TRAVELTIME AND REAERATION CHARACTERISTICS FOR A REACH OF THE RIO GRANDE, ALBUQUERQUE, NEW MEXICO, OCTOBER 1991

By Scott D. Waltemeyer

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 94-4071

Prepared in cooperation with the
CITY OF ALBUQUERQUE

Albuquerque, New Mexico
1994

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, *Secretary*
U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, *Director*

For additional information
write to:

District Chief
U.S. Geological Survey
Water Resources Division
4501 Indian School Rd. NE, Suite 200
Albuquerque, New Mexico 87110

Copies of this report can
be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, Colorado 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot	0.3048	meter
mile	1.609	kilometer
foot per second	0.3048	meter per second
mile per hour	1.609	kilometer per hour
cubic foot per second	0.02832	cubic meter per second
pound	453.6	gram

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the equation:

$$^{\circ}F = 9/5\,(^{\circ}C) + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

TRAVELTIME AND REAERATION CHARACTERISTICS FOR A REACH OF THE RIO GRANDE, ALBUQUERQUE, NEW MEXICO, OCTOBER 1991

By Scott D. Waltemeyer

ABSTRACT

Traveltime and reaeration characteristics were determined in October 1991 for a reach of the Rio Grande in Albuquerque, New Mexico. Rhodamine WT dye and propane gas tracers were injected simultaneously at two sites in the Rio Grande at different times. Traveltime characteristics were determined using stream-velocity data, tracer-dye data, and tracer-gas data. Traveltimes determined by the stream-velocity method were essentially the same as those determined by the tracer-dye and tracer-gas technique. The mean velocity of the stream was 1.12 miles per hour at a flow of about 300 cubic feet per second.

Reaeration characteristics were determined using tracer dye and a tracer gas. Reaeration coefficients were calculated by the peak method and area method. Reaeration coefficients were adjusted for water temperature and the effects of high wind movement on the water surface. The mean value of the adjusted reaeration coefficient determined by the peak method was 7.0 per day, and the range was from 4.6 to 8.3 per day. Determined by the area method, the mean value was 7.7 per day and the range was from 5.5 to 10.4 per day. The reaeration coefficient for this reach of the Rio Grande was relatively small, as expected for a low-gradient stream.

INTRODUCTION

Maintaining suitable water quality in streams is an important consideration for cities. Nationwide, cities are required to meet specific Federal and State standards for effluent from wastewater treatment plants. Knowledge of the receiving water's capability to assimilate wastewater and to remain within the limits required by standards is crucial to plant managers and regulatory agencies. Traveltime and reaeration measurements for a stream can provide useful information about the stream's dispersion characteristics and the oxygen-absorption process of the stream. Specifically, such data can provide planners and managers with information about how rapidly wastes move downstream, how they are dispersed laterally and longitudinally within the stream, and how rapidly streams can assimilate certain forms of treated wastes. Chemicals in wastewater, such as organic compounds, nitrogen compounds, and chlorine, can deplete a stream's dissolved-oxygen concentration to a level below that required by water-quality standards. Stream reaeration is the primary process by which a stream replenishes the oxygen consumed in the biodegradation of organic wastes.

The U.S. Geological Survey, in cooperation with the City of Albuquerque, conducted a study to determine traveltime and reaeration characteristics of a reach of the Rio Grande extending upstream and downstream from the city's Southside Water Reclamation Plant (fig. 1). These data will provide the basis for a water-quality model being developed for the Rio Grande in the Albuquerque area.

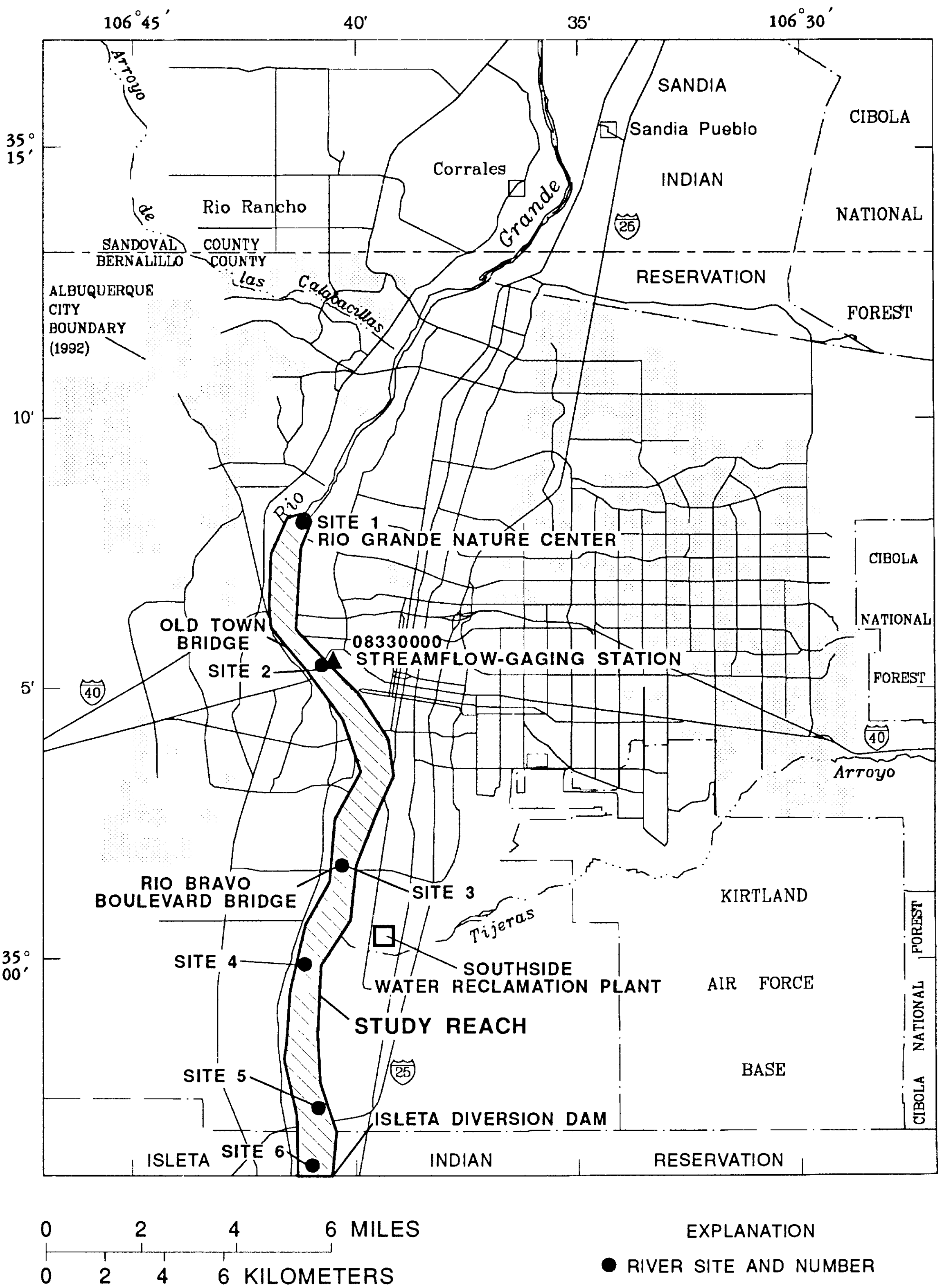

Figure 1.--Location of selected streamflow-gaging station, river sites, and study reach of the Rio Grande at Albuquerque, New Mexico.

Purpose and Scope

This report describes the results of a study to determine traveltime and reaeration characteristics for a reach of the Rio Grande at Albuquerque, New Mexico. Equations were derived from streamflow-gaging-station data to estimate stream velocity and traveltime. Tracer dye (rhodamine WT) and tracer gas (propane) were injected simultaneously at two sites and at different times in the Rio Grande in October 1991. Traveltime and reaeration measurements were made and analyzed. This report includes results of that data collection and analysis.

Description of the Study Reach

A study reach of about 16.2 miles of the Rio Grande at Albuquerque, New Mexico (fig. 1), extending from the Rio Grande Nature Center in Albuquerque to the Isleta Diversion Dam south of Albuquerque, was selected to characterize the reaeration capacity of the river. The study reach extends upstream and downstream from the City of Albuquerque Southside Water Reclamation Plant. Five cross sections on the Rio Grande were selected that divide the study reach into four subreaches for evaluation. Diversion conveyance channels on both sides of the study reach were used to stabilize the streamflow in the Rio Grande for the study.

Acknowledgments

Equipment and technical expertise were provided by Barbara Ruddy and Norman Spahr of the Colorado District, U.S. Geological Survey. Special thanks are extended to Nicole Seguin and Robert Hogrefe from the City of Albuquerque; Mimi Dannel and Troy Nichols from the U.S. Environmental Protection Agency; and Ernest Cobb from the U.S. Geological Survey, Reston, Virginia, for assisting in the injection and sampling for the study. The efforts of Tom Ryan of the U.S. Army Corps of Engineers and Subhas Shah of the Middle Rio Grande Conservancy District to stabilize the streamflow of the Rio Grande during the study are greatly appreciated.

INJECTION, SAMPLING, AND ANALYTICAL METHODS

Rhodamine WT dye and propane gas were injected as tracers simultaneously at two sites at different times in the Rio Grande. The Rio Bravo Boulevard Bridge (site 3) was the injection site on October 29, 1991, and the Rio Grande Nature Center (site 1) was the injection site on October 30, 1991 (fig. 1). Because the Rio Grande is a wide, flat river, two injection points in the cross section at each site (sites 1 and 3) were selected for injection of the dye and gas tracers to ensure mixing throughout the stream. These points were located in the center of the two main flow channels of the stream, one near the left bank and one near the right bank.

Dye and gas concentrations and release rates applicable for the Rio Grande discharge were calculated from equations presented by Kilpatrick and others (1989). The dye solution was injected continuously with a variable-output pump for the same time period as the gas, about 2 hours. Dye quantities were determined from information presented by Rathbun (1979). The tracer-dye technique, procedures, dyes, and equipment used are presented in Hubbard and others (1982). Propane gas was injected into the river by bubbling the gas through diffuser plates that were placed on the river bottom. Gas was released from two 120-pound high-pressure cylinders regulated by two-stage regulators, through a rotameter to control and monitor the flow rate, and lastly through the diffusers into the river. The estimated residence time of the propane gas was calculated by equations presented by Kilpatrick and others (1989). The equations for estimated residence time were considered as not applicable for a wide river such as the Rio Grande; the estimated residence time was found to be overestimated by the equations. Therefore, the study reach was separated into two injection locations and times (sites 1 and 3, as discussed above) as a conservative approach because of the short residence time of the tracer gas.

The movement and change in concentration of the dye and gas clouds were monitored by sampling downstream sites at selected points in the cross section of the river. The sampling points in the cross sections were as follows: October 29, 1991 (Rio Grande sites 4, 5, 6)--site 4 was sampled at points 4A, 4B, 4C, and 4D, site 5 was sampled at points 5A and 5B, and site 6 was sampled at only one point in the centroid (center of mass) of flow; October 30, 1991 (Rio Grande sites 2, 3, 4)--site 2 was sampled at points 2A, 2B, and 2C, site 3 was sampled at points 3A and 3B, and site 4 was sampled at points 4A and 4B. Dye and gas sampling points were determined on the quartiles or quantities of equal discharge increments of the cross section using the discharge measurements. After lateral mixing was observed at the first site, cross-section sampling was reduced to two locations at the centroid of flow in each cross section, except at site 6.

Water samples were collected simultaneously at each downstream site for the determination of tracer-dye concentrations and tracer-gas concentrations. Duplicate water samples were collected for the tracer-dye concentration analysis: one sample for field analysis to monitor immediately the travel of the dye cloud and one sample for the final laboratory analysis. Samples were collected in 1.1-fluid-ounce glass bottles with polyseal caps. The samples were collected from about middepth to the surface using a depth-integrated hand sampling technique. Samples for the tracer-gas concentration analysis were collected in 20-milliliter septum-capped vials, which were placed in standard direct-displacement water samplers. The samples were collected from about middepth to the surface using a depth-integrated technique, overfilling the bottle. Samples were preserved with four drops $NaSO_4^-$ after 5 milliliters of water were withdrawn from each sample. The samples were inverted and chilled until subsequent laboratory analysis.

Dye concentrations were analyzed using fluorometric procedures presented by Wilson (1968). Calibration curves were determined from dye standards prepared from the dye lot used. True dye concentrations were obtained from the fluorometer-determined concentrations and the calibration curves. Propane concentrations were determined from the static head space with a gas-chromatograph flame ionization detector.

TRAVELTIME CHARACTERISTICS

Traveltime refers to the movement of water or waterborne materials from point to point in a stream for steady or gradually varying flow conditions. Traveltime characteristics of a stream vary with flow conditions. In this study, traveltime is estimated by the stream-velocity technique and the tracer technique. Traveltimes were estimated from mean stream velocities primarily for planning the sampling frequency and for estimating arrival times for the tracer dye and tracer gas. Traveltime of tracers in streams may be used to predict the time of arrival, passage time, and peak concentration of a substance released or spilled upstream or to determine time-of-travel for use in water-quality models. The traveltime for the dye and gas tracer subsequently was evaluated and compared to results from the stream-velocity technique.

Stream-Velocity Technique

Traveltime is related to velocity of the stream and distance of travel. Mean velocity of the stream was derived from discharge measurements at the streamflow-gaging station 08330000, Rio Grande at Albuquerque. Twenty-two discharge values ranging from 200 to 2,000 cubic feet per second for the period 1985 through 1991 were used to derive the following regression equation to estimate mean velocity.

$$V = 0.248\,Q^{0.33} \qquad (1)$$

where V is mean velocity, in feet per second; and
Q is mean discharge, in cubic feet per second.

The discharge data were transformed to base 10 logarithms. The adjusted R^2 (coefficient of determination) for the equation was 0.81 and the average standard error of estimate was 64 percent. The independent variable was tested at the statistical significance level of 5 percent for inclusion in the model with the dependent variable. A p-value of 0.0001 was the smallest level of significance that would have been allowed before rejection of the hypothesis. The traveltimes listed in table 1 were estimated using equation 1.

Equation 2 was derived from traveltimes shown in table 1 to allow calculations of traveltimes to each site at various rates of discharge.

$$T = a\,Q + b \qquad (2)$$

where T is traveltime, in hours; and
a,b are linear-regression coefficients.

Equation 2 may be used with the regression coefficients a and b, shown in table 1 for each site, to estimate traveltime to that site at other discharges. This evaluation was made on the premise that the stream-velocity technique has transferability to the entire study reach.

Table 1.--Traveltimes and coefficients for estimating traveltime based on discharge measurements at streamflow-gaging station 08330000, Rio Grande at Albuquerque, New Mexico

[Site locations shown in figure 1. ft^3/s, cubic feet per second; --, not applicable]

Site	Distance downstream from site 1 (miles)	Traveltime, in hours, for selected discharges					Linear regression coefficients	
		250 ft^3/s	500 ft^3/s	750 ft^3/s	1,000 ft^3/s	1,500 ft^3/s	a	b
1	0	0	0	0	0	0	--	--
2	3.76	3.60	2.86	2.51	2.28	1.99	-0.00120	3.61
3	8.92	8.47	6.72	5.89	5.36	4.68	-0.00283	8.49
4	12.19	11.52	9.13	8.01	7.28	6.36	-0.00386	11.5
5	14.86	14.02	11.12	9.75	8.87	7.75	-0.00469	14.1
6	16.16	15.39	12.20	10.70	9.73	8.50	-0.00515	15.4

Tracer Technique

Measurements of traveltime were made during the determination of the reaeration coefficient, as discussed in the Reaeration Characteristics section, by injecting a fluorescent tracer dye (rhodamine WT) and a tracer gas (propane) simultaneously into the river and measuring the changes in tracer concentrations at sites downstream. Traveltime is determined by observing the time required for movement of the tracer cloud between sampling sites. The mean traveltime for the flow in a reach is defined as the difference in elapsed time of the centroids of the time-concentration curves of the tracer at the upstream and downstream ends of the reach. A complete description of the methods, procedures, and equipment used for traveltime measurements is presented in Hubbard and others (1982) and Kilpatrick and others (1989).

Traveltime Results

The traveltimes determined by the stream-velocity technique and tracer technique for October 29, 1991, were virtually the same. The stream-velocity technique was developed from mean velocity data at site 2 (streamflow-gaging station 08330000, Rio Grande at Albuquerque). A subreach downstream from site 2 (subreach 4-5) was used for the comparison of traveltimes. For the stream-velocity technique, the traveltime for subreach 4-5 (Rio Grande sites 4 to 5, subreach length of 2.67 miles) was 2.4 hours. The travel rate for subreach 4-5 was estimated to be 1.12 miles per hour. This was determined by using equation 1 and a mean discharge of about 300 cubic feet per second for subreach 4-5. The mean velocity was estimated to be 1.63 feet per second. For the tracer technique, the traveltime for subreach 4-5 was 2.53 hours for the tracer dye and 2.36 hours for the tracer gas. The dye peak travel rate for subreach 4-5 (table 2) was 1.06 miles per hour, and the tracer-gas (centroid of mass) travel rate was 1.13 miles per hour (table 3).

Table 2.--Streamflow and tracer characteristics used for determining reaeration coefficients by the peak method for a study reach of the Rio Grande at Albuquerque, New Mexico, October 29-30, 1991

Streamflow and tracer characteristics (symbol)	Measurement unit	River subreach[1]			
		2-3	3-4	4-5	5-6
Date of measurement		10-30-91	10-30-91	10-29-91	10-29-91
Mean water temperature (T)	Degrees Celsius	6.0	5.0	10.5	10.0
Reach length (L)	Miles	5.16	3.27	2.67	1.30
Dye peak traveltime from injection site:					
Upstream end (t_{du})	Hours	5.53	10.87	4.95	7.48
Downstream end (t_{dd})	Hours	10.87	14.88	7.48	9.42
Dye peak travel rate (V_d)	Miles per hour	0.97	0.81	1.06	0.67
Dye peak concentration:					
Upstream end (C_{du})	Micrograms per liter	15.7	12.2	19.2	15.3
Downstream end (C_{dd})	Micrograms per liter	12.2	8.1	15.3	14.3
Gas concentration at dye peak:					
Upstream end (C_{gu})	Micrograms per liter	3.03	0.22	7.62	4.00
Downstream end (C_{gd})	Micrograms per liter	0.22	0.08	4.00	2.31
Streamflow during tracer passage:					
Upstream end (Q_u)	Cubic feet per second	323	281	311	295
Downstream end (Q_d)	Cubic feet per second	281	319	295	289
Area under dye time-concentration curve:					
Upstream end (A_{du})	Micrograms-hour per liter	40.06	39.93	38.51	38.52
Downstream end (A_{dd})	Micrograms-hour per liter	39.93	29.85	38.52	38.46
Reaeration coefficient by peak method adjusted to 20 degrees Celsius ($K_{2_{20}}$)	Day^{-1}	21.8	11.2	7.7	12.2

[1]Identified by endpoints--upstream and downstream site numbers on figure 1.

Table 3.--Streamflow and tracer characteristics used for determining reaeration coefficients by the area method for a study reach of the Rio Grande at Albuquerque, New Mexico, October 29-30, 1991

Streamflow and tracer characteristics (symbol)	Measurement unit	River subreach[1]			
		2-3	3-4	4-5	5-6
Date of measurement		10-30-91	10-30-91	10-29-91	10-29-91
Mean water temperature (T)	Degrees Celsius	6.0	5.0	10.5	10.0
Gas centroid traveltime from injection site:					
Upstream end (t_{gu})	Hours	5.36	10.62	4.82	7.18
Downstream end (t_{gd})	Hours	10.62	14.31	7.18	9.03
Gas centroid travel rate (V_g)	Miles per hour	0.98	0.89	1.13	0.70
Streamflow during tracer passage:					
Upstream end (Q_u)	Cubic feet per second	323	268	311	289
Downstream end (Q_d)	Cubic feet per second	268	221	289	289
Area under gas time-concentration curve:					
Upstream end (A_{gu})	Micrograms-hour per liter	6.94	0.61	18.08	8.50
Downstream end (A_{gd})	Micrograms-hour per liter	0.61	0.26	8.50	5.39
Reaeration coefficient by area method adjusted to 20 degrees Celsius ($K_{2_{20}}$)	Day^{-1}	22.9	13.5	14.7	10.4

[1]Identified by endpoints--upstream and downstream site numbers on figure 1.

REAERATION CHARACTERISTICS

Stream reaeration is the physical absorption of oxygen from the atmosphere by a flowing stream. The reaeration coefficient is the rate constant for the absorption of oxygen from the atmosphere. The primary use of reaeration coefficients is to quantify the process of reaeration in dissolved-oxygen water-quality models. These models, which simulate the exchange of dissolved oxygen, are used to calculate waste-load allocations for the stream so that dissolved-oxygen-concentration standards are not exceeded.

Reaeration coefficients were calculated from the differences in tracer-dye and tracer-gas transport downstream. In general, a known quantity of tracer gas is injected into the stream, and a desorption coefficient for the gas is determined from the measurement of the change in gas concentrations downstream. A reaeration coefficient for oxygen is determined from this desorption coefficient for the tracer gas and a laboratory constant, using one of the two methods described below. Tracer dye is injected simultaneously with the tracer gas as a conservative tracer, or as the dispersion and dilution tracer. Propane was used as the tracer gas and rhodamine WT dye was used as the dispersion and dilution tracer.

Reaeration coefficients were determined using two methods. The peak method uses the peak concentrations of the tracer gas and tracer dye, and the area method uses the areas under the tracer-gas time-concentration curves. The reaeration coefficients were adjusted to a base water temperature and adjusted for the effects of wind on the water surface. Traveltime data also are determined during the reaeration measurements by the use of the gas or dye time-concentration curves, which complement values estimated using the stream-velocity technique.

Peak Method

Generally, reaeration coefficients are calculated from the peak concentrations of the tracer dye and tracer gas. The peak method uses traveltime of the peak concentration of dye, peak concentrations of the dye and gas, and an adjustment for dye loss. A brief description of the peak method is presented in this report; complete details are given in Kilpatrick and others (1989) and in Ruddy and Britton (1989). The tracer-gas desorption coefficient (K_g) using the peak method was determined with the following equation:

$$K_g = \frac{1}{t_{dd} - t_{du}} \ln \frac{\frac{(C_{gu})}{(C_{du})}}{\frac{(C_{gd})}{(C_{dd})}} J_n \quad (3)$$

where K_g is tracer-gas desorption coefficient, in hour^{-1};
t_{dd}, t_{du} is traveltime of the peak concentration of the tracer dye at the downstream and upstream ends of the subreach, in hours;
$\ln$ is natural logarithm, base e;
C_{gu}, C_{gd} is peak concentration of the tracer gas at the upstream and downstream ends of the subreach, in micrograms per liter;
C_{du}, C_{dd} is peak concentration of the dye at the upstream and downstream ends of the subreach, in micrograms per liter; and
J_n is dye-loss correction factor (defined by eq. 4).

Dye loss and flow accrual were evaluated and accounted for prior to the reaeration-coefficient calculations. The time-concentration curves at the upstream and downstream ends of the subreach were corrected by using the following equation:

$$J_n = \frac{Q_u A_{du}}{Q_d A_{dd}} \quad (4)$$

where Q_u, Q_d is discharge at the upstream and downstream ends of the subreach, in cubic feet per second; and
A_{du}, A_{dd} is area under the dye time-concentration curve at the upstream and downstream ends of the subreach, in micrograms-hour per liter.

Streamflow and tracer characteristics for determining reaeration coefficients by the peak method are shown in table 2. For the peak method the gas mass was assumed to have the same dispersion and dilution characteristics as the dye mass moving downstream. The gas concentrations were affected by the Rio Grande's process of dispersion and dilution and by the gas release to the atmosphere. The peak dye concentrations were adjusted for this dispersion and dilution by using equation 4 a' the upstream end of a subreach, $J_n = 1.00$. The water samples were collected until dye concentrations were less than 10 percent of the peak concentration observed during the field data collection.

Area Method

Reaeration coefficients computed by the area method provide an advantage of being independent of the measurement of the dye. The area method uses traveltime of the tracer-gas mass, area of the tracer-gas time-concentration curve, and subreach discharge to determine reaeration coefficients. Desorption of propane was used to calculate the reaeration coefficients from the areas under the tracer-gas time-concentration curves. A brief description of the area method is presented in this report; complete details are in Kilpatrick and others (1989) and in Ruddy and Britton (1989). The following equation was used:

$$K_g = \frac{1}{t_{gd} - t_{gu}} \, ln \, \frac{A_{gu}Q_u}{A_{gd}Q_d} \qquad (5)$$

where K_g is tracer-gas desorption coefficient, in $hour^{-1}$;
t_{gd}, t_{gu} is traveltime of the centroids of the tracer-gas mass at the downstream and upstream ends of the subreach, in hours;
ln is natural logarithm, base e;
A_{gu}, A_{gd} is area of the tracer-gas time-concentration curves at the upstream and downstream ends of the subreach, in micrograms-hour per liter; and
Q_u, Q_d is discharge at the upstream and downstream ends of the subreach, in cubic feet per second.

Streamflow and tracer characteristics for determining reaeration coefficients by the area method are shown in table 3.

Calculation of Reaeration Coefficients

Reaeration coefficients (Kg) usually are adjusted to a common base value for temperature and wind because the coefficients vary with these factors. The coefficients were adjusted to a standard base of 20 degrees Celsius (°C) by the following equation (Kilpatrick and others, 1989):

$$K_{2_{20}} = 1.39 \, K_{g_t} \, (1.0241)^{(20-t)} \qquad (6)$$

where $K_{2_{20}}$ is the reaeration coefficient, in day^{-1}, at 20 °C;
K_{g_t} is desorption coefficient, measured by propane tracer gas, in day^{-1}; and
t is mean subreach water temperature, in °C.

Resulting reaeration coefficients, adjusted for temperature, are listed in tables 2 and 3. Reaeration coefficients were adjusted for the effects of wind on the water surface of the river. The following equation corrects for the change in reaeration resulting from wind as proposed by Mattingly (1977):

$$(K_2)_0 = K_{2_{20}} / (0.2395\, V_a^{1.643} + 1) \qquad (7)$$

where $(K_2)_0$ is reaeration coefficient adjusted to zero wind speed, in day^{-1};
$K_{2_{20}}$ is reaeration coefficient determined from prevailing windy conditions, in day^{-1}; and
V_a is wind speed, in meters per second at 20 centimeters above the water surface.

Hourly wind data from the Albuquerque Weather Service Forecast Office at the airport were used for the wind adjustments. Wind speed applicable for the time of data collection at subreach 2-3 was 3.6 meters per second, at subreach 3-4 was 3.0 meters per second, at subreach 4-5 was 1.4 meters per second, and at subreach 5-6 was 1.5 meters per second. The wind-speed data from the airport were reported in miles per hour at 22 feet above ground surface. These data were adjusted to 20 centimeters above ground surface by the following equation developed for the conversion.

$$V_a = 0.272\, V_{22} \qquad (8)$$

where V_a is mean wind speed, in miles per hour at 20 centimeters above ground surface; and
V_{22} is mean wind speed, in miles per hour at 22 feet above ground surface.

Equation 8 was developed from wind-speed data for 1.5 feet, 33 feet, and 100 feet above ground surface (Blair and Fite, 1965). Adjusted wind-speed data were converted to meters per second for use in equation 7.

Reaeration-Coefficient Results

Time-concentration curve characteristics of the tracer dye and tracer gas were determined for the sites as follows:

October 29, 1991 (injection at site 3)--site 4 (4A, 4B, 4C, and 4D), site 5 (5A and 5B), and one location at site 6; and
October 30, 1991 (injection at site 1)--site 2 (2A, 2B, and 2C), site 3 (3A and 3B), and site 4 (4A and 4B).

Time-concentration curve characteristics of the tracer dye and tracer gas for the sites in the study reach of the Rio Grande, October 29-30, 1991, are listed in table 4. The final curves used for the dye characteristics are shown in figures 2 and 3, and the final curves used for the gas characteristics are shown in figures 4 and 5.

The dye and gas injections on October 29, 1991, showed well-defined gas time-concentration curves at river subreaches 4-5 and 5-6. Numerous samples depicted these curve definitions with minimum scatter in the data. The dye and gas injections on October 30, 1991, for subreaches 2-3 and 3-4 were for a longer river reach. The gas was detected in minute concentrations at site 4 of subreach 3-4; therefore, the gas-concentration curve for site 4 was poorly defined by only two points for the area method. In comparison, the dye-concentration curve was adequately defined for the peak method. The coefficients computed by the two methods were very similar. However, because the gas concentrations were minimal for the method, more reliance should be given to the peak method for determining the reaeration coefficients.

Reaeration coefficients determined for existing conditions, adjusted to a base water temperature of 20 °C and adjusted to wind movement of zero miles per hour, are listed in table 5. Wind movement during the time of data collection varied considerably. Wind-adjusted reaeration coefficients were found to be similar among the study subreaches of the Rio Grande, except for subreach 3-4 where minimal gas remained for the definition of a curve. The peak method for subreaches 2-3, 3-4, 4-5, and 5-6 showed a maximum variation of 39 percent from the mean value of 6.4 per day. In these subreaches, the coefficients ranged from 4.6 to 8.3 for the peak method. The area method for subreaches 2-3, 3-4, 4-5, and 5-6 had a maximum variation of 35 percent from the mean value of 7.7 per day. In these subreaches, the coefficients ranged from 5.5 to 10.4 for the area method. The adjusted reaeration coefficients for subreaches 2-3, 4-5, and 5-6 should represent the Rio Grande flowing through Albuquerque.

Stream reaeration is the physical absorption of oxygen from the atmosphere by a flowing stream. Reaeration is the process of how a stream replenishes oxygen consumed in the biodegradation of organic wastes. The principle behind coefficient development is that the tracer gas is desorbed from the stream to the atmosphere inversely to how oxygen is absorbed. The primary use of reaeration coefficients is to quantify the process of reaeration in dissolved-oxygen water-quality models. These models simulate exchange of dissolved oxygen and are used to calculate waste-load allocations for the stream so that dissolved-oxygen-concentration standards are not violated. The Rio Grande is hydraulically the same throughout the study reach and characterized by a low-gradient, wide, braided channel. The reaeration coefficients were found to be relatively small as expected for a low-gradient stream. The studied reach of the Rio Grande exhibited less reaeration than a turbulent, high-gradient stream.

Table 4.--Time-concentration curve characteristics of the tracer dye and tracer gas for a study reach of the Rio Grande at Albuquerque, New Mexico, October 29-30, 1991

[Site locations shown in figure 1. --, no data]

	Area under curve (micrograms-hour per liter)		Traveltime of centroid (hours)		Peak concentration (micrograms per liter)		Traveltime of peak (hours)	
Site	Propane gas	Dye	Propane gas	Dye	Propane gas	Dye	Propane gas	Dye
October 29, 1991, constant-rate injection at 08:00 am to 10:00 pm								
4A	17.00	37.11	4.77	4.52	8.9	19.0	3.82	5.00
4B	--	36.60	--	4.54	--	18.7	--	5.02
4C	--	38.63	--	4.42	--	18.8	--	4.63
4D	19.15	41.69	4.87	4.44	9.2	20.1	4.53	5.13
5A	8.27	35.84	7.27	7.00	4.0	14.7	7.17	7.58
5B	8.72	41.20	7.09	7.00	4.2	15.9	7.00	7.37
6	5.39	38.46	9.03	8.88	2.3	14.3	8.67	9.42
October 30, 1991, constant-rate injection at 08:15 am to 10:15 pm								
2A	--	35.60	--	4.96	--	16.7	--	5.75
2B	6.39	41.30	5.26	4.96	3.1	18.2	4.58	5.58
2C	7.49	43.27	5.35	4.96	3.4	18.7	5.00	5.42
3A	0.55	38.72	10.62	10.50	0.2	11.9	10.25	10.75
3B	0.67	41.15	10.62	10.50	0.3	12.6	10.75	11.00
4A	0.28	28.88	14.25	14.25	0.1	8.0	13.25	14.75
4B	0.25	30.82	14.37	14.25	0.1	8.2	14.50	15.00

Table 5.--Reaeration coefficients for a study reach of the Rio Grande at Albuquerque, New Mexico, October 29-31, 1991

[units, in day^{-1}]

	River subreach[1]							
	2-3		3-4		4-5		5-6	
	Method of analysis							
Reaeration coefficient	Peak	Area	Peak	Area[2]	Peak	Area	Peak	Area
Unadjusted, K_2	11.3	12.0	5.7	6.8	4.4	8.4	6.9	5.9
Temperature adjusted to 20 degrees Celsius, $K_{2_{20}}$	21.8	22.9	11.2	13.5	7.7	14.7	12.2	10.4
Wind adjusted, $(K_2)_0$	7.4	7.7	4.6	5.5	5.5	10.4	8.3	7.1

[1] Identified by endpoints--upstream and downstream site numbers on figure 1.
[2] Based on two data points.

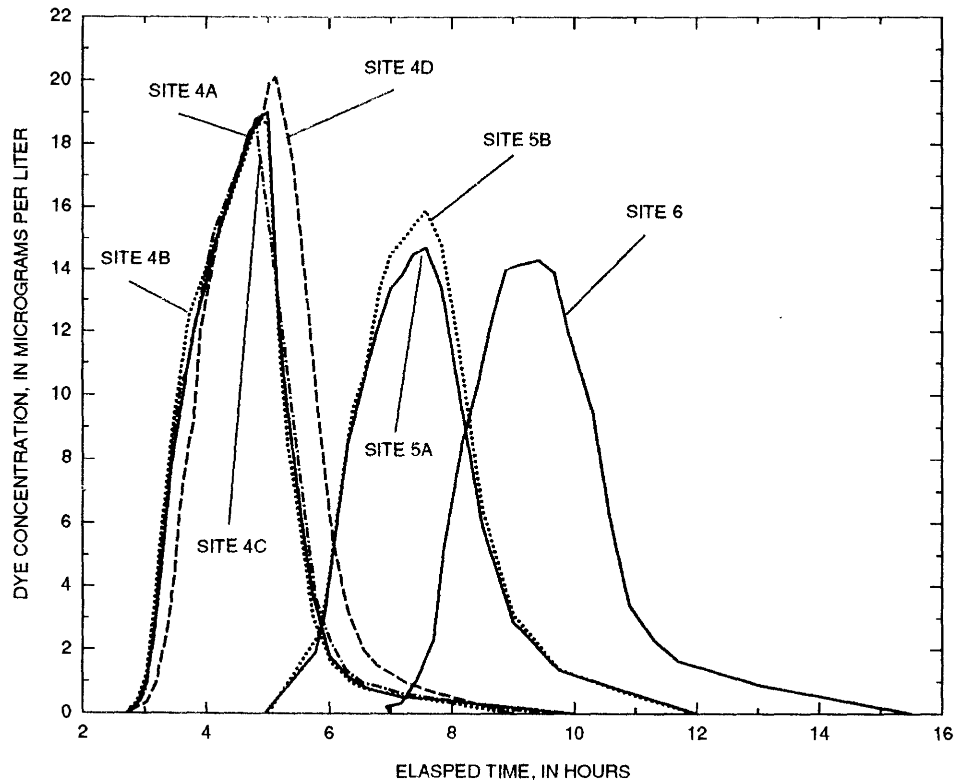

Figure 2.--Time-concentration curve characteristics of the tracer dye for sites 4, 5, and 6 of the Rio Grande at Albuquerque, New Mexico, October 29, 1991.

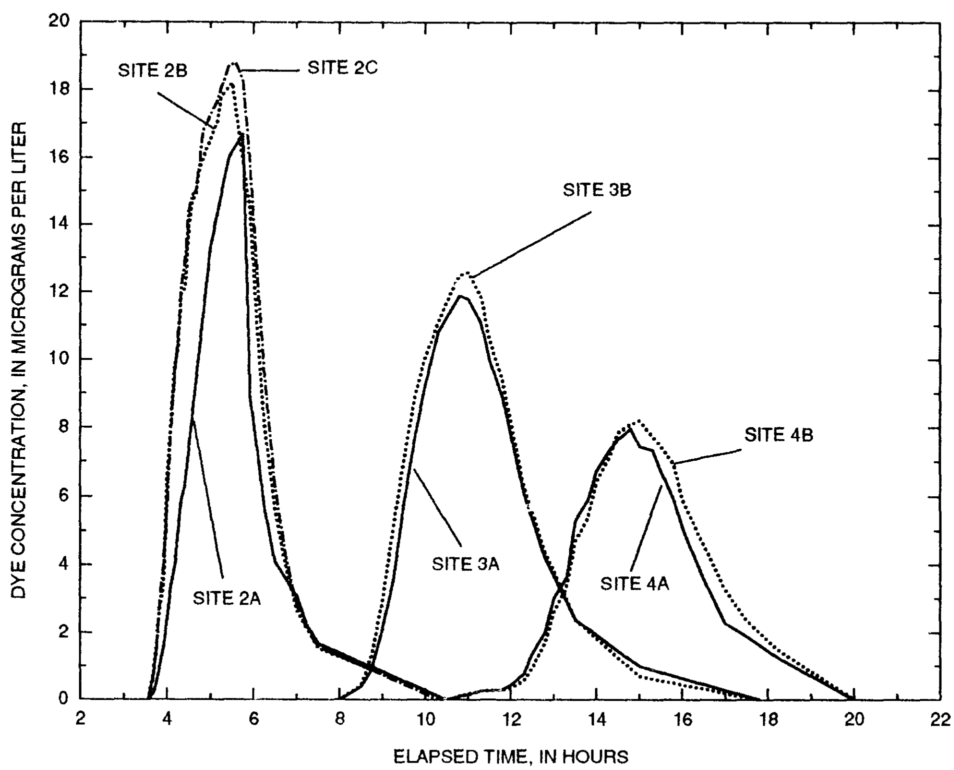

Figure 3.--Time-concentration curve characteristics of the tracer dye for sites 2, 3, and 4 of the Rio Grande at Albuquerque, New Mexico, October, 30, 1991.

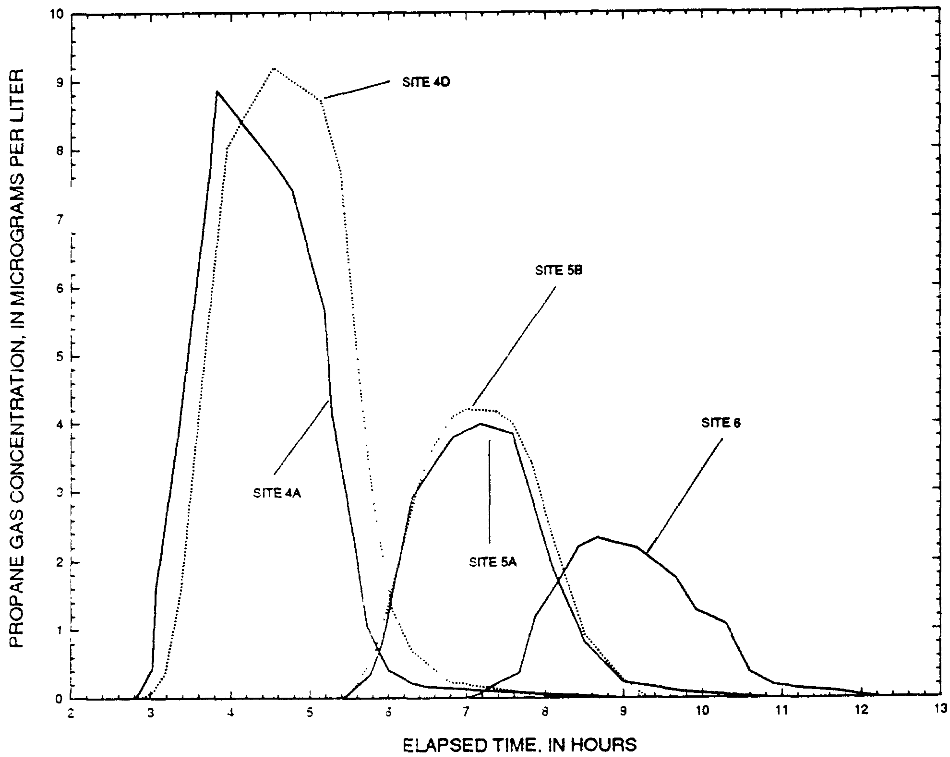

Figure 4.--Time-concentration curve characteristics of the tracer gas for sites 4, 5, and 6 of the Rio Grande at Albuquerque, New Mexico, October 29, 1991.

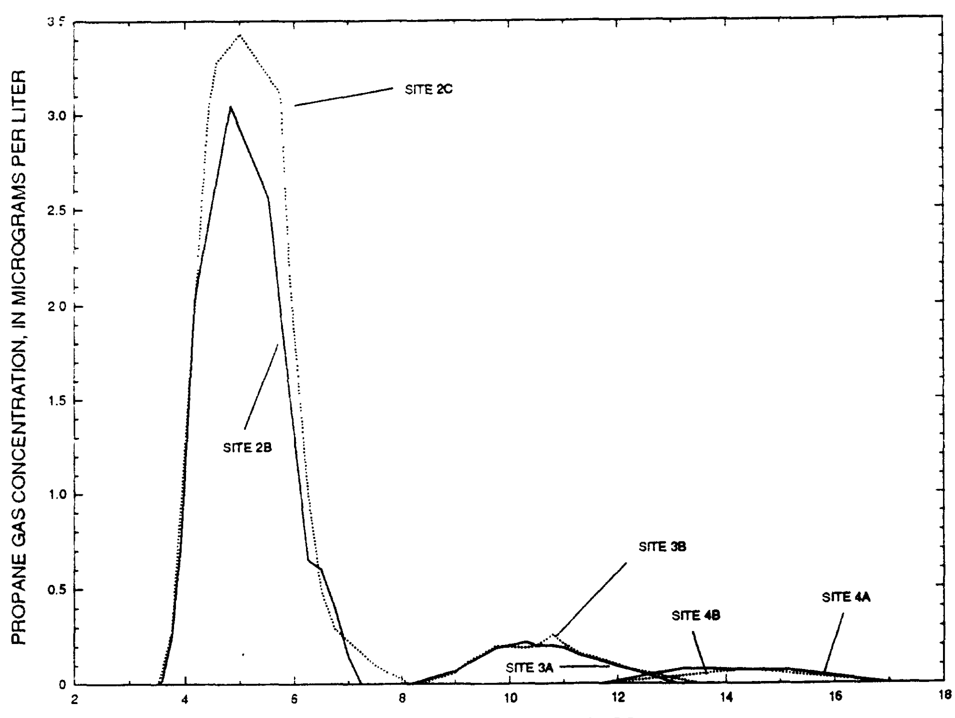

Figure 5.--Time-concentration curve characteristics of the tracer gas for sites 2, 3, and 4 of the Rio Grande at Albuquerque, New Mexico, October 30, 1991.

SUMMARY

Traveltime and reaeration characteristics were determined in October 1991 for a reach of the Rio Grande in Albuquerque, New Mexico. Rhodamine WT dye and propane gas tracers were injected simultaneously at two sites at different times in the Rio Grande. The Rio Bravo Boulevard Bridge was the injection site on October 29, 1991, and the Rio Grande Nature Center was the injection site on October 30, 1991. Five sampling cross sections were selected on the Rio Grande that divided the study reach into four subreaches for evaluation. Diversion conveyance channels on both sides of the study reach were used to stabilize the streamflow in the Rio Grande for the study. The movement and change in concentration of the dye and gas clouds were monitored by sampling downstream sites at selected points in the cross sections.

Traveltimes were estimated from mean stream velocities primarily for planning the sampling frequency and for estimating arrival times for the tracer dye and tracer gas. Traveltime characteristics for a range of discharge rates were also determined from streamflow data. The traveltime derived from the stream-velocity method for a stream subreach of 2.67 miles in length and a mean flow of about 300 cubic feet per second was 2.4 hours. The stream velocity was about 1.12 miles per hour. Traveltimes for the same subreach were determined by the stream-velocity technique and tracer technique. The determined traveltimes were 2.53 hours for the tracer dye and 2.36 hours for the tracer gas. The dye peak travel rate was 1.06 miles per hour and the tracer-gas (centroid of mass) travel rate was 1.13 miles per hour.

Reaeration coefficients were calculated by the peak method and area method. The reaeration coefficients were adjusted for water temperature and the effects of high wind movement on the water surface. For the peak method, the adjusted reaeration coefficients were similar among the subreaches. The reaeration-coefficient mean value using the peak method for the study reach was 6.4 per day and ranged from 4.6 to 8.3 per day. Reaeration coefficients determined by the area method showed larger variation; the mean value for the study reach was 7.7 per day and ranged from 5.5 to 10.4 per day. The Rio Grande is hydraulically the same throughout the study reach and characterized by a low-gradient, wide, braided channel. The reaeration coefficients were found to be on the lower end of the scale as expected for a low-gradient stream. The studied reach of the Rio Grande exhibited less reaeration than a turbulent, high-gradient stream.

REFERENCES

Blair, T.A., and Fite, R.C., 1965, Weather elements, a text in elementary meteorology (fifth ed.): Englewood Cliffs, N.J., Prentice Hall, Inc., 32 p.

Hubbard, E.F., Kilpatrick, F.A., Martens, L.A., and Wilson, J.F., Jr., 1982, Measurement of time of travel and dispersion in streams by dye tracing: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A9, 44 p.

Kilpatrick, F.A., and others, 1989, Determination of stream reaeration coefficients by use of tracers: U.S. Geological Survey Techniques of Water Resources Investigations, book 3, chap. A18, 52 p.

Mattingly, G.E., 1977, Experimental study of wind effects on reaeration, in Journal of Hydraulics Division: American Society of Civil Engineers, March 1977, p. 311-323.

Rathbun, R.E., 1979, Estimating the dye and gas quantities for modified tracer technique measurements of stream reaeration coefficients: U.S. Geological Survey Water-Resources Investigations 79-27, 52 p.

Ruddy, B.C., and Britton, L.J., 1989, Traveltime and reaeration of selected streams in the North Platte and Yampa River Basins, Colorado: U.S. Geological Survey Water-Resources Investigations Report 88-4205, 56 p.

Wilson, J.F., Jr., 1968, Fluorometric procedures for dye tracing: U.S.Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A12, 31 p.

★U.S. GOVERNMENT PRINTING OFFICE:1994-576-464/05130