TIME-OF-TRAVEL AND REAERATION DATA FOR SEVEN SMALL STREAMS IN ALABAMA, JUNE 1983 TO AUGUST 1984

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FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC UNITS

The analyses and compilations used in this report were made in inch-pound units of measurements. Conversion factors for inch-pound units and metric (SI) units are listed below.

Inch-pound units	Multiply by	To obtain metric units
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per second (ft/s)	0.3048	meter per second (m/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
mile (mi)	1.609	kilometer (km)
pounds (lb)	0.4536	kilograms (kg)
square mile (mi^2)	2.59	square kilometer (km^2)

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ABSTRACT

Time-of-travel and reaeration data were collected from June 1983 to August 1984 for seven selected small streams in Alabama. Rhodamine WT[1] was used as a tracer for the water in the time-of-travel studies and propane gas for the reaeration studies. Mean velocities through the study reaches ranged from 0.06 to 0.67 foot per second. Computed reaeration coefficients, corrected to a temperature of 20° Celsius, ranged from 1.70 to 45.8 days-1.

INTRODUCTION

This report describes the data and the data collection techniques used for time-of-travel and reaeration studies conducted from June 1983 to August 1984 on seven small streams in Alabama. Time-of-travel data and reaeration coefficients are used in water quality models to estimate the effects of organic loadings on dissolved oxygen concentrations along stream reaches. These studies were conducted in cooperation with the Alabama Department of Environmental Management.

The objectives of these studies were to estimate solute travel times and, by two methods, reaeration coefficients for reaches of several small streams in Alabama. The information obtained from these studies can be used to assess the aplicability of various methods for making estimates of travel times and reaeration coefficients for other stream reaches. The study sites are

1/ The use of brand names in this report is for identification purposes only and does not constitue endorsement by the U.S. Geological Survey.

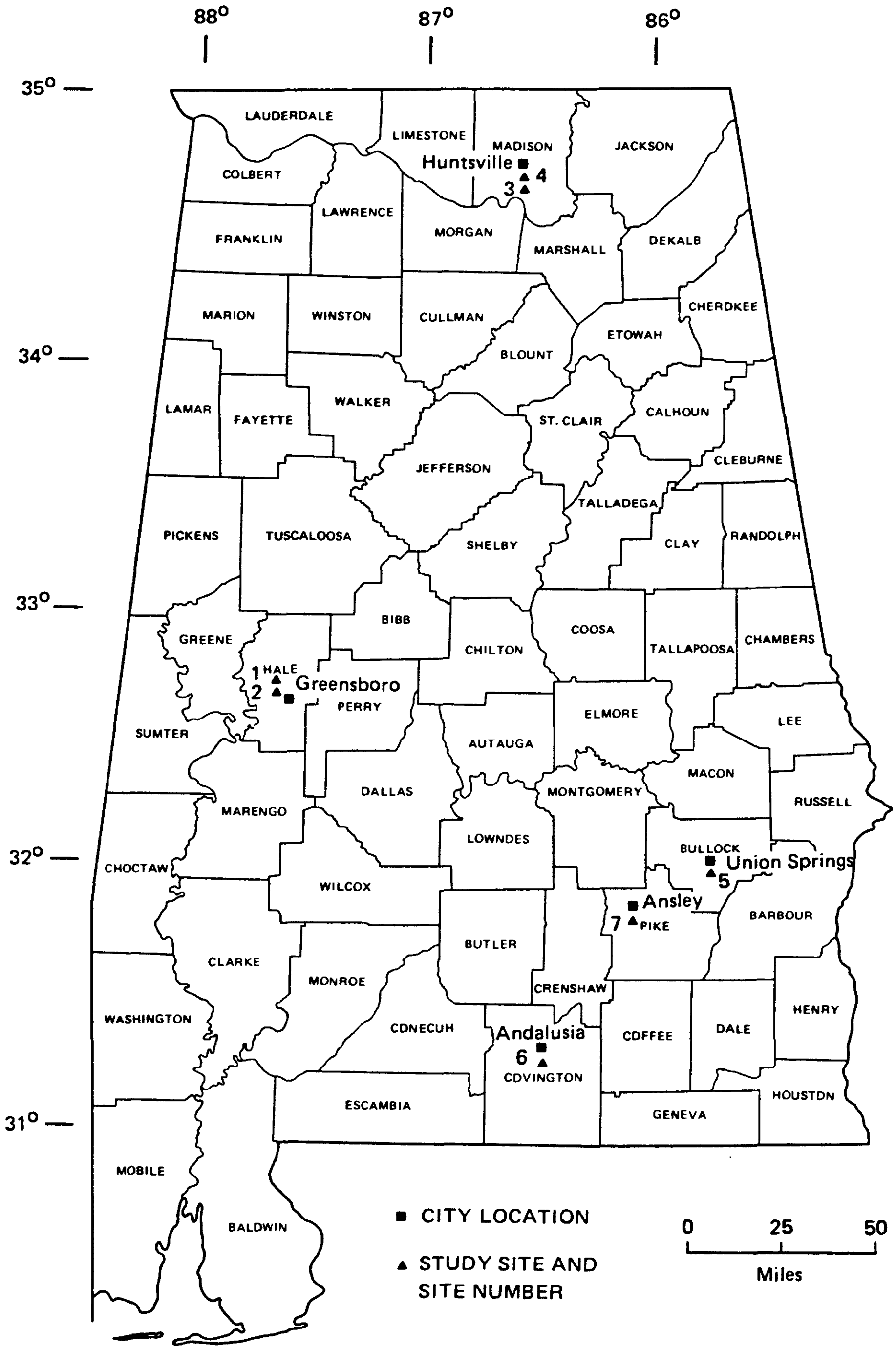

Figure 1.--Location of study sites.

Table 1. Site identifiers and names

Site number[2]	Site identifier	Site name
1	32465130873923	Colwell Creek below Greensboro, Alabama
2	3243390873632	Colwell Creek near Greensboro, Alabama
3	3438390863618	Huntsville Spring Branch below Martin Road near Huntsville, Alabama
4	3440210863606	Huntsville Spring Branch above Martin Road near Huntsville, Alabama
5	3207100854254	Conecuh River near Union Springs, Alabama
6	3116230862913	Bay Branch near Andalusia, Alabama
7	3149510860724	Indian Creek near Ansley, Alabama

[2] See figure 1.

identified in table 1, and their locations are shown in figure 1. The dates on which studies were conducted and the type of data (time-of-travel, area, or steady-state reaeration) collected at each site are shown in table 2.

METHOD OF INVESTIGATION

The methods of conducting time of travel studies described by Hubbard and others (1982) were employed during these studies. The tracer dye used for the time-of-travel studies had a further function as a tracer for the gas used for the reaeration studies.

The most widely used technique for estimating reaeration coefficients for stream reaches is through the use of theoretical, semiempirical, or empirical equations. Other techniques include the *in situ* measurement of the desorption coefficient of radioactive and hydrocarbon gases. Gas desorption techniques have been described by Tsivoglou (1967), Rathbun and Grant (1978), and Yotsukura and others (1983).

Table 2. Study number, date, and type of data collected at each site

Site number[3]	Study number	Date of study	Type of data collected
1	01	08/23/83	Time of travel
2	02	08/21/83	Time of travel
1	03	10/26/83	Time of travel
2	04	10/27/83	Time of travel Area method reaeration
2	05	07/19/84	Time of travel Steady state method reaeration
3	06	08/30/83	Time of travel Area method reaeration
4	07	08/31/83	Time of travel Area method reaeration
5	08	11/09/83	Time of travel Area method reaeration
5	09	06/12/84	Time of travel
5	10	06/14/84	Time of travel Steady state method reaeration
6	11	11/30/83	Time of travel Area method reaeration
6	12	06/26/84	Time of travel Steady state method reaeration
7	13	08/13/84	Time of travel
7	14	08/14/84	Time of travel
7	15	08/16/84	Time of travel Steady state method reaeration
7	16	08/29/84	Time of travel
7	17	08/30/84	Time of travel Steady state method reaeration
7	18	08/31/84	Time of travel Steady state method reaeration

[3] See figure 1 and table 1.

Each of these techniques has advantages and disadvantages. The principal advantages of using the equations available for estimating the reaeration coefficient are ease of application and low cost. The disadvantages are the difficulty of determining the values of the variables required and the difficulty in determining which of the many available equations to use for a particular stream reach.

The basis of techniques for determining the rate constant for the absorption of oxygen by measuring the desorption rate of a gas is that the ratio of absorption of oxygen by a body of water to the desorption of a gas by the same body of water is a constant and is not affected by mixing conditions in the stream (Rathbun and Grant, 1978). The principal advantage of the gas desorption technique is that the gas desorption rate coefficient can be computed directly from sample data. The principal disadvantage of the gas desorption technique is in the expense of the field procedures and laboratory analyses. The radioactive gas technique has the further disadvantage that permits to use radioactive materials must be obtained and training in the use of these materials must be provided for the personnel conducting the field operations.

Two methods employing the hydrocarbon gas desorption technique, the area method (Rathbun and Grant, 1978) and the steady-state method (Yotsukura, 1983), were used during these studies. Both these methods require injection of a hydrocatbon gas and a tracer into the stream far enough upstream of the reach being investigated that complete transverse mixing occurs before the injected gas and tracer dye enter the reach. Water samples for gas and tracer analysis are collected at two or more locations in the study reach. Propane and Rhodamine WT were used as the gas and tracer, respectively, for the field studies described in this report.

ESTIMATING GAS AND DYE QUANTITIES AND INJECTION RATES

The procedures described by Rathbun (1979) were used to estimate the quantities of the hydrocarbon gas and dye required and to determine the injection rates for each. These estimates require that measurements or estimates of the reaeration coefficient; stream discharge and mean depth, width and velocity of flow; and channel length. To obtain reasonable estimates of these variables, preliminary time-of-travel studies using slug injections of a dilute solution of rhodamine WT dye were made in most of the study reaches. Discharge measurements were made as a part of the preliminary investigation. Water samples for dye analysis were collected with an automatic sampler at the downstream end of the study reach. Channel slopes were computed from channel lengths and elevations obtained from topographic maps. A reconnaissance of the study reach was made during the preliminary time-of-travel study to select possible sites for intermediate sampling cross sections.

The length of reach required for mixing and the quantities and injection rates of gas and dye required for the reaeration study were computed using data obtained during the preliminary time-of-travel study. The locations of the sampling cross sections were selected and the arrival time of the dye cloud and the time required for the cloud to pass each sampling cross section were estimated.

FIELD PROCEDURES

The tracer dye was injected at one or more points in the injection cross section with a small, calibrated, positive-displacement pump. Gas was injected through one or more flat-plate diffusers placed on the stream bed in the cross section. For reaeration studies employing the area method, the dye and gas were injected simultaneously over a short period of time to approximate a slug injection. For reaeration studies employing the steady-state method, a slug injection of dye was made and the gas was injected at a constant rate until the dye concentrations at the downstream sampling cross section were less than 10 percent of the maximum dye concentrations in the dye cloud as it passed that sampling cross section. Gas and dye injection rates were monitored throughout their respective injection periods.

Discharge measurements were made at the sampling cross sections to determine the the center of discharge in the cross section. Automatic samplers were placed in the sampling cross sections at the center of discharge and the timing mechanisms adjusted so that water samples for dye analysis were collected at regular intervals throughout the expected time of passage of the dye cloud. This sampling procedure was used for collecting water for dye analysis for all the time-of-travel and reaeration studies. Additional water samples for dye analysis were collected at 15-minute intervals during the period that water samples for gas analysis were collected for studies employing the steady-state method of determining the reaeration coefficient.

Water samples were collected for gas analysis at the center of discharge in the stream immediately downstream of the automatic samplers. These samples were collected using samplers designed to expell all the air from the sample container and the sampler and to permit sealing the sample container without exposing the sample to air. Water samples for gas analysis were collected synchronously with the samples collected for dye analysis during studies employing the area method of determining the reaeration coefficient. Water samples for gas analysis were collected at each sampling cross section at 15-minute intervals for a period of 1 to 2 hours following the passage of the dye cloud during studies employing the steady-state method of determining the reaeration coefficient.

SAMPLE ANALYSIS

Preliminary estimates of the time of arrival of the dye cloud at the sampling cross sections and of the time required for the cloud's passage were adequate for selecting sampling cross sections and developing sampling schedules. These estimates were not accurate enough to ensure adequate sample coverage had they been followed rigorously. Therefore, water samples collected for dye analysis were split and one portion analyzed on a continuing basis in a mobile laboratory during the field studies. The portion of the sample remaining was retained in the original sample container. The data obtained from the field analysis were used to adjust the sample schedules to ensure adequate water sampling for dye and gas analysis.

All the samples collected for gas analyses and the retained portion of the samples collected for dye analysis were returned to the laboratory. The samples collected for dye analysis were analyzed again in the laboratory using standard fluorometry techniques. Samples collected for gas analysis were analyzed by the U.S. Geological Survey National Water Quality Laboratory, Doraville, Georgia.

TIME-OF-TRAVEL DATA

Time of travel data are shown in table 3. A single character identifier was assigned to the injection cross section and each of the sampling cross sections in the reach. The character I identifies the injection cross section. The sampling cross sections were assigned single character identifiers alphabeticaly in downstream order. Stream reaches are identified by combining the cross section identifier for the cross section at the upstream end of the reach with the cross section identifier at the downstream end of the reach. Reach IA is the reach between the injection cross section and the first sampling cross section downstream of the injection cross section. Mean values of discharge through the reach were computed from discharges measured in the reach during the field study.

The mean velocities through the individual reaches ranged from 0.06 to 0.67 foot per second were obtained by substituting into the equation:

$$v = L_r/dt \qquad (1)$$

where: v is the mean velocity of the dye cloud in feet per second,

L_r is the length of the reach in feet, and

dt is the difference between the mean time of the dye cloud at the sampling cross section at the upstream end of the reach and the mean time of the dye cloud at the sampling cross section at the downstream end of the reach in seconds.

The mean time of the dye cloud is defined for purposes of this report as the 1st-order moment of the distribution (Yotsukura, 1983).

Table 3--Time-of-travel data

Site number	Study number	Reach	Reach length (feet)	Mean discharge through reach (cubic feet per second)	Mean velocity of dye cloud through reach (feet per second)	Arrival time of leading edge of the dye cloud at upstream end of reach	Arrival time of leading edge of the dye cloud at downstream end of reach	Arrival time of trailing edge of the dye cloud at upstream end of reach	Arrival time of trailing edge of the dye cloud at downstream end of reach	Mean arrival time of the dye cloud at upstream end of reach	Mean arrival time of the dye cloud at downstream end of reach
						(minutes following injection)					
1	01	IA	1000	0.79	0.19	0	35	0	225	0	89
1	01	IB	2000	0.79	0.10	0	210	0	540	0	349
1	01	AB	1000	0.79	0.06	35	210	225	540	89	349
2	02	IA	1000	1.25	0.16	0	20	0	225	0	103
2	02	IB	2000	1.25	0.19	0	75	0	345	0	178
2	02	AB	1000	1.25	0.22	20	75	225	345	103	178
1	03	IA	1000	1.62	0.12	0	15	0	150	0	136
1	03	IB	2000	1.62	0.10	0	180	0	570	0	342
1	03	AB	1000	1.62	0.08	15	180	150	570	136	342
2	04	IA	1000	1.78	0.20	0	40	0	150	0	84
2	04	IB	2000	1.78	0.24	0	90	0	210	0	140
2	04	AB	1000	1.78	0.30	40	90	150	210	84	140
2	05	IA	1000	1.62	0.25	0	28	0	264	0	67
2	05	IB	2000	1.50	0.31	0	56	0	364	0	106
2	05	AB	1000	1.45	0.43	28	56	264	364	67	106
3	06	IA	1000	45.6	0.20	0	40	0	115	0	84
3	06	IB	2400	45.6	0.20	0	150	0	360	0	205
3	06	IC	4200	45.6	0.19	0	300	0	505	0	373
3	06	AB	1400	45.6	0.19	40	150	115	360	84	205
3	06	AC	3200	45.6	0.18	40	300	115	360	84	373
3	06	BC	1800	45.6	0.18	150	300	360	505	205	373
4	07	IA	1800	28.7	0.38	0	35	0	120	0	80
4	07	IB	5000	28.7	0.40	0	150	0	300	0	206
4	07	IC	6800	28.7	0.30	0	260	0	540	0	376
4	07	AB	3200	28.7	0.42	35	150	120	300	80	206
4	07	AC	5000	28.7	0.28	35	260	120	540	80	376
4	07	BC	1800	28.7	0.18	150	260	300	540	206	376

Table 3--Time-of-travel data--Continued

Site number	Study number	Reach	Reach length (feet)	Mean discharge through reach (cubic feet per second)	Mean velocity of dye cloud through reach (feet per second)	Arrival time of leading edge of the dye cloud at upstream end of reach	Arrival time of leading edge of the dye cloud at downstream end of reach	Arrival time of trailing edge of the dye cloud at upstream end of reach	Arrival time of trailing edge of the dye cloud at downstream end of reach	Mean arrival time of the dye cloud at upstream end of reach	Mean arrival time of the dye cloud at downstream end of reach
						(minutes following injection)					
5	08	1A	400	1.36	0.17	0	15	0	85	0	40
5	08	1B	900	1.36	0.09	0	100	0	270	0	168
5	08	1C	1900	1.36	0.08	0	260	0	570	0	392
5	08	AB	500	1.36	0.07	15	100	85	270	40	168
5	08	AC	1500	1.36	0.07	15	260	85	570	40	392
5	08	BC	1000	1.36	0.07	100	260	270	570	168	392
5	09	1C	1900	0.95	0.12	0	180	0	745	0	272
5	10	1A	400	1.06	0.18	0	10	0	130	0	37
5	10	1B	900	1.06	0.10	0	60	0	330	0	143
5	10	1C	1900	1.06	0.10	0	206	0	655	0	330
5	10	AB	500	1.06	0.08	10	60	130	330	37	143
5	10	AC	1500	1.06	0.09	10	206	130	655	37	330
5	10	BC	1000	1.06	0.09	60	206	330	655	143	330
6	11	1A	600	5.30	0.67	0	2	0	40	0	15
6	11	1B	3400	5.30	0.44	0	90	0	250	0	129
6	11	1C	7300	5.30	0.28	0	250	0	645	0	436
6	11	AB	2800	5.30	0.41	2	90	40	250	15	129
6	11	AC	6700	5.30	0.27	2	250	40	645	15	436
6	11	BC	3900	5.30	0.21	90	250	250	645	129	436
6	12	1A	800	2.99	0.67	0	5	0	160	0	20
6	12	1B	3400	2.99	0.44	0	35	0	355	0	128
6	12	1C	5900	2.99	0.28	0	235	0	705	0	352
6	12	AB	2600	2.99	0.40	5	35	160	355	20	128
6	12	AC	5100	2.99	0.26	5	235	160	705	20	352
6	12	BC	2500	2.99	0.19	35	235	355	705	128	352
7	13	1C	5850	2.69	0.26	0	170	0	585	0	380
7	14	1C	5850	3.33	0.20	0	375	0	795	0	493

Table 3--Time-of-travel data--Continued

Site number	Study number	Reach	Reach length (feet)	Mean discharge through reach (cubic feet per second)	Mean velocity of dye cloud through reach (feet per second)	Arrival time of leading edge of the dye cloud at upstream end of reach	Arrival time of leading edge of the dye cloud at downstream end of reach	Arrival time of trailing edge of the dye cloud at upstream end of reach	Arrival time of trailing edge of the dye cloud at downstream end of reach	Mean arrival time of the dye cloud at upstream end of reach	Mean arrival time of the dye cloud at downstream end of reach
						(minutes following injection)					
7	15	IA	1000	0.94	0.19	0	50	0	285	0	87
7	15	IB	3450	1.17	0.28	0	155	0	480	0	209
7	15	IC	5850	1.27	0.26	0	250	0	690	0	377
7	15	AB	2450	1.39	0.33	50	155	285	480	87	209
7	15	AC	4850	1.44	0.28	50	250	285	690	87	377
7	15	BC	2400	1.49	0.24	155	250	480	690	209	377
7	16	IA	1000	1.62	0.26	0	42	0	190	0	64
7	16	IB	3450	1.62	0.28	0	140	0	415	0	202
7	16	AB	2450	1.62	0.30	42	140	130	415	64	202
7	17	IA	1000	1.08	0.23	0	40	0	180	0	73
7	17	IB	3450	1.08	0.26	0	140	0	450	0	222
7	17	IC	5850	1.09	0.24	0	260	0	790	0	413
7	17	AB	2450	1.08	0.27	40	140	180	450	73	222
7	17	AC	4850	1.10	0.24	40	260	180	790	73	413
7	17	BC	2400	1.12	0.21	140	260	450	790	222	413
7	18	IA	1000	0.66	0.20	0	45	0	180	0	85
7	18	IB	3450	0.75	0.22	0	177	0	510	0	260
7	18	IC	5850	0.82	0.21	0	355	0	810	0	468
7	18	AB	2450	0.84	0.23	45	177	180	510	85	260
7	18	AC	4850	0.90	0.21	45	355	180	810	85	468
7	18	BC	2400	0.96	0.19	177	355	510	810	260	468

REAERATION DATA

Table 4 shows reaeration coefficients and the physical data describing the stream reaches for which reaeration data were obtained using the area method. Computed reaeration coefficients, adjusted to 20° Celsius, raised from 1.70 to 45.8 $days^{-1}$. Table 5 shows the equivalent data for stream reaches for which reaeration data were obtained using the steady state method.

Mean values of the reach area, width, and depth were obtained by substituting into the equation:

$$q = v \times w \times d \qquad (2)$$

where: q is the computed mean discharge through the reach, in cubic feet per second;

v is the mean velocity through the reach, in feet per second, obtained by the solution of equation 1;

w is the mean width of the reach in feet; and

d is the mean depth of the reach in feet.

Table 4.--Reaeration data obtained using the area method

Site number	Study number	Reach identifier	Reach length (feet)	Reach slope (foot per foot)	Mean discharge through reach (cubic feet per second)	Mean velocity of the dye cloud (feet per second)	Mean cross section area of reach (square feet)	Mean width of reach (feet)	Mean depth of reach (feet)	Mean water temperature (degrees Celsius)	Reaeration coefficient ($days^{-1}$ at 20 degrees Celsius)
2	04	AB	1000	0.0030	1.78	0.30	5.94	10.6	0.56	16.0	1.70
3	06	AB	1400	0.0006	45.6	0.19	238.0	72.0	3.3	20.0	8.33
4	07	AB	3200	0.0006	28.7	0.42	68.0	68.0	1.0	20.0	3.49
5	08	AB	500	0.0016	1.36	0.07	19.5	20.5	0.95	19.0	4.77
5	08	AC	1500	0.0014	1.36	0.07	19.5	21.0	0.93	19.0	5.25
5	08	BC	1000	0.0011	1.36	0.07	19.6	21.5	0.91	19.0	5.53
6	11	AB	2800	0.0029	5.30	0.41	12.9	13.7	0.94	13.5	9.52
6	11	AC	6700	0.0028	5.30	0.27	19.7	17.0	1.16	13.5	9.20
6	11	BC	3900	0.0028	5.30	0.21	25.1	19.0	1.32	13.5	9.08

Table 5--Reaeration data obtained using the steady state method

Site number	Study number	Reach identifier	Reach length (feet)	Reach slope (foot per foot)	Mean discharge through reach (cubic feet per second)	Mean velocity of the dye cloud (feet per second)	Mean cross section area of reach (square feet)	Mean width of reach (feet)	Mean depth of reach (feet)	Mean water temperature (degrees Celsius)	Reaeration coefficient (days^{-1} at 20 degrees Celsius)
2	05	AB	1000	0.0030	1.45	0.43	3.41	11.0	0.31	24.5	1.94
5	10	AB	500	0.0016	1.06	0.08	13.5	20.7	0.65	27.0	7.29
5	10	AC	1500	0.0014	1.06	0.09	11.8	19.0	0.62	27.0	8.42
5	10	BC	1000	0.0011	1.06	0.09	11.8	19.4	0.61	27.0	9.06
6	12	AB	2600	0.0027	2.99	0.40	7.50	13.4	0.56	24.0	16.9
6	12	AC	5100	0.0027	2.99	0.26	11.5	16.5	0.70	24.0	15.5
6	12	BC	2500	0.0028	2.99	0.19	15.8	19.3	0.82	24.0	16.0
7	15	AB	2450	0.0033	1.39	0.33	4.13	12.9	0.32	22.5	29.6
7	15	AC	4850	0.0033	1.44	0.28	5.13	12.5	0.41	23.0	39.2
7	15	BC	2400	0.0033	1.49	0.24	6.24	14.5	0.43	23.5	45.8
7	17	AB	2450	0.0033	1.08	0.27	3.96	13.2	0.30	21.5	36.6
7	18	AB	2450	0.0033	0.84	0.23	3.63	11.7	0.31	21.5	31.4

SUMMARY

Time-of-travel and reaeration data were obtained for seven small streams in Alabama. The area method (Rathbun, 1978) and the steady-state method (Yotsukura, 1983) were used to obtain reaeration coefficients. Mean velocities through the study reaches ranged from 0.06 to 0.67 foot per second. Computed reaeration coefficients, corrected to 20° Celsius ranged from 1.70 to 45.8 $days^{-1}$. Tabels showing the locations of the study sites and the type of studies conducted at each site are contained in this report. Additional tables show the time of travel data and reaeration data obtained. The tables also contain physical descriptions of the stream reaches studied so the information in this report may be compared with the time-of-travel and reaeration data of similar streams in other areas.

SELECTED REFERENCES

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

Rathbun, R. E., and Grant, R. S., 1978, Comparison of the radioactive and modified techniques for measurement of stream reaereation coefficients: U.S. Geological Survey Water-Resources Investigations Report 78-68, 57 p.

Rathbun, R. E., 1979, Estimating the gas and dye quantities for modified tracer technique measurements of stream reaeration coefficients: U. S. Geological Survey Water-Resources Investigations Report 79-27, 42 p.

Tsivoglou, E. C., 1967, Tracer measurement of stream reaeration: Federal Water Pollution Control Administrative Report, 86 p.

Yotsukura, N., Stedfast, D. A., Draper, R. E., and Brutsaret, W. H., 1983, An assessment of steady-state propane-gas tracer method for reaeration coefficients--the Cowaselon Creek, New York: U. S. Geological Survey Water-Resources Investigations Report 83-4183, 88 p.