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Reaeration-Rate Coefficients for Two Reaches on the Truckee River Downstream from Reno, Nevada, 1999

By Michael S. Lico *and* R. Lynn Taylor

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED UNITS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
pound (lb)	0.4536	kilogram
square inch (in^2)	6.452	square centimeter

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32. Degrees Fahrenheit can be converted to degrees Celsius by using the formula °C = 0.556(°F-32).

Abbreviated Units:

L/min	liter per minute	mL/min	milliliter per minute
mL	milliliter	µg/L	microgram per liter

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ABSTRACT

Gas-tracer and dye-tracer studies were done by the U.S. Geological Survey in August and September 1999 for two reaches (from Lockwood to below Tracy (lower bridge) and from Wadsworth to Dead Ox Wash) of the Truckee River downstream from Reno, Nevada. Data collected during these studies were used to calculate reaeration-rate coefficients. Propane gas and rhodamine WT dye were injected into the river at Lockwood and Wadsworth, Nevada. The loss of propane gas measured downstream resulting from desorption was used to calculate the reaeration-rate coefficients. Reaeration-rate coefficient for the reach between Mustang Bridge No. 2 and Patrick (McCarran Bridge) was 15.6 per day at a temperature of 20 °C; mean streamflow was 570 cubic feet per second and mean stream temperature was 14.8 °C during sampling. Inadequate propane gas recovery prevented the calculation of reaeration-rate coefficients for the reach between Wadsworth and Dead Ox Wash.

INTRODUCTION

Background

The Truckee River, located in eastern California and western Nevada, is facing increased stress due to continued growth in the Reno and Sparks urban areas. Studies by Nowlin (1987) and Caupp and others (1997) as well as current efforts are being used to understand the dynamic processes that control the quality of water in the river. Models are currently being developed that will give regulatory agencies the necessary information to better manage the river and enhance water quality, especially downstream from the Truckee Meadows (Caupp and others, 1997).

An important water-quality characteristic of any river is its ability to absorb oxygen from the atmosphere. This ability to absorb oxygen is known as reaeration and can be expressed with a term designated the "reaeration-rate coefficient" (Kilpatrick and others, 1989). The reaeration-rate coefficient is an important component of water-quality models that deal with dissolved oxygen. Allowable discharges from waste-water treatment facilities that will not adversely affect the water quality of a stream are calculated using the reaeration-rate coefficient (Melching and Flores, 1999).

Nowlin (1987) reported calculated reaeration-rate coefficients for the Truckee River, downstream from Reno and Sparks, ranging from 2.52 to 17.1 per day for streamflow ranging from 47 to 380 ft^3/s, respectively. These reaeration-rate coefficients were calculated using measurements made with the gas-tracer method, with ethylene as the tracer gas.

Purpose and Scope

The purpose of this report is to present hydrologic data collected during two reaeration studies done on August 30 and September 1, 1999. These studies involved data collection from two separate reaches on the Truckee River, the upper reach from Lockwood to below Tracy (lower bridge), Nev., and the lower reach from Wadsworth to Dead Ox Wash, Nev. Also presented are reaeration-rate coefficients calculated from these data and coefficients reported in a previous study done in 1979-80 (Nowlin, 1987).

Acknowledgments

The authors wish to thank the following personnel from the U.S. Geological Survey (USGS) who assisted in data-collection activities for this report: Kip K. Allander, E. James Crompton, Arthur W. Johnson, Joseph D. Joyner, Timothy G. Rowe, and Karen A. Thomas. Rhea P. Williams and Ray J. Hoffman, also of the USGS, assisted in the planning stages of the project. The authors also thank the Pyramid Lake Paiute Tribe for granting permission to access parts of the river on Tribal lands.

PROPANE GAS AND DYE INJECTION AND WATER SAMPLING

Two reaches of the Truckee River were selected for study: the upper reach from Lockwood to below Tracy (lower bridge) and the lower reach from Wadsworth to Dead Ox Wash (fig. 1 and table 1). Propane gas was used as a tracer for the reaeration studies described herein. The studies were carried out using the procedures detailed by Kilpatrick and others (1989) and Kilpatrick and Wilson (1989). Propane gas was introduced into the stream using two 100-lb gas cylinders, a regulator, a flowmeter, and four ceramic plate diffusers (total surface area of about 400 in^2). Diffusers were placed in flowing water at depths of 3.5 to 4 ft. The calculated injection rate is a function of stream discharge, stream velocity, stream depth, travel time to the sampling point furthest downstream, and the absorption efficiency of the propane gas. The injection rate also is affected by physical limitations of the delivery

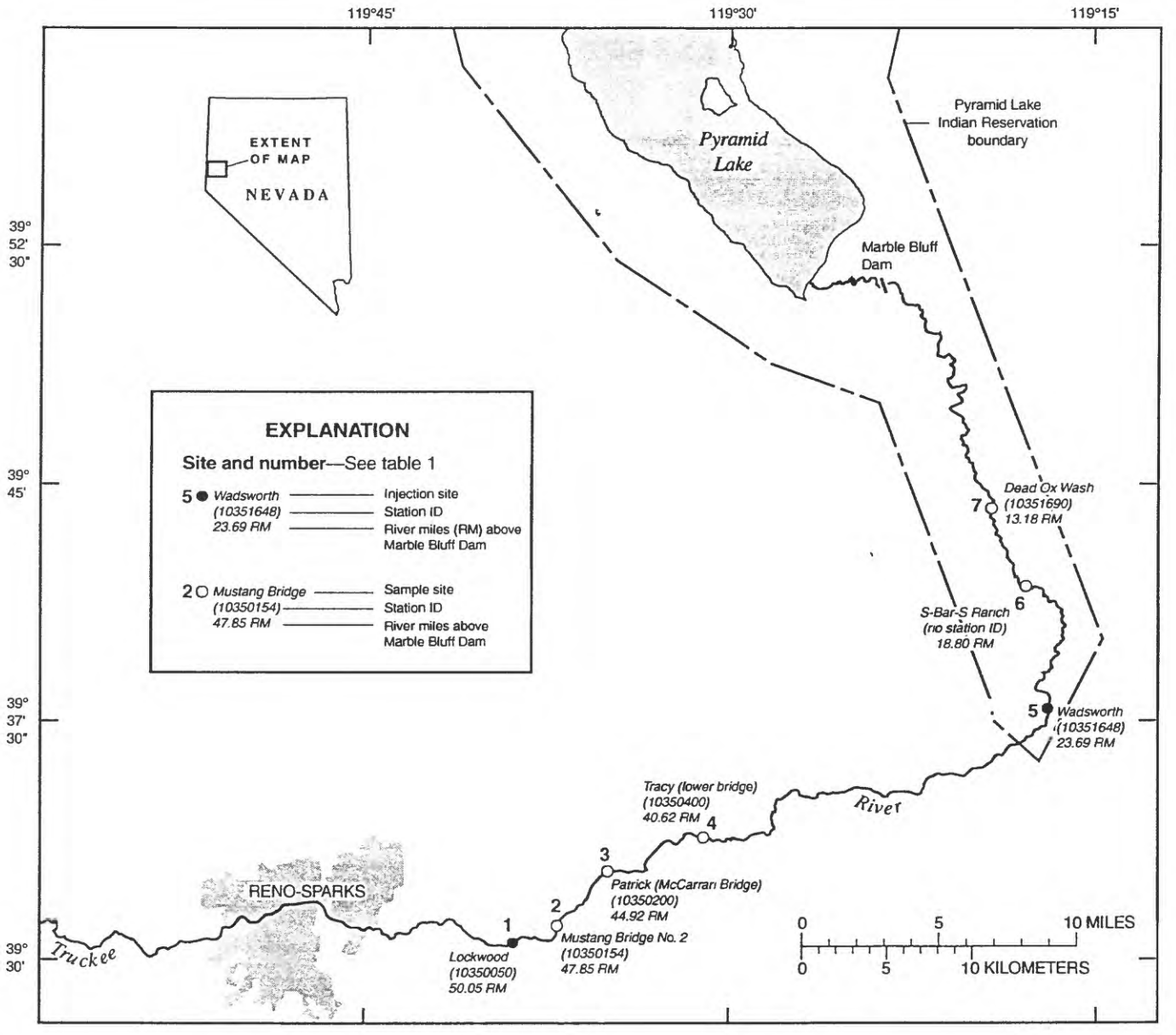

Figure 1. Location of sampling sites on the Truckee River downstream from Reno, Nevada, August 30 and September 1, 1999.

Table 1. Location and general description of sampling sites on the Truckee River, Nevada, for studies on August 30 and September 1, 1999

[–, no USGS station number assigned]

Site number (fig. 1)	Site name	USGS station number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	River miles above Marble Bluff Dam, Nev. [1]
	Upper Reach				
1	At Lockwood	10350050	393036	1193852	50.05
2	At Mustang Bridge no. 2 near Hafed	10350154	393108	1193703	47.85
3	At Patrick (McCarran Bridge)	10350200	393249	1193459	44.92
4	Below Tracy (lower bridge)	10350400	393352	1193102	40.62
	Lower Reach				
5	At Old U.S. Hwy 40 Bridge at Wadsworth	10351648	393755	1191654	23.69
6	At S-Bar-S Ranch	--	394053	1191620	[2]18.80
7	At Dead Ox Wash near Nixon	10351690	394414	1191924	13.18

[1] From La Camera and others (1985).

[2] S-Bar-S site is 2.05 miles upstream from USGS site number 10351684 (La Camera and others, 1985).

system. Air temperature was the limiting factor in the injection rate of propane at Lockwood. The injection rate of propane was approximately 30 L/min at Lockwood and 40 L/min at Wadsworth.

Each of the reaeration studies involved the injection of a dye tracer, as well as the propane gas discussed above, to determine if processes other than desorption were removing propane gas from the stream. Differences in total dye mass from upstream to downstream can be used to account for losses of propane from mechanisms other than desorption. Losses of propane gas can be due to backwaters and diversions of streamflow from the river. Propane concentrations also can be reduced by dilution from inflow to the river. During the study, the total of inflows and diversions, in the reaches investigated, was less than the error associated with the streamflow measurements.

The dye tracer used in the Truckee River was rhodamine WT, a nontoxic and conservative fluorescent red chemical dye. A solution of dye was made in the laboratory by mixing equal volumes of water and concentrated rhodamine dye. This dye solution was injected at a constant rate (approximately 140 mL/min) into the centroid of flow at the same time propane gas was injected. The times of dye and propane gas injection, streamflow, dye concentration, and dye volumes are listed in tables 2 and 3. Total masses of dye injected into the river at Lockwood and Wadsworth are listed in table 4.

Water samples for propane gas were collected at three locations downstream from Lockwood and two locations downstream from Wadsworth (fig. 1). At each location, water samples were collected in 40-mL glass vials using a self-purging sampler described by Kilpatrick and others (1989). Duplicate samples were collected at all sampling times. Each 40-mL vial, while submerged beneath the water in the sampler, was injected with 1 mL of formalin solution as a preservative, and then capped. Frequency of water-sample collection for propane gas analysis was determined by the concentration of rhodamine WT dye in the stream (tables 2 and 3, and figs. 2 and 3). During the time period of the peak rhodamine dye concentration, samples were collected every 5 minutes. Selected water samples were sent to the USGS laboratory in Ocala, Fla., for propane analysis using gas chromatography.

CALCULATION OF REAERATION-RATE COEFFICIENTS

Reaeration-rate coefficients were calculated using equation 1 (Kilpatrick and others, 1989) and data in tables 2-4. The calculations are based on the rate of desorption of propane gas from the river. Water temperature, dye loss, and travel time between sampling points are important factors in the equations that determine the reaeration-rate coefficient of a stream.

Table 2. Concentration of rhodamine WT dye and propane gas in water samples collected on September 1, 1999, from the Truckee River at Mustang Bridge No. 2, Patrick (McCarran Bridge), and below Tracy (lower bridge), Nevada

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second; g/L, grams per liter; µg/L, micrograms per liter; NS, not sampled; <, less than]

Injection site: Truckee River at Lockwood
Date of injection: September 1, 1999
Streamflow (ft^3/s): 647
Water temperature (°C): 14.0
Begin injection time: 7:21 am End injection time: 9:28 am
Dye volume (liters): 16.3 Dye concentration (g/L): 112

Sampling site:	Mustang Bridge No. 2	Patrick (McCarran Bridge)	Below Tracy
River miles below injection:	2.20	5.13	9.43
Streamflow during sampling period (ft^3/s):	562	578	539
Water temperature (°C):	14.5	15.0	17.0

Mustang Bridge No. 2			Patrick (McCarran Bridge)			Below Tracy (lower bridge)		
Time	Dye (µg/L)	Propane (µg/L)	Time	Dye (µg/L)	Propane (µg/L)	Time	Dye (µg/L)	Propane (µg/L)
800	0.05	NS	1046	0.05	NS	1325	0.06	NS
810	.05	NS	1056	.43	NS	1340	.04	NS
820	.04	NS	1115	3.3	NS	1355	.11	NS
830	.1	NS	1130	7.1	NS	1410	.06	NS
840	.61	NS	1140	9.5	NS	1425	.3	NS
850	3.2	NS	1147	10.5	NS	1440	.84	NS
900	8.3	NS	1151	11.2	NS	1455	2.45	NS
910	12.0	NS	1157	11.9	NS	1505	3.4	NS
920	14.0	NS	1202	12.2	NS	1515	5.1	NS
925	14.9	NS	1207	11.4	2.0	1525	6.3	NS
930	15.2	6.1	1212	13.2	1.9	1530	7.2	NS
935	15.4	7.3	1217	13.8	2.2	1535	7.9	NS
940	15.9	5.3	1222	13.9	2.2	1540	8.6	NS
945	15.5	5.5	1227	14.1	2.9	1545	9.0	NS
950	16.0	6.5	1232	14.2	2.4	1550	9.7	NS
955	16.0	7.2	1237	14.3	2.1	1555	10.5	NS
1000	16.0	6.3	1242	14.3	2.0	1600	10.9	<1
1005	16.0	6.1	1247	14.2	2.1	1605	11.2	<1
1010	15.9	6.3	1252	14.2	2.2	1610	11.6	<1
1020	15.8	6.9	1257	14.2	1.9	1615	12.0	<1
1025	15.8	6.1	1302	13.8	2.6	1620	12.1	<1
1030	15.8	5.9	1307	12.2	1.7	1625	12.3	<1
1035	15.7	5.6	1320	10.8	NS	1630	12.6	<1
1040	15.5	6.5	1335	7.1	NS	1635	12.6	<1
1045	15.3	6.3	1350	4.3	NS	1640	12.4	<1
1050	14.4	NS	1405	2.6	NS	1645	12.3	<1
1055	12.7	NS	1420	1.6	NS	1650	12.1	<1
1100	8.8	NS	1435	1	NS	1655	11.9	<1
1105	7.4	NS	1505	.42	NS	1700	11.5	<1
1110	5.3	NS	1535	.17	NS	1705	10.9	<1
1115	3.8	NS				1710	10.3	NS
1120	2.9	NS				1715	9.6	NS
1135	1.05	NS				1720	9.1	NS
1150	.39	NS				1735	7.1	NS
1205	.19	NS				1750	5.2	NS
						1805	3.9	NS
						1820	2.7	NS
						1835	1.85	NS
						1905	.86	NS
						1935	.56	NS

Table 3. Concentration of rhodamine WT dye and propane gas in water samples collected on August 30, 1999, from the Truckee River at S-Bar-S Ranch and Dead Ox Wash, Nevada

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second; g/L, grams per liter; µg/L, micrograms per liter; --, sample destroyed; NS, not sampled; <, less than]

Injection site: Truckee River at Old Highway 40 Bridge at Wadsworth, Nev.
Date of injection: August 30, 1999
Streamflow (ft^3/s): 446
Water temperature (°C):18.5
Begin dye injection: 7:21 am End dye injection: 9:08 am
Dye volume (liters): 16.6 Dye concentration (g/L): 112

Sampling site:	S-Bar-S Ranch	Dead Ox Wash
River miles below injection:	4.89	10.51
Streamflow during sampling period (ft^3/s):	455	465
Water temperature (°C):	20.0	21.5

S-Bar-S Ranch			Dead Ox Wash		
Time	Dye (µg/L)	Propane (µg/L)	Time	Dye (µg/L)	Propane (µg/L)
1039	0.06	NS	1300	0	NS
1057	.11	NS	1315	.5	NS
1110	.04	NS	1330	.4	NS
1125	.39	NS	1345	.4	NS
1140	2.4	NS	1400	.3	NS
1200	7.8	NS	1415	.3	NS
1210	11.0	NS	1430	.3	NS
1220	13.3	NS	1445	.2	NS
1225	14.5	2.6	1500	.3	NS
1230	15.3	2.7	1515	.3	NS
1235	15.8	3.4	1530	.6	NS
1240	16.1	2.2	1540	.9	NS
1245	16.4	2.7	1550	1.5	NS
1250	14.8	--	1600	2.7	NS
1255	16.9	3.7	1610	4.0	NS
1300	17.3	4.0	1620	5.4	NS
1305	17.6	3.9	1625	6.3	NS
1310	17.4	3.2	1631	7.4	NS
1315	17.0	4.2	1637	7.9	NS
1322	16.5	3.6	1642	9.3	NS
1327	14.7	3.2	1647	9.9	NS
1332	13.1	2.3	1652	10.6	NS
1337	12.9	NS	1657	11.2	NS
1342	12.0	NS	1701	11.9	NS
1347	10.5	NS	1705	12.2	<1

S-Bar-S Ranch			Dead Ox Wash		
Time	Dye (µg/L)	Propane (µg/L)	Time	Dye (µg/L)	Propane (µg/L)
1352	9.0	NS	1710	11.8	<1
1357	7.8	NS	1715	12.8	<1
1405	6.3	NS	1720	13.2	<1
1420	4.0	NS	1725	13.7	<1
1435	2.3	NS	1730	13.7	<1
1450	1.45	NS	1735	13.8	<1
1520	.87	NS	1740	13.4	<1
1550	.55	NS	1745	13.3	<1
1620	.35	NS	1750	12.9	<1
1650	.3	NS	1755	12.6	<1
			1800	12.0	<1
			1805	11.2	<1
			1810	10.4	<1
			1815	10.1	NS
			1820	8.7	NS
			1835	7.1	NS
			1850	5.3	NS
			1905	3.8	NS
			1920	2.8	NS
			1935	2.05	NS
			1950	1.65	NS
			2005	1.25	NS
			2035	.8	NS
			2105	.62	NS

Table 4. Mass of rhodamine WT dye injected into and recovered from reaeration sampling sites on Truckee River downstream from Reno, Nevada, for studies on August 30 and September 1, 1999

Upper Reach			Lower Reach		
Site	Mass of dye (grams)	R_r, Dye recovery ratio	Site	Mass of dye (grams)	R_r, Dye recovery ratio
Lockwood (injection site)	1,800	--	Wadsworth (injection site)	1,900	--
Mustang Bridge No. 2	[1]1,900	1.0	S-Bar-S Ranch	1,600	0.84
Patrick (McCarran Bridge)	[1]1,900	1.0	Dead Ox Wash	1,600	.84
Below Tracy	1,700	.94			

[1] Recovery of more than 100 percent of dye is assumed to be in error. Calculations will assume 100 percent recovery.

The propane desorption-rate coefficient, $K_{P\gamma}$, in per day, at ambient stream temperature, γ, can be calculated by:

$$K_{P\gamma} = \frac{24}{(t_d - t_u)} \ln \frac{\left[\frac{C_g}{C_p/R_r}\right]_u}{\left[\frac{C_g}{C_p/R_r}\right]_d} \quad (1)$$

where t_d and t_u are the downstream and upstream times of peak dye concentration from the midpoint of dye injection period, respectively, in hours;

24 is a conversion factor from hours to days;

C_g is the concentration of propane gas at the peak dye concentration, in micrograms per liter;

C_p is the observed peak dye concentration, in micrograms per liter; and

R_r is the dye recovery ratio.

The dye recovery ratio, R_r, is the ratio of the weight of dye recovered at the downstream site and the weight injected upstream. The propane-desorption rate coefficient is related to the reaeration-rate coefficient, $K_{2\gamma}$, at temperature γ by $1.39K_{P\gamma}$ (Kilpatrick and others, 1989).

Typically, the reaeration-rate coefficient is expressed at a standard temperature of 20 °C. Adjustment of the calculated reaeration-rate coefficient from the ambient stream temperature to 20 °C was accomplished using the following formula

$$K_{2\,20} = K_{2\gamma}(1.0241)^{(20-\gamma)} \quad (2)$$

where $K_{2\,20}$ is the reaeration-rate coefficient expressed at 20 °C, and

$K_{2\gamma}$ is the reaeration-rate coefficient as measured by tracer gas at stream temperature γ (Kilpatrick and others, 1989).

Propane gas concentrations were below the laboratory reporting limit of 1 µg/L for furthest downstream sites in each reach, just below Tracy (lower bridge) and Dead Ox Wash. Accordingly, no reaeration-rate coefficients were calculated for reaches where propane was not detected. The data used in equations 1 and 2 and the calculated reaeration-rate coefficient are listed in tables 4 and 5. The reaeration-rate coefficient for the reach of the Truckee River between Mustang Bridge No. 2 and Patrick (McCarran Bridge) on September 1, 1999, was 15.6 per day at a mean streamflow of 570 ft^3/s. Nowlin (1987) reported reaeration-rate coefficients ranging from 2.52 to 17.1 per day for streamflows ranging from 47 to 380 ft^3/s.

The reaeration-rate coefficient for the reach between Mustang Bridge No. 2 and Patrick (McCarran Bridge) calculated from data collected during this study was plotted against the coefficient calculated using the relation developed by Nowlin (1987; fig. 4). This relation is

$$K_2 = CSv \quad (3)$$

where C is the oxygen escape coefficient (4,370 for the Truckee River),

S is the stream slope, and

v is the average velocity in the reach unit, in feet per second.

The stream slope used for this reach was 0.00108 (Glen Hess, U.S. Geological Survey, written commun., 2000). The average velocity determined by streamflow measurements was 2.72 ft/s.

SUMMARY

Data collected from previous studies, as well as from current efforts are being used to understand the dynamic processes that control the quality of water in the Truckee River. An important water-quality characteristic of any river is its ability to absorb oxygen from the atmosphere. This ability to absorb oxygen is known as reaeration and can be expressed using a reaeration-rate coefficient. The coefficient calculated for the reach of the Truckee River between Mustang Bridge No. 2 and Patrick (McCarran Bridge), from field tests completed on September 1, 1999, was 15.6 per day at a temperature of 20 °C. Reaeration-rate coefficients were not calculated for the reaches between Patrick (McCarran Bridge) and below Tracy (lower bridge) and between S-Bar-S and Dead Ox Wash. Streamflow and stream-temperature ranges on August 30 and September 1, 1999, were 446 to 647 ft^3/s and 14.0 to 21.5 °C, respectively.

Table 5. Reaeration-rate coefficients and data used in calculating the coefficients for two reaches on the Truckee River downstream from Reno, Nevada

[Abbreviations: °C, degrees Celsius, µg/L, micrograms per liter; <, less than]

Stream reach	Travel time of dye (hours) [1]		Peak concentrations (µg/L)				Mean water temperature (°C)	K_p, Propane desorption rate coefficient at ambient temperature (per day)	$K_{2\ 20}$, Reaeration-rate coefficient at 20 °C (per day)
			Dye		Propane gas				
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream			
Injection at Lockwood, September 1, 1999									
Mustang Bridge to Patrick (McCarran Bridge)	1.50	4.20	16.0	14.3	7.2	2.1	14.8	9.94	15.6
Patrick (McCarran Bridge) to below Tracy (lower bridge)	4.20	8.08	14.3	12.6	2.1	<1.0	16.0	[2]--	[2]--
Injection at Wadsworth, August 30, 1999									
S-Bar-S Ranch to Dead Ox Wash	4.85	9.35	17.6	13.8	3.9	<1.0	20.8	[2]--	[2]--

[1] Travel times are from midpoint of dye injection period to peak dye concentration at recovery site.

[2] Propane gas concentration at downstream sampling sites was less than the analytical reporting limit of 1.0 µg/L, thus reaeration-rate coefficients could not be calculated.

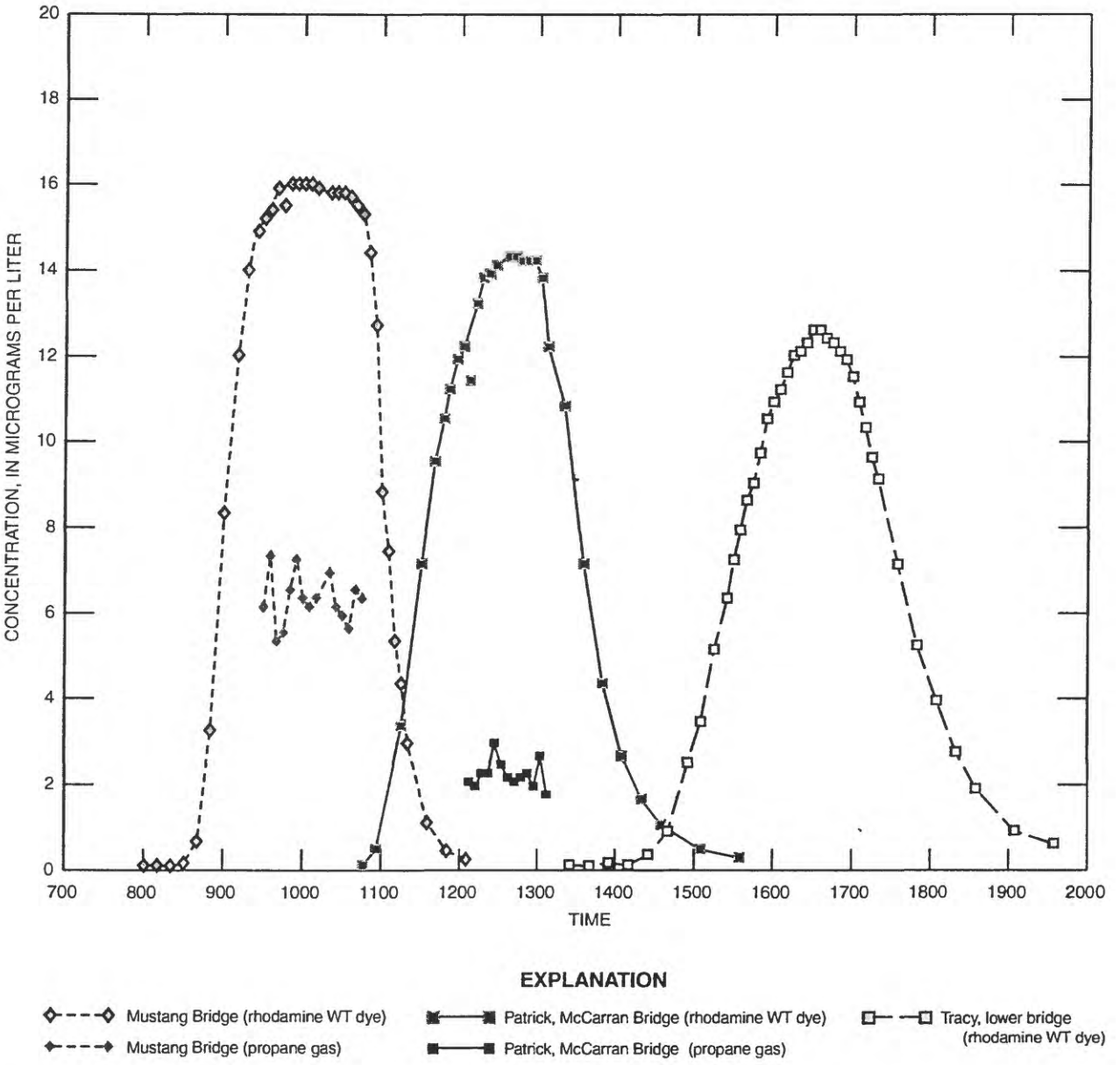

Figure 2. Concentrations of rhodamine WT dye and propane gas in water samples collected from the Truckee River at Mustang Bridge No. 2 to below Tracy (lower bridge) on September 1, 1999. Dye and propane were injected at Lockwood, Nevada, from 7:21 am to 9:28 am. No propane gas was detected in samples collected from the Truckee River below Tracy (lower bridge), Nevada.

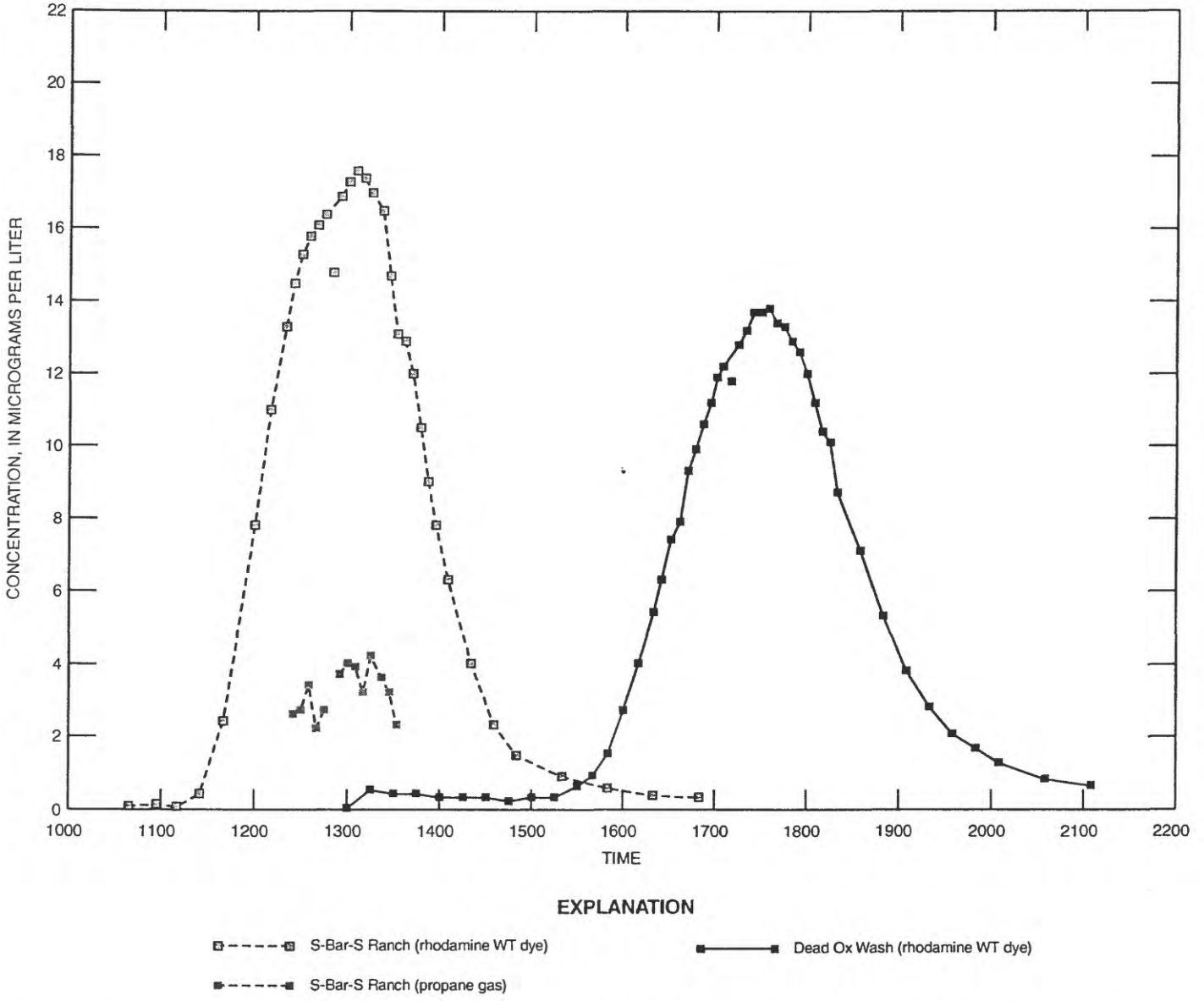

Figure 3. Concentrations of rhodamine WT dye and propane gas in water samples collected from the Truckee River at S-Bar-S Ranch and Dead Ox Wash on August 30, 1999. Dye and propane were injected at Wadsworth, Nevada, from 7:21 am to 9:08 am. No propane gas was detected in samples collected from the Truckee River at Dead Ox Wash, Nevada.

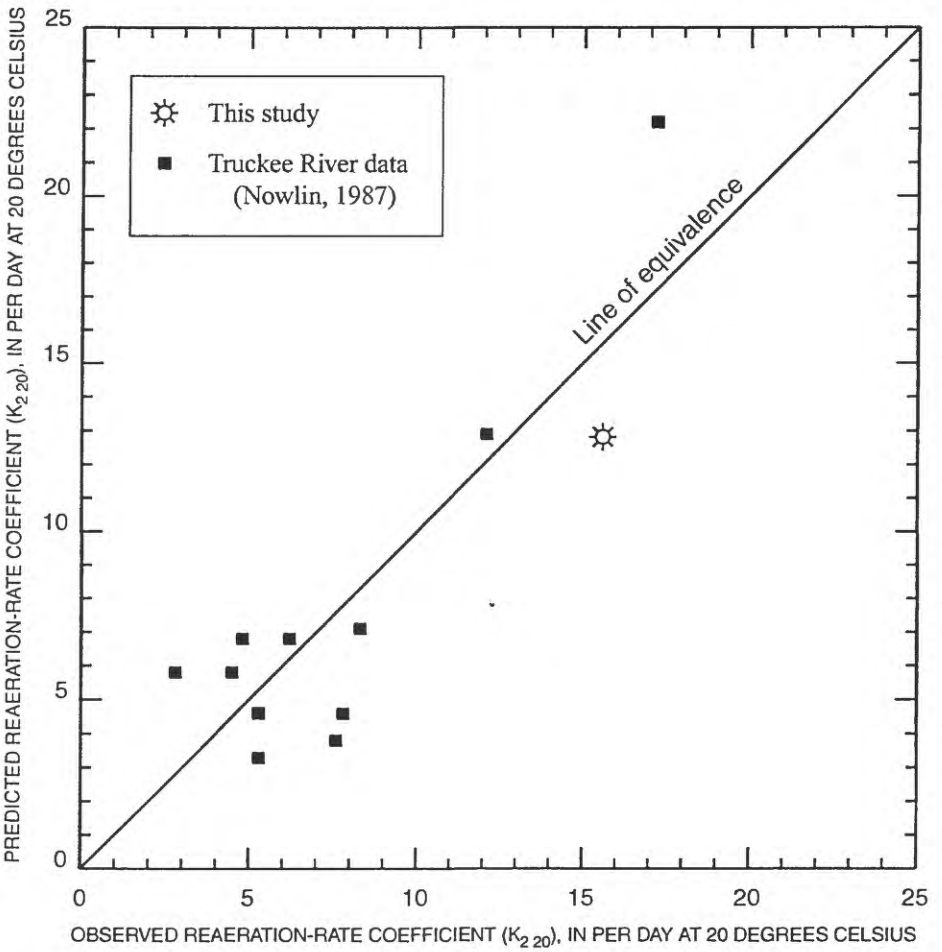

Figure 4. Reaeration-rate coefficient for the Truckee River between Mustang Bridge No. 2 and Patrick (McCarran Bridge) determined from this study versus the coefficient calculated using the data from this study and the relation developed by Nowlin (1987). Data from Nowlin (1987), a previous study on the Truckee River, also are plotted.

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