TRAVELTIME AND REAERATION OF SELECTED STREAMS IN THE NORTH PLATTE AND YAMPA RIVER BASINS, COLORADO

by Barbara C. Ruddy and Linda J. Britton

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to metric (International System) units by using the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
cubic foot per second	0.028317	cubic meter per second
foot	0.3048	meter
mile	1.609	kilometer
mile per hour	1.609	kilometer per hour
ounce, fluid	29.57	milliliter
square mile	2.590	square kilometer

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 9/5\ °C + 32$$

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ABSTRACT

Traveltime characteristics were measured using rhodamine-WT dye as a tracer in the Canadian and Michigan Rivers in the North Platte River basin and in the Yampa, Elk, and Williams Fork Rivers, and Trout and Fish Creeks in the Yampa River basin. Reaeration coefficients were determined using the modified tracer technique with ethlyene and propane gas for selected stream reaches during low flow conditions.

Stream-reach velocities determined during traveltime and reaeration measurements ranged from 0.09 mile per hour at 5.1 cubic feet per second on the Canadian River to 4.04 miles per hour at 746 cubic feet per second on the Williams Fork River. A modified longitudinal dispersion model or results from cumulative traveltime curves were used to estimate traveltimes in the measured streams for streamflow conditions other than those measured. Traveltime-discharge curves were developed using the estimated and measured traveltimes.

Reaeration coefficients were determined for 20 different subreaches in the study area. Reaeration coefficients ranged from 1.6 per day in a pooled subreach of the Yampa River near Craig, Colorado, to 98 per day in a turbulent subreach of Trout Creek near Oak Creek, Colorado.

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INTRODUCTION

Various energy-resource developments, such as coal and oil shale, are now (1986) operational or being planned in Colorado. Policy decisions that affect the location and extent of energy development require consideration of all aspects of environmental effect. One possible environmental problem concerns the population growth associated with energy development and related stream water-quality problems caused by increased waste-water discharges to streams.

Traveltime and reaeration measurements on selected streams in energy-development areas can provide useful data about stream dispersion characteristics. Specifically, such data can provide planners and managers with information about how fast wastes move downstream, how they are dispersed laterally and longitudinally in streams, and how rapidly streams can assimilate certain forms of treated wastes. To provide this information, the U.S. Geological Survey made a study of the traveltime and reaeration characteristics of selected streams in the North Platte and Yampa River basins during 1980 to 1982.

Purpose and Scope

This report describes the results of a study to determine traveltime and reaeration characteristics of selected streams in the North Platte and Yampa River basins. Traveltime and/or reaeration measurements were made on the following stream reaches in the North Platte River basin (fig. 1): (a) The Canadian River from about 15 miles southeast of Walden downstream to near Cowdrey and (b) the Michigan River from near Walden for 2 miles downstream.

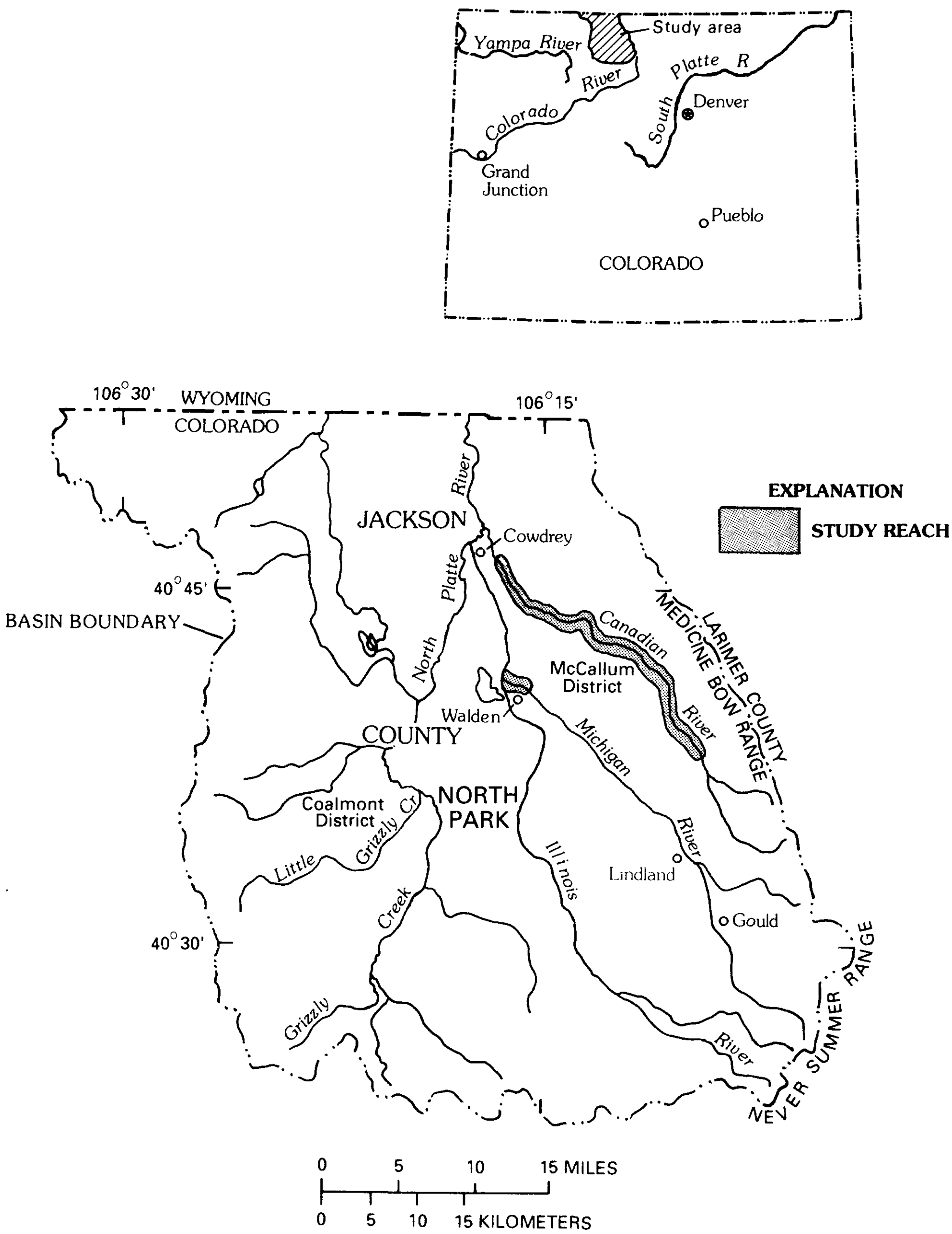

Figure 1.--North Platte River basin study area.

Measurements were done on the following stream reaches in the Yampa River basin (fig. 2): (a) The Yampa River from near Craig downstream to the mouth; (b) the Yampa River from Steamboat Springs downstream for 5 miles; (c) the Elk River from Glen Eden to the mouth, near Milner; (d) the Williams Fork from about 25 miles east of Oak Creek downstream to near the mouth, 8 miles southwest of Craig; (e) Trout Creek from about 6 miles west of Oak Creek downstream to near the mouth, south of Milner; and (f) Fish Creek from about 7 miles south of Milner to the mouth.

The report includes results of data collected from 1980 to 1982. Additional data collected as part of other studies on the Yampa and Elk Rivers during 1978 and 1979 also are included in this report.

General Description of Study Areas

The North Platte River basin is in north-central Colorado (fig. 1) and has a drainage area of about 2,030 square miles. The basin encompasses all of Jackson County. However, most of the population and economic activity is centered around Walden, the Jackson County seat. Coal-resource development and recreation, including a proposed ski area, are expected to provide the greatest potential for growth in Jackson County.

Ranching is the predominant land use, and most of the bottomland along streams in the North Park valley is irrigated hay meadow and pasture. Sagebrush and dry grass rangelands lie between the irrigated bottomlands and the forested mountainsides. On the edges of the basin, the land rises abruptly upward on slopes densely covered with aspen, spruce, pine, and fir. Above timberline at about 11,000 feet, tundra and rock extend to the mountain summits.

The Yampa River basin in northwestern Colorado (fig. 2) and south-central Wyoming (not shown in fig. 2) has a drainage area of about 8,080 square miles. Within the basin are parts of Garfield, Grand, Moffat, Rio Blanco, and Routt Counties in Colorado. Steele and others (1979) state that the majority of the population and economic activity within the basin is located in Moffat and Routt Counties, which comprise about two-thirds of the basin area. Discussions of economic, physiographic, and energy-development features of the Yampa River basin are given by Steele and others (1979)--as part of an assessment study of the Yampa River basin during the late 1970's.

The streamflow regime of the North Platte and Yampa River basins can be characterized as follows: In early spring, after ice break up, increases in streamflow result from melting of the snowpack in the mountains. Streamflows generally begin to recede in June and July in response to the depletion of the snowpack. Short duration and moderate increases in streamflow may occur in July and August due to rainstorm activity. Base-flow conditions normally prevail throughout the winter.

Acknowledgments

The authors extend their appreciation to the many residents, both private and commercial, for permitting access to sites along the stream reaches during field-data collection. Assistance in collecting the data provided by personnel of the Colorado offices of the U.S. Geological Survey also is appreciated.

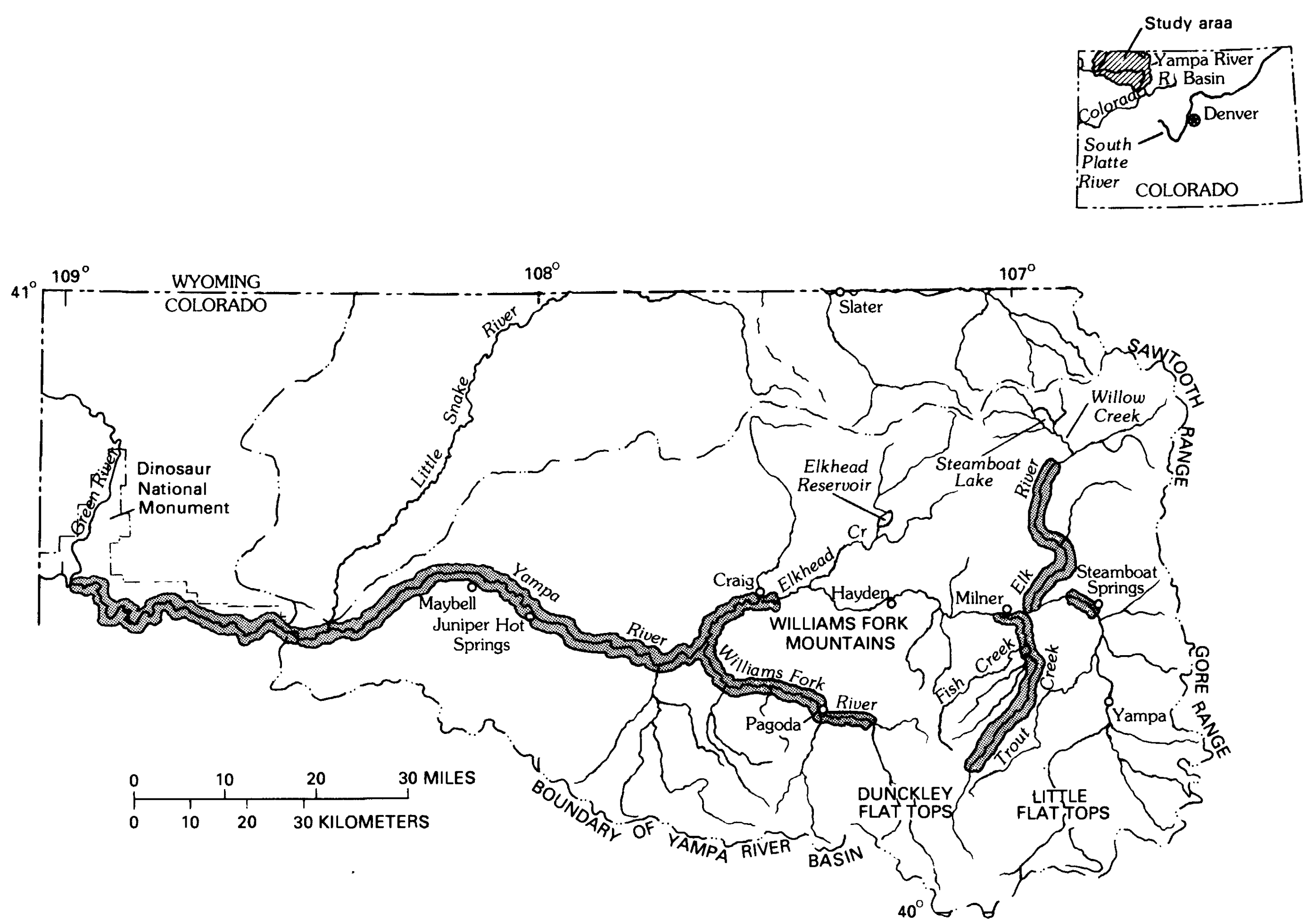

Figure 2.--Yampa River basin study area.

Laboratory assistance by John Vaupotic of the U.S. Geological Survey in determination of tracer-gas concentrations for reaeration analysis is gratefully acknowledged. All data collection on the Yampa River, with the exception of the Steamboat Springs area reaeration measurement, was directed by Daniel P. Bauer.

DETERMINATION OF TRAVELTIME CHARACTERISTICS

Traveltime characteristics of a stream vary with flow conditions. Therefore, measurements of the rate of movement and dispersion of a substance injected into a stream for a range of flow conditions was necessary to determine traveltime characteristics for the selected stream reaches. For some stream reaches, a mathematical model was used to estimate traveltimes at flows other than those measured.

Dye-Tracer Technique

A fluorescent tracer dye, rhodamine WT, was injected into selected stream reaches to measure traveltime characteristics for the existing flow condition. Because the injected dye is a solute, it mixes completely with the water and simulates water movement and dispersion. Thus the movement, concentration, and dispersion of the dye cloud simulates the characteristics of soluble contaminants that might be introduced into a stream. A complete description of the methods, procedures, dyes, and equipment used for traveltime measurements is presented in Hubbard and others (1982). The dye was injected at selected locations along the stream reaches; the resultant dye clouds were monitored at selected downstream sampling sites. Generally, the water samples were collected at approximately the center of streamflow. The water samples collected at each site were analyzed using fluorometric procedures described by Wilson (1968). The intensity of fluorescence measured is directly proportional to the concentration of dye in the sample. To verify field results, duplicate water samples were collected and analyzed in the laboratory.

As the dye cloud travels downstream, it continuously disperses; thus it takes longer to pass each successive site, and the peak concentration decreases. As noted in previous studies (Bauer and others, 1979; Hubbard and others, 1982), the mixing or dispersion of the dye cloud occurs in all dimensions of the stream channel. Complete mixing of the dye usually occurs first in the vertical direction, while complete lateral mixing takes longer, depending upon the width, velocity, and other stream properties. Longitudinal mixing continues indefinitely because of the lack of boundaries and is the primary dispersion component of interest. All measurements on streams described in this report are based on samples collected as near the center of flow as possible.

Traveltime Simulation Method

For some reaches, a modified longitudinal dispersion model was used to simulate traveltime at other than measured discharges (McQuivey and Keefer, 1976; Bauer and others, 1979). This model contains two major parameters, as follows: The damping coefficient, D_*, in feet per second; mean stream velocity, $\bar{U}$, in feet per second. The damping coefficient is defined as $D_*=U_*/K$, where U_* is the shear velocity, in feet per second, and K is von Karman's constant. A number of subreaches are defined for each stream where traveltime is to be simulated. The number of subreaches is determined using stream-reach hydraulic properties. Predictions of relative dye concentrations are made for the end of each subreach. The time of peak concentrations then can be determined for each measurement site by using the times of the relative dye concentrations computed by the model at the end of each model subreach. Bauer and others (1979) give a complete description of the model used in this study.

Calibrating the model to simulate traveltimes is accomplished by changing $\bar{U}$ and D_* for each subreach until the times (leading edge and peak of the dye cloud) of the simulated injection match the times measured in the field. Once the model is calibrated, traveltimes at hypothetical discharges can be simulated using the following procedure:

1. Develop the relations of shear velocity (U_*) and mean velocity ($\bar{U}$) versus discharge from discharge measurements made at the index streamflow stations in the study reach.

2. Using the results from the calibrated model, determine for each subreach the ratios U_*gage/D_*model and $\bar{U}$gage/$\bar{U}$model.

3. Choose different index-discharge values and determine corresponding $\bar{U}$ gage and U_* gage values.

4. Compute respective $\bar{U}$ model and D_* model values for the reach from the ratios found in procedure 2. It is assumed the ratios are constant for different flows.

5. Use the new parameter values in the model to obtain simulated traveltimes.

This technique was used for stream reaches where adequate discharge measurements were available at index stations. Measurements are needed for the definition of the curves of mean and shear velocity versus discharge.

DETERMINATION OF REAERATION COEFFICIENTS USING A MODIFIED TRACER TECHNIQUE

Reaeration coefficients were measured for selected stream reaches using a modification of a tracer technique developed by Tsivoglou (1967). Ethylene and propane were used as tracer gases, and rhodamine-WT dye was used as the dispersion and dilution tracer. Only a brief description of the tracer technique is included in this report, but more complete details are in Rathbun and others (1975) and in Rathbun and Grant (1978).

Basically, a known quantity of a tracer gas is injected into the stream, and a desorption coefficient for the gas is determined from measurements of the gas concentrations at various points downstream. Using a constant determined in the laboratory, this desorption coefficient for the tracer gas is converted to a reaeration coefficient for oxygen. The modified tracer technique allows for the injection of two tracer gases simultaneously and, therefore, allows for two measurements of the reaeration coefficient in a single experiment if desired.

The following assumptions are inherent in the tracer technique (Tsivoglou, 1967): (1) The ratio of the reaeration coefficient and the tracer-gas desorption coefficient is independent of mixing conditions, water temperature, and the presence of pollutants for the range of conditions that occur in natural streams; (2) the dispersion-dilution tracer is conservative; and (3) 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 from the air-water interface.

Generally, reaeration coefficients are calculated from the peak concentrations of the tracer gases and dilution tracer, but they also can be computed from the areas under the tracer-gas concentration-time curves. The area method uses the concentration versus time data for those cross sections where sufficient samples are obtained to define the complete concentration versus time curve. Traveltime data also is determined during reaeration measurements by use of the gas or dye concentration-time curves. This data complements data collected during traveltime measurements.

Peak Method

The basic equation for the tracer-gas desorption coefficient (K_G) using the peak method is as follows:

$$K_G = 1/(t_d - t_u) \ln[(C_{GU}/C_{DU})/(C_{GD}/C_{DD}J_n)] \tag{1}$$

where K_G = tracer-gas desorption coefficient, per hour;
t_d, t_u = traveltime of the peak concentration of the dye at the downstream and upstream ends of the reach, in hours;
$\ln$ = natural logarithm, base e;
C_{GU}, C_{GD} = peak concentration of the tracer gas at the upstream and downstream ends of the reach, in micrograms per liter;
C_{DU}, C_{DD} = peak concentration of the dye at the upstream and downstream ends of the reach, in micrograms per liter; and
J_n = dye-loss correction factor.

The rhodamine-WT dye curves must be corrected for dye loss and flow accrual before the reaeration coefficients are computed. It can be shown from the concentration of mass that:

$$Q_1A_1 = Q_2A_2 = Q_3A_3 = \ldots Q_nA_n \tag{2}$$

where: Q = discharge at each of n cross sections where samples are collected;

and A = corresponding area under the dye concentration versus time curve for each cross section where samples are collected.

If there is dye loss, then Q_2A_2 will be less than Q_1A_1, and Q_nA_n will be less than $Q_{n-1}A_{n-1}$. The correction procedure is to multiply each point on the dye curve by a correction factor (J), as follows:

$$Q_1A_1 = Q_2A_2J_2 = \ldots Q_nA_nJ_n \tag{3}$$

where: $J_2 = Q_1A_1/Q_2A_2$; and
$J_n = Q_1A_1/Q_nA_n$.

It is important that dye concentration-time curves be defined completely so that the term A includes all of the dye mass in transport. The gas concentrations in the river are affected by the processes of dispersion and dilution as well as release to the atmosphere. The use of the corrected peak dye concentrations C_{DU} and C_{DD} adjust the results of equation 1 for dispersion and dilution. Therefore, during reaeration measurements, the dye often is referred to as the dispersion-dilution tracer.

Area Method

The reaeration coefficients can be calculated from the areas under the tracer-gas concentration-time curves for those reaches where sufficient samples are collected for complete concentration-time curve definition. The basic equation is:

$$K_G=1/(t_{cd}-t_{cu})\ln(A_U/A_D) \quad (4)$$

where: t_{cd}, t_{cu} = traveltime of the centroids of the tracer-gas mass at the downstream and upstream ends of the reach; and
A_U, A_D = areas of the tracer-gas concentration versus time curves at the upstream and downstream ends of the reach.

If there is flow accrual, the areas must be corrected, and equation 4 becomes:

$$K_G=1/(t_d-t_u)\ln[(A_UQ_U)/(A_DQ_D)] \quad (5)$$

where: Q_U, Q_D = discharge at the upstream and downstream ends of the reach.

The advantage of the area method is that it is independent of the dye measurement, and thus, the nonconservative nature of the dye is not critical. The disadvantage of the area method is that complete tracer-gas concentration-time curves needs to be defined. In contrast, the peak method only requires complete dye-concentration curves.

Calculation of Reaeration Coefficients

The tracer-gas desorption coefficient (K_G) that was calculated by the peak or area method is converted to a reaeration coefficient (K_2 in natural base e units) as follows:

$$K_2=RK_G \quad (6)$$

where R = ratio of the absorption coefficient for oxygen to the desorption coefficient for the tracer gas (determined in the laboratory).

The values of R for the ethylene and propane determined in laboratory studies by Rathbun and others (1978) are 1.15 for ethylene and 1.39 for propane.

Reaeration coefficients usually are reported at a common temperature of 20 °C. Measured coefficients were adjusted to 20 °C by the following equation (Elmore and West, 1961):

$$K_{2(20)}=K_{2(t)}(1.0241)^{20-t} \tag{7}$$

where $K_{2(20)}$ = reaeration coefficient at 20 °C;

$K_{2(t)}$ = measured reaeration coefficient; and

t = mean reach water temperature, in degrees Celsius.

Reaeration Sampling and Analytical Methods

Ethylene and propane gases were injected into the stream reaches by bubbling them through diffuser plates that had been placed on the stream bottom. The gases were released from high-pressure cylinders through two-stage regulators, through a rotameter for monitoring the flow rate, and then through the diffusers into the stream.

The dye (rhodamine WT) was injected at the same point and for the same time period as the tracer gases. The dye solution was injected continuously using a direct-displacement pump. Gas and dye injection concentrations and rates applicable for the stream discharges were determined from equations presented by Rathbun (1979).

Dye samples were collected in 1.1-fluid-ounce bottles with polyseal caps for field monitoring and subsequent analysis in the laboratory. The dye samples were collected as a function of time at approximately the center of flow.

Samples of water for the determination of tracer-gas concentrations were collected from the center of flow in 40-milliliter septum capped vials. The vial was placed in a small version of a standard water sampler, and the sample was collected from about mid-depth to the surface so that the bottle was overfilled. Samples were preserved for later laboratory analysis by adding 1 milliliter of 37-percent formalin stock solution to each sample.

Ethylene and propane concentrations in the water samples were determined in the laboratory using a stripping and trapping procedure at low temperature for preconcentration, which was followed by analysis in a gas-chromatograph with a flame-ionization detector. The procedure and detailed techniques for sample storage and preservation are described in Shultz and others (1976). Dye concentrations were determined using standard fluorometric techniques described by Wilson (1968) and by Hubbard and others (1982).

NORTH PLATTE RIVER BASIN

Canadian River

The Canadian River originates from two forks on the west side of the Medicine Bow Range (fig. 1) at an elevation of about 11,000 feet. The river flows in a northwesterly direction to its confluence with the North Platte River near Cowdrey at an elevation of about 8,000 feet. The upper parts of the river basin (upstream from the study area) are in a densely forested area, but the lower parts are relatively broad valleys of brush and native grasslands.

Once the river enters the valley, channel slope is small, and the river meanders a distance of about 40 miles with a change in elevation of approximately 400 feet. During higher flows, the river is comprised of relatively deep pools of slow moving water, but lower flows expose sandbars that have large riffle areas. Most of the river is completely open, and only limited shade is provided by the vegetation along the banks.

Land use in the basin is almost entirely ranching. During the growing season (May-August), a considerable demand is placed on the Canadian River water for flood-type irrigation of hay meadows within and adjacent to the flood plains. These diversions, together with associated return flows, greatly affect the natural flow of the river and its tributaries. In addition to ranching, there are three operating coal mines in the Canadian River basin, a number of oil and gas wells, and a fluorspar mine.

Location and Extent of Study Reach

The study reach along the Canadian River extends from approximately 51 miles upstream from the mouth (site 1) to about 4 miles upstream from the mouth (site 20), as shown in figure 3. Traveltime data were collected in June and August 1980, and June and July 1981. During June, the flow conditions could be described as high, whereas the July and August flow conditions could be characterized as medium and low. In addition, reaeration measurements were made during two low-flow periods. A description of the injection and sampling sites for the various measurements is listed in table 1 and the location of the sites is shown in figure 3.

Traveltime Results

Dye-curve characteristics from the traveltime measurements are listed in table 2. Mean velocities for all measurements ranged from 0.09 to 1.29 miles per hour. Mean velocities between injection sites and the first measurement downstream were greater than the actual mean velocity of the water because the dye goes through a mixing period during which it travels faster than the mean velocity of the entire water mass. Discharges during the June 1980 measurement from sites 1 to 11 increased from 43 to 134 cubic feet per second because snowmelt runoff in tributaries contributed to the Canadian River. For measurements made during moderate and low flows, variations in discharge are apparent because of withdrawals of water for irrigation.

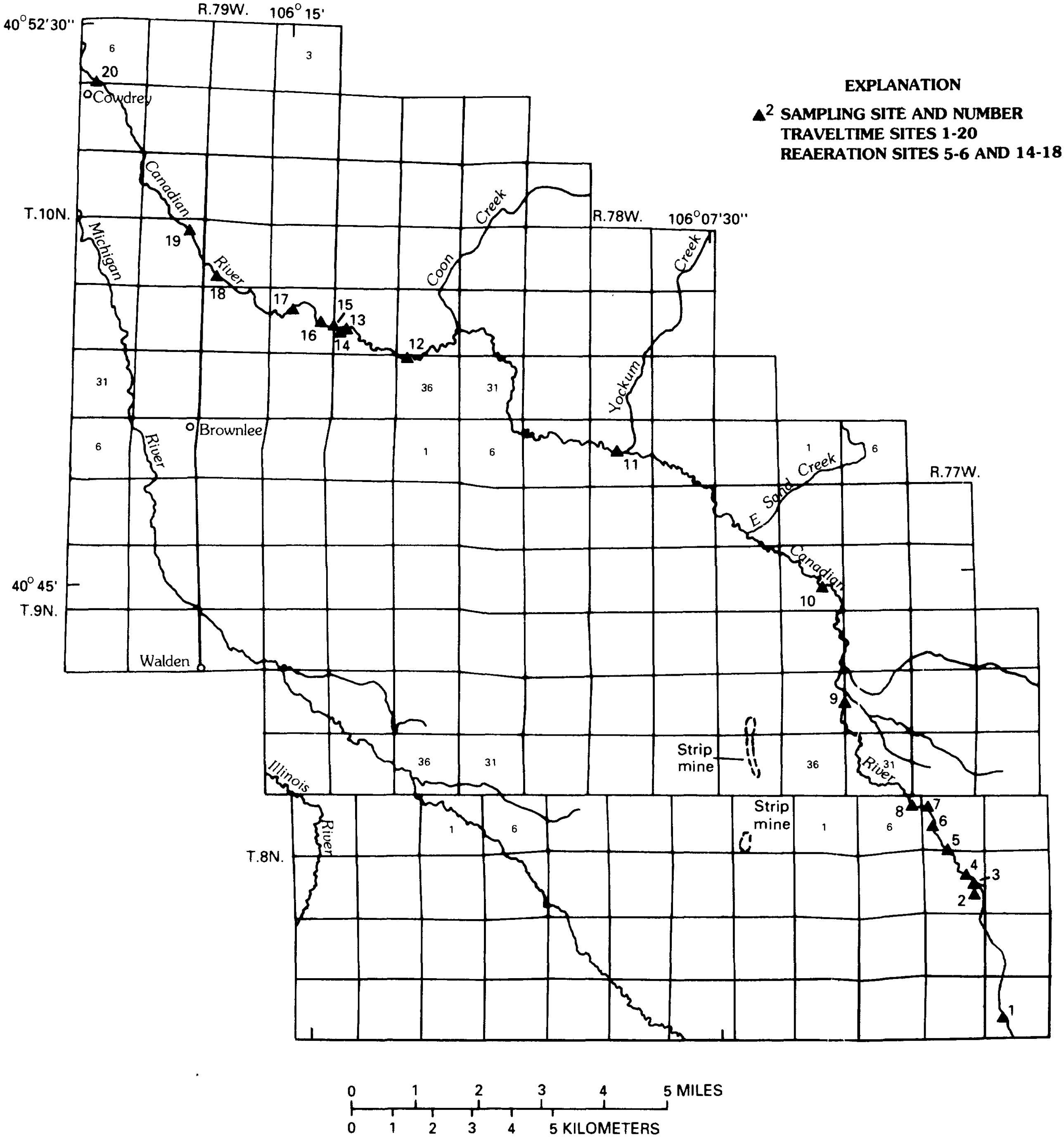

Figure 3.--Injection and sampling sites for traveltime and reaeration measurements on the Canadian River.

Table 1.--*Injection and sampling sites for traveltime and reaeration measurements on the Canadian River*

[Flow conditions: H, high flow; M, medium flow; L, low flow; Site type: I, injection; S, sampling]

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
1	H	I	50.80	Canadian River at Rodgerson Ranch.
2	M	I	48.15	Canadian River upstream from Mace Ranch.
3	M,L	I,S	47.94	Canadian River near Mace Ranch.
4	L	S	47.90	Canadian River near Mace Ranch.
5	L	S	47.59	Canadian River downstream from Mace Ranch.
6	L	S	46.71	Canadian River upstream from Dickens Ranch.
7	L	S	45.75	Canadian River 0.54 mile upstream from gage near Lindland.
8	H,M	S	45.21	Canadian River at gage near Lindland.
9	H,M	I,S	40.17	Canadian River 5.04 miles downstream from gage near Lindland.
10	H,M	S	34.76	Canadian River 10.45 miles downstream from gage near Lindland.
11	H,M	I,S	27.09	Canadian River near Blevins Ranch.
12	H,M	I,S	17.16	Canadian River 2.06 miles upstream from gage near Brownlee.
13	L	I	15.10	Canadian River at gage near Brownlee.
14	H,M,L	S	14.89	Canadian River downstream from Jackson County Road 8.
15	L	S	14.61	Canadian River upstream from Dwinell Ranch.
16	L	S	14.20	Canadian River upstream from Dwinell Ranch.
17	L	S	13.42	Canadian River 1.68 miles downstream from gage near Brownlee.
18	L	S	10.83	Canadian River 4.27 miles downstream from gage near Brownlee.
19	H,M	S	9.62	Canadian River 5.48 miles downstream from gage near Brownlee.
20	H,M	S	4.08	Canadian River at State Highway 125.

Traveltimes at other flow conditions were simulated using the index-station method described earlier. Two streamflow-gaging stations are operated by the U.S. Geological Survey on the Canadian River. These stations, 06619400 Canadian River near Lindland (site 8) and 06619450 Canadian River near Brownlee (site 13), were used as the index stations for the simulations. Relations of shear velocity versus discharge and mean velocity versus discharge were developed for each station using 1978 to 1981 discharge-measurement data. These relations are shown in figures 4 and 5.

Table 2.--*Data collected during traveltime measurements on the Canadian River*

[--, not applicable; ND, no data]

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye cloud			Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
				Leading edge (hours)	Peak (hours)	Centroid (hours)			
Canadian River, slug injection of 500 milliliters of 20-percent dye solution at 0045 hours on June 3, 1980, at site 1									
1	8,261	0.00	43	--	--	--	--	--	--
3	8,219	2.86	43	4.72	5.54	5.96	0.48	4.57	16.5
8	8,150	5.59	64	7.95	9.04	9.52	.72	5.80	6.9
9	8,096	10.65	60	12.98	14.33	14.94	.93	7.35	5.2
10	8,050	16.04	82	18.87	20.83	21.80	.79	10.38	2.8
11	7,990	23.71	134	26.25	28.72	29.79	.96	12.92	1.0
Canadian River, slug injection of 1,500 milliliters of 20-percent dye solution at 2350 hours on June 2, 1980, at site 11									
11	7,990	.00	134	--	--	--	--	--	--
12	7,941	9.93	133	7.13	7.75	8.31	1.19	4.95	14.5
14	7,929	12.20	133	8.72	9.33	10.07	1.29	6.03	12.0
19	7,901	17.47	133	12.62	13.67	14.59	1.16	8.21	7.4
20	7,970	23.01	131	17.32	18.42	19.84	1.06	11.01	5.0
Canadian River, continuous injection of 1,170 milliliters of 0.42-percent dye solution for 72 minutes beginning at 1008 hours on August 12, 1980, at site 3									
3	8,219	.00	2.3	--	--	--	--	--	--
5	8,211	.35	5.1	2.53	3.82	3.77	.09	3.54	8.6
6	8,188	1.23	4.3	5.22	6.75	6.92	.28	5.70	6.5
7	8,160	2.19	5.7	10.00	12.67	--	.16	9.50	3.8
8	8,150	2.73	5.4	12.17	14.50	--	.27	10.08	3.2
Canadian River, continuous injection of 2,075 milliliters of 1.42-percent dye solution for 72 minutes beginning at 0915 hours on August 13, 1980, at site 13									
13	7,950	.00	4.4	--	--	--	--	--	--
14	7,929	.21	3.9	.33	1.22	1.09	.19	1.77	24.6
15	7,928	.49	4.0	1.42	2.33	2.24	.24	2.43	22.6
16	7,926	.90	3.8	2.02	3.25	3.18	.44	3.48	20.5
17	7,922	1.68	4.0	4.17	5.42	5.79	.30	6.75	15.0
18	7,908	4.27	3.6	12.28	14.68	ND	.26	12.80	6.0
19	7,901	5.48	ND	16.42	18.33	ND	.30	14.41	4.5
Canadian River, slug injection of 1,500 milliliters of 20-percent dye solution at 2200 hours on June 15, 1981, at site 12									
12	7,941	.00	41	--	--	--	--	--	--
14	7,929	2.27	49	1.96	2.27	2.35	.97	1.22	168.0
19	7,901	7.54	43	8.12	9.03	9.40	.75	4.36	45.0
20	7,870	13.08	32	15.02	16.37	16.84	.75	5.98	19.6
Canadian River, slug injection of 400 milliliters of 20-percent dye solution at 0322 hours on June 16, 1981, at site 2									
2	8,227	.00	ND	--	--	--	--	--	--
3	8,219	.21	32	.28	.42	.46	.46	.60	128.0
8	8,150	2.94	33	3.72	4.50	4.61	.66	2.53	25.5
9	8,096	7.98	8.6	10.88	13.83	14.31	.53	10.04	3.2
Canadian River, slug injection of 1,000 milliliters of 20-percent dye solution at 2100 hours on June 16, 1981, at site 9									
9	8,096	.00	8.6	--	--	--	--	--	--
10	8,050	5.41	10.4	15.13	17.42	18.05	.30	10.70	58.0
Canadian River, continuous injection of 1,880 milliliters of 4.44-percent dye solution for 60 minutes beginning at 0838 hours on July 7, 1981, at site 13									
13	7,950	.00	17	--	--	--	--	--	--
14	7,929	.21	19	.22	1.28	.96	.22	1.78	9.8
16	7,926	.90	17	1.17	2.20	2.00	.66	2.50	8.8
17	7,922	1.68	10	3.17	4.23	4.47	.32	3.91	5.9
18	7,908	4.27	15	7.23	8.74	9.40	.52	7.77	2.6

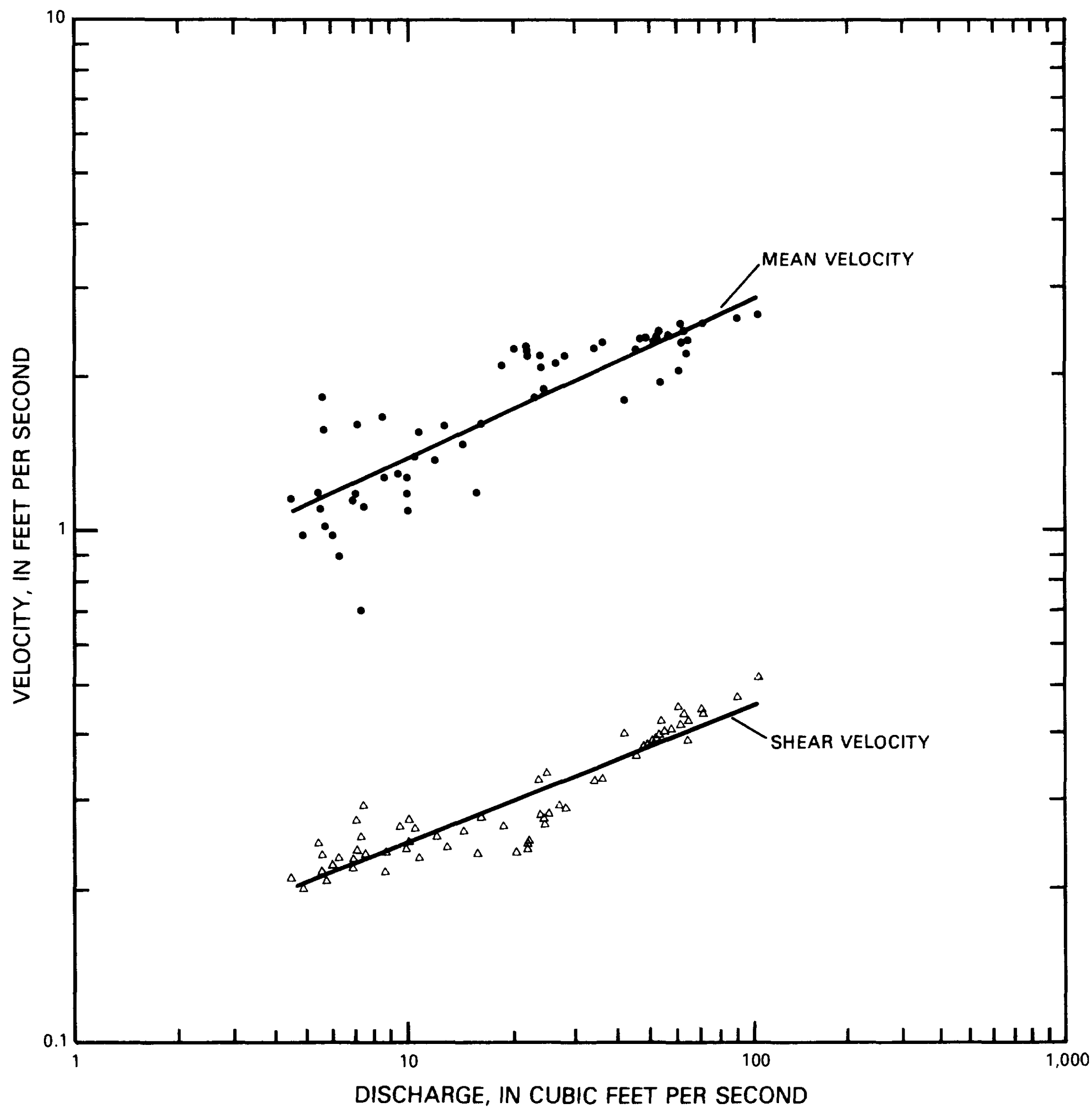

Figure 4.--Relations of mean velocity and shear velocity to discharge at station 06619400, Canadian River near Lindland (site 8; table 1 and fig. 3).

Using stations 06619400 and 06619450 as indexes, the Canadian River study reach was divided into an upper (sites 1 to 11) and a lower (sites 11 to 20) reach for simulation. The results of the simulated traveltimes are shown in figures 6 and 7. The simulations were developed using data collected in June 1980. Data collected in August 1980 and June and July 1981 were used for verification of the simulated results. Figure 6 is based on injections at site 1, and figure 7 is based on injections at site 11. The traveltimes shown in figures 6 and 7 are for peak concentrations. Leading edges of solutes normally will travel about 20-percent faster than the peaks.

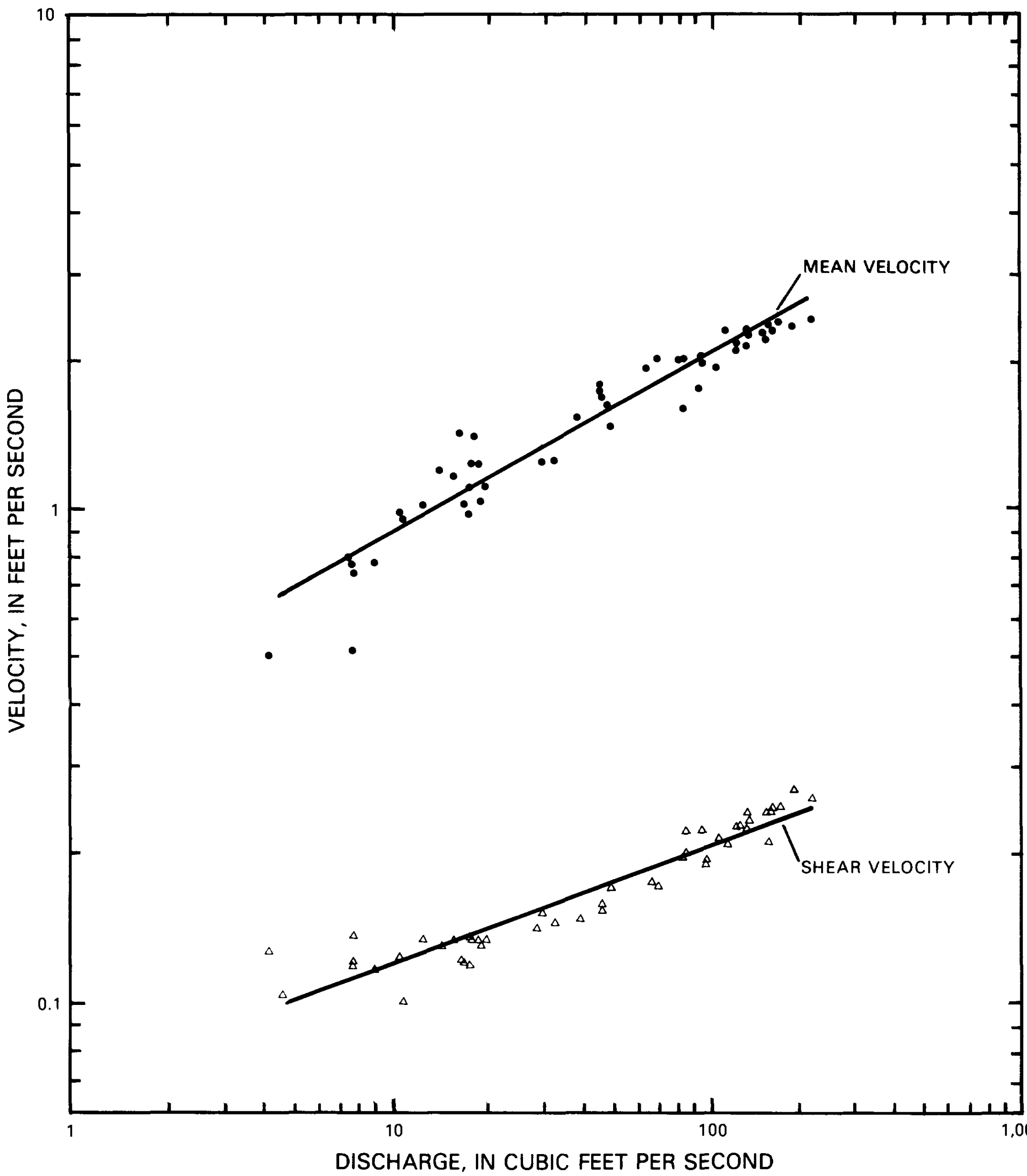

Figure 5.--Relations of mean velocity and shear velocity to discharge at station 06619450, Canadian River near Brownlee (site 13; table 1 and fig. 3).

The simulation technique assumes a relation between the discharge at the index station and the discharge in the sampling reach. The traveltime curves shown in figures 6 and 7 need to be used with care during periods of high irrigation demand, when the relation of discharge at the gage to discharge in the reach may be affected.

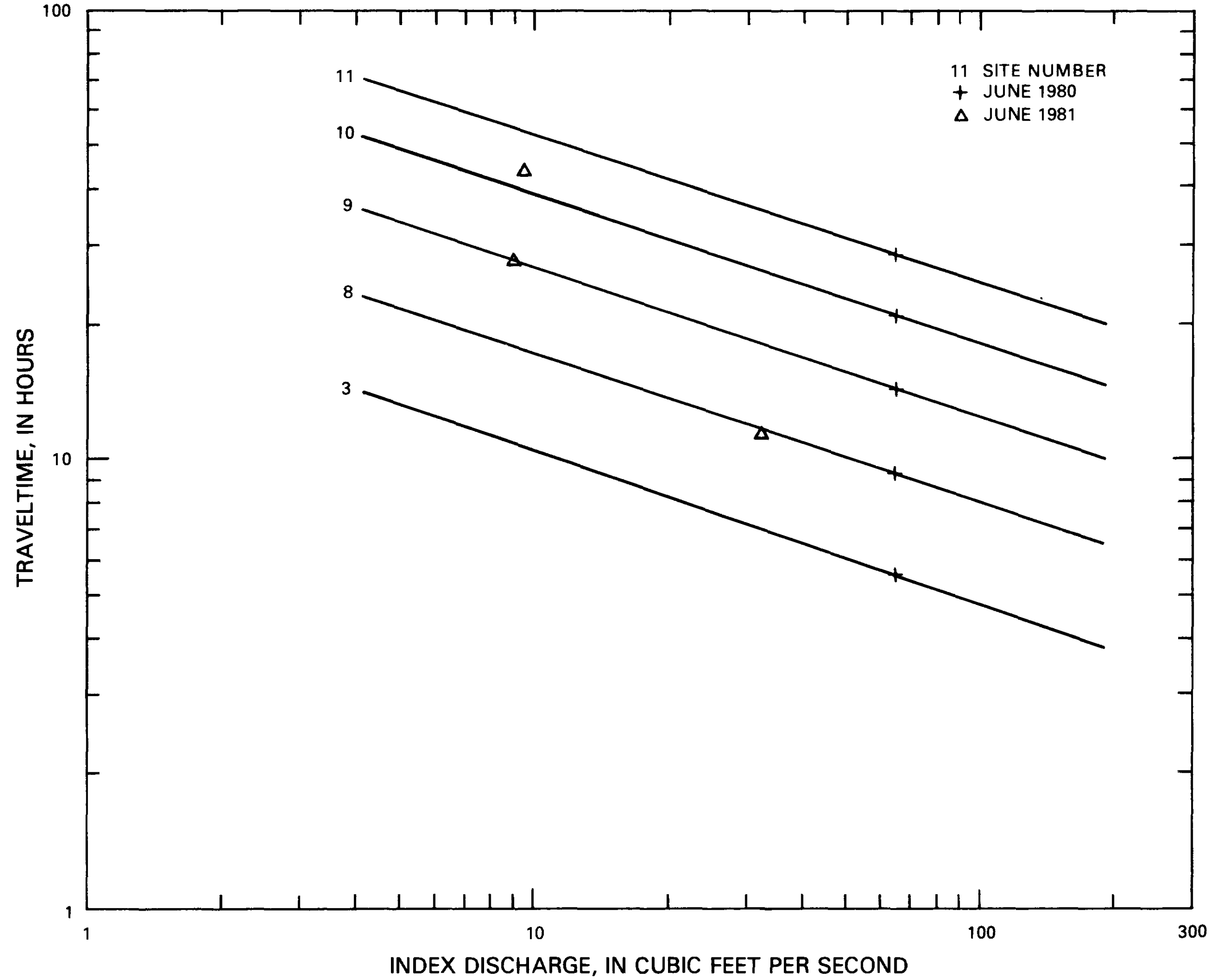

Figure 6.--Simulated cumulative-traveltime curves for the Canadian River, using index station 06619400 (site 8; table 1 and fig. 3).

Reaeration Results

Reaeration measurements were made during 1979 and 1980 on the Canadian River. Sampling sites are listed in table 1. Basic dye-curve characteristics for the continuous injections done for the reaeration determination are listed in table 2. Additional characteristics of the dye curves and data from the ethylene and propane gas concentration-time curves are listed in table 3. The data for the sites listed in table 3 correspond to the continuous injection data for the same sites and dates listed in table 2. Each group of sites listed in table 3 are measurements from a single injection. Insufficient gas samples were collected during August 12, 1980, at site 7 to completely describe the concentration-time curve; therefore, areas and traveltimes of centroids for ethylene and propane are not listed for this site.

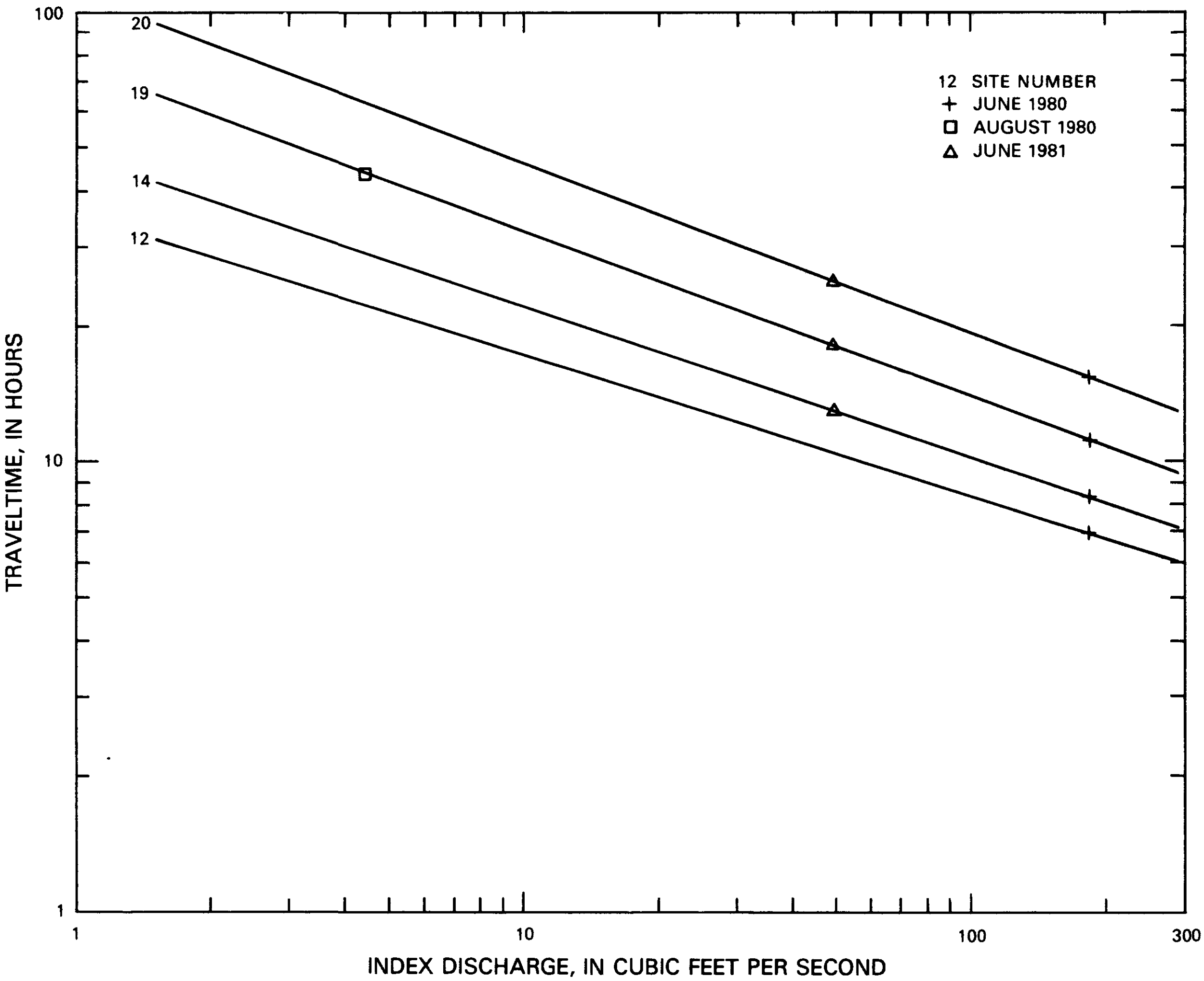

Figure 7.--Simulated cumulative-traveltime curves for the Canadian River, using index station 06619450 (site 13; table 1 and fig. 3)

Using the information in table 3 and equations 1 and 5, reaeration coefficients were calculated according to the procedure discussed previously. Results of the calculations are listed in table 4. Reaeration coefficients were adjusted to 20 °C using equation 7. Reaeration coefficients were determined for different discharges in the lower reaches. The reaeration coefficients for sites 16 to 17 increased with a decrease in discharge. This probably is due to the lack of riffles that existed during the higher flow, which is a typical condition of the Canadian River.

Table 3.--*Dye and tracer-gas concentration-time-curve characteristics for the Canadian River*

Site	Area of curve (micrograms-hour per liter)			Traveltime of centroid (hours)			Peak concentration (micrograms per liter)			Traveltime of peak (hours)			Date of measurement (mo/d/yr)
	Ethylene	Propane	Dye	Ethylene	Propane	Dye	Ethylene	Propane	Dye	Ethylene	Propane	Dye	
5	154.07	89.45	13.30	3.67	3.66	3.77	110	65.0	8.6	3.70	3.70	3.82	08/12/80
6	29.97	22.65	13.30	6.64	6.67	6.92	17.5	13.4	6.5	6.58	6.58	6.75	08/12/80
14	529.91	221.74	25.89	1.00	.99	1.09	450	188	24.6	1.02	.98	1.22	08/13/80
15	321.20	140.41	25.39	2.16	2.15	2.24	250	105	22.6	2.25	2.18	2.33	08/13/80
16	156.49	74.00	24.50	3.05	3.04	3.18	122	56.0	20.5	3.15	2.97	3.25	08/13/80
17	12.99	10.56	24.50	5.29	5.31	5.79	10.1	7.8	15.0	5.17	5.17	5.42	08/13/80
14	145.80	56.49	8.76	.89	.89	.96	150	60.0	9.8	1.12	1.03	1.28	07/07/81
16	85.07	40.38	8.13	1.88	1.89	2.00	95.0	43.0	8.8	1.88	1.88	2.20	07/07/81
17	43.70	22.82	7.46	4.37	4.40	4.47	33.0	17.0	5.9	4.17	4.23	4.23	07/07/81
18	3.49	2.13	5.40	9.09	8.82	9.40	1.7	1.3	2.6	8.37	8.45	8.74	07/07/81

Table 4.--*Reaeration coefficients for selected subreaches of the Canadian River*

[ft^3/s, cubic feet per second; °C, degrees Celsius]

Subreach as defined by site numbers	Mean discharge (ft^3/s)	Water temperature (°C)	Reaeration coefficient based on measured water temperatures (per day)				Reaeration coefficient adjusted to 20 °C (per day)				Date of measurement (mo/d/yr)
			Peak method		Area method		Peak method		Area method		
			Ethylene	Propane	Ethylene	Propane	Ethylene	Propane	Ethylene	Propane	
5-6	4.7	19.0	16.2	16.7	16.8	17.0	16.6	17.1	17.1	17.4	08/12/80
14-15	3.9	14.6	14.3	17.1	11.9	13.1	16.3	19.5	13.6	15.0	08/13/80
15-16	3.9	17.4	17.8	18.6	22.3	24.0	19.0	19.8	23.8	25.6	08/13/80
16-17	3.9	21.0	27.7	25.5	30.7	28.6	27.1	24.9	29.9	27.9	08/13/80
14-17	3.9	17.8	22.1	21.8	22.8	23.5	23.3	23.0	24.1	24.8	08/13/80
14-16	18	17.6	14.9	13.6	17.1	13.7	15.8	14.3	18.1	14.5	07/07/81
16-17	13	20.6	17.8	19.4	13.6	15.0	17.5	19.1	13.4	14.8	07/07/81
17-18	12	24.3	12.8	12.6	12.5	15.0	11.6	11.4	11.3	13.5	07/07/81
14-18	15	21.0	14.4	14.6	13.4	14.8	14.1	14.2	13.1	14.5	07/07/81

Michigan River

The Michigan River originates from two forks that head in the Never Summer Range near the eastern edge of Jackson County (fig. 1). The forks merge near Gould, and the Michigan River flows in a northwesterly direction to its confluence with the North Platte River about 2 miles northwest of Cowdrey. Like the Canadian River, the headwaters of the basin are densely forested, but as the river leaves the mountains near Gould, it enters a broad valley of brush and grassland. The upstream part of the river basin is in State and National forests, whereas the downstream part of the basin is privately owned, and ranching is the primary land use.

Location and Extent of Study Reach

The Michigan River flows through the town of Walden, and the discharge outlet for the Walden Sewage Treatment Plant is located immediately downstream from the town. The study reach for the Michigan River extends from the sewage treatment plant outlet downstream for 1.7 miles (fig. 8). Reaeration measurements were made once in August 1980 when the flow conditions would be characterized as low. Descriptions of the injection and sampling sites for the reaeration measurements on the Michigan River are listed in table 5.

Table 5.--*Injection and sampling sites for reaeration measurements on the Michigan River*

[Flow conditions: H, high flow; M, medium flow; L, low flow; Site type: I, injection; S, sampling]

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
1	L	I	19.31	Michigan River downstream from water treatment plant near Walden.
2	L	S	19.14	Michigan River downstream from Queen ditch near Walden.
3	L	S	18.91	Michigan River downstream from North Park ditch No. 4, near Walden.
4	L	S	17.61	Michigan River upstream from mouth of Illinois River.

Reaeration Results

Dye-curve data collected during the reaeration measurement on the Michigan River are listed in table 6. The total stream reach measured was 1.7 miles, and the mean velocity of the dye cloud ranged from 0.17 to 0.25 mile per hour. Characteristics of the ethylene, propane, and dye-concentration versus time curves are listed in table 7. Areas of the

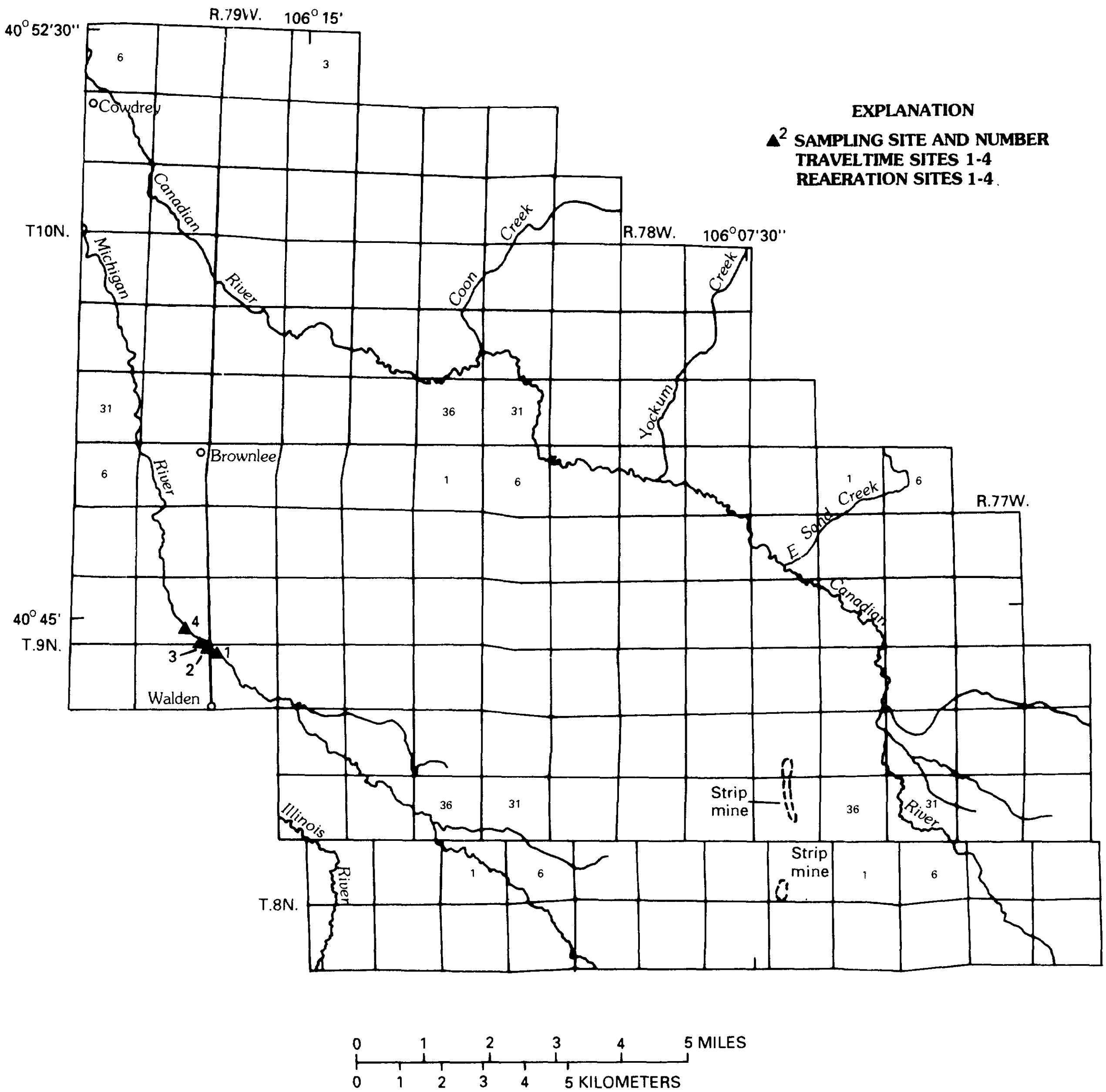

Figure 8.--Injection and sampling sites for traveltime and reaeration measurements on the Michigan River.

concentration versus time curves and traveltime of the centroids are not given for ethylene and propane because an insufficient number of samples were collected to adequately define the entire curve. Subsequently, reaeration calculations were made using only the peak method.

Table 6.--*Data collected during reaeration measurement on the Michigan River*

[--, not applicable]

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye cloud		Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
				Leading edge (hours)	Peak (hours)			
Michigan River, continuous injection of 2,480 milliliters of 0.31-percent dye solution for 55 minutes beginning at 0856 hours on August 18, 1980, at site 1								
1	8,043	0.00	--	--	--	--	--	--
2	8,041	.17	8.9	0.32	1.15	0.17	1.75	10.1
3	8,038	.40	8.7	1.03	2.03	.22	2.92	8.4
4	8,021	1.70	5.3	5.10	6.90	.25	6.13	3.8

Table 7.--*Dye and tracer-gas concentration-time-curve characteristics for the Michigan River*

Site	Area of curve (micrograms per hour per liter)	Traveltime of centroid (hours)	Peak concentration (micrograms per liter)			Traveltime of peak (hours)			Date of measurement (mo/d/yr)
	Dye	Dye	Ethylene	Propane	Dye	Ethyllene	Propane	Dye	
2	9.41	1.00	220	140	10.1	1.15	1.15	1.15	08/14/80
3	8.75	2.06	141	91.0	8.4	1.78	1.78	2.03	08/14/80
4	7.99	7.23	7.2	8.1	3.8	6.83	6.83	6.90	08/14/80

Reaeration coefficients for the Michigan River were calculated from the information contained in tables 6 and 7, using the peak method (eq. 1).. Results of the calculations are listed in table 8. The average reaeration coefficient for the entire reach (adjusted to a water temperature of 20 °C). was 16.0 per day. Fluctuations of discharge in the reaches in table 8 occurred because of irrigation withdrawals and return flows.

Table 8.--*Reaeration coefficients for selected subreaches of the Michigan River*

[ft^3/s, cubic feet per second; °C, degrees Celsius]

Subreach as defined by site numbers	Mean discharge (ft^3/s)	Water temperature (°C)	Reaeration coefficient based on water temperatures (per day) Peak method		Reaeration coefficient adjusted to 20 °C (per day) Peak method		Date of measurement (mo/d/yr)
			Ethylene	Propane	Ethylene	Propane	
2-3	8.8	14.6	11.2	12.9	12.7	14.7	08/14/80
3-4	7.0	17.8	15.6	15.1	16.5	15.9	08/14/80
2-4	7.6	16.8	15.0	14.8	16.1	15.9	08/14/80

YAMPA RIVER BASIN

Yampa River

The Yampa River is a major tributary to the Green River; its headwaters are on the west edge of the Gore Range at an elevation of about 12,000 feet. The river flows eastward to the town of Yampa, then northward to Steamboat Springs, and then westward through Craig to the Green River (fig. 2).

The headwaters of the Yampa River originate in rugged mountains and steep stream valleys; the river flows through large, broad valleys in the middle part of the basin to dissected plateaus and steep-walled canyons in the lower part of the basin. Vegetation types range from conifer forests and irrigated grasslands in the upstream reaches to sagebrush rangelands and desert in the downstream reaches of the river. Most of the water yield to the Yampa River results from melting snow pack. Approximately 80 percent of the Yampa River runoff occurs during April, May, and June. Land uses in the basin consist of grazing of livestock, irrigated farming, coal mining, and oil and gas production. A primary use of the river is for recreation, such as fishing and white-water rafting.

Location and Extent of Study Reaches

Traveltime data were collected on the Yampa River from Craig downstream for 137 miles to the confluence with the Green River. Reaeration data were collected on three reaches from Craig downstream to the Juniper Hot Springs area, and on one reach near Steamboat Springs. Sampling sites are shown in figure 9 and are listed in table 9.

Traveltime Results

Traveltime computations were made for two reaches: (1) An upstream reach extending from Craig (site 7) to a county bridge crossing 0.2 mile upstream from the Little Snake River confluence (site 27); and (2) a downstream reach extending from site 27 to the confluence with the Green River (site 32).

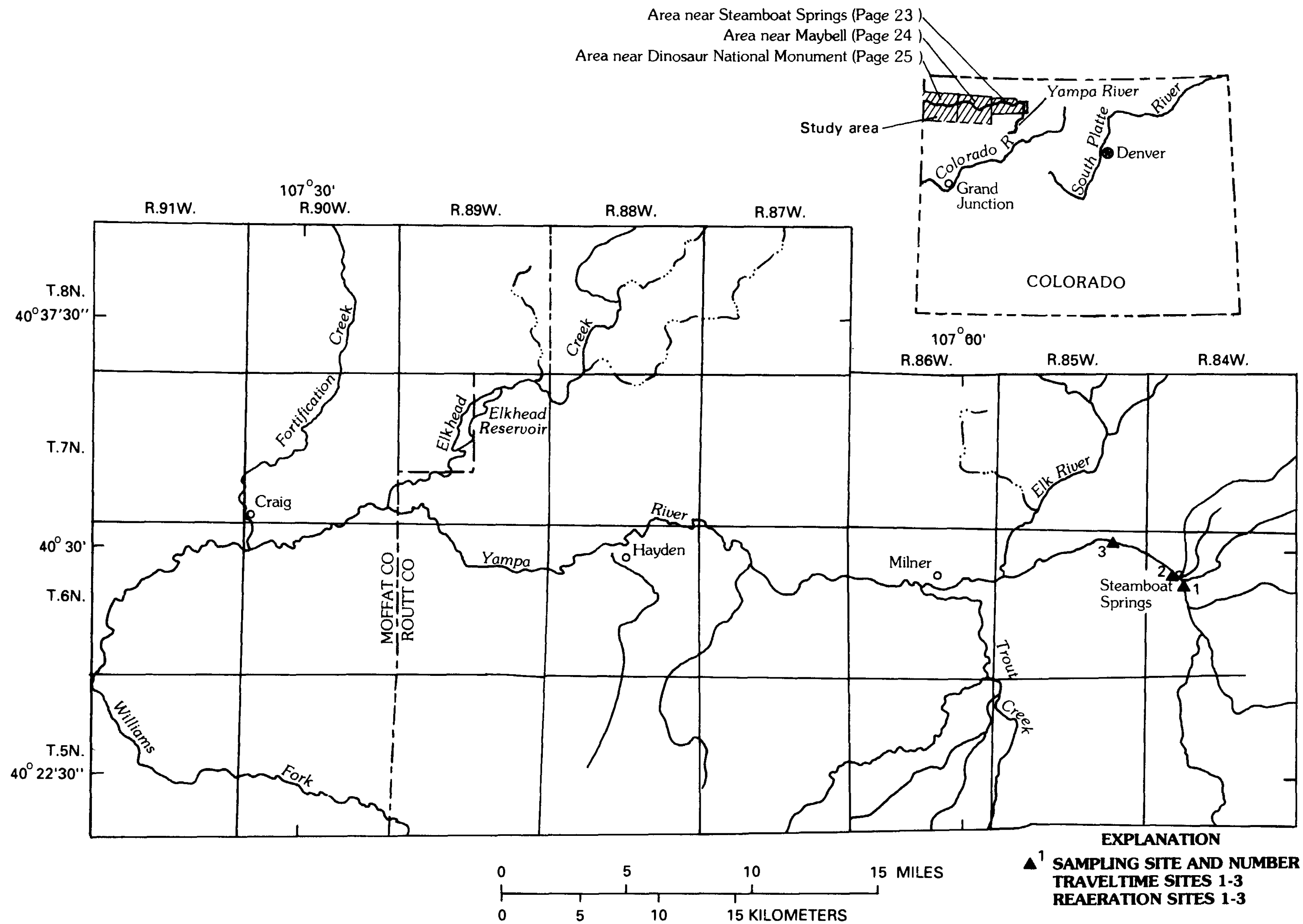

Figure 9.--Injection and sampling sites for traveltime and reaeration measurements on the Yampa River.

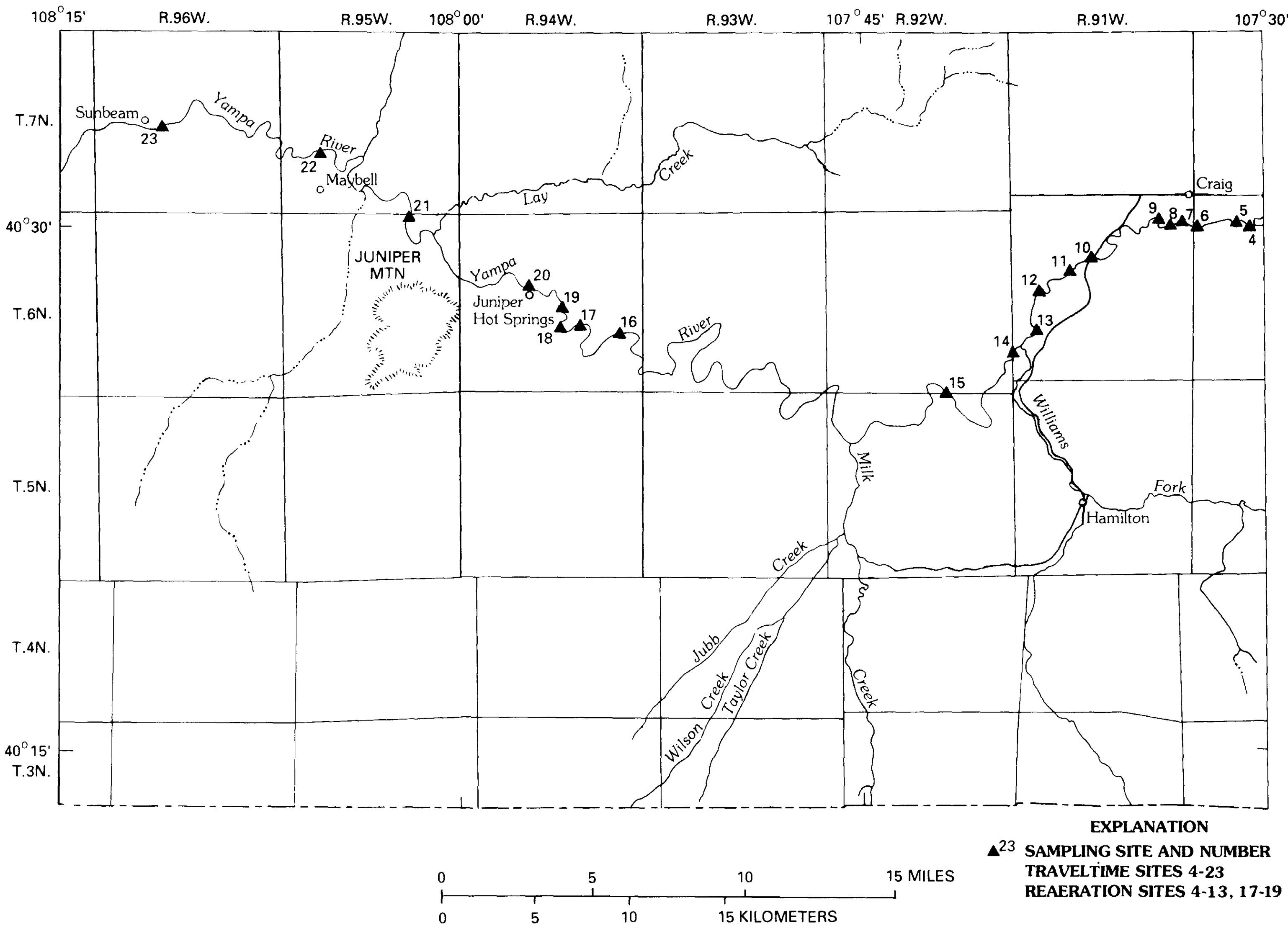

Figure 9.--Injection and sampling sites for traveltime and reaeration measurements on the Yampa River--Continued.

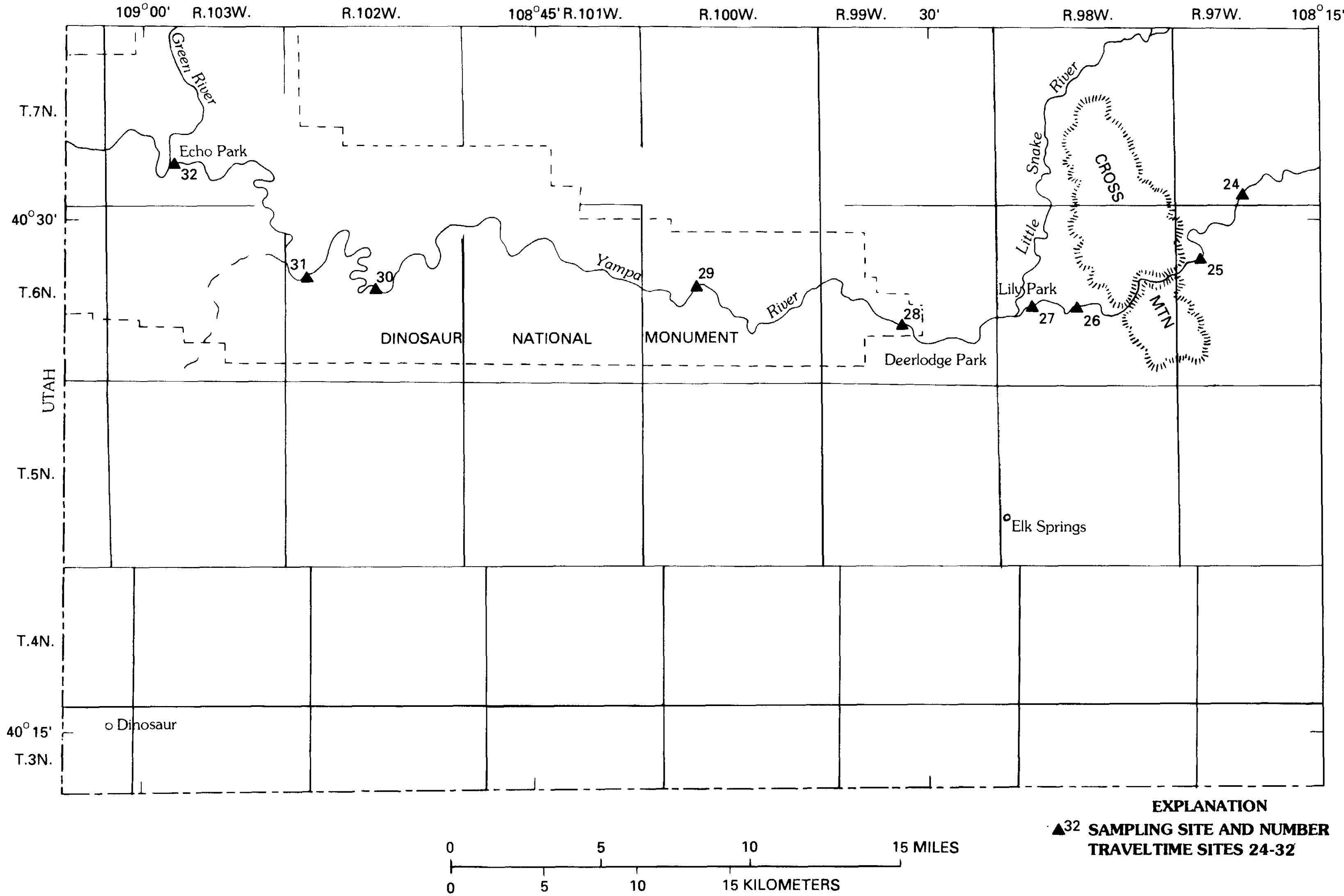

Figure 9.--Injection and sampling sites for traveltime and reaeration measurements on the Yampa River--Continued.

Table 9.--*Injection and sampling sites for traveltime and reaeration measurements on the Yampa River*

[Flow conditions: H, high flow; M, medium flow; L, low flow; Site type: I, injection; S, sampling]

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
1	L	I	196.10	Yampa River at railroad crossing upstream from Steamboat Springs.
2	L	S	194.85	Yampa River 0.75 mile downstream from gaging station at Steamboat Springs.
3	L	S	191.80	Yampa River downstream from KOA campground near Steamboat Springs.
4	L	I	145.58	Yampa River at golf course at Craig.
5	L	S	145.00	Yampa River at golf course at Craig.
6	L	S	142.71	Yampa River at water filtration plant at Craig.
7	M,L	I	142.40	Yampa River at old State Highway 13 bridge at Craig.
8	L	S	142.22	Yampa River downstream from old State Highway 13 bridge.
9	L	S	141.75	Yampa River at railroad bridge downstream from old State Highway 13 bridge.
10	M,L	I,S	137.40	Yampa River at new State Highway 13 bridge, downstream from Craig.
11	L	S	135.74	Yampa River 1.66 miles downstream from State Highway 13 bridge.
12	L	S	134.33	Yampa River 3.07 miles downstream from State Highway 13 bridge.
13	L	S	133.03	Yampa River 0.58 mile upstream from Williams Fork.
14	M,L	I	132.20	Yampa River 0.25 mile downstream from Williams Fork.
15	M,L	S	125.30	Yampa River 1.90 miles downstream from Ralston Draw.
16	M,L	I	99.80	Yampa River at Government Bridge.
17	L	I	97.16	Yampa River 2.64 miles downstream from Government Bridge.
18	L	S	96.02	Yampa River 3.78 miles downstream from Government Bridge.
19	L	S	94.43	Yampa River 5.37 miles downstream from Government Bridge.
20	L	I,S	93.90	Yampa River at Juniper Hot Springs, downstream from bridge.
21	M,L	I,S	86.40	Yampa River at U.S. Highway 40 bridge near Maybell.
22	M,L	S	79.00	Yampa River at county bridge 1.3 miles north of Maybell.
23	M	S	70.70	Yampa River at bridge upstream from Sunbeam.

Table 9.--*Injection and sampling sites for traveltime and reaeration measurements on the Yampa River*--Continued

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
24	L	I	62.00	Yampa River 3.70 miles upstream from mouth of Cross Mountain Canyon.
25	L	S	58.30	Yampa River at mouth of Cross Mountain Canyon.
26	L	S	52.60	Yampa River 1.7 miles upstream from Little Snake River.
27	M,L	I,S	51.10	Yampa River at bridge near Lily Park on Tuttle Ranch.
28	M	S	46.25	Yampa River at Deerlodge Park.
29	M	S	36.10	Yampa River at Tepee Rapids Campground.
30	M	S	19.30	Yampa River at Harding Hole.
31	M	S	11.60	Yampa River at Mantle Ranch.
32	M	S	0.00	Yampa River at mouth at Echo Park.

Bauer and others (1979) present traveltime data for the Yampa River upstream from Craig. A summary of the data collected for the two reaches is listed in table 10. Mean velocities during the measurements ranged from 0.17 to 2.75 miles per hour, and discharges ranged from 48 to 5,140 cubic feet per second.

The streamflow-gaging station 09251000, Yampa River near Maybell, was used as an index station, along with the modeling techniques de-scribed earlier, to simulate traveltimes for the two reaches of the Yampa River. The index station is site 21 in figure 9 and in table 9. The rela-tions of mean and shear velocity versus discharge for station 09251000 are illustrated in figure 10 and are based on data collected from approximately 1971 to 1981. Because of the channel-geometry characteristics in the vicinity of the station, a curvilinear relation was required for the mean velocity and shear velocity. This transition zone illustrated in figure 10 corresponds to a change from a pool-and-riffle regime to a channel-control regime.

The results of the traveltime simulations are shown in figures 11 and 12. Site numbers in the figures refer to those listed in table 9. The simulated peak traveltime relations were developed based on the April and July 1979 high-flow and September 1978 low-flow field measurements. Measured data are listed in table 10 and are plotted in figures 11 and 12. The model was calibrated using the high- and low-flow data for the upper reach (sites 7 to 27). Only the high-flow data were used for calibration for the lower reach (sites 27 to 32) because low-flow data were not collected. Figure 11 is based on injections at site 7, and figure 12 is based on injections at site 27.

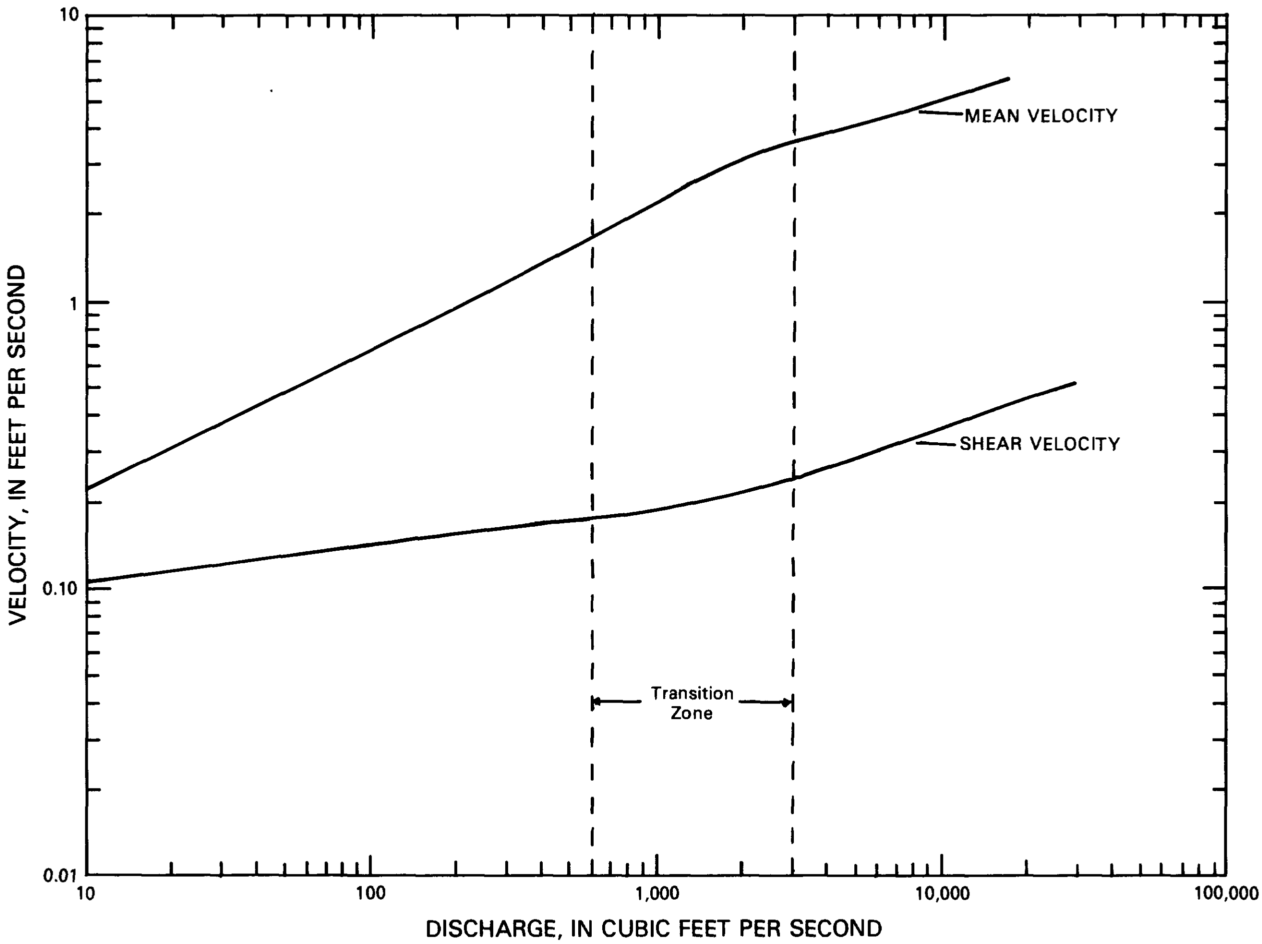

Figure 10.--Relations of mean velocity and shear velocity to discharge at station 09251000, Yampa River near Maybell (site 21; table 9 and fig. 9).

Reaeration Results

Reaeration measurements were made on the Yampa River during October 1979 and September 1981. The 1979 data were collected on three reaches from Craig to the Juniper Hot Springs area. Reaeration measurements in 1981 were made on one reach near Steamboat Springs and on another reach at Craig. The 1981 data were collected to provide verification of data previously collected during this project and of data presented by Bauer and others (1979).

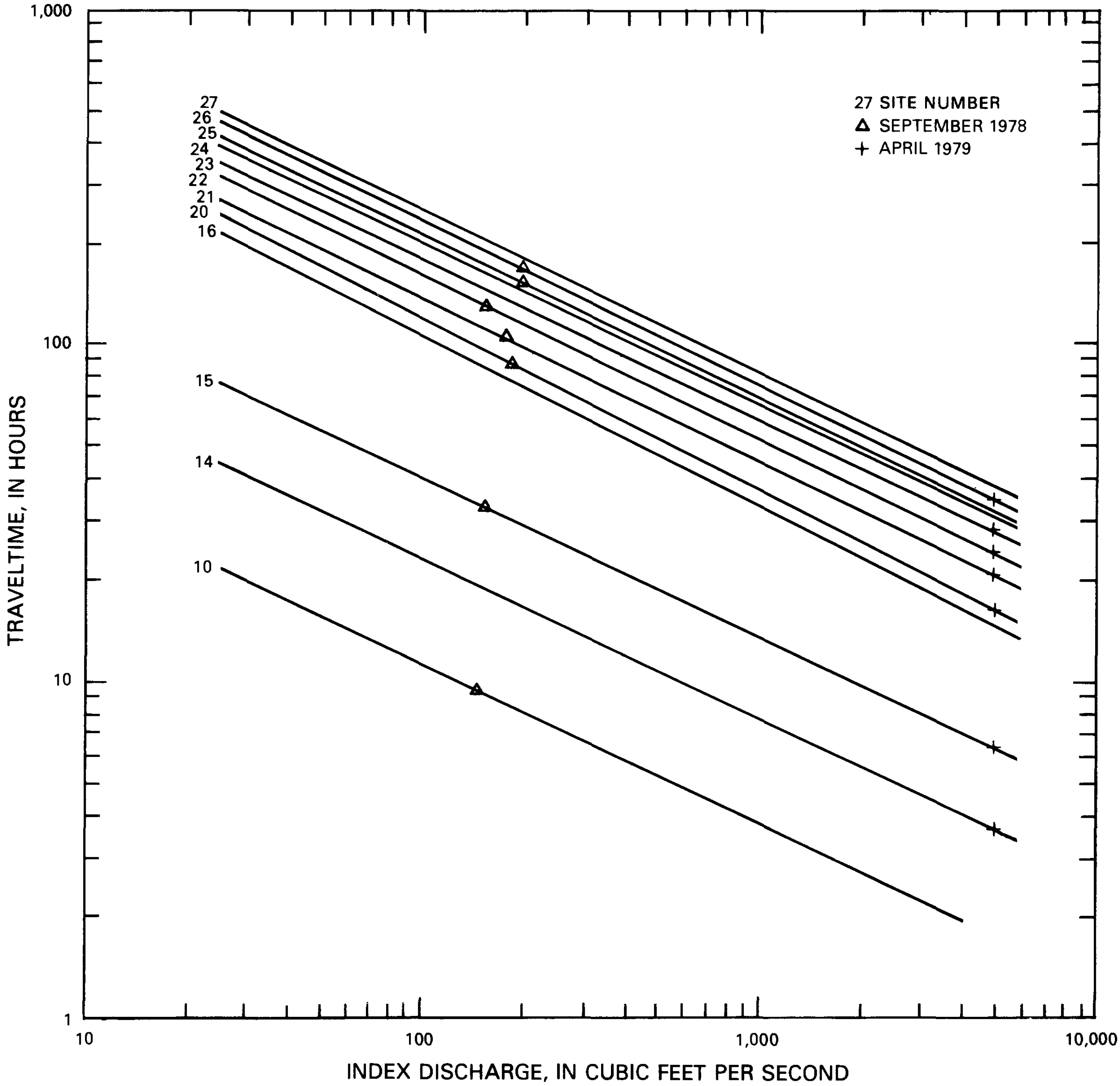

Figure 11.--Simulated cumulative-traveltime curves for the Yampa River from Craig to the Little Snake River, using index station 09251000, Yampa River near Maybell (site 21; table 9 and fig. 9).

Dye-curve characteristics for the continuous injections are listed in table 10. Additional dye-curve characteristics and values from the ethylene and propane concentration versus time curves are listed in table 11. An insufficient number of gas samples were collected on the Yampa River to define the entire concentration-time curves; therefore, only the peak method was used to determine reaeration coefficients. Ethylene samples at the peak for site 5 on October 16, 1979, were destroyed in transit; therefore, a peak concentration could not be determined for this site. Using the information in table 11 and equation 1, reaeration coefficients were calculated according to the procedure described earlier. Results of the calculations are listed in table 12.

Table 10.--*Data collected during traveltime measurements on the Yampa River*

[--, not applicable; ND, no data]

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye cloud: Leading edge (hours)	Cumulative traveltime of dye cloud: Peak (hours)	Cumulative traveltime of dye cloud: Centroid (hours)	Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
		Yampa River, slug injection of 4,000 milliliters of 20-percent dye solution at 0848 hours on September 13, 1978, at site 7							
7	6,165	0.00	153	--	--	--	--	--	--
10	6,140	5.15	153	4.70	9.77	10.72	0.48	12.00	8.5
15	6,079	17.09	180	26.60	34.50	38.34	.43	33.60	2.4
		Yampa River, slug injection of 1,000 milliliters of 20-percent dye solution at 0935 hours on September 13, 1978, at site 14							
14	6,114	.00	185	--	--	--	--	--	--
15	6,079	6.85	180	10.70	13.90	ND	.44	14.40	1.8
		Yampa River, slug injection of 2,000 milliliters of 20-percent dye solution at 0700 hours on September 13, 1978, at site 16							
16	5,980	.00	175	--	--	--	--	--	--
20	5,960	5.90	175	9.00	10.60	12.44	.48	13.50	3.8
21	5,907	13.33	152	22.00	28.50	33.27	.35	37.30	1.7
		Yampa River, slug injection of 1,000 milliliters of 20-percent dye solution at 0700 hours on September 13, 1978, at site 20							
20	5,960	.00	175	--	--	--	--	--	--
21	5,907	7.43	152	10.20	13.70	15.92	.46	19.50	2.0
		Yampa River, slug injection of 2,000 milliliters of 20-percent dye solution at 2400 hours on September 12, 1978, at site 21							
21	5,907	.00	152	--	--	--	--	--	--
22	5,878	7.40	156	11.00	13.90	17.24	.53	13.55	3.9
		Yampa River, slug injection of 2,000 milliliters of 20-percent dye solution at 0630 hours on September 12, 1978, at site 24							
24	5,841	.00	198	--	--	--	--	--	--
25	5,820	3.70	198	5.00	6.95	8.32	.44	12.00	6.4
26	5,620	9.45	193	9.00	16.60	18.17	.80	17.50	3.6
		Yampa River, slug injection of 9,000 milliliters of 20-percent dye solution at 0617 hours on April 30, 1979, at site 7							
7	6,165	.00	--	--	--	--	--	--	--
10	6,138	5.15	ND	1.17	1.50	2.05	2.75	3.00	8.1
14	6,114	10.24	5,140	3.10	3.60	4.31	2.36	3.80	2.8
15	6,079	17.09	5,140	5.60	6.40	6.83	2.57	4.00	2.0
16	5,980	42.64	5,140	14.00	16.00	16.30	2.72	6.00	1.2
21	5,907	55.97	5,140	18.67	21.70	22.28	2.63	9.00	1.0
		Yampa River, slug injection of 6,000 milliliters of 20-percent dye solution at 0700 hours on April 28, 1979, at site 21							
21	5,907	.00	4,490	--	--	--	--	--	--
22	5,878	7.40	4,490	2.50	3.00	3.87	2.18	4.75	5.4
23	5,860	15.75	4,490	5.83	6.67	7.07	2.29	5.15	2.1
27	5,619	35.30	4,490	13.50	15.70	16.17	2.25	7.00	.96

Table 10.--*Data collected during traveltime measurements on the Yampa River*

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye cloud: Leading edge (hours)	Cumulative traveltime of dye cloud: Peak (hours)	Cumulative traveltime of dye cloud: Centroid (hours)	Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
Yampa River, slug injection of 12,000 milliliters of 20-percent dye solution at 0245 hours on July 10, 1979, at site 27									
27	5,619	0.00	--	--	--	--	--	--	--
28	5,593	4.85	2,800	3.12	3.60	3.71	1.28	2.78	16.2
29	5,480	15.00	2,800	7.25	8.12	8.53	2.13	5.40	6.0
30	5,184	31.80	2,800	13.00	14.35	14.74	2.71	6.25	4.6
31	5,128	39.50	2,800	16.10	18.00	18.31	2.16	7.55	4.0
32	5,062	51.10	2,800	22.15	23.90	24.45	1.89	7.85	3.2
Yampa River, continuous injection of 1,036 milliliters of unknown percent dye solution for 90 minutes beginning at 1204 hours on October 16, 1979, at site 4									
4	6,178	.00	--	--	--	--	--	--	--
5	6,176	.58	112	.67	1.93	1.60	0.53	2.17	12.7
6	6,165	2.87	105	2.75	5.93	6.50	.69	10.50	7.5
9	6,159	3.84	113	6.25	9.18	10.70	.34	17.08	4.1
Yampa River, continuous injection of 1,505 milliliters of unknown percent dye solution for 120 minutes beginning at 1006 hours on October 17, 1979, at site 10									
10	6,138	.00	--	--	--	--	--	--	--
11	6,130	1.66	112	2.30	5.13	5.35	.46	8.95	10.2
12	6,122	3.07	102	3.37	7.52	8.45	.67	16.63	8.0
13	6,115	4.37	106	6.92	10.58	11.42	.64	16.67	5.9
Yampa River, continuous injection of 1,687 milliliters of unknown percent dye solution for 120 minutes beginning at 1014 hours on October 18, 1979, at site 17									
17	5,972	.00	--	--	--	--	--	--	--
18	5,968	1.14	149	2.32	4.23	4.15	.40	6.35	11.5
19	5,963	2.73	138	4.40	7.18	8.15	.58	10.40	8.6
Yampa River, continuous injection of 2,745 milliliters of 4.7-percent dye solution for 90 minutes beginning at 0745 hours on September 23, 1981, at site 1									
1	6,715	.00	49	--	--	--	--	--	--
2	6,680	1.25	49	1.58	3.17	3.20	.39	5.09	14.4
3	6,620	4.30	49	4.97	7.00	7.80	.66	9.53	8.5
Yampa River, continuous injection of 2,795 milliliters of 3.5-percent dye solution for 90 minutes beginning at 0715 hours on September 24, 1981, at site 4									
4	6,178	.00	--	--	--	--	--	--	--
5	6,176	.58	48	.78	2.00	1.84	.32	2.89	15.0
6	6,165	2.87	70	5.83	8.50	9.24	.31	11.84	4.0
8	6,162	3.18	70	7.25	10.00	11.03	.17	12.75	3.0

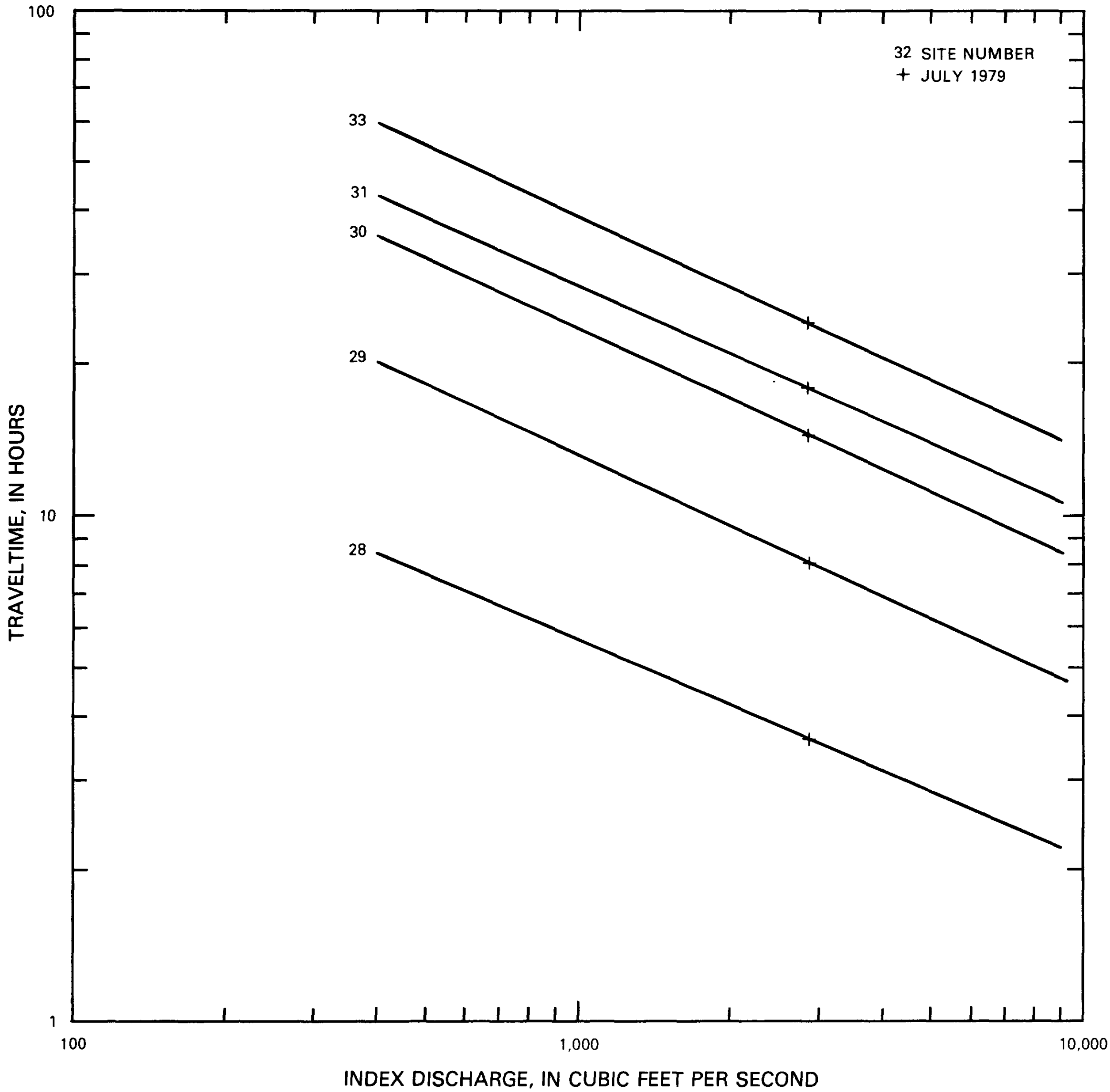

Figure 12.--Simulated cumulative-traveltime curves for the Yampa River from the Little Snake River to the Green River, using index station 09251000, Yampa River near Maybell (site 21; table 9 and fig. 9).

The data in table 12 indicate a change from 5.2 to an average of 4.6 per day for the reaeration coefficient for subreach 5-6 from 1979 to 1981. There is also a corresponding decrease in discharge from 108 to 59 cubic feet per second. The average adjusted reaeration coefficient for sites 2 to 3 during 1981 was 22.2 per day, which is less than the values reported by Bauer and others (1979) for the upper Yampa River at a larger discharge.

Table 11.--*Dye and tracer-gas concentration-time-curve characteristics for the Yampa River*

[ND, no data]

Site	Area of curve (micrograms-hour per liter)	Peak concentration (micrograms per liter)			Traveltime of peak (hours)			Date of measurement (mo/d/yr)
	Dye	Ethylene	Propane	Dye	Ethylene	Propane	Dye	
5	18.42	ND	27.6	12.7	ND	1.67	1.93	10/16/79
6	16.82	7.1	11.2	7.5	6.08	5.93	5.93	10/16/79
9	14.33	2.9	5.7	4.1	9.27	9.18	9.18	10/16/79
11	29.89	11.9	16.1	10.2	4.93	4.93	5.13	10/17/79
12	29.34	5.9	9.3	8.0	7.52	7.52	7.52	10/17/79
13	24.63	2.5	4.6	5.9	10.42	10.42	10.58	10/17/79
18	23.22	13.9	13.9	11.5	4.07	4.43	4.23	10/18/79
19	23.57	6.9	6.5	8.6	7.22	7.23	7.18	10/18/79
2	25.85	21.0	12.0	14.4	3.03	3.00	3.17	09/23/81
3	25.96	.68	.68	8.5	6.67	6.67	7.00	09/23/81
5	21.10	120	45.0	15.0	2.00	2.00	2.00	09/24/81
6	14.07	11.2	5.3	4.0	8.00	8.00	8.50	09/24/81
8	12.30	5.9	3.1	3.0	9.58	9.58	10.00	09/24/81

Elk River

The Elk River is one of the major tributaries of the Yampa River (fig. 2). The river originates from two forks that rise from the Sawtooth Range at an elevation of about 11,000 feet and flows southwesterly to its confluence with the Yampa River about 5 miles west of Steamboat Springs. The vegetation in the upstream part of the river basin (upstream from the study reach area) consists of dense stands of conifers, whereas downstream vegetation varies from forests in the steep stream valleys to native grassland where the river valley broadens at lower elevations.

Land use in the Elk River basin includes grazing, recreation, and timber production on federally owned land, while irrigated and dry-land farming and ranching utilize a smaller percentage of privately owned land. Due to increased development of coal resources and economic growth in the Yampa River basin, several reservoirs have been proposed for construction in the Elk River basin that will regulate the surface water for storage and recreation.

Table 12.--*Reaeration coefficients for selected subreaches of the Yampa River*

[ft^3/s, cubic feet per second; °C, degrees Celsius; ND, no data]

Subreach as defined by site numbers	Mean discharge (ft^3/s)	Water temperature (°C)	Reaeration coefficient based on water temperatures (per day) Peak method		Reaeration coefficient adjusted to 20 °C (per day) Peak method		Date of measurement (mo/d/yr)
			Ethylene	Propane	Ethylene	Propane	
5-6	108	13.8	ND	4.4	ND	5.2	10/16/79
6-9	109	12.6	3.2	1.6	3.8	2.0	10/16/79
5-9	112	13.0	ND	3.2	ND	3.8	10/16/79
11-12	107	14.1	6.7	5.9	7.7	6.8	10/17/79
12-13	104	13.0	6.2	5.8	7.4	6.9	10/17/79
11-13	109	13.4	6.4	5.9	7.5	6.9	10/17/79
18-19	144	15.1	4.4	5.9	4.9	6.7	10/18/79
2-3	49	17.0	20.9	20.4	22.5	21.9	09/23/81
5-6	59	17.0	4.5	4.3	4.9	4.6	09/24/81
6-8	70	18.0	9.0	8.6	9.5	9.0	09/24/81
5-8	59	17.5	5.4	5.1	5.7	5.4	09/24/81

Location and Extent of Study Reach

Traveltime data were collected on a 23 mile reach of the Elk River from Clark downstream to 0.27 mile upstream from the mouth (figure 13 and table 13). Two field data-collection periods were used; the first in September 1978 and the second in May 1979. The 1978 data collection was done during low-flow conditions, and the 1979 data collection was done during medium-flow conditions.

Traveltime Results

Dye-curve characteristics from the traveltime measurements are listed in table 14. For the medium-flow measurement of May 1979, the stream discharge was 413 cubic feet per second and only was noted for the first reach from site 1 to site 3. Because of large tributary inflows, the discharge downstream from site 3 was considerably larger than 413 cubic feet per second. Major tributaries downstream from site 3 include Salt, Deep, Big, and Mad Creeks.

Traveltimes at other discharges were simulated for the Elk River using streamflow-gaging station 09241000, Elk River at Clark, as an index station and using the computer-modeling technique described earlier. The index

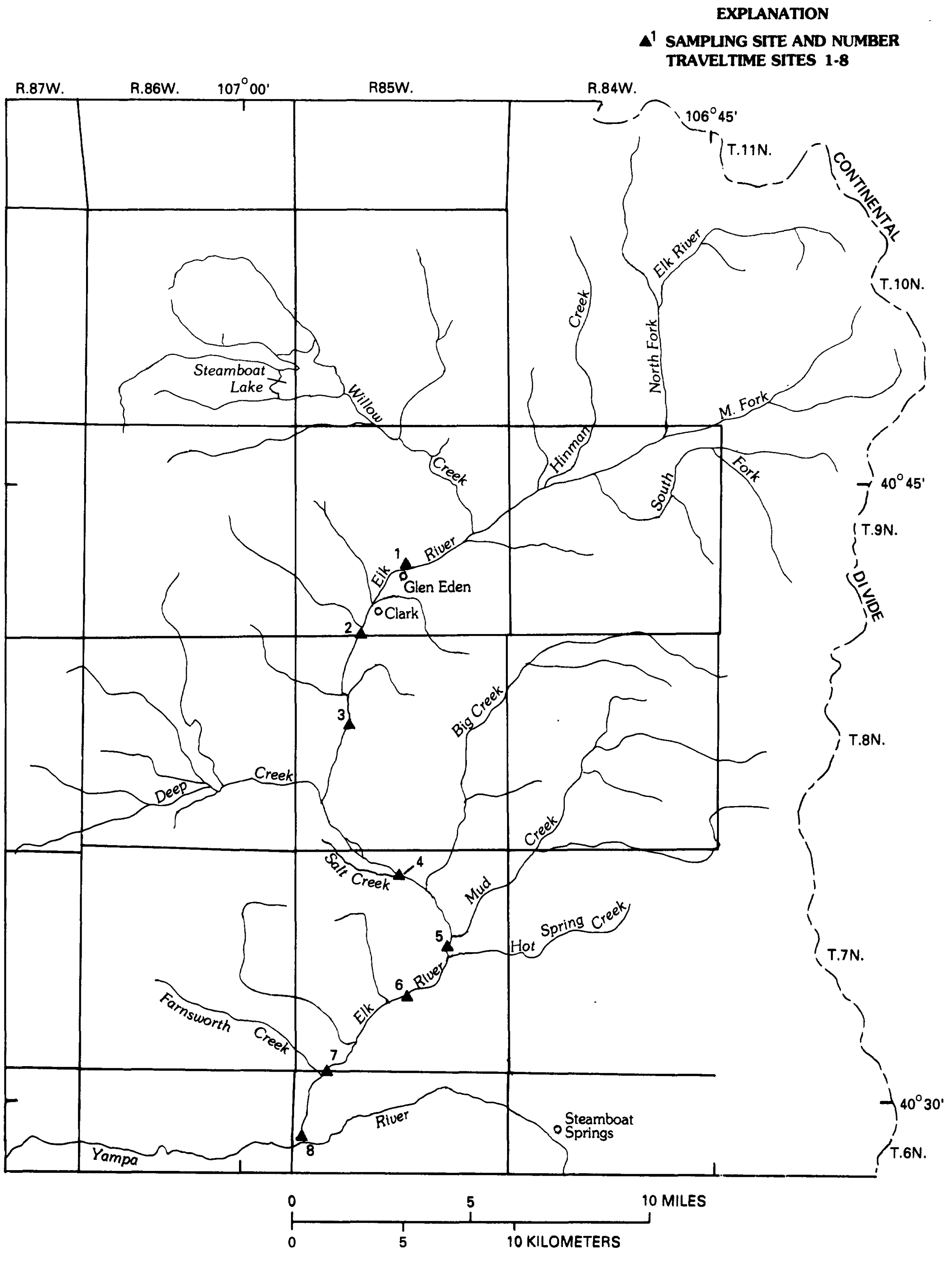

Figure 13.--Injection and sampling sites for traveltime measurements on the Elk River.

Table 13.--*Injection and sampling sites for traveltime measurements on the Elk River*

[Flow conditions: H, high flow; M, medium flow; L, low flow; Site type: I, injection; S, sampling]

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
1	L,M	I	23.43	Elk River at bridge crossing at Glen Eden.
2	L	S	21.60	Elk River at county bridge, 0.9 mile downstream from Clark.
3	L,M	S	18.22	Elk River at Moon Hill Bridge.
4	L,M	I,S	12.20	Elk River at county bridge, 0.3 mile upstream from Salt Creek confluence.
5	L	S	9.83	Elk River 0.9 mile downstream from Big Creek confluence.
6	L,M	I,S	6.84	Elk River at county bridge, 0.1 mile upstream from Elk Valley Ditch outlet.
7	L	S	3.07	Elk River at county bridge, 0.5 mile upstream from Farnsworth Creek confluence.
8	L,M	S	0.27	Elk River at U.S Highway 40 bridge.

station is designated as site 1. Relations of mean and shear velocity versus discharge for station 09241000 are shown in figure 14. These relations were developed using data from 1971 to 1981. The results of the traveltime simulations are shown in figure 15. Figure 15 is based upon injections at site 1.

The traveltime simulations presented in figure 15 were developed using the measured field data obtained during September 1978 and May 1979. For this stream reach, two separate model simulations were made using the measured data as separate calibration sets. Simulation results for low- and medium-flow conditions were obtained independently. Because of the large irrigation effects, a transition (fig. 15) was developed between the low- and medium-flow simulations. The traveltimes for the downstream subreaches were substantially slower than anticipated for the low-flow September 1978 measurements as seen in figure 15. To form the relation shown in figure 15, a curvilinear transition zone from 100 to 300 cubic feet per second was estimated to connect the two model-simulated curves. This transition zone is only approximate and will vary, depending on the irrigation practices at the time of measurement.

Williams Fork

The Williams Fork, the principal tributary of the Yampa River to the south, rises from two forks with headwaters at elevations near 10,000 feet. After the forks join near Pagoda, the river flows in a northwesterly direction along the south side of the Williams Fork Mountains to its confluence about 8 miles southwest of Craig (fig. 2).

Table 14.--*Data collected during traveltime measurements on the Elk River*

[--, not applicable; ND, no data]

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye clouds: Leading edge (hours)	Cumulative traveltime of dye clouds: Peak (hours)	Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
Elk River, slug injection of 1,000 milliliters of 20-percent dye solution at 0620 hours on September 16, 1979, at site 1								
1	7,265	0.00	78	--	--	--	--	--
2	7,150	1.83	78	1.63	2.12	0.82	1.57	140.0
3	7,003	5.21	75	5.00	6.08	.86	3.63	55.3
Elk River, slug injection of 1,000 milliliters of 20-percent dye solution at 1110 hours on September 15, 1978, at site 4								
4	6,796	.00	68	--	--	--	--	--
5	6,720	2.37	77	2.26	2.95	.66	3.88	10.9
6	6,650	5.36	95	5.16	7.36	.66	10.34	5.5
Elk River, slug injection of 1,000 milliliters of 20-percent dye solution at 0928 hours on September 15, 1978, at site 6								
6	6,650	.00	95	--	--	--	--	--
7	6,582	3.77	59	2.53	7.46	.47	15.50	2.5
8	6,525	6.57	86	5.53	11.53	.57	18.00	2.5
Elk River, slug injection of 3,000 milliliters of 20-percent dye solution at 1200 hours on May 3, 1979, at site 1								
1	7,265	.00	413	--	--	--	--	--
3	7,003	5.21	413	1.67	2.10	2.24	2.50	14.2
4	6,796	11.23	ND	3.80	4.40	2.51	3.90	5.8
6	6,650	16.59	ND	5.50	6.40	2.82	4.00	3.4
8	6,525	23.16	ND	7.83	8.67	2.86	4.50	3.0

The upstream parts of the basin are heavily forested, but the river in the study area (fig. 16) flows through an alluvial valley that consists of native grasses and aspens. Land use primarily is livestock grazing and hay production. Near the confluence with the Yampa River, the river flows along the side of a coal mine (Williams Fork Strip No. 1). Water from the Williams Fork primarily is used for irrigation and domestic and stock wells.

Location and Extent of Study Reach

The Williams Fork study reach (fig. 16) extends from 10 miles east of Pagoda downstream 37 miles to the mouth, about 8 miles southwest of Craig. Traveltime measurements were made on the Williams Fork in June 1980 and November 1982. Reaeration measurements were made during the low-flow periods of August 1980 and July 1981. The June sampling period is considered to be a high-flow period. Descriptions of the injection and sampling sites for the various measurements are listed in table 15 and the locations of the sites are shown in figure 16.

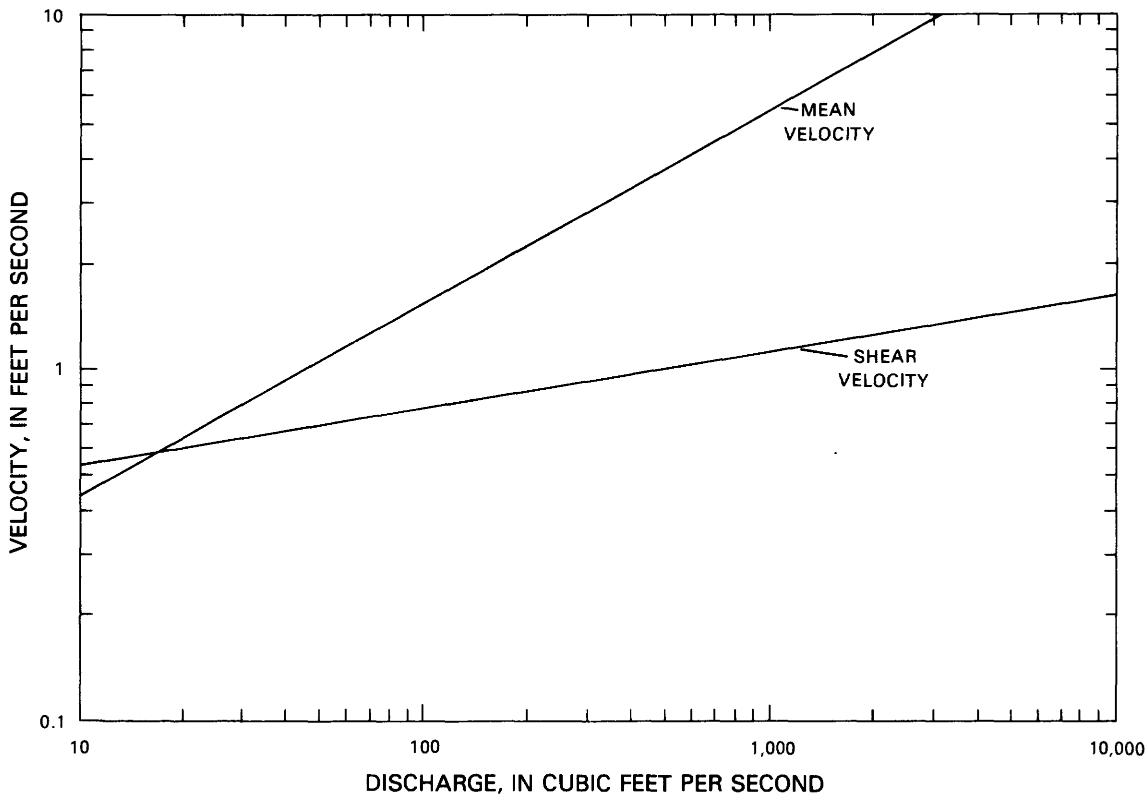

Figure 14.--Relations of mean velocity and shear velocity to discharge at station 09241000, Elk River near Clark (site 1; table 13 and fig. 13).

Traveltime Results

Dye-curve characteristics from the traveltime measurements are listed in table 16. Using the centroids of the dye clouds and discharges measured at the sampling sites, centroid traveltime versus discharge curves were drawn for the study reach (fig. 17). Figure 17 is based on injections at site 1. Traveltimes were not simulated using the previously described computer-modeling technique because of insufficient streamflow-gaging station data and the lack of an index station near the study reach.

To use figure 17 to estimate traveltimes at other discharges, the discharge of the reach of interest would need to be measured or estimated. Centroid traveltimes were used, because for multiple injections as were done during November 1982, summation of the centroid traveltimes yields more accurate results for the overall reach than the summation of peak traveltimes.

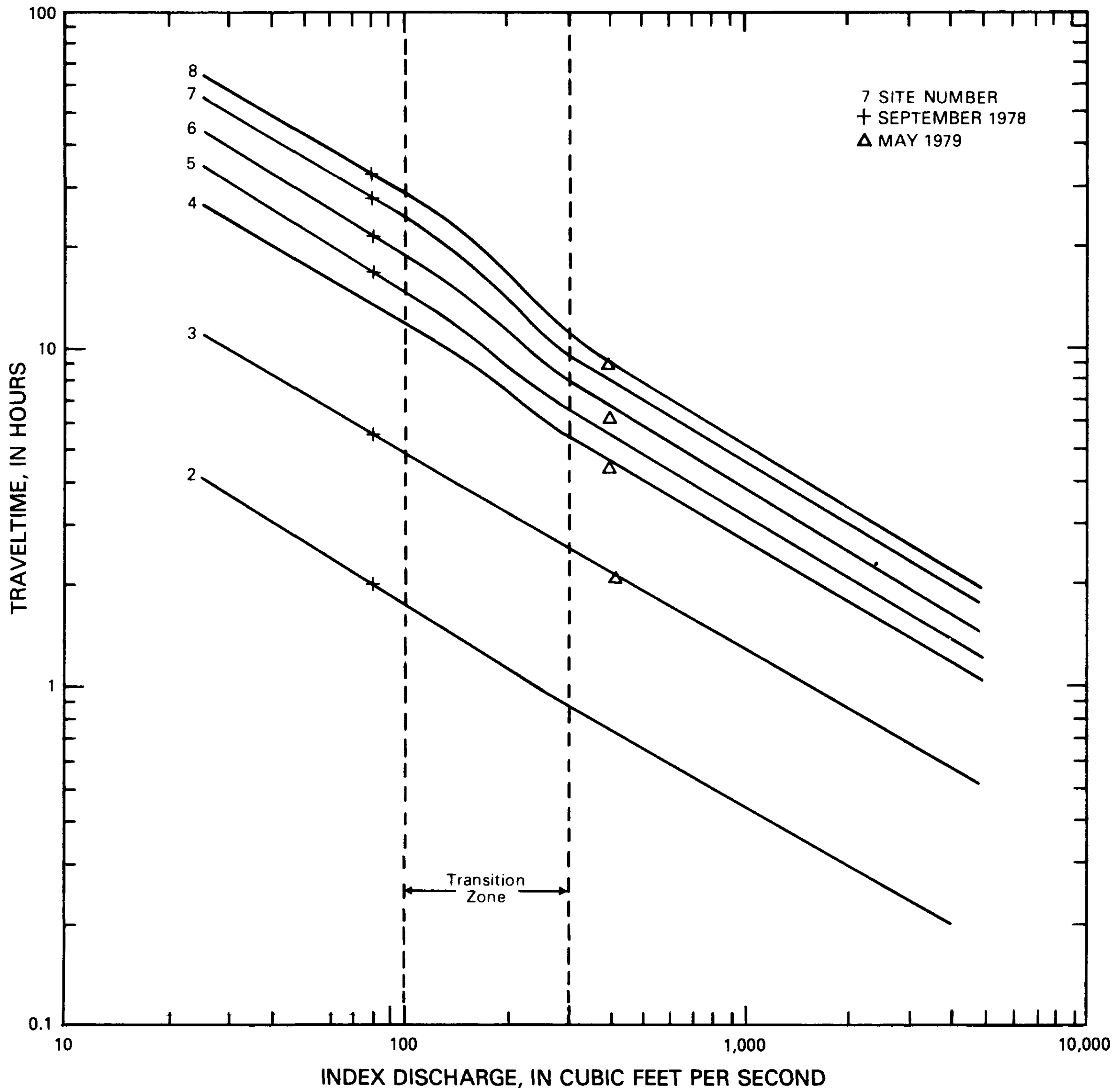

Figure 15.--Simulated cumulative-traveltime curves for the Elk River, using index station 09241000, Elk River near Clark (site 1; table 13 and fig. 13).

During the November 1982 measurements there was some ice cover on the upstream river sites (1 to 5). Because of friction, ice cover has the effect of increasing the traveltime, compared to that expected during ice-free periods.

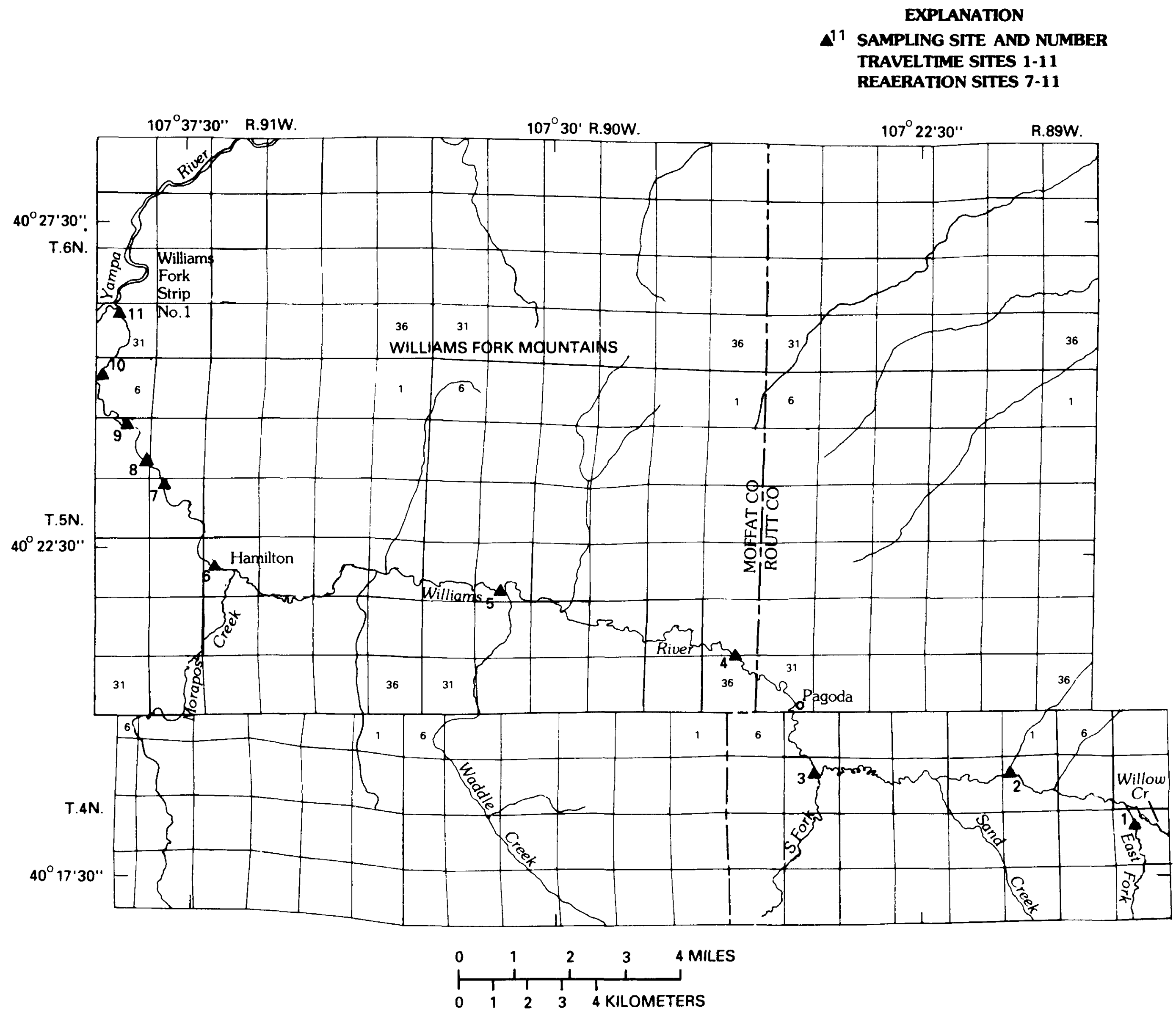

Figure 16.--Injection and sampling sites for traveltime and reareation measurements on the Williams Fork.

Table 15.--*Injection and sampling sites for traveltime and reaeration measurements on the Williams Fork*

[Flow conditions: H, high flow; M, medium flow; L, low flow; Site type: I, injection; S, sampling]

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
1	H,M	I	37.31	Williams Fork 0.4 mile upstream from Willow Creek.
2	H,M	S	34.32	Williams Fork at Ellis Ranch.
3	H,M	I,S	27.66	Williams Fork at Moffat County Highway 317 bridge.
4	H,M	I,S	23.24	Williams Fork at Sealy Ranch.
5	H,M	S	16.16	Williams Fork 0.07 mile downstream from Waddle Creek at bridge.
6	H,M	I,S	8.34	Williams Fork at State Highway 13 and 789 bridge.
7	M,L	I,S	5.28	Williams Fork at Jepkema Ranch.
8	L	S	4.74	Williams Fork 3.6 miles downstream from State Highway 13 and 789 bridge.
9	L	S	3.80	Williams Fork 3.8 miles upstream from mouth.
10	L	S	2.03	Williams Fork upstream from Williams Fork Strip Mine No. 1.
11	H,M,L	S	0.43	Williams Fork at Williams Fork Strip Mine No. 1.

Reaeration Results

Reaeration measurements were made during August 1980 and July 1981. Sampling sites are listed in table 15. Dye-curve characteristics for the continuous injections are listed in table 16. Additional characteristics of the dye curves and data from the gas concentration versus time curves are listed in table 17.

Reaeration coefficients (table 18) were calculated using equations 1 and 5 and the information listed in table 17. Reaeration measurements were made only on the lower 5 miles of the Williams Fork because that was the only reach that had adequate access. During 1980, insufficient data were available for the determination of reaeration coefficients by the area method. Values for the 1980 measurement include only propane; the ethylene injection apparatus failed during the injection. The discharge during the 1980 and 1981 measurements was nearly the same, as were the calculated reaeration coefficients. Average reaeration coefficients ranged from 9.3 to 19.0 per day.

Table 16.--*Data collected during traveltime measurements on the Williams Fork*

[--, not applicable; ND, no data]

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye cloud: Leading edge (hours)	Cumulative traveltime of dye cloud: Peak (hours)	Cumulative traveltime of dye cloud: Centroid (hours)	Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
		Williams Fork, slug injection of 1,800 milliliters of 20-percent dye solution at 2223 hours on June 9, 1980, at site 1							
1	6,904	0.00	746	--	--	--	--	--	--
2	6,746	2.99	746	0.53	0.74	0.74	4.04	0.64	22.0
3	6,551	9.65	1,080	2.33	2.83	2.91	3.07	1.84	8.2
4	6,459	14.07	1,080	3.63	4.12	4.26	3.27	2.20	4.6
5	6,326	21.15	1,080	5.58	6.33	6.44	3.25	2.34	3.5
6	6,220	28.97	1,080	8.17	9.03	9.14	2.90	2.55	2.6
11	6,117	36.88	1,150	10.50	11.37	11.64	3.16	2.83	2.3
		Williams Fork, continuous injection of 2,035 milliliters of 3.60-percent dye solution for 75 minutes beginning at 0907 hours on August 19, 1980, at site 7							
7	6,182	.00	45	--	--	--	--	--	--
8	6,172	.54	42	.98	1.87	1.88	.29	2.85	16.2
9	6,156	1.48	38	3.13	4.88	5.15	.29	5.40	11.5
10	6,136	3.25	39	5.43	7.58	7.87	.65	6.40	9.2
11	6,117	4.85	36	7.92	10.22	10.62	.58	7.45	7.7
		Williams Fork, continuous injection of 1,970 milliliters of 2.80-percent dye solution for 69 minutes beginning at 0830 hours on July 9, 1981, at site 7							
7	6,182	.00	42	--	--	--	--	--	--
8	6,172	.54	42	.80	1.90	1.73	.31	2.30	12.5
9	6,156	1.48	42	3.15	4.52	4.71	.32	4.32	9.1
10	6,136	3.25	42	5.20	7.00	7.20	.71	5.63	7.3
11	6,117	4.85	42	7.30	9.33	9.72	.63	6.78	5.9
		Williams Fork, slug injection of 600 milliliters of 20-percent dye solution at 0805 hours on November 18, 1982, at site 1							
1	6,904	.00	ND	--	--	--	--	--	--
2	6,746	2.99	55	1.83	2.30	2.55	1.17	2.42	26.0
3	6,551	9.65	80	7.33	9.33	10.36	.85	11.84	2.8
4	6,459	14.07	70	11.25	14.33	15.62	.84	14.42	2.0
		Williams Fork, slug injection of 400 milliliters of 20-percent dye solution at 0836 hours on November 18, 1982, at site 3							
3	6,551	.00	80	--	--	--	--	--	--
4	6,459	4.42	70	2.80	4.00	5.15	.86	9.03	3.4
		Williams Fork, slug injection of 900 milliliters of 20-percent dye solution at 0513 hours on November 17, 1982, at site 4							
4	6,459	.00	70	--	--	--	--	--	--
5	6,326	7.08	82	7.20	9.25	9.97	.71	8.63	7.4
6	6,220	14.90	64	16.50	20.75	20.92	.71	11.83	2.8
		Williams Fork, slug injection of 600 milliliters of 20-percent dye solution at 0545 hours on November 17, 1982, at site 6							
6	6,220	.00	64	--	--	--	--	--	--
7	6,182	3.06	51	3.83	4.80	4.98	.61	3.50	13.0
11	6,117	7.91	51	8.58	9.75	10.29	.91	5.50	6.0

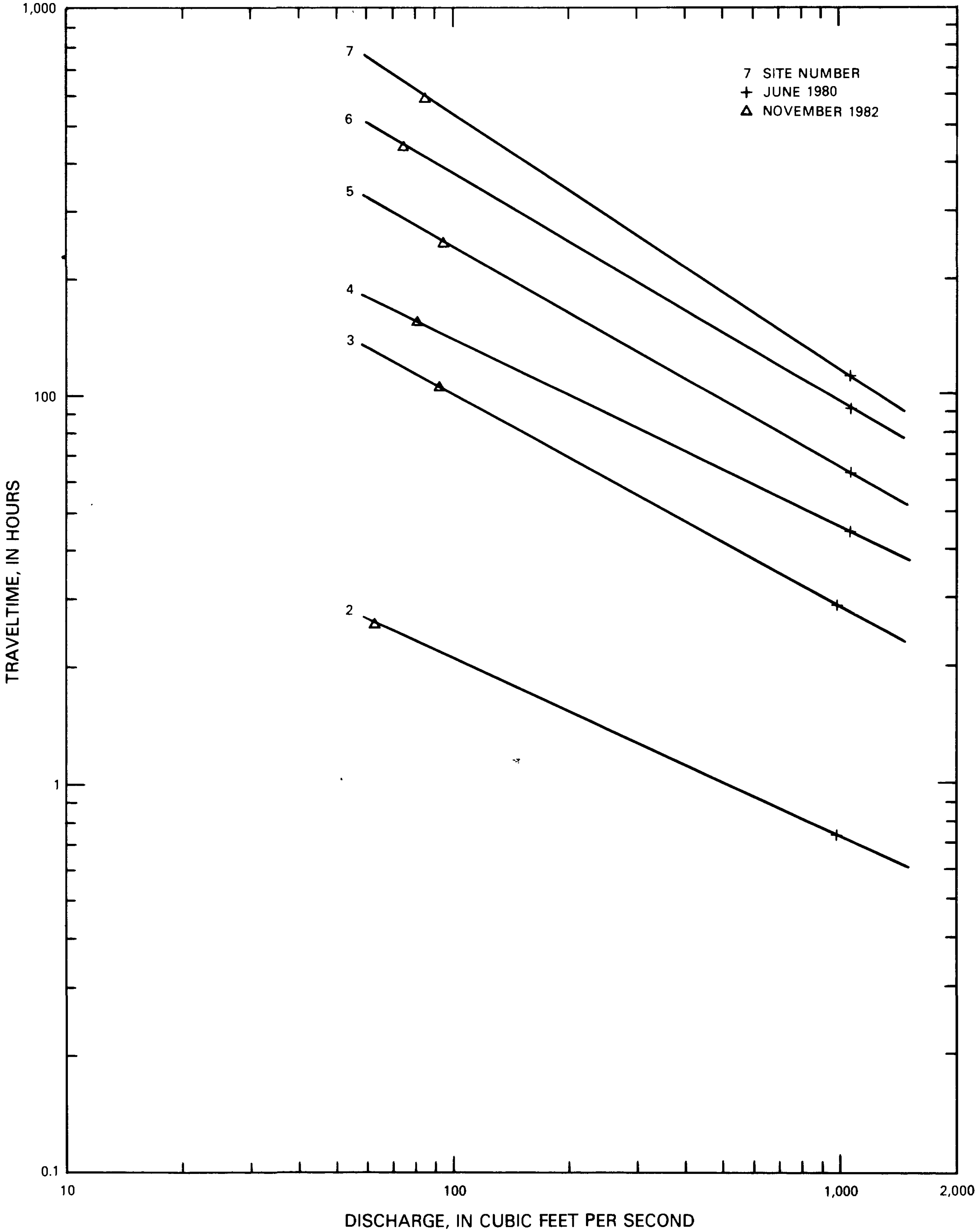

Figure 17.--Cumulative centroid-traveltime curves for the Williams Fork.

Table 17.--*Dye and tracer-gas concentration-time-curve characteristics for the Williams Fork*

[ND, no data]

Site	Area of curve (micrograms-hour per liter)			Traveltime of centroid (hours)			Peak concentration (micrograms per liter)			Traveltime of peak (hours)			Date of measurement (mo/d/yr)
	Ethylene	Propane	Dye	Ethylene	Propane	Dye	Ethylene	Propane	Dye	Ethylene	Propane	Dye	
8	ND	ND	21.17	ND	ND	1.88	ND	24.0	15.9	ND	1.97	1.87	08/19/80
9	ND	ND	20.87	ND	ND	5.15	ND	8.8	11.5	ND	4.80	4.88	08/19/80
10	ND	ND	20.67	ND	ND	7.87	ND	3.0	9.2	ND	7.55	7.58	08/19/80
11	ND	ND	19.77	ND	ND	10.62	ND	0.6	7.6	ND	10.03	10.22	08/19/80
8	63.70	38.30	14.52	1.71	1.68	1.73	54.0	32.5	12.5	1.83	1.75	1.90	07/09/81
9	21.80	13.80	15.50	4.60	4.57	4.71	15.0	9.3	9.1	4.43	4.43	4.52	07/09/81
10	7.66	6.93	14.35	7.07	7.11	7.20	4.0	3.5	7.3	6.90	6.90	7.00	07/09/81
11	2.26	2.38	13.60	9.42	9.49	9.72	1.0	1.0	5.9	9.17	9.17	9.33	07/09/81

Table 18.--*Reaeration coefficients for selected subreaches of the Williams Fork*

[ft^3/s, cubic feet per second; °C, degrees Celsius; ND, no data]

Subreach as defined by site numbers	Mean discharge (ft^3/s)	Water temperature (°C)	Reaeration coefficient based on measured water temperatures (per day)				Reaeration coefficient adjusted to 20 °C (per day)				Date of measurement (mo/d/yr)
			Peak method		Area method		Peak method		Area method		
			Ethylene	Propane	Ethylene	Propane	Ethylene	Propane	Ethylene	Propane	
8-9	40	18.2	ND	8.9	ND	ND	ND	9.3	ND	ND	08/19/80
9-10	38	19.6	ND	10.3	ND	ND	ND	10.4	ND	ND	08/19/80
10-11	38	18.8	ND	18.5	ND	ND	ND	19.0	ND	ND	08/19/80
8-11	39	18.5	ND	12.4	ND	ND	ND	12.8	ND	ND	08/19/80
8-9	42	21.9	10.2	11.9	10.2	11.8	9.7	11.4	9.8	11.3	07/09/81
9-10	42	23.5	12.4	10.3	11.7	9.1	11.4	9.5	10.7	8.4	07/09/81
10-11	42	23.9	14.6	15.0	14.3	14.8	13.3	13.7	13.0	13.5	07/09/81
8-11	42	22.9	12.3	12.3	11.9	11.9	11.4	11.5	11.1	11.1	07/09/81

Trout Creek

Trout Creek flows through the southeast and central parts of Routt County in a northerly direction from the Little Flat Tops of the Routt National Forest, through the eastern edge of the Yampa coal field to its confluence with the Yampa River west of Milner (figs. 2 and 18). Elevations range from nearly 12,000 feet in the densely forested part of the basin, to 6,500 feet in the arid, sagebrush area near the confluence. Irrigated hay meadows predominate the valley bottom in the lower section of the basin. Trout Creek flows adjacent to the Edna Mine, operated by Pittsburg Midway Coal Company, which has been operating in the basin for more than 40 years.

Location and Extent of Study Reach

The Trout Creek study reach (fig. 18) extends downstream from a site approximately 28 miles upstream from the mouth to a site about 1 mile upstream from the mouth, near Milner. Traveltime measurements were made on Trout Creek in June 1980 and May 1981. The reaeration measurements were done during the low-flow periods of August 1980 and 1981. Descriptions of the injection and sampling sites for the various measurements are listed in table 19 and the locations of the sites are shown in figure 18.

Traveltime Results

Traveltime measurements were made on Trout Creek in June 1980 during high-flow conditions and in May 1981 during low-flow conditions. Data collected during these measurements are listed in table 20. Dye-cloud velocities ranged from 0.28 to 2.51 miles per hour, and discharges ranged from 6.2 to 271 cubic feet per second.

Traveltime data for other flow conditions were not simulated using the computer-modeling technique described earlier because of the unavailablity of index gaging-station data. However, cumulative traveltime curves for the centroids of the dye clouds for sites 1 to 7 are shown in figure 19. The curves only are given for sites 1 to 7, because access problems coupled with large diversions of flow for agriculture did not allow a second measurement of traveltime data at exactly the same sites downstream from site 7.

The curves shown in figure 19 are for centroid traveltimes, because the summation of centroid traveltime is a more accurate description of actual conditions than the summation of peak traveltimes for multiple injections. The curves are based on injections at site 1.

Reaeration Results

Reaeration measurements were made on selected subreaches of Trout Creek during August 1980 and 1981. The 1981 measurements were made on approximately the same subreaches as the 1980 measurements to provide a check on the larger reaeration rates that occurred during 1980 on the upstream reach and to increase the length of measured distance on the downstream reach. Dye-curve

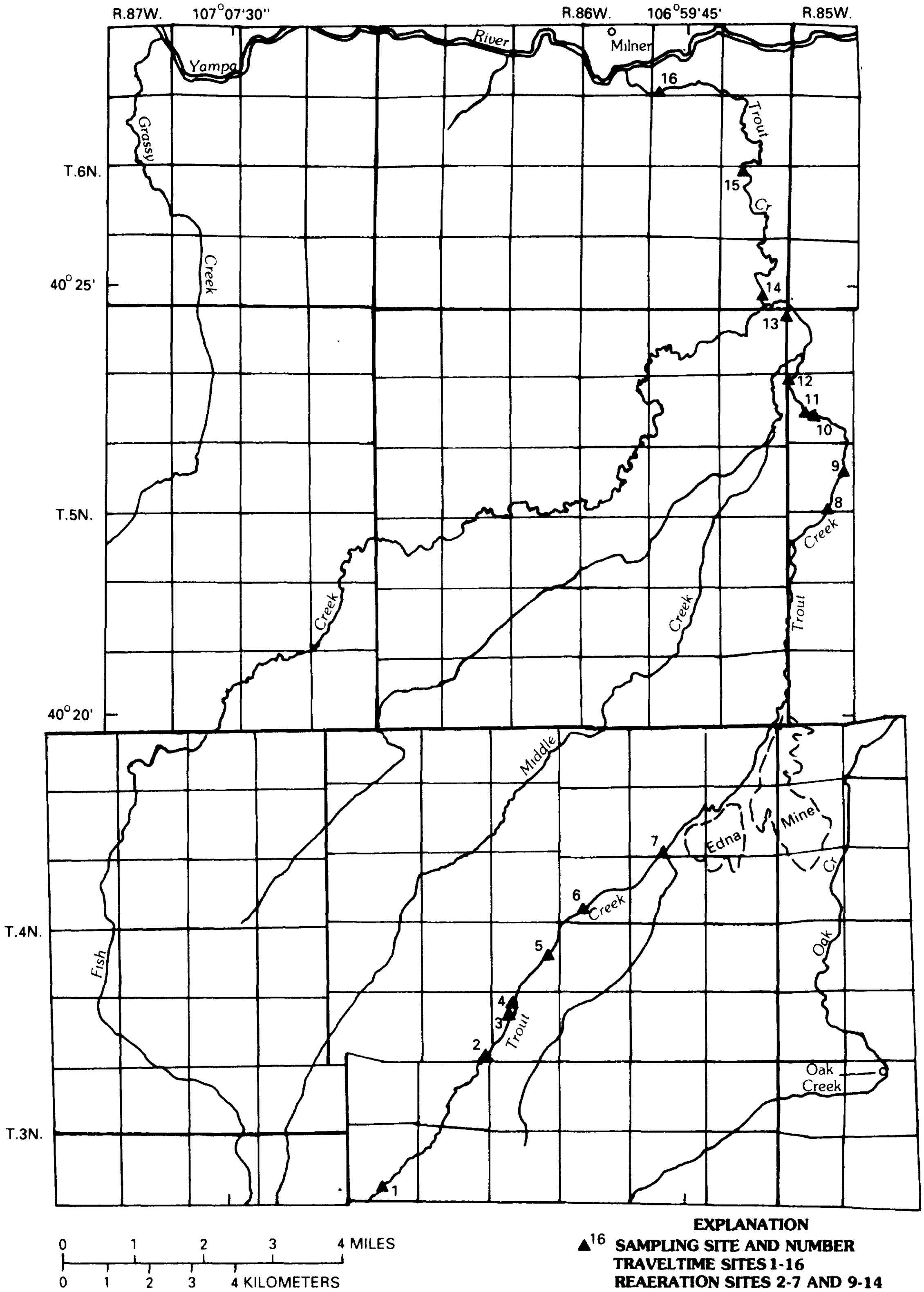

Figure 18.--Injection and sampling sites for traveltime and reaeration measurements on Trout Creek.

Table 19.--*Injection and sampling sites for traveltime and reaeration measurements on Trout Creek*

[Flow conditions: H, high flow; M, medium flow; L, low flow; Site type: I, injection; S, sampling]

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
1	H,L	I	28.49	Trout Creek near Pinnacle Peak.
2	L	I	25.45	Trout Creek 4.48 miles upstream from Routt County Road 27.
3	L	S	24.90	Trout Creek 3.93 miles upstream from Routt County Road 27.
4	H,L	S	24.80	Trout Creek 3.83 miles upstream from Routt County Road 27.
5	L	S	23.56	Trout Creek upstream from Trout Creek School.
6	L	S	22.39	Trout Creek downstream from Trout Creek School.
7	H,L	I,S	20.97	Trout Creek at Routt County Road 27.
8	L	I	13.31	Trout Creek downstream from Trout Creek Ditch No. 4
9	H,L	I,S	12.38	Trout Creek 8.59 miles downstream from Routt County Road 27.
10	L	I,S	10.96	Trout Creek 10.01 miles downstream from Routt County Road 27.
11	L	S	10.79	Trout Creek upstream from Middle Creek.
12	L	S	10.07	Trout Creek upstream from Middle Creek.
13	L	S	8.47	Trout Creek upstream from Fish Creek.
14	L	S	7.90	Trout Creek at Fish Creek.
15	H,L	S	4.38	Trout Creek downstream from Denver And Rio Grande Western Railroad bridge.
16	L	S	.75	Trout Creek near Milner.

traveltime data for the continuous injections are listed in table 20. Additional dye-curve characteristics and characteristics of the ethylene and propane concentration versus time curves are listed in table 21.

Using the information in table 21 and equations 1 and 5, reaeration coefficients for the subreaches measured were calculated and are listed in table 22. The subreach from sites 3 to 5 is characteristic of a high-altitude mountain stream that has a fairly steep gradient and a large degree of turbulence. As such, the reaeration rate is extremely fast (97 and 98 per day). Because of the rapid reaeration rate, the tracer-gas concentrations decreased to unmeasurable levels downstream from site 5. The subreaches from sites 5 to 6 and 6 to 7 are of similar nature to the subreach from sites 3 to 5 and would be expected to have similar reaeration coefficients.

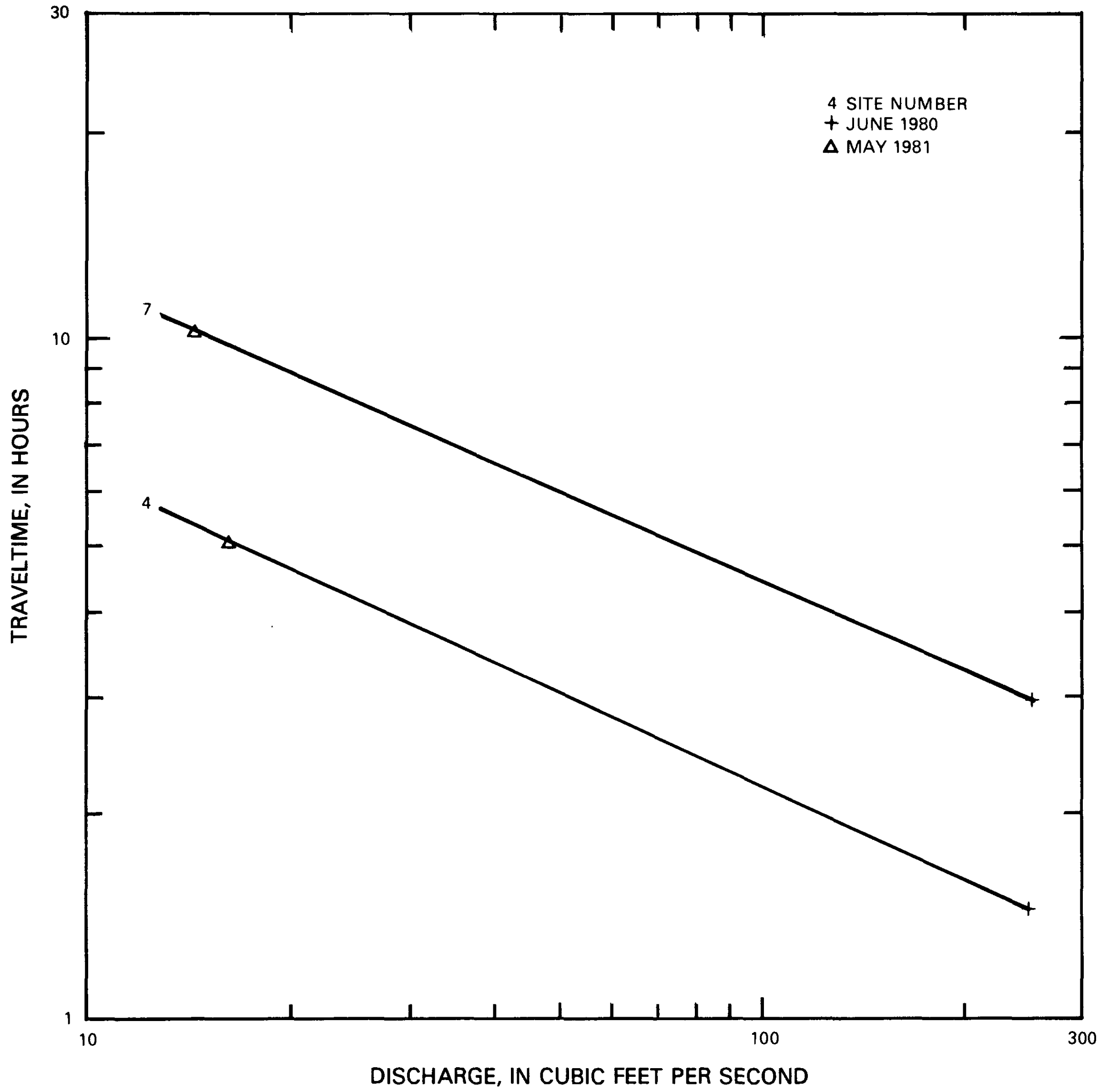

Figure 19.--Cumulative centroid-traveltime curves for Trout Creek.

Insufficient gas samples were collected on the upstream reach and on the downstream reach during 1980 to completely define the tracer-gas concentration versus time curve, and therefore only the peak method of determining a reaeration coefficient was used for these sites. Adjusted reaeration coefficients for the downstream subreaches ranged from 18.0 to 42.0 per day.

Table 20.--*Data collected during traveltime measurements on Trout Creek*

[--, not applicable; ND, no data]

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye cloud: Leading edge (hours)	Peak (hours)	Centroid (hours)	Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
		Trout Creek, slug injection of 500 milliliters of 20-percent dye solution at 2200 hours on June 11, 1980, at site 1							
1	8,000	0.00	--	--	--	--	--	--	--
4	7,575	3.69	245	1.03	1.32	1.47	2.51	1.70	5.9
7	7,219	7.52	245	2.30	2.75	3.02	2.47	2.73	3.2
		Trout Creek, slug injection of 750 milliliters of 20-percent dye solution at 0427 hours on June 12, 1980, at site 7							
7	7,219	.00	245	--	--	--	--	--	--
9	6,730	8.59	245	3.40	3.93	4.13	2.08	2.23	4.9
15	6,529	16.59	271	6.98	7.67	8.01	2.06	3.42	2.6
		Trout Creek, continuous injection of 1,805 milliliters of 1.01-percent dye solution for 60 minutes beginning at 0911 hours on August 20, 1980, at site 2							
2	7,641	.00	14	--	--	--	--	--	--
3	7,585	.55	14	.55	1.28	1.22	.45	1.73	11.0
5	7,458	1.89	14	1.88	2.90	2.83	.83	2.69	9.0
6	7,360	3.06	14	3.73	4.88	5.07	.52	4.55	7.6
7	7,219	4.48	13	5.73	7.22	7.47	.59	8.00	5.4
		Trout Creek, continuous injection of 1,705 milliliters of 0.69-percent dye solution for 60 minutes beginning at 0837 hours on August 21, 1980, at site 9							
9	6,780	.00	ND	--	--	--	--	--	--
11	6,655	1.41	6.9	3.52	4.80	4.99	.28	4.48	13.5
12	6,624	2.31	6.2	5.73	7.30	7.68	.33	5.72	9.9
		Trout Creek, slug injection of 400 milliliters of 20-percent dye solution at 1140 hours on May 19, 1981, at site 8							
8	6,780	.00	ND	--	--	--	--	--	--
11	6,655	2.52	19	3.93	4.58	4.72	.53	2.34	42.0
13	6,578	4.84	23	6.92	7.73	7.89	.73	2.91	25.0
15	6,529	8.93	41	11.97	13.23	13.75	.70	6.63	7.2
16	6,490	12.56	39	16.62	18.33	18.82	.72	7.46	5.9
		Trout Creek, slug injection of 300 milliliters of 20-percent dye solution at 0200 hours on May 20, 1981, at site 1							
1	8,000	.00	ND	--	--	--	--	--	--
4	7,575	3.69	16	4.09	4.63	5.10	.72	3.66	21.0
6	7,360	6.10	16	6.92	7.65	8.28	.76	5.51	11.6
7	7,219	7.52	14	8.80	9.75	10.48	.64	6.73	7.8
		Trout Creek, slug injection of 100 milliliters of 20-percent dye solution at 1300 hours on May 21, 1981, at site 8							
8	6,780	.00	ND	--	--	--	--	--	--
9	6,730	.93	18	1.57	1.87	1.92	.43	1.11	23.6
		Trout Creek, continuous injection of 2,150 milliliters of 1.12-percent dye solution for 70 minutes beginning at 0830 hours on August 18, 1981, at site 2							
2	7,641	.00	ND	--	--	--	--	--	--
3	7,585	.55	18	1.07	1.90	1.85	.30	1.81	9.6
5	7,458	1.89	19	2.47	3.50	3.36	.89	2.33	8.9
6	7,360	3.06	18	2.98	4.13	4.07	1.65	3.24	8.2
7	7,219	4.48	18	4.07	5.23	5.29	1.16	3.85	6.9
		Trout Creek, continuous injection of 1,930 milliliters of 1.28-percent dye solution for 60 minutes beginning at 0800 hours on August 19, 1981, at site 10							
10	6,662	.00	ND	--	--	--	--	--	--
12	6,624	.89	16	1.18	1.97	1.89	.47	1.65	15.0
13	6,578	2.49	16	3.55	4.62	4.92	.53	2.55	13.5
14	6,566	3.06	16	4.67	5.77	5.82	.63	2.90	12.2

Table 21.--*Dye and tracer-gas concentration-time-curve characteristics for Trout Creek*

[ND, no data]

Site	Area of curve (micrograms-hour per liter)			Traveltime of centroid (hours)			Peak concentration (micrograms per liter)			Traveltime of peak (hours)			Date of measurement (mo/d/yr)
	Ethylene	Propane	Dye	Ethylene	Propane	Dye	Ethylene	Propane	Dye	Ethylene	Propane	Dye	
3	ND	ND	10.69	ND	ND	1.22	7.6	14.4	11.0	1.28	1.23	1.28	08/20/80
5	ND	ND	9.48	ND	ND	2.83	.08	.24	9.0	2.99	2.83	2.90	08/20/80
6	ND	ND	9.48	ND	ND	5.07	ND	ND	7.6	ND	ND	4.88	08/20/80
7	ND	ND	8.00	ND	ND	7.47	ND	.09	5.4	ND	ND	7.22	08/20/80
11	ND	ND	18.36	ND	ND	4.99	2.2	4.3	13.5	4.70	4.70	4.80	08/20/80
12	ND	ND	17.15	ND	ND	7.68	.05	.15	9.9	7.07	7.07	7.30	08/20/80
3	11.72	4.59	11.34	1.82	1.82	1.85	10.3	4.0	9.6	1.82	1.78	1.90	08/18/81
5	ND	ND	10.42	ND	ND	3.36	.11	.08	8.9	ND	ND	3.50	08/18/81
6	ND	ND	10.18	ND	ND	4.07	ND	ND	8.2	ND	ND	4.13	08/18/81
7	ND	ND	8.83	ND	ND	5.29	ND	ND	6.9	ND	ND	5.23	08/18/81
12	47.71	42.80	14.25	1.86	1.86	1.89	49.0	18.0	15.0	1.80	1.82	1.97	08/19/81
13	5.33	2.84	14.25	4.56	4.59	4.92	4.9	2.5	13.5	4.56	4.56	4.62	08/19/81
14	2.34	1.35	13.98	5.69	5.73	5.82	2.1	1.2	12.2	5.77	5.77	5.77	08/19/81

Table 22.--*Reaeration coefficients for selected subreaches of Trout Creek*

[ft^3/s, cubic feet per second; °C, degrees Celsius; ND, no data]

Subreach as defined by site numbers	Mean discharge (ft^3/s)	Water temperature (°C)	Reaeration coefficient based on measured water temperatures (per day)				Reaeration coefficient adjusted to 20 °C (per day)				Date of measurement (mo/d/yr)
			Peak method		Area method		Peak method		Area method		
			Ethylene	Propane	Ethylene	Propane	Ethylene	Propane	Ethylene	Propane	
3-5	14	2.8	ND	82	ND	ND	ND	97	ND	ND	08/20/80
11-12	6.6	21.1	39.3	43.1	ND	ND	38.2	42.0	ND	ND	08/20/80
3-5	18	12.6	78	82	ND	ND	93	98	ND	ND	08/18/81
12-13	16	17.0	23.0	23.0	20.0	30.0	25.0	25.0	21.0	32.0	08/19/81
13-14	16	21.1	18.0	18.0	26.0	28.0	18.0	18.0	25.0	27.0	08/19/81
12-14	16	18.7	22.0	22.0	21.0	29.0	23.0	23.0	22.0	30.0	08/19/81

Fish Creek

Fish Creek, a tributary to Trout Creek, flows in a northeasterly direction from the Dunckley Flat Tops at an elevation near 10,000 feet, to its confluence with Trout Creek at an elevation of 6,700 feet, approximately 5 miles south of Milner (fig. 2). Vegetation in the Fish Creek drainage consists mainly of sagebrush, oak brush, and various types of native grasses. Land use is mostly grazing and coal mining.

Location and Extent of Study Reach

The study reach on Fish Creek (fig. 20) extends from 12 miles southwest of Milner downstream for 24 miles to the mouth. Traveltime measurements were made on Fish Creek during June 1980 and May 1981. The 1980 measurements were made during moderate-flow conditions, and the 1981 measurements were made during low-flow conditions. No reaeration measurements were made on Fish Creek.

Traveltime Results

Traveltime-measurement sites are shown in figure 20 and are listed in table 23. Data collected during traveltime measurements are listed in table 24. Mean velocities for the traveltime measurements ranged from 0.27 to 0.63 mile per hour. In the upstream part of the study reach, sites 1 to 4, there were numerous beaver dams. These dams had a large effect on the traveltime through the study reach. Because the dams vary in size and numbers with time, the traveltime characteristics of this part of the study reach also will change.

Table 23.--*Injection and sampling sites for traveltime measurements on Fish Creek*

[Flow conditions: H, high flow; M, medium flow; L, low flow; Site type: I, injection; S, sampling]

Site	Flow conditions	Site type	Distance from mouth (miles)	Name
1	L	I	24.62	Fish Creek at Long Gulch.
2	L	S	23.07	Fish Creek at upper gaging station.
3	L	S	21.80	Fish Creek downstream from Fish Creek Canyon.
4	L	S	19.43	Fish Creek at Routt County Road 27.
5	M,L	I,S	9.76	Fish Creek at middle gaging station.
6	M	S	.51	Fish Creek near Energy Fuels Mine.
7	L	S	.14	Fish Creek near mouth at gaging station.

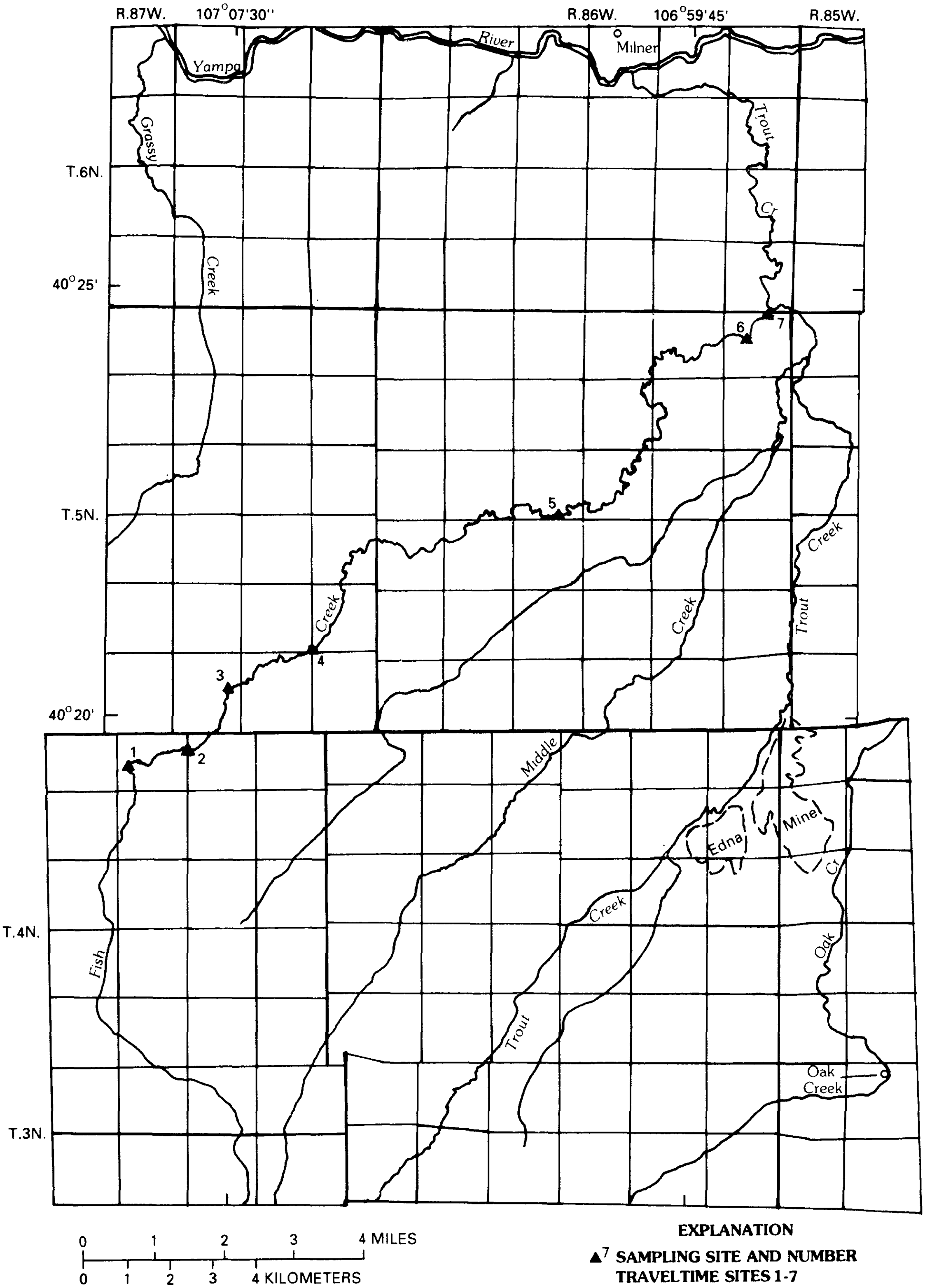

Figure 20.--Injection and sampling sites for traveltime measurements on Fish Creek.

Table 24.--*Data collected during traveltime measurements on Fish Creek*

[--, not applicable; ND, no data]

Site	Elevation (feet)	Distance downstream from injection (miles)	Stream discharge (cubic feet per second)	Cumulative traveltime of dye cloud: Leading edge (hours)	Cumulative traveltime of dye cloud: Peak (hours)	Cumulative traveltime of dye cloud: Centroid (hours)	Mean velocity of dye cloud (miles per hour)	Time for dye cloud to pass site (hours)	Peak dye concentration (micrograms per liter)
		Fish Creek, slug injection of 330 milliliters of 20-percent dye solution at 2102 hours on June 11, 1980, at site 5							
5	6,653	0.00	26	--	--	--	--	--	--
6	6,568	9.25	26	16.13	17.60	18.03	0.51	8.20	16.3
		Fish Creek, slug injection of 300 milliliters of 20-percent dye solution at 0103 hours on May 19, 1981, at site 1							
1	6,990	.00	ND	--	--	--	--	--	--
3	6,869	2.82	12	6.55	7.33	7.50	.38	3.48	38.0
4	6,802	5.19	12	13.30	15.37	16.15	.27	9.37	11.9
5	6,653	14.86	12	31.67	34.53	35.81	.49	15.66	7.4
7	6,564	24.48	12	56.07	59.33	61.66	.37	22.26	4.3
		Fish Creek, slug injection of 100 milliliters of 20-percent dye solution at 1430 hours on May 20, 1981, at site 1							
1	6,990	.00	ND	--	--	--	--	--	--
2	6,915	1.55	12	2.40	2.70	2.47	.63	.90	46.0

SUMMARY

Traveltime and reaeration characteristics provide useful data on stream dispersion characteristics and waste assimilation. Continuous and slug injections of rhodamine-WT dye and subsequent measurement of the dye concentrations downstream provided traveltime information for selected reaches of the Canadian and Michigan Rivers in the North Platte River basin and for the Yampa, Elk, and Williams Fork Rivers and Trout and Fish Creeks in the Yampa River basin.

Extension of measured traveltime to other flow conditions was achieved for the Canadian, Yampa, and Elk Rivers by simulating traveltimes for various discharges using a longitudinal dispersion model and index discharge gaging stations. Results of the simulations enabled the development of traveltime-discharge curves. Traveltime-discharge curves allow for determination of traveltime for various discharges if the discharge at the index station is known or can be estimated.

Index discharge stations were not available for the Williams Fork or Trout Creek. For these stream reaches, traveltime-discharge curves were developed using subreach discharge and cumulative dye curve centroid traveltimes. Insufficient data were collected for the Michigan River and Fish Creek to develop traveltime-discharge curves.

A modified tracer technique was used to determine reaeration coefficients for the Canadian, Michigan, Yampa, and Williams Fork Rivers and Trout Creek. This technique involves the injection of ethylene and propane gas and Rhodamine-WT dye and subsequent measurement of downstream gas and dye concentrations.

Reaeration rates determined for 20 different subreaches ranged from 98 per day on the upstream subreach of Trout Creek to 1.6 per day on the Yampa River near Craig, Colo. The range in reaeration coefficients corresponds to differences between a high velocity turbulent mountain stream and a low velocity pooled reach. The results presented in this report will provide base-line data for subsequent work in determining waste assimilative capacities of the selected stream reaches.

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