3.5	.37	.25	3800	175	8.0
.12	.05	2.1	3.5	.47	.25	---	---	7.5
.00	.00	1.8	2.6	.28	.17	---	---	7.5
.02	.01	1.9	2.7	.26	.17	---	50	7.5
9.3	.85	2.4	20	7.2	6.5	5	0	27
9.2	.88	.42	17	7.7	7.0	---	---	37
9.1	.31	.15	15	7.8	7.2	530	---	31
8.7	.55	1.3	12	7.3	6.7	---	---	28
9.8	.71	.59	11	8.4	8.3	2	0	25
22	.44	.15	20	9.9	9.3	0	0	32

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)	DISSOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJELDAHL NITROGEN (N) (MG/L)
		76-10-13	2350	19.0	1250	9.1	8.1	19
		76-10-14	0500	14.0	1300	7.3	8.4	15
		76-10-14	0740	19.0	1200	5.1	7.6	18
25	381600104272600	76-04-01	1615	20.0	880	8.9	8.5	3.2
		76-04-01	1945	18.5	900	6.5	7.8	2.3
		76-04-01	2355	15.5	910	5.0	7.6	4.7
		76-04-02	0230	13.5	910	4.6	7.8	4.8
		76-04-02	0500	12.0	920	4.6	7.3	3.1
		76-04-02	0800	12.0	920	6.4	7.3	1.7
		76-04-02	1100	15.0	880	8.7	8.2	3.6
		76-04-02	1330	16.0	880	9.4	8.4	3.8
		76-04-02	1630	17.0	900	8.5	8.3	3.7
		76-10-13	0920	13.0	760	7.2	8.0	.92
		76-10-13	1330	16.0	770	8.0	8.2	.95
		76-10-13	1650	18.0	810	8.6	8.3	1.2
		76-10-13	1755	18.0	810	8.6	8.3	1.1
		76-10-14	0100	15.0	780	5.8	8.2	.88
		76-10-14	0430	13.5	800	6.1	8.0	.98
		76-10-14	0655	11.5	790	6.3	7.9	1.1
		76-10-14	0820	12.5	790	6.9	7.9	.58
26	381556104273300	76-04-01	1600	18.5	2300	9.0	8.2	1.3
		76-04-01	2345	12.0	2300	7.9	7.5	1.1
		76-04-02	0500	9.5	2500	8.2	7.8	1.2
		76-04-02	1050	14.0	2400	10.6	8.4	1.3
		76-04-02	1625	15.0	2300	10.8	8.3	1.0
		76-10-13	0900	11.5	930	8.5	8.2	.66
		76-10-13	1745	16.0	960	8.1	8.3	.63
		76-10-14	0050	12.5	1010	8.1	7.8	.49
		76-10-14	0810	10.5	1100	8.4	8.1	.69
28	381532104252100	76-04-01	1700	20.5	890	9.1	8.5	2.5
		76-04-02	0040	14.5	930	5.8	7.9	4.4
		76-04-02	0540	12.0	980	5.0	---	3.3
		76-04-02	1150	15.5	900	9.4	8.3	3.1
		76-04-02	1710	17.0	910	8.9	8.3	2.9
		76-10-13	1010	13.0	800	7.4	8.1	.79
		76-10-13	1410	17.0	800	8.4	8.0	.74
		76-10-13	1850	18.0	830	8.4	8.2	.75
		76-10-14	0215	14.5	800	5.8	8.1	.72
		76-10-14	0515	13.5	810	6.0	7.9	.73
		76-10-14	0910	12.5	800	6.5	7.9	1.2

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITROGEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)	TOTAL COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)
21	0.59	0.16	20	11	11	---	---	37
19	.09	3.7	19	12	11	---	---	52
20	.42	.26	19	11	9.6	10	0	41
1.8	.53	1.2	4.9	.83	.43	---	---	14
1.2	.78	1.1	4.2	.66	.51	1100	480	15
3.1	.41	.79	5.9	.75	.65	---	---	12
3.1	.39	.71	5.9	.84	.63	---	---	13
2.8	.48	.91	4.5	.92	.70	---	---	15
2.0	.56	1.2	3.5	.81	.59	---	---	16
2.1	.64	1.1	5.3	.59	.44	---	---	13
2.0	.46	1.1	5.4	.46	.37	---	---	15
2.0	.55	1.2	5.4	.59	.49	---	---	12
.01	.25	1.8	2.9	.28	.17	720	40	4.0
.15	.39	1.4	2.8	.27	.19	700	50	4.0
.00	.03	2.0	3.2	.36	.21	---	---	4.8
.26	.47	1.6	3.2	.35	.21	4100	150	4.4
.00	.00	2.2	3.1	.36	.23	---	---	5.0
.00	.00	2.2	3.2	.38	.23	---	---	4.5
.03	.03	2.1	3.2	.31	.20	---	---	4.5
.00	.00	1.8	2.4	.27	.15	---	---	4.4
.03	.02	.65	2.0	.05	.02	25	42	2.0
.04	.03	.72	1.9	.06	.01	---	---	1.9
.02	.03	.72	2.0	.06	.01	150	135	1.9
.05	.03	.65	2.0	.08	.06	---	---	2.5
.03	.01	.52	1.5	.03	.00	40	46	2.6
.01	.01	.45	1.1	.24	.07	---	265	1.8
.01	.01	.47	1.1	.17	.06	460	165	1.9
.01	.01	.52	1.0	.21	.05	---	---	1.9
.00	.00	.33	1.0	.19	.05	---	135	.8
.98	.49	1.6	4.6	.63	.31	---	---	9.8
2.7	.43	.97	5.8	.69	.57	---	---	13
2.3	.51	.99	4.8	.75	.63	---	---	9.1
2.2	.56	1.1	4.8	.61	.47	---	---	15
1.5	.48	1.4	4.8	.47	.37	700	230	15
.02	.26	1.6	2.7	.27	.17	---	10	4.4
.00	.15	.50	1.4	.24	.04	2500	30	4.0
.01	.21	2.0	3.0	.33	.23	4700	200	4.4
.01	.01	2.0	2.7	.37	.21	---	---	5.0
.01	.00	2.1	2.8	.37	.22	---	---	5.1
.01	.00	1.8	3.0	.30	.17	---	---	4.0

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPER-ATURE (DEG C)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	DIS-SOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)
29	07109500	76-04-01	1745	19.0	900	7.6	8.5	2.2
		76-04-02	0115	14.5	950	5.6	7.9	4.0
		76-04-02	0600	11.5	1000	4.9	---	3.2
		76-04-02	1120	15.0	940	9.6	8.3	2.7
		76-04-02	1750	16.0	920	8.5	8.2	2.8
		76-10-13	1040	13.5	800	7.6	8.0	1.0
		76-10-13	1500	17.0	800	8.1	8.1	.73
		76-10-13	1945	17.5	830	8.2	8.1	.87
		76-10-14	0310	14.0	820	5.1	8.1	.69
		76-10-14	0600	13.0	810	5.5	7.9	.90
		76-10-14	1000	12.5	800	6.7	7.9	.62
30	381440104234200	76-04-01	1800	15.0	2580	8.2	7.9	.88
		76-04-02	0615	7.0	2600	9.4	---	.67
		76-04-02	1820	12.0	2550	7.9	7.9	1.0
		76-10-13	1100	12.5	2600	10.8	8.1	.63
		76-10-13	2020	14.0	3000	9.9	8.0	.91
		76-10-14	0345	10.5	2800	8.2	7.9	1.2
		76-10-14	1030	11.5	2700	10.6	8.1	.58
31	381432104205500	76-04-01	1430	19.0	950	11.0	8.5	2.5
		76-04-01	2300	15.0	1000	4.6	7.8	2.4
		76-04-02	0612	---	---	---	---	1.6
		76-04-02	0945	13.0	1000	8.8	8.0	3.4
		76-04-02	1645	16.0	950	9.4	8.4	2.6
		76-10-13	0910	13.0	800	6.5	7.4	.71
		76-10-13	1525	17.0	750	7.2	8.1	.73
		76-10-13	1915	16.5	800	6.5	8.2	.69
		76-10-14	0005	15.0	775	5.7	8.0	.74
		76-10-14	0500	13.0	750	5.6	8.0	.57
		76-10-14	1110	14.0	800	7.3	8.1	.59
32	381443104184200	76-04-01	1515	19.0	1000	8.0	8.0	3.1
		76-04-01	1925	16.5	950	6.9	8.1	.97
		76-04-02	0250	12.0	1000	5.4	7.7	1.9
		76-04-02	0625	10.0	1010	5.4	7.4	.97
		76-04-02	1345	15.0	1025	7.4	7.7	.87
		76-04-02	1715	15.0	1000	6.8	7.8	1.4
		76-10-13	0945	13.0	750	7.1	7.7	.91
		76-10-13	1555	17.0	750	7.4	8.2	.53
		76-10-13	2000	16.0	800	6.9	8.2	.71
		76-10-14	0030	15.0	700	6.1	8.0	.55
		76-10-14	0530	13.0	775	6.4	8.0	.81

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITROGEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)	TOTAL COLIFORM (COL. PER 100 ML)	FECAL COLIFORM (COL. PER 100 ML)	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)
0.76	0.45	1.8	4.4	0.62	0.30	---	---	11
2.5	.42	1.2	5.6	.63	.52	20000	16000	10
2.3	.50	1.2	4.9	.78	.60	---	---	8.1
1.8	.59	1.5	4.8	.69	.49	---	---	14
1.1	.44	1.8	5.0	.43	.34	---	---	15
.01	.29	1.6	2.9	.29	.16	1000	45	3.3
.03	.29	1.4	2.4	.26	.15	---	---	2.6
.00	.06	2.0	3.0	.36	.20	---	---	3.8
.00	.00	2.0	2.7	.34	.20	---	---	3.3
.00	.01	1.7	2.6	.35	.17	---	---	---
.00	.04	1.8	2.4	.30	.16	---	60	2.7
.04	.05	7.0	7.9	.04	.01	60	80	1.0
.04	.04	7.3	8.0	.04	.02	70	18	.8
.02	.04	7.3	8.3	.01	.01	68	58	1.5
.01	.01	4.8	5.4	.02	.02	2080	560	1.0
.00	.01	5.0	5.9	.06	.02	2260	1160	1.9
.00	.01	4.9	6.1	.05	.02	---	---	1.5
.01	.01	4.9	5.5	.02	.02	---	695	1.3
1.5	.39	1.9	4.8	.64	.41	160	70	13
.94	.53	2.1	5.0	.58	.42	---	---	10
1.3	.67	1.5	3.8	.70	.50	---	---	10
2.4	.28	1.4	5.1	.70	.53	---	---	11
.99	.47	2.1	5.2	.49	.34	920	170	11
.00	.07	2.1	2.9	.36	.21	---	---	3.2
.05	.20	1.6	2.5	.25	.15	920	60	2.8
.00	.02	1.9	2.6	.34	.18	10300	840	1.9
.00	.00	2.2	2.9	.32	.18	---	---	2.4
.00	.00	2.1	2.7	.35	.20	---	---	2.5
.00	.01	2.1	2.7	.30	.16	3600	80	2.4
1.1	.44	2.3	5.8	.82	.43	---	---	8.9
.04	.43	2.8	4.2	.41	.32	---	---	---
.69	.39	2.2	4.5	.53	.41	2500	240	8.6
.04	1.3	2.0	4.3	.67	.47	2500	240	8.6
.70	.88	2.1	3.9	.68	.49	---	---	5.1
.69	.41	2.6	4.4	.55	.40	600	220	12
.00	.18	1.8	2.9	.36	.17	---	---	3.0
.01	.10	1.7	2.3	.28	.13	1200	40	2.6
.00	.07	1.8	2.6	.30	.17	940	85	2.3
.00	.04	2.3	2.9	.34	.18	---	---	2.4
.01	.02	2.2	3.0	.40	.16	---	---	2.2

Table 12.--*Selected physical data and laboratory analyses of nutrients,*

SITE STATION	STATION IDENTIFIER	DATE OF SAMPLE	TIME	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)	DISSOLVED OXYGEN (MG/L)	PH (UNITS)	TOTAL KJELDAHL NITROGEN (N) (MG/L)
		76-10-14	1050	13.0	870	7.1	8.0	0.59
34	381332104153900	76-04-01	1540	22.0	5000	8.2	8.3	.49
		76-04-02	0745	5.0	5000	11.2	8.1	.48
		76-04-02	1745	12.0	5000	9.2	8.3	.76
		76-10-13	1015	12.5	2000	8.9	8.0	.61
		76-10-13	1615	21.0	2150	7.6	8.3	.40
		76-10-14	0055	9.0	3500	9.1	8.1	.48
		76-10-14	1025	12.0	3500	9.1	8.2	.56
35	381338104142400	76-04-01	1610	21.0	1100	6.7	8.0	1.7
		76-04-01	2035	14.0	1100	7.4	7.9	.97
		76-04-02	0045	11.0	1100	7.0	8.0	.69
		76-04-02	0325	9.0	1050	7.0	7.9	.56
		76-04-02	0850	10.5	1125	8.4	7.7	.86
		76-04-02	1052	14.0	1150	8.2	7.7	2.0
		76-04-02	1445	17.0	1100	7.2	8.0	2.1
		76-04-02	1820	14.0	1100	7.9	7.9	1.2
		76-10-13	1040	14.0	950	8.1	8.0	.84
		76-10-13	1650	18.0	800	6.7	8.2	.73
		76-10-13	2030	15.0	800	7.5	8.2	.60
		76-10-14	0115	13.0	900	7.2	7.9	.59
		76-10-14	0615	12.0	800	7.3	7.9	.69
		76-10-14	1000	13.0	825	8.2	8.0	.83
37	07117000	76-04-01	1710	20.0	1100	8.3	8.5	.98
		76-04-01	2215	12.5	1100	8.2	8.1	.78
		76-04-02	0140	9.0	1100	8.4	8.1	.88
		76-04-02	0430	7.5	1050	9.4	8.1	.77
		76-04-02	0900	11.0	1150	9.9	8.0	.67
		76-04-02	1158	16.0	1100	9.2	8.3	1.0
		76-04-02	1600	17.0	1100	8.8	8.4	.96
		76-04-02	1928	12.0	1100	7.8	8.3	1.1
		76-10-13	1120	14.5	950	8.2	8.2	.92
		76-10-13	1720	18.0	850	7.4	8.4	1.2
		76-10-13	2120	15.0	800	7.3	8.3	.73
		76-10-14	0150	13.0	750	7.7	8.2	.71
		76-10-14	0645	10.0	850	8.0	8.2	.69
		76-10-14	0915	12.0	850	8.4	8.3	.79

bacteria, and biochemical oxygen demand of streamflow--Continued

TOTAL AMMONIA NITRO-GEN (N) (MG/L)	TOTAL NITRITE (N) (MG/L)	TOTAL NITRATE (N) (MG/L)	TOTAL NITRO-GEN (N) (MG/L)	TOTAL PHOS-PHORUS (P) (MG/L)	TOTAL ORTHO PHOS-PHORUS (P) (MG/L)	TOTAL COLI-FORM (COL. PER 100 ML)	FECAL COLI-FORM (COL. PER 100 ML)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)
0.01	0.09	2.0	2.7	0.36	0.18	3400	80	2.3
.03	.01	.03	.53	.01	.01	10	0	.9
.04	.00	.11	.59	.01	.01	10	0	.8
.03	.00	.11	.87	.00	.01	1	2	1.6
.00	.00	.15	.76	.12	.01	---	260	1.0
.04	.00	.07	.47	.06	.01	660	400	2.5
.01	.00	.08	.57	.04	.01	---	---	1.6
.00	.00	.15	.71	.04	.02	900	110	1.0
.42	.42	2.5	4.6	.62	.34	---	---	10
.04	.32	3.1	4.4	.49	.35	---	---	7.5
.03	.10	2.7	3.5	.42	.29	---	---	---
.04	.08	2.7	3.4	.38	.28	---	---	---
.03	.55	2.7	4.1	.50	.34	1200	290	3.8
.61	.22	2.2	4.4	.48	.33	---	---	---
.58	.36	2.4	4.9	.50	.37	---	---	5.0
.24	.35	2.9	4.4	.53	.39	265	68	6.1
.00	.20	2.0	3.0	.34	.17	---	---	2.9
.05	.09	1.8	2.6	.32	.16	3500	180	2.0
.00	.01	1.6	2.2	.29	.12	1500	145	1.7
.00	.01	2.1	2.7	.35	.17	---	---	1.8
.00	.01	2.2	2.9	.34	.18	---	---	2.0
.00	.01	2.0	2.8	.35	.17	4900	164	2.2
.10	.15	2.4	3.5	.42	.29	---	---	5.5
.03	.25	2.8	3.8	.40	.31	---	---	---
.04	.16	2.9	4.0	.38	.39	---	---	5.0
.04	.05	2.9	3.7	.42	.30	---	---	3.4
.04	.03	2.4	3.1	.37	.27	200	80	2.5
.03	.05	2.4	3.4	.40	.28	---	---	2.6
.08	.14	2.5	3.6	.39	.39	---	---	3.0
.11	.15	2.6	3.8	.38	.39	31	46	3.2
.02	.18	2.0	3.1	.37	.17	---	---	2.3
.00	.03	.18	1.4	.31	.01	2000	110	2.0
.01	.05	2.0	2.7	.37	.18	1200	32	1.6
.00	.00	1.6	2.3	.32	.13	---	---	1.8
.00	.01	2.0	2.7	.35	.18	---	---	1.8
.00	.00	2.0	2.8	.34	.17	5200	320	1.8

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