# REAERATION COEFFICIENTS OF SIX STREAMS IN NEW YORK

## A comparison of results obtained by a hydrocarbon-gas tracer method with those obtained by radioactive tracers and predictive equations

By David A. Stedfast and Richard E. Draper

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## CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert units used in this report to the metric (International System) units.

| Multiply Inch-Pound Unit | by | To obtain metric unit |
|---|---|---|
| foot (ft | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| feet per second (ft/s) | 0.3048 | meter per second (m/s) |
| square foot ($ft^2$) | 0.0929 | square meter ($m^2$) |
| square mile ($mi^2$) | 2.59 | square kilometer ($km^2$) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| gallon (gal) | 3.785 | liter (L) |
| pound (lb) | 0.454 | kilogram (kg) |

# REAERATION COEFFICIENTS OF SIX STREAMS IN NEW YORK

## A Comparison of Results Obtained by a Hydrocarbon-Gas-Tracer Method with those Obtained by Radioactive Tracers and Predictive Equations

By David A. Stedfast and Richard E. Draper


## Abstract

Stream-reaeration measurements were made in selected reaches on six streams in New York State from 1978 to 1981 with hydrocarbon-gas and dye tracers. The sites were Canandaigua Outlet near Canandaigua, Oswego River at Fulton, Hudson River at Fort Miller, Cayadutta Creek near Johnstown, Chenango River near Morrisville, and Payne Brook near Hamilton. The reaches represent a wide range of discharge, water-surface slope, velocity, and streambed composition. Flows ranged from less than 2 $ft^3/s$ (cubic feet per second) on the Chenango River to 4,100 $ft^3/s$ on the Hudson River, and water-surface slope ranged from less than 1 ft/mi (foot per mile) on the Hudson and Oswego Rivers to more than 50 ft/mi on Cayadutta Creek. The corresponding stream-reaeration coefficients ranged from 0.77 units per day for one reach on Canandaigua Outlet to 52 units per day on Cayadutta Creek. The reaeration coefficients for Canandaigua Outlet compared well with those obtained on the same reach 10 years earlier with radioactive tracers. Comparison of measured reaeration coefficients with those calculated from 10 predictive equations based on stream-channel characteristics yielded mean errors that range from 51 percent to 103 percent. No single equation gave reliable accuracy for all stream reaches.


## INTRODUCTION

The New York State Department of Environmental Conservation is responsible for establishing limits for municipal and industrial wastewater discharges to streams and rivers. Some wastewater-treatment facilities within the State must soon be upgraded, and some municipalities will need to construct new ones because of increased volumes of effluent and (or) more stringent quality standards for receiving waters.

The design of a facility depends largely on the stream's capacity to assimilate organic waste. The rate of reaeration (oxygen transfer), which occurs at the interface between air and water, is an important factor in the rate at which organic substances are consumed by microorganisms and also in the resultant dissolved-oxygen concentration of the stream. This rate, expressed as a coefficient, can be calculated through a dissolved-oxygen balance technique. This technique, which requires the identification and measurement of all oxygen sources and sinks except reaeration, is expensive and time consuming, and the results may be only marginally reliable.

Several empirical techniques for estimating reaeration rates have been developed, but when applied to the same stream, they yield widely differing results. An improved direct method of measuring reaeration, developed by

Tsivoglou and others (1965, 1967, and 1968), uses radioactive krypton gas, tritium, and dye tracers. This method provides more consistent values than the predictive equations but is limited in application because the use of radioactive tracers in streams has been banned in New York. A more recent tracer technique, developed by Rathbun and others (1975, 1977) uses hydrocarbon-gas tracers with rhodamine-WT[1] dye and provides results consistent with those given by the radioactive-tracer technique (Rathbun and Grant, 1978). In this method, the desorption coefficient of propane and (or) ethylene is measured and then related to the adsorption coefficient of oxygen. The dye tracer rhodamine-Wt is used to indicate the presence of the gas, and the traveltime and is the conservative tracer against which the nonconservative hydrocarbon gas is compared to compute its desorption. Since rhodamine-Wt dye is not completely conservative, stream discharge must be accurately measured at each sampling point to allow for a mass recovery adjustment of dye concentrations to conservative values. At present, the krypton and hydrocarbon-gas tracer methods yield results that are more accurate than the dissolved-oxygen-balance technique. In addition, the hydrocarbon-gas-tracer method costs significantly less and requires less manpower than either the radioactive-tracer or dissolved-oxygen-balance techniques.

## Purpose and Scope

This report presents results of a study by the U.S. Geological Survey, in cooperation with the New York State Department of Environmental Conservation, begun in 1978, to evaluate the hydrocarbon-gas tracer method of measuring stream-reaeration coefficients. Six streams of different sizes were selected to represent a wide range of discharge, slope, and channel geometry.

This report (1) describes the hydrocarbon-gas-tracer method used to obtain reaeration coefficients for selected reaches on the six streams, (2) compares the coefficients obtained on Canandaigua Outlet by the hydrocarbon-gas tracer method with the coefficients obtained 10 years earlier on the same reach by Tsivoglou and others (1974) by the radioactive-tracer method, and (3) compares measured reaeration coefficients with values derived by predictive equations to provide information on equation accuracy. Results of this comparison provide a basis for selection of an appropriate method for any type of stream in the future.

This report also describes the study reach on each of the six streams and, the principles of stream reaeration and of the hydrocarbon-gas-tracer method. A comparison is made between the coefficients obtained by hydrocarbon tracers and those obtained by radioactive krypton tracer 10 years earlier on the same reach. The report also presents and discusses 10 published predictive equations and tabulates their results for each reach, in terms of percent mean error, for comparison.

## Previous Study

A report by Tsivoglou (1974) provided information on reaeration-rate coefficients for a range of flow conditions on Canandaigua Outlet, the outflow from Canandaigua Lake in central New York. These coefficients were measured

[1] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

through use of radioactive tracers on several reaches of the outlet just downstream from Canandaigua Lake under several flow conditions. Tsivoglou developed a model from these measurements to predict the reaeration-rate coefficient from discharge, traveltime, and change in water-surface elevation. The results given in that report are compared with the reaeration coefficients obtained on the same reach in this study.

## Acknowledgments

This study was done in cooperation with the New York State Department of Environmental Conservation, which also provided assistance during the field measurements. Niagara Mohawk and Fort Miller Pulp and Paper Company assisted by shutting down the power-dam turbines during the Oswego River and the Hudson River measurements, respectively. David Troutman and Salvatore Schiavo of the U.S. Geological Survey, who headed this study during 1978-79, planned and supervised the reaeration measurements that were made during that time.

# DESCRIPTION OF METHODS

Stream-reaeration coefficients can be calculated by several methods. Three of these methods were used for comparison in this study. The first entails the use of radioactive krypton-gas tracers and tritium tracers; the second method uses only hydrocarbon-gas tracers and dye. (The use of radioactive tracers has been banned in New York.) The third method uses hydraulic characteristics of the stream in an empirical equation. The radioactive-tracer method was not used during this study, but the published values obtained in a previous study by Tsivoglou (1974) on Canandaigua Outlet by radioactive tracers were used for comparison.

## Radioactive-Tracer Method

The original gas-tracer method for measuring stream-reaeration coefficients was developed and field tested by Tsivoglou and others (1965, 1967, 1968, and 1974). In this method, radioactive krypton-gas and tritium are injected into the stream instantaneously. Water samples are then collected at two or more locations downstream of the injection site and analyzed to determine the concentrations of both tracers. These concentrations are used to calculate the desorption coefficients of radioactive krypton-gas in the stream. The concentrations of the conservative tracer, tritium, is used to calculate the traveltime of the tracers and to allow or compensate for the reduction of the krypton-gas concentrations due to dispersion and dilution. Once the desorption coefficient of krypton-gas has been calculated, it can be directly related to the stream's reaeration coefficient. A more complete description of the method is given in the reports cited above.

## Hydrocarbon-Gas-Tracer Method

The radioactive-gas and hydrocarbon-gas techniques are the same in principle. For the first, tritium is used as the conservative tracer against which the nonconservative krypton gas is compared to compute a reaeration rate. As any tracer moves downstream, concentrations are attenuated or reduced through natural dispersion. The krypton gas is reduced more rapidly because it not only undergoes the same dispersion but is escaping the water, as intended. The rate of krypton-gas escape in relation to the concentration of the conservative tritium is a direct measure of the reaeration capabilities of the stream.

The methods used in this study, developed by Rathbun and others (1975, 1977), use a hydrocarbon-gas tracer whose desorption (loss to the atmosphere) characteristics can be related to the adsorption characteristics of oxygen. The tracer gas (propane or ethylene) and a fluorescent tracer (rhodamine-Wt dye) are injected simultaneously into the river upstream of the study reach. As the gas-and-dye cloud travels downstream, it is sampled at two or more sites. Unlike tritium, rhodamine-Wt dye is not entirely conservative and undergoes various decay and adsorption losses as it moves downstream. By measuring stream discharge at the sampling locations, one can, through mass recovery computations, determine the conservative concentrations of the dye tracer.

The gas and dye concentrations in the samples are then measured in the laboratory and used to compute the desorption coefficient of the gas. A direct linear relationship between the desorption coefficient of the hydrocarbon gas and the adsorption coefficient of oxygen, given by Rathbun and others (1978), is then used to compute the reaeration coefficient for the reach studied. According to Rathbun and others (1978), this relationship is independent of mixing conditions, water temperature, and water quality and provides a constant conversion factor.

Two separate analytical methods described by Rathbun and Grant (1978) can be used to calculate the desorption coefficient of the tracer gas. The "peak concentration" method, which was originally developed by Tsivoglou and others (1968), uses the conservative tracer to indicate traveltime and to adjust peak gas concentrations for dispersion. The "area" method uses the mass of tracer gas at each sampling site to compute the desorption coefficient. Both techniques have been field tested and verified by Rathbun and Grant (1978) and Grant and Skavroneck (1980). The equations used to calculate the desorption coefficient of the tracer gas are:

Peak method: $$K_{G,T} = 1/\Delta t \ \ln \left[(C_G/C_D)_u/(C_G/C_{DJ})_d\right] \tag{1}$$

Area method: $$K_{G,T} = 1/\Delta t \ \ln \left[(A_G Q)_u/(A_G Q)_d\right] \tag{2}$$

where: $K_{G,T}$ = desorption coefficient of the tracer gas at the stream-water temperature, T;
$u,d$ = subscripts signifying upstream and downstream sampling sites, respectively;
$\Delta t$ = traveltime of dye peak between the upstream and downstream sampling sites;
$C_G$ = peak concentration of gas tracer;
$C_D$ = peak concentration of dye tracer;
$Q$ = stream discharge at sampling site;
$A_G$ = area under the curve for gas concentration versus time;

$J = (QA_D)_u/(QA_D)_d$, dye-loss-correction factor

where: $A_D$ = area under the dye concentration-time curve for each sampling site.

Once the desorption coefficient of the tracer gas has been calculated, the stream-reaeration coefficient can be calculated from the following equation with the appropriate desorption ratio, R.

$$K_{2,T} = (K_{G,T})R \tag{3}$$

where: $K_{2,T}$ = stream-reaeration-rate coefficient at stream-water temperature, T;
$K_{G,T}$ = gas-tracer desorption rate at stream-water temperature, T;
R = desorption ratio for ethylene (1.15);
R = desorption ratio for propane (1.39).

The reaeration coefficient of a stream is dependent on water temperature, and coefficients must be corrected to a reference water temperature (20°C in this study) to enable comparison. The following relationship, developed by Elmore and West (1961), was used to make water-temperature adjustments to the reaeration coefficients presented herein. This relationship can also be used to calculate the stream-reaeration coefficient at any water temperature, $T_1$, given a stream reaeration coefficient at any other water temperature, $T_2$.

$$K_{2,T1} = K_{2,T2}\ (1.0241)^{(T_1-T_2)} \tag{4}$$

where: $T_1$ = reference water temperature, in °C (20°C in this report),
$T_2$ = field water temperature, in °C.

Another indicator of the degree of stream reaeration is the dissolved-oxygen-deficit ratio. This ratio is independent of traveltime and is typically used to describe the amount of reaeration occurring in stream water that passes over dams or weirs. When water flows over one of these structures, the traveltime is typically short, and the exchange of oxygen is much larger than in the reach upstream and downstream of the structure. Under these conditions, the dissolved-oxygen-deficit ratio is sometimes a more useful measure of reaeration than the reaeration coefficient. The traveltime across the hydraulic structure is generally hard to measure and entails seconds or minutes instead of hours or days, which are the typical time units used for reaeration coefficients. The dissolved-oxygen-deficit ratio is defined by the following equation:

$$r_T = (C_s-C_u)/(C_s-C_d) \tag{5}$$

where: $r_T$ = dissolved-oxygen-deficit ratio at the stream temperature, T;
$C_s$ = saturation concentration of dissolved oxygen at the stream temperature and elevation;
$C_u$ = upstream dissolved-oxygen concentration;
$C_d$ = downstream dissolved-oxygen concentration.

This ratio can also be calculated from the reaeration coefficient through the following equation:

$$r_T = \exp^{(\Delta t\ K_{2,T})} \qquad (6)$$

All dissolved-oxygen-deficit ratios presented in this report were calculated from the reaeration coefficient.

## Predictive Equations

The measurement of reaeration coefficients by dissolved-oxygen balance or tracer techniques is both time consuming and expensive. An alternative to field measurements is the use of predictive equations that relate the reaeration coefficient to hydraulic characteristics of the stream. The predictive equations currently available, however, yield widely differing reaeration coefficients for any given stream reach. For this reason, reaeration coefficients obtained from the predictive equations were compared to those measured in the field to determine which, if any, could consistently predict the observed field values with an acceptable degree of accuracy.

The 10 equations presented below were chosen from the most accurate and commonly used equations evaluated by Rathbun (1977), Grant and Skavroneck (1980), and House and Skavroneck (1980). The hydraulic values used in each are an average for the reach. $K_2$ is the reaeration coefficient to base e, calculated from the following equations, in units per day at 20°C.

| | Source | $K_2$ equation formula |
|---|---|---|
| 1. | Bennett and Rathbun (1972): | $K_2 = 20.18\ V^{0.607}\ H^{-1.689}$ |
| 2. | Churchill and others (1962): | $K_2 = 11.6\ V^{0.969}\ H^{-1.67}$ |
| 3. | Isaacs and Gaudy (1968): | $K_2 = 8.61\ VH^{-1.5}$ |
| 4. | Krenkel and Orlob (1963): | $K_2 = 234\ (VS)^{0.408}\ H^{-0.66}$ |
| 5. | Langbein and Durum (1967): | $K_2 = 7.61\ VH^{-1.33}$ |
| 6. | Negulescu and Rojanski (1969): | $K_2 = 10.91\ (V/H)^{0.85}$ |
| 7. | O'Conner and Dobbins (1958): | $K_2 = 12.27\ (VS)^{0.408}\ H^{-0.66}$ |
| 8. | Padden and Gloyna (1971): | $K_2 = 6.86\ V^{0.703}\ H^{-1.054}$ |
| 9. | Parkhurst and Pomeroy (1972): | $K_2 = 48.36\ (1+.17F^2)\ (VS)^{0.375}\ H^{-1}$ |
| 10. | Tsivoglou and Neal (1976): | $K_2 = C(\Delta h/T)$ $C = 2.64$ when $1 \leq Q \leq 10$; $C = 1.30$ when $25 \leq Q \sim 3{,}000$ |

The independent variables in the above equations are defined as follows:

$g$ = acceleration due to gravity, 32.2 ft/s$^2$;
$H$ = mean hydraulic depth, in feet;
$V$ = mean velocity, in ft/s;
$s$ = slope of energy grade line, in ft/ft;
$\Delta h$ = decrease in water-surface elevation from upstream end to downstream end, in ft;
$T$ = traveltime, in hours;
$Q$ = discharge, in ft$^3$/s
$F$ = Froude number = $V/(gH)^{1/2}$

## METHODS OF DATA COLLECTION AND COMPUTATION OF REAERATION COEFFICIENTS

Reaeration coefficients were calculated from the 10 predictive equations and from the gas- and dye-tracer measurements. Procedures for types of computations are described below.

### Field Methods

The hydrocarbon gas-tracer method was performed as follows: (1) simultaneous injection of the tracer gas and dye into the stream, (2) measurement of stream discharge and water temperature at two or more downstream sampling sites, (3) timed sampling of the tracers at the sampling sites, and (4) analysis of water samples to obtain dye and gas concentrations, from which the reaeration coefficients were calculated.

Gas cylinders equipped with regulators, and rotometers (flow meters) were used to inject and monitor the flow of gas, either propane or ethylene, through porous stone or tile diffusers submerged in the stream. These diffusers are similar to those used for aeration in sewage-treatment facilities. The porous tile diffusers, which have a 2-μ pore size, were used at all but Canadaigua Outlet, where porous stone diffusers were used. Dye solution was injected into the stream from graduated cylinders through plastic tubing by special flow-calibrated laboratory pumps. The period of gas and dye injection typically lasted from 20 minutes to 2 hours, depending on stream size and flow rate.

Stream discharges were measured by a current meter in accordance with U.S. Geological Survey stream-gaging methods described by Buchanan and Somers (1969). Water temperature was measured with a calibrated liquid column thermometer accurate to within $\pm$ 0.5°C.

Samples for dye analysis were collected in 35-mL screw-cap vials after each sample bottle was first rinsed with river water. Continuous flow-through fluorometers were used at some locations to monitor the dye for sample-scheduling purposes. Hydrocarbon-gas samples were collected in 45-mL glass bottles with Teflon seal caps. At the Canandaigua reach, gas samples were collected by hand or grab-type sampler. At all other streams, a displacement-type sampler was used that flushed the sample bottle about three times before filling. To each bottle, 1 mL of reagent-grade formalin solution was added to inhibit biological degradation during shipping. Both the dye and gas samples were stored out of direct sunlight. A few gas samples developed bubbles during shipping and storage, but these constituted less than 15 percent of the total number of samples. Samples that contained bubbles were noted at the laboratory and analyzed but were not used in calculations because gas leaving solution would give a low concentration value.

The gas samples collected in the field were sent to the U.S. Geological Survey Central Laboratory in Doraville, Ga., for analysis, where propane and (or) ethylene gas concentrations were measured by gas chromatography according to methods of Shultz and others (1976). Gas concentrations were corrected for the addition of formalin to the sample. Dye samples were analyzed at the U.S. Geological Survey office in Albany, N.Y., by fluorometric procedures of Wilson (1968).

Reaeration coefficients were computed from dye and gas concentrations for each stream reach by eq. 1 for the "peak" technique described by Rathbun and Grant (1978). The "area" method, also described by Rathbun and Grant (1978), uses equation 2, which requires a large number of samples. It was therefore applied only to one reach of the Hudson River. The reaeration coefficients and other pertinent data are summarized in table 1.

*Table 1.-- Reaeration-measurement data.*

(Reach locations are shown in figs. 2-7.)

| Stream reach[1] | Date | Discharge[2] ($ft^3/s$) | Travel-time (hours) | Reaeration coefficient at 20°C (units/day) | Oxygen deficit ratio at 20°C[5] |
|---|---|---|---|---|---|
| Canandaigua Outlet | | | | | |
| 1-2 | 7-19-78 | 8.00 | 16.35 | [4]0.77 | — |
| 2-3 | 10-24-78 | 23.8 | 9.00 | [4]1.8 | — |
| 3-4 | 10-23-78 | 53.4 | 5.67 | [4]18 | — |
| Oswego River | | | | | |
| 1-3 | 8-12-79 | 1,600 | 2.42 | 4.6 | 1.6 |
| 1-4 | 8-12-79 | 1,600 | 2.92 | 9.7 | 3.2 |
| 1-5 | 8-12-79 | 1,600 | 5.14 | 9.5 | 7.6 |
| 3-4 | 8-12-79 | 1,600 | 0.50 | 35 | 2.1 |
| 3-5 | 8-12-79 | 1,600 | 2.72 | 14 | 4.8 |
| 4-5 | 8-12-79 | 1,600 | 2.22 | 6.0 | |
| Hudson River | | | | | |
| 1-3 | 7-17-79 | 3,900 | 2.07 | 4.1 | 1.4 |
| 1-3 | 7-13-80 | 1,500 | 3.00 | 3.1 | 1.5 |
| 1-5 | 7-13-80 | 1,500 | 7.75 | 2.3 | 2.1 |
| 2-3 | 7-13-80 | 1,500 | 0.67 | [5]9.8 | [5]1.4 |
| 2-5 | 7-13-80 | 1,500 | 5.42 | 2.8 | 1.9 |
| 3-5 | 7-13-80 | 1,500 | 4.75 | 1.8 | |
| Cayadutta Creek | | | | | |
| 1-2 | 8- 4-81 | 29.3 | 2.75 | 52 | — |
| Chenango River | | | | | |
| 1-2 | 8- 5-81 | 2.37 | 6.47 | 12 | — |
| Payne Brook | | | | | |
| 1-2 | 8- 6-81 | 13.1 | 11.14 | 3.7 | — |

[1] Hyphenated numbers indicate upstream and downstream sampling site.
[2] Reach average.
[3] Calculated from reaeration coefficient.
[4] Average reaeration coefficient calculated from ethylene tracer data and propane tracer data.
[5] Average of area and peak methods.

## Predictive Equations

The predictive equations require a set of reach-averaged hydraulic data for each stream reach; these were obtained from U.S. Geological Survey 7 1/2-minute topographic maps and field measurements. The hydraulic values used in the predictive equations for all stream reaches studied are summarized in table 2. The terms used in these equations are explained below.

Mean velocity, flow area, and depth of stream reach.--These were calculated through the following equations:

mean velocity (ft/s) = reach length / dye traveltime
mean flow area ($ft^2$) = reach-averaged discharge / mean velocity
mean depth (feet) = mean flow area / mean water-surface width

Traveltime, stream discharge (reach-average), and mean water-surface width.--These were calculated from the field data gathered during the reaeration measurements. Additional water-surface-width data on the Oswego and Hudson Rivers were obtained from topographic maps.

*Table 2.--Hydraulic values used in predictive equations to obtain stream-reaeration coefficients*[1].

(Equations are listed on p. 4-6; locations are shown in figs. 2 through 7)

| Stream reach[2] | Date | Length (ft) | Fall (ft) | Slope (ft/ft) | Mean depth (ft) | Velocity (ft/s) | Discharge[3] ($ft^3/s$) | Travel time (h) | Froude number |
|---|---|---|---|---|---|---|---|---|---|
| Canandaigua Outlet | | | | | | | | | |
| 1-2 | 7-19-78 | 8,450 | 2.0 | $2.4 \times 10^{-4}$ | 1.5 | 0.14 | 8.00 | 16.35 | 0.02 |
| 2-3 | 10-24-78 | 8,980 | 11.0 | $1.2 \times 10^{-3}$ | 1.4 | .28 | 23.8 | 9.00 | .04 |
| 3-4 | 10-23-78 | 14,260 | 41.3 | $2.90 \times 10^{-3}$ | 1.2 | .70 | 53.4 | 5.67 | .11 |
| Oswego River | | | | | | | | | |
| 4-5 | 8-12-79 | 3,960 | .08 | $2.0 \times 10^{-5}$ | 6.7 | .45 | 1,600 | 2.22 | .03 |
| Hudson River | | | | | | | | | |
| 3-5 | 7-13-80 | 9,100 | .18 | $2.0 \times 10^{-5}$ | 5.7 | .53 | 1,500 | 4.75 | .04 |
| Caydautta Creek | | | | | | | | | |
| 1-2 | 8- 4-81 | 10,930 | 105 | $9.61 \times 10^{-3}$ | .6 | 1.10 | 29.3 | 2.75 | .25 |
| Chenango River | | | | | | | | | |
| 1-2 | 8- 5-81 | 5,820 | 19.6 | $3.37 \times 10^{-3}$ | .6 | .25 | 2.37 | 6.47 | .06 |
| Payne Brook | | | | | | | | | |
| 1-2 | 8- 6-81 | 6,330 | 7.5 | $1.2 \times 10^{-3}$ | 2.8 | .16 | 13.1 | 11.14 | .02 |

1 Data not given for stream reaches with dams.
2 Numbers indicate upstream and downstream sampling site of each reach. Locations are shown in figures 2 through 7.
3 Reach average.

Stream-reach length and change in water-surface elevation (slope).--These were measured on U.S. Geological Survey 7 1/2-minute topographic maps. Reach slopes of the Chenango River and Payne Brook were also measured by field level surveys. The results agreed closely with those derived from the topographic maps. Reach slopes of the Oswego and Hudson Rivers were calculated from water-surface-elevation data collected at the Barge Canal locks upstream and downstream from the study reach.

The Froude number.--This was calculated from the above-mentioned stream characteristics through the equations given in the preceding section.

## CRITERIA FOR SITE SELECTION

Reaeration measurements were made on six streams in the central part of New York--Canandaigua Outlet near Canandaigua, Oswego River at Fulton, Hudson River at Fort Miller, Cayadutta Creek near Johnstown, Chenango River near Morrisville, and Payne Brook near Hamilton (fig. 1). Multiple reaeration measurements were made on the Canandaigua Outlet and the Hudson River.

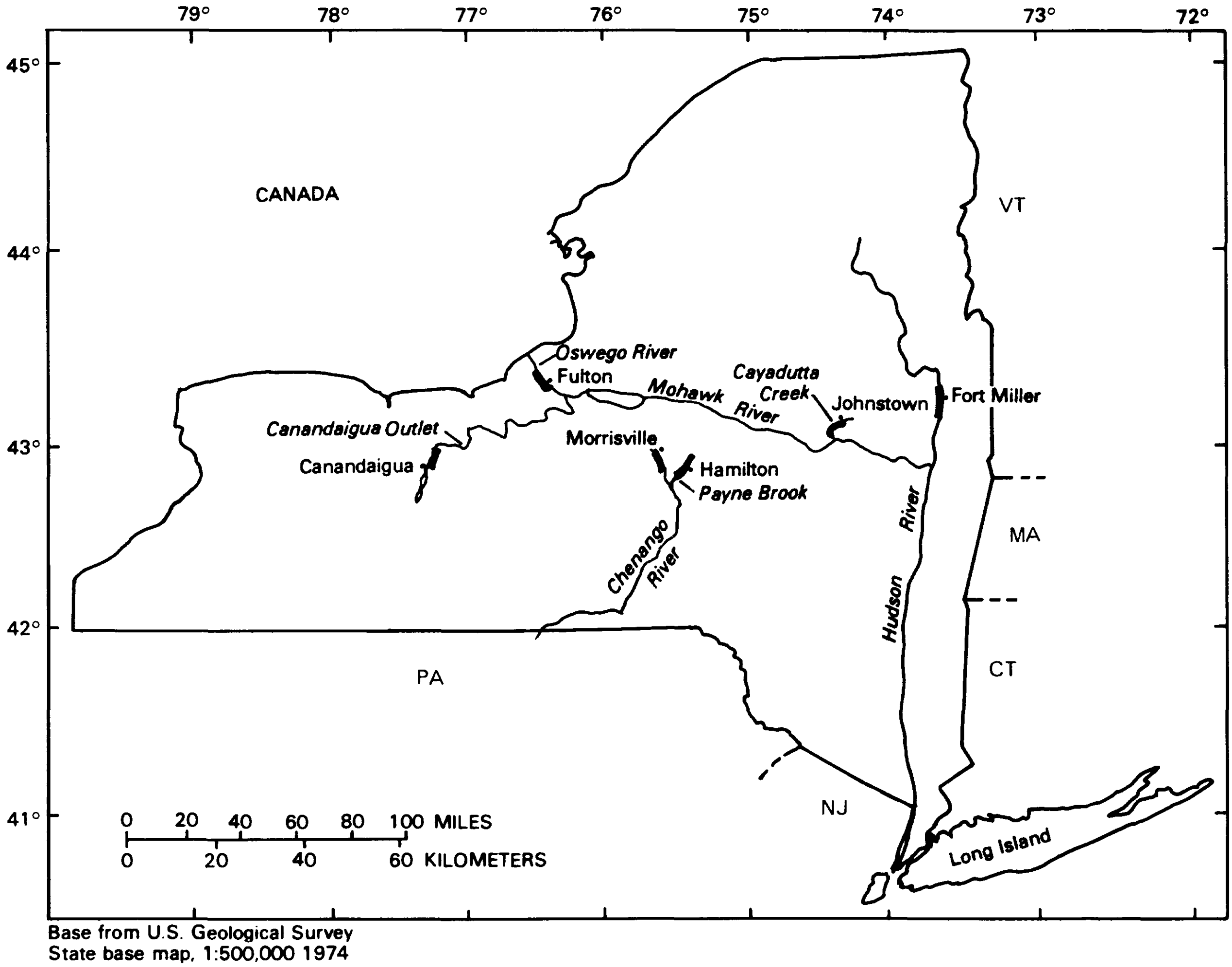



*Figure 1.--Locations of streams studied in New York. (Site maps are given in figs. 2 through 7.)*

Canandaigua Outlet was chosen as the site for the first hydrocarbon-gas tracer measurements because it is the site of earlier measurements by Tsivoglou (1974) who used radioactive tracers. These first measurements were intended to verify that the hydrocarbon-tracer technique was an acceptable alternative to the radioactive-tracer method for streams in New York. The remaining five streams were chosen from a group of several whose water quality is of special interest to the New York State Department of Environmental Conservation. The sampling sites were selected to provide a wide range of stream discharge, turbulence, and channel geometry to enable a broad evaluation of the predictive equations.

## SITE DESCRIPTIONS

This section describes the physical characteristics of each site studied and summarizes the field procedures used at each. The sites are given in chronological order by sampling date. All reaches are designated by the upstream and downstream sampling site numbers. For example, reach 1-2 is the section between sampling sites 1 and 2. (See fig. 2.)

### Canandaigua Outlet

Canandaigua Outlet flows northward from Canandaigua Lake to the Oswego River (fig. 2). The lake actually has two outlets--the natural meandering streambed and the Feeder Canal, a manmade channel 3,000 ft to the west. These outlets join approximately 1.5 mi north of the lake. Effluent from the Canandaigua sewage-treatment facility discharges to the Feeder Canal 1/2 mi below the lake, and the reach selected for study begins just upstream (south) of the junction of the two outlets. Both outlets are regulated by structures at the lake, but during the reaeration studies, flow from the lake to the main outlet was halted, and flow to the Feeder Canal was held at a constant rate to help provide "steady state" conditions.

The sampling area extends from the first injection site near the lake on the Feeder Canal to Littleville, 7 mi downstream. The four sampling sites were, in downstream order, at Phelps Street, Castle Road, Chapin, and Littleville. The three reaches between the sampling sites differ in slope, width, depth, turbulence, and water quality, as determined by a concurrent water-quality survey conducted by New York State Department of Environmental Conservation. Major geographic features and locations of the injection sites and sampling sites are shown in figure 2.

#### *Hydraulic Characteristics*

Stream characteristics vary significantly along the study reach. The streambed is rocky in places and silty in others and contains several deep pools with low velocity. Weed growth can be substantial, especially in late summer. Depth ranges from a few inches to 5 ft, width ranges from 5 ft to more than 100 ft, and velocities vary accordingly. The slope of the streambed is nearly flat (approximately 1 ft/mi) in the first 2 mi below the lake but gradually increases to 15 ft/mi near Littleville. A long-term U.S. Geological Survey gaging station is maintained at Chapin.

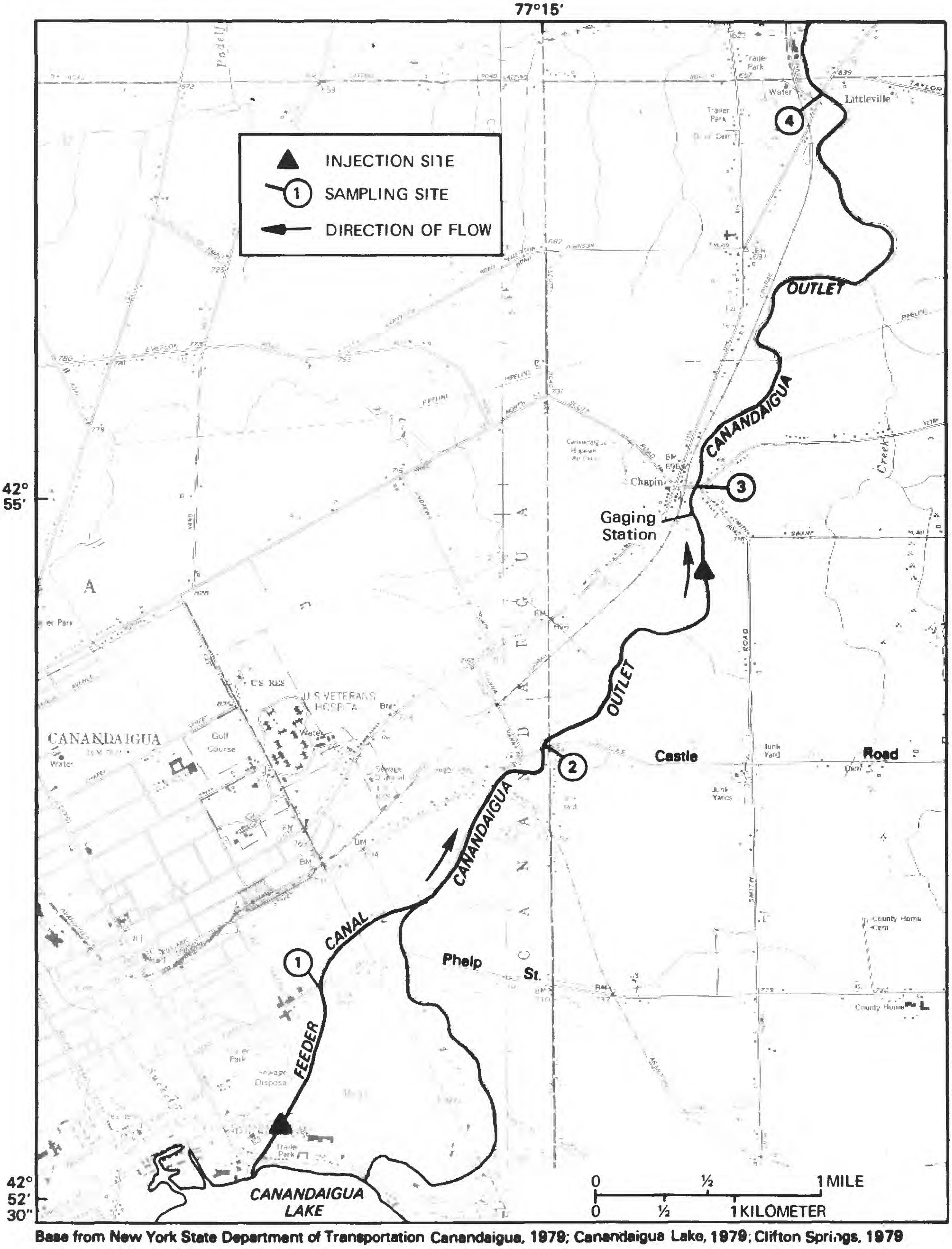



*Figure 2.--Location of injection and sampling sites on Canandaigua Outlet.*

Reach 1-2 has a relatively flat slope, poor water quality (depressed oxygen concentration; high biochemical oxygen demand [BOD]), and uniform channel geometry. Reach 2-3 has improved water quality because suspended organic materials have partly settled out, and natural waste-assimilation processes have taken effect. Rooted aquatic vegetation was observed in places, and streambed characteristics range from deep, wide pools to intermittent riffles. Reach 3-4 has much improved water quality because the stream changes from pool and riffle to turbulent, fast moving, and relatively shallow, which enables faster BOD assimilation due to the increased reaeration rate.

### *Reaeration Measurements*

Three reaeration measurements were conducted on Canandaigua Outlet. The first, in June 1978, was intended to familiarize participants with the field techniques and helped ascertain the amount of gas required for injection to ensure detectable concentrations downstream. Results of the first survey were inadequate for determining reaeration coefficients but accomplished the first two objectives. Subsequent measurements were made in July and October 1978 to compare results of the hydrocarbon-gas-tracer technique with those of Tsivoglou's earlier work (1974) with radioactive tracers on this stream.

Ethylene and propane were used as the hydrocarbon gas tracers for the studies, and rhodamine-WT dye was used as the conservative tracer. Porous stone tube diffusers were placed in the center of the streamflow for gas injection. Because the two gases differ in solubility, two diffusers were used for propane and one for ethylene. Injection sites were 0.6, 0.4, and 0.5 mi upstream from cross sections 1, 2, and 3, respectively. For each test, the quantity of injected dye ranged from 1.6 L to 6.5 L, and both hydrocarbon-gas quantities ranged from 1.5 kg to 7 kg. The quantities depended on streamflow, reach length, and estimated reaeration rate for each reach at the time of the measurement.

Samples were collected in 45-mL screw-cap glass vials with Teflon liners during the July and October measurements because gas bubbles had formed in the 60-mL BOD bottles used in the June measurement. Gas samples were collected when peak dye concentrations were observed. The stream discharge was also measured at each site during the sampling.

Reaeration coefficients, discharge, and traveltimes from the July and October studies are summarized in table 1. No coefficients were calculated for reaches 2-3 and 3-4 during the July study because gas concentrations at the downstream sampling sites were below the analytical detection limit of 0.01 µg/L. These low concentrations probably resulted from three conditions--small discharge, shallow depth, and high water temperature, explained as follows, (1) The extremely low streamflow resulted in long traveltimes, and, because gas loss is a product of the transfer coefficient and traveltime, either too much traveltime was allowed, or reach lengths for these flow conditions were excessive. (2) Stream depths of less than 1.5 ft at injection sites reduced the efficiency of the injection process. (3) High water temperatures (23.5°C to 25.0°C) reduced the solubility of the gases.

Reaeration coefficients calculated from gas-tracer data were consistently higher for ethylene than for propane. Similar observations were made by

Rathbun and Grant (1978) in studies on Black Earth Creek and the Madison effluent channel in Wisconsin. In general, ethylene, which is an unsaturated hydrocarbon, is more chemically reactive than saturated hydrocarbons such as propane. Also, hydrocarbons are known to be chemically reactive with halogens such as fluorine and chlorine, especially in the presence of sunlight. Although halogens are not normally found in stream waters in signficant concentrations, except downstream of industrial or domestic sewage-treatment plants, they would be expected downstream of sewage-treatment plants where residual chlorine in the effluent is required by State regulations. All three of the above-mentioned stream reaches are downstream of sewage-treatment plants; therefore, the differences in desorption coefficients between ethylene and propane is probably due to chemical reactions.

Canandaigua Outlet was the first stream in New York for which reaeration coefficients were measured by the hydrocarbon-gas technique. Refinements in sampling procedure, estimation of gas quantities to be injected, diffuser design, and sample handling on other stream reaches resulted from the initial effort on Canandaigua Outlet.

## Oswego River

The study reach on the Oswego River was a 2.65-mi section starting 1.2 miles upstream of Lock 2 and extending north over two dams to the north side of Fulton (fig. 3). Five sampling sites were established; the downstream sampling site was near the Fulton sewage-treatment plant. Locations of major geographic features, sampling sites, and the injection site are shown in figure 3.

The Oswego River at Fulton is part of the State-operated Oswego Canal, which is a major navigation course. The navigation channel in the river is along the east bank of most of the reach. Only the injection site and sampling site 5 are in the navigation channel. Two hydroelectric powerplants are at the upstream dam, and two more are at the downstream dam. Only two of these plants were active during the study--one on the east side of the upstream dam and one on the west side of the downstream dam. Hydraulic head across the first dam is 17 ft and at the second dam is 27 ft.

### *Hydraulic Characteristics*

The river channel, which is manmade and walled in parts of the reach, has an average streambed slope of 1.1 ft/mi and a streambed composition ranging from mud to ledge and gravel. The steam-channel width ranges from 600 ft at the injection site up to 900 ft at sampling site 5. The depth typically ranged from 10 to 12 ft in the navigation channel and upstream of the dams and from 1 to 3 ft downstream of the spillway of the second dam.

### *Reaeration Measurements*

Reaeration measurements were made on the Oswego River at Fulton on August 12 and 13, 1979. The river discharge remained virtually constant at

1,600 ft³/s during the measurement, and the average stream velocity as determined from the dye tracers was 0.76 ft/s. On the morning of August 13, 1979, heavy fog made sampling at site 5 both difficult and hazardous. The river-water temperature was between 22.0°C and 23.5°C during the entire measurement.

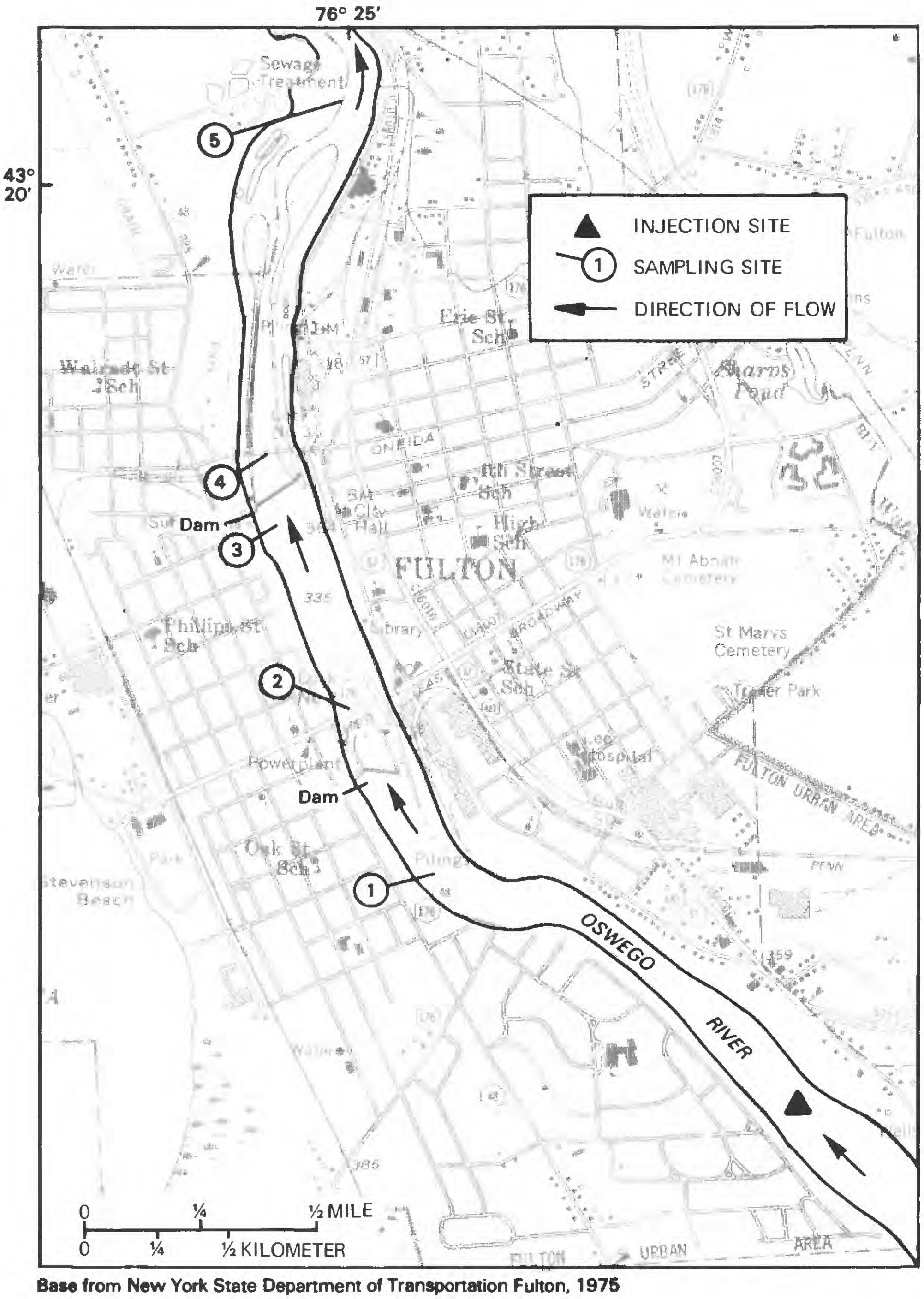



*Figure 3.--Location of injection and sampling sites on the Oswego River.*

Ethylene gas and dye were injected from two boats anchored near the navigation channel. The gas was bubbled through six porous tile diffusers anchored on the river bottom near the center of the channel. Dye was injected by two peristaltic pumps that pumped the dye through Tygon tubing to the injection site at each gas diffuser. Water vapor often froze on the gas regulators from the refrigeration effect of the expanding gas, making it difficult to maintain a constant flow rate through the regulator and flow meter. A total of 13.8 kg of ethylene gas and 43.3 L of dye were injected into the river during the 105-min injection period.

Grab samples were collected for dye and gas analysis from boats and bridges at the five sampling sites downstream from the injection site. The gas samples that were later analyzed were chosen on the basis of results of the dye analysis. A flow-through fluorometer was placed at sampling sites 1 and 5 to indicate when sampling should begin and end.

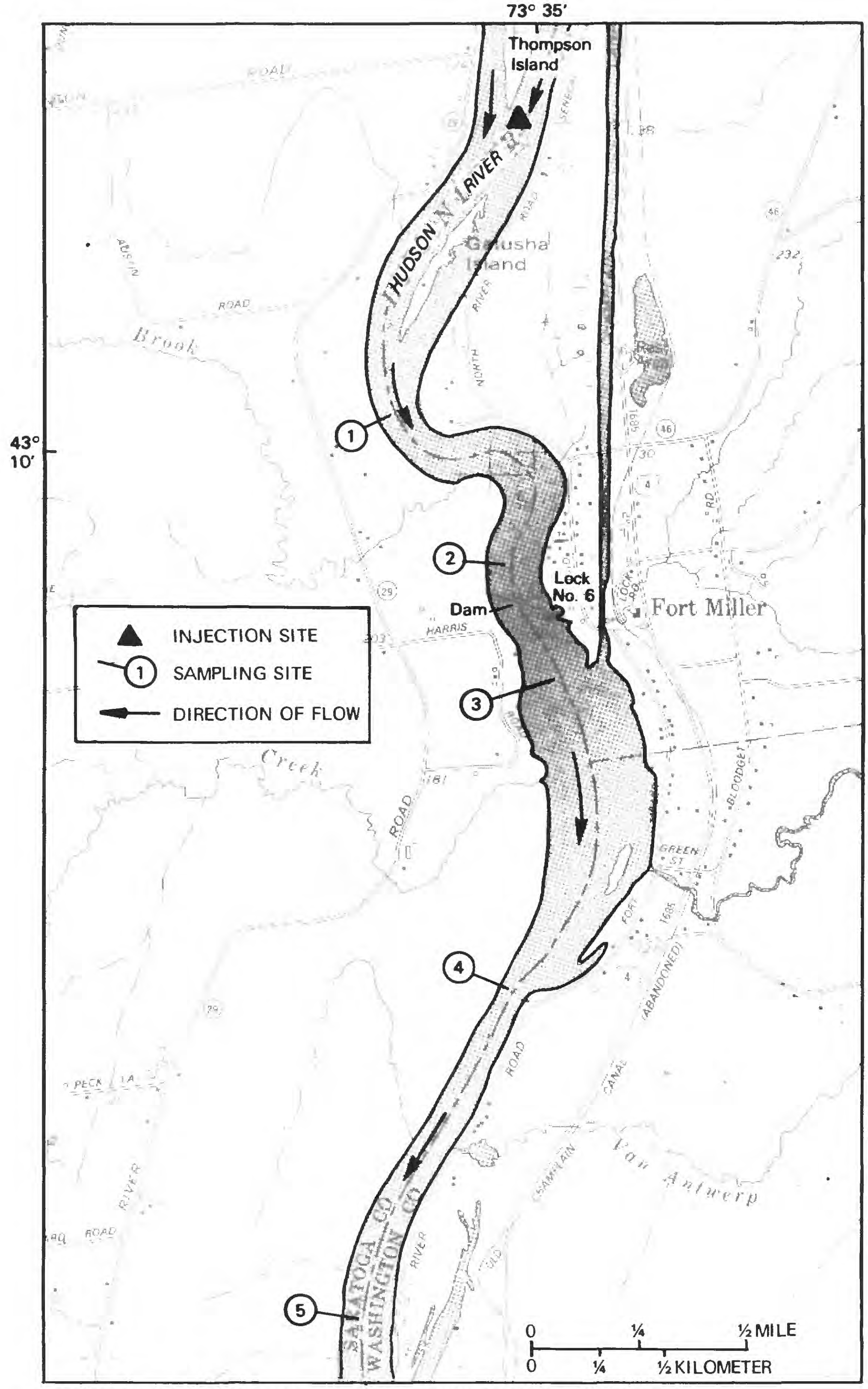
Two discharge measurements were made by current meter--one at the bridge below Lock 2, the other at the Hinmansville Bridge 5 mi upstream from the study reach, to measure the inflow. These two discharge measurements, combined with pool-elevation records and powerplant-operation records, were used to compute the slight variations in flow that occurred just before and during the reaeration measurement.

Both powerplants were shut down on August 12 with plans to remain down until 0800 hours on August 13 so that all river flow would pass over the dam. However, the rising stage of the river pool upstream from the first powerplant and the potential flooding necessitated the release of some of the water through the hydroelectric generating facility. Fortunately, a constant river flow rate through Fulton was obtained before the dye and gas reached the first sampling site, and no lockages occurred during the study to disrupt the flow. However, the diversion at the first powerplant resulted in a failure to sample the centroid of the tracer at site 2; therefore, the data from that site could not be used for calculating reaeration coefficients.

The reaeration coefficient for the entire Oswego River reach through Fulton was 9.5 per day with a 5.1-hour traveltime for a flow of 1,600 $ft^3/s$. This relatively high coefficient is attributed to the two large dams in the middle of the reach. The reaeration coefficient and the oxygen-deficit ratio for the first dam could not be calculated because sampling site 2 was incorrectly located. However, the reaeration coefficients and dissolved-oxygen-deficit ratios for the reach from sites 1 through 3, which includes the first dam, and all other reaches studied, were successfully measured (table 1).

## Hudson River

The Hudson River study reach was a 3.5-mi reach starting at the downstream end of Thompson Island, approximately 5 mi south of Hudson Falls, and extending southward past the dam at Fort Miller (fig. 4). Most of this reach is part of the New York State Champlain Canal. The reach between Thompson Island and the Fort Miller Dam is not a part of the navigation channel, however, but is a free-flowing section between locks. The river channel ranges in width from 400 ft on either side of Thompson Island to 1,200 ft




Base from New York State Department of Transportation Fort Miller, 1967

*Figure 4.--Location of injection and sampling sites on the Hudson River.*

about 0.05 mile downstream of the dam. A small hydroelectric powerplant is on the east bank of the Fort Miller Dam. The 11 ft of hydraulic head at this dam is used for power generation. Powerplant operations were suspended during this study.

### *Hydraulic Characteristics*

The river banks along this reach are steep and covered with heavy brush and trees. Heavy growths of aquatic vegetation develop seasonally in backwater areas. The streambed is composed mostly of muck except immediately below the Fort Miller dam, where it consists mostly of cobbles and rock ledges. The river depth ranges from 8 ft at the injection site to 22 ft in the navigation channel at sampling site 5. The streambed slope above and below the dam averages 2 ft/mi.

### *Reaeration Measurements*

Two reaeration measurements were made--the first on July 19, 1979, the second on July 13, 1980. The river discharge increased from 3,700 $ft^3/s$ to 4,100 $ft^3/s$ during the 1979 measurement, and the average stream velocity over the entire reach, as determined from the dye tracers, was 0.59 ft/s. During the 1980 measurement, the river flow decreased from 1,800 $ft^3/s$ to 1,200 $ft^3/s$, and the mean velocity for the reach was 0.51 ft/s. The river-water temperature averaged 27.0°C during the 1979 study and 23.5°C in 1980. The hydroelectric plant on the east bank of the Fort Miller dam was shut down during both measurements, and all river flow passed over the dam.

During the 1979 measurement, ethylene gas and rhodamine WT dye were injected into the river in the center of both channels at Thompson Island. Two diffusers and one dye-injection line were placed in each channel. In 1980, the entire flow area of both channels was divided into six equal areas, and a porous tile diffuser was then placed in the centroid of each. Dye was injected at three of the areas. The dye and gas injection lasted 2 hours. In the 1979 measurement, 51.8 L of dye and 6.6 kg of gas were injected, but in 1980, only 23.1 L of dye and 10.1 kg of ethylene gas were injected. During both measurements, freezing water vapor on the gas regulators made a constant rate of ethylene flow difficult to maintain, as in the Oswego River measurement.

Samples for dye and gas analysis were taken from boats at each sampling section. During the 1979 study, samples were collected at only one spot in each cross section--the estimated centroid of flow. Dye concentrations were analyzed in the field at the time of collection to determine when gas samples should be taken. Only sites 1, 2, and 3 were sampled during the 1979 measurement. The analysis of section 2 data indicated that the dye was incompletely mixed and that the samples had not been collected at the centroid of flow. In 1980, samples were collected at three locations at section 1, at five locations at sections 2 and 3, and at one location at sections 4 and 5. At sections 1, 2, and 3, the river cross section was divided into areas of equal flow, and each was sampled at its centroid. Analysis of these data indicate that the dye and gas tracers were completely mixed by the time they had reached cross section 2.

The river-discharge variations during both measurements were estimated from discharge data collected at the Fort Edward gaging station, 8.5 mi upstream from the dam at Fort Miller, then routed downstream with a diffusion analogy routing model. A current meter and two dye-dilution discharge measurements were made during the 1980 study along with a continuous record of stage data at the injection site and just upstream of the dam. These three discharge measurements and the stage data were used to calibrate and verify the routing model, which was used to compute flows during the 1979 measurement.

The oxygen-deficit ratios (table 1) calculated for the Fort Miller dam during the 1979 and 1980 measurements are almost the same, even though the flows were significantly different. However, the reaeration coefficients differ significantly as a result of the 1-hour difference in traveltime. During the 1980 study, the reaeration coefficient measured over the dam was calculated by both the area and peak methods described by Rathbun and Grant (1976); the peak method yielded a value of 9.7 per day and the area method gave a value of 9.9 per day—a difference of 2 percent. The excellent agreement between these two values indicates that either method will probably give acceptable results.

## Cayadutta Creek

Cayadutta Creek is a small, steep, fast-moving stream that flows into the Mohawk River at Fonda, N.Y. The study reach starts just upstream of the Johnstown sewage-treatment plant and runs 2.1 mi westward to Sammonsville. The locations of the injection site and the two sampling sites are shown in figure 5. The upstream sampling site was at the Union Avenue bridge, approximately 100 ft upstream of the sewage-treatment-plant outfall. The downstream sampling site was in Sammonville at the route 334 bridge.

### *Hydraulic Characteristics*

The streambed in the 2.1-mi study reach averages 30 ft in width and is composed mostly of gravel, rocks, and ledges. The creek's 0.6-ft mean depth remained fairly constant throughout the reach. This reach has a slope of 51 ft/mi—the steepest among the six streams studied.

### *Reaeration Measurement*

The reaeration measurement on Cayadutta Creek near Johnstown was made on August 4, 1981. The average river-water temperature was 24.0°C. Foam 1 to 3 ft thick was floating on the water for several hundred yards downstream from the Johnstown sewage-treatment-plant outfall, and patches of foam were seen even at the sampling site 2.1 mi downstream. Creek water had an odor and brown hue caused by the sewage-treatment plant, which discharges a waste equivalent of about 1,000 lb/d of biochemical oxygen demand (BOD). This large organic loading is due mostly to tannery and domestic effluent.

Rhodamine-WT dye and propane gas were injected into the creek upstream of the sewage-treatment plant outfall. Two porous tile diffusers and one 9-kg propane cylinder with a regulator were used to inject the gas. A positive displacement pump was used with a 20-L container of dye solution to inject the dye. The injection lasted 35 minutes, and 1.7 kg of propane and 0.2 L of dye were injected. Complete lateral mixing of both tracers occurred upstream of the first sampling site.

The dye concentration was monitored by a fluorometer at both sampling sites, and water samples were collected at both sampling sites to define the relationship between dye concentration and time. Samples for propane analysis were collected only when the dye concentration neared its peak. The creek discharge was also measured at each site during the sampling.

Cayadutta Creek had the largest reaeration coefficient of the six rivers studied--52 units per day. This extremely high value is attributed to the steep slope and the wide, shallow, rocky character of the streambed, which cause constant turbulence.

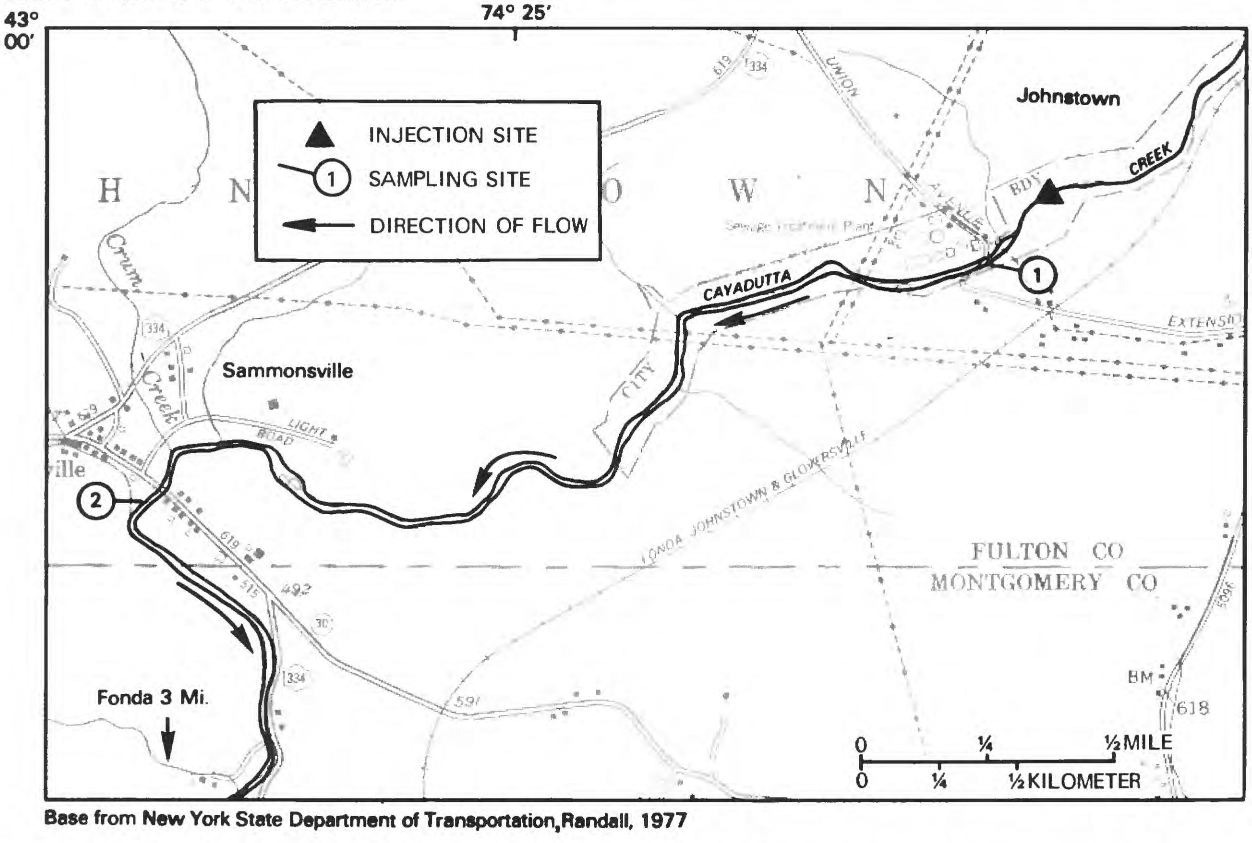



*Figure 5.--Location of injection and sampling sites on Cayadutta Creek.*

## Chenango River

The Chenango River flows southward from just north of Morrisville to the Susquehanna River at Binghamton. The 1.1-mi study reach is just south of Morrisville (fig. 6). Two sampling sites were used--one at the Route 105 bridge, 100 ft upstream of the Morrisville sewage-treatment plant outfall; the other was at the abandoned South Road bridge site. Locations of the injection and sampling sites are shown in figure 6. The Chenango River in this reach meanders through pastureland and forms small pools and riffles. This reach has only one major tributary--the Electric Light stream, which enters the reach 1,000 ft upstream of the lower sampling site.

*Hydraulic Characteristics*

The Chenango River streambed, which is composed mostly of silty sand and gravel, has a slope of 18 ft/mi and ranges from 4 to 25 ft in width in the study reach. The depths typically vary from 0.2 ft in the riffles to 1 ft in the pools.

*Reaeration Measurement*

A reaeration measurement was made on August 5, 1981. Effluent discharge from the Morrisville sewage-treatment plant was relatively small because the college at Morrisville was not in session. The river-water temperature averaged 20.5°C during the measurement.

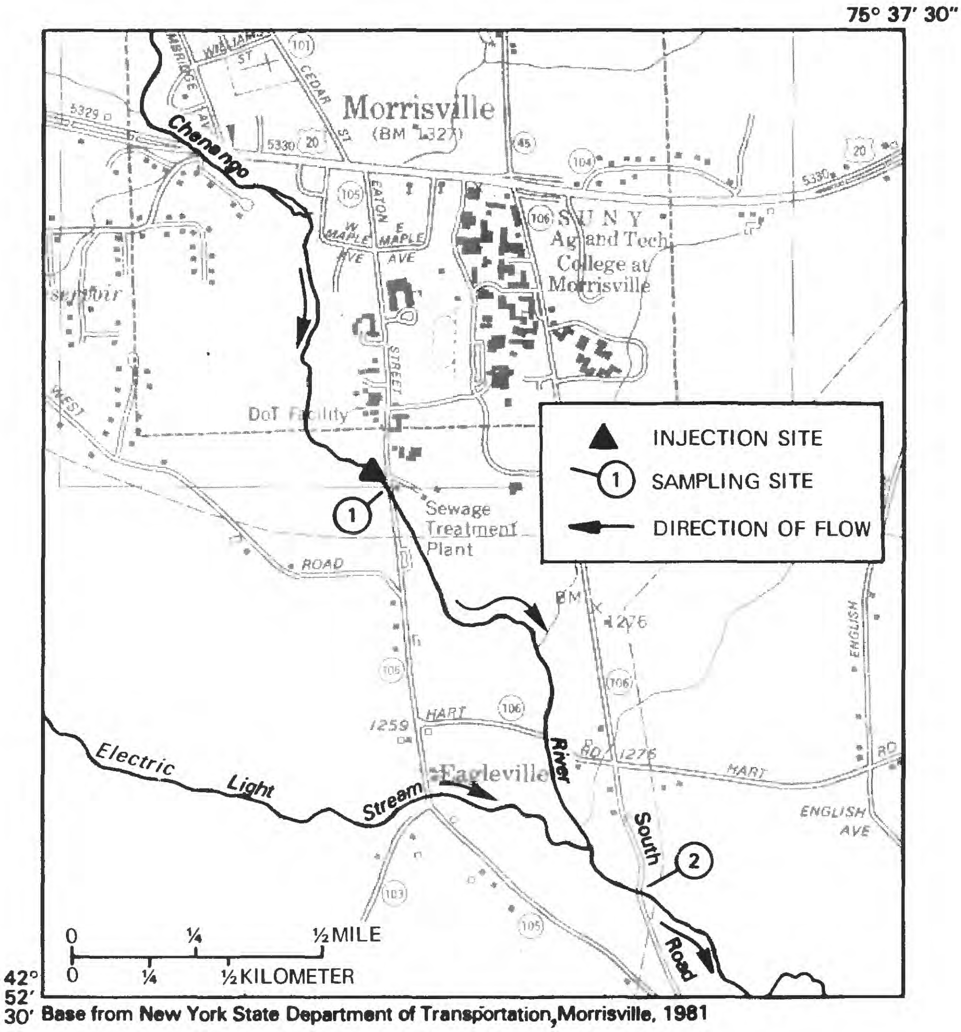



*Figure 6.--Location of injection and sampling sites on the Chenango River.*

Dye and propane gas were injected into the river and sampled with the same equipment and by the same procedures as at Cayadutta Creek. The injection lasted 45 minutes, during which time 1.6 kg of propane and 0.8 L of dye were used. This large injection of propane caused a high peak propane concentration of several hundred parts per billion at the first sampling site, but the peak concentration at the downstream site was only 1/100 as large because the reaeration coefficient is fairly large--12 units per day. The river discharge was also measured at each site during the sampling.

## Payne Brook

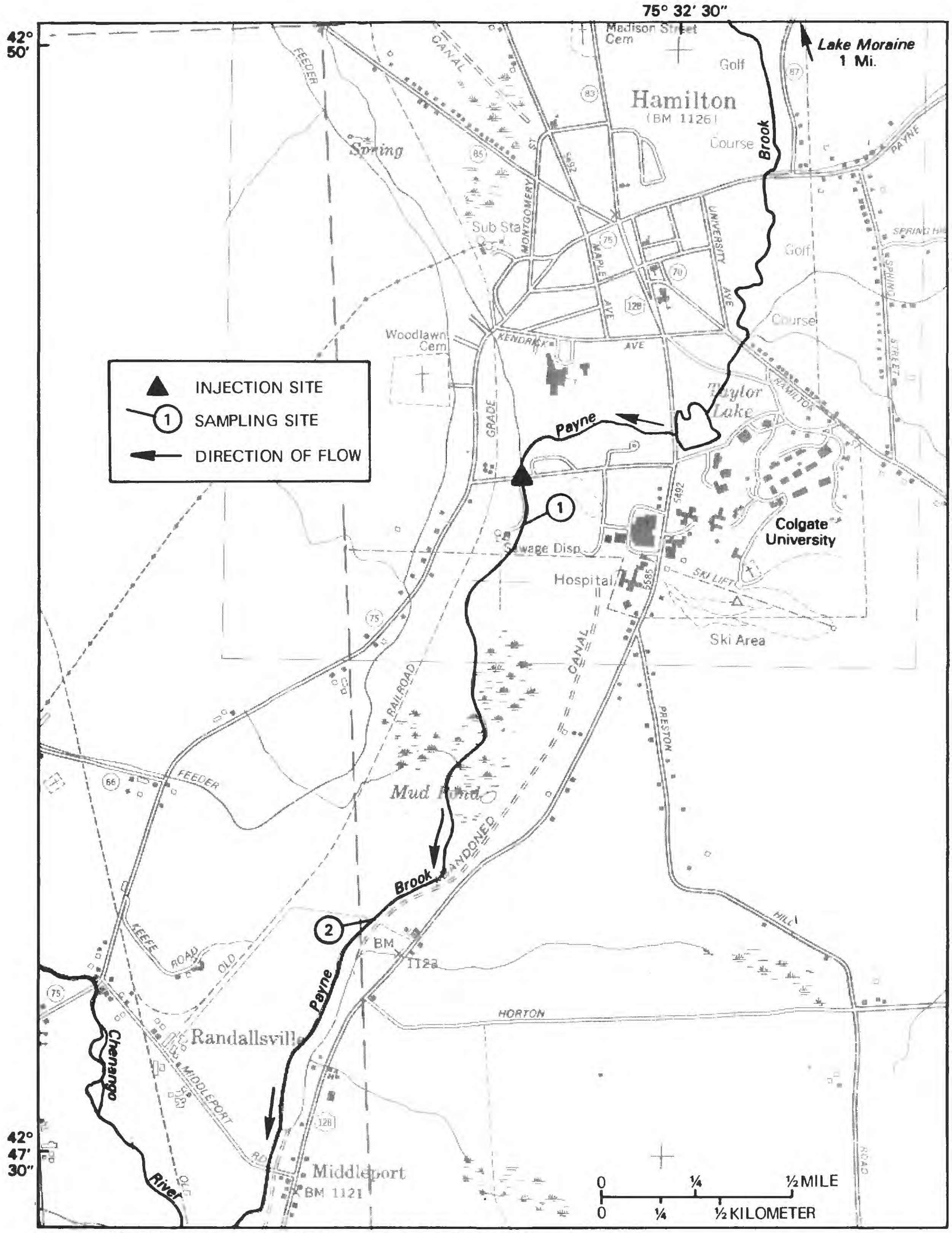
Payne Brook, the last of the six streams studied, begins at the outlet of Lake Moraine and flows southwestward 4.5 mi to its mouth on the Chenango River at Randallsville. The study reach extends 1.3 mi south-southwestward from Hamilton (fig. 7). The upstream sampling site was just upstream of the Hamilton sewage-treatment plant outfall; the downstream sampling site was at a bridge over the stream at an unpaved farm road 1.2 mi downstream. Between the two sites is a swamp known as Mud Pond. Locations of the injection site and sampling sites are shown in fig. 7.

### *Hydraulic Characteristics*

The streambed, composed of muck and silty sand, has a slope of 6 ft/mi. Considerable amounts of algae and water plants were observed in some parts of the stream during the field measurements. This reach, which averaged approximately 15 to 20 ft in width, is 2.5 ft deep and slow moving, without significant riffles. Flow was obstructed in places by fallen trees and other debris.

### *Reaeration Measurement*

The reaeration measurement on this reach was made on August 6, 1981. The Hamilton sewage-treatment plant was discharging a relatively small waste load because Colgate University was not in session at the time. The stream-water temperature averaged only 16.5°C, probably because most of the stream is deep, narrow, and shaded by trees. During the 45-min injection period, 1.4 kg of propane gas and 0.4 L of rhodamine-WT dye were injected into the stream. The injection and sample collection were performed with the same equipment and procedures as on Cayadutta Creek. The stream discharge was also measured at each site during the sampling. The traveltime of the gas and dye was noticeably longer than had been estimated from data obtained during two previous time-of-travel measurements made during the 1970's. The reason for this decrease has not been determined. The 11.1-hour traveltime between sites 1 and 2 caused the dye and gas curves at site 2 to have small peaks and a long duration. The reaeration coefficient of 3.7 units per day for this reach is relatively large for the stream's slow movement.



Base from New York State Department of Transportation, Hamilton, 1981

*Figure 7.--Location of injection and sampling sites on Payne Brook.*

# COMPARISON OF RESULTS OF HYDROCARBON-GAS-TRACER METHOD WITH RESULTS OF RADIOACTIVE-TRACER METHOD AND PREDICTIVE EQUATIONS

## Comparison With Results of Previous Radioactive-Tracer Study at Canandaigua Outlet

The reaeration capacity of Canandaigua Outlet was studied during the early 1970's by Tsivoglou, who used radioactive tracers under a variety of flow conditions. The report on those studies (Tsivoglou, 1974) gives a predictive equation based on radioactive-tracer measurements to obtain reaeration coefficients from stream discharge, traveltime, and changes in water-surface elevation between sampling points. That equation was used in the 1978-82 study to compare Tsivoglou's coefficients obtained through radioactive tracers with those obtained through propane and ethylene tracers in 1978-81. In figure 8, the reaeration coefficients derived from ethylene, propane, and the radioactive tracers are plotted against the values calculated from equation 7, which was derived by Tsivoglou (1974) for Canandaigua Outlet.

This equation was developed from a significant number of measurements made on several reaches of the outlet during 1972 and the channel hydraulic characteristics.

$$K_{2,20} = (2.84 - 0.035Q)\ \Delta h/t \qquad (7)$$

where: $K_{2,20}$ = base e reaeration coefficient, in units per day at 20°C;
$Q$ = stream discharge, in $ft^3/s$;
$\Delta h$ = decrease in water-surface elevation, in feet;
$t$ = traveltime, in hours.

Data points in figure 8 are grouped by the reaches used in the 1978-82 gas-tracer measurements on Canandaigua Outlet. Overall, the figure shows excellent agreement between the reaeration coefficients measured by radioactive and hydrocarbon gas tracers for all three reaches. The relationships for the individual reaches, as plotted in figure 8, are discussed below.

Reach 1-2. Coefficients measured in July 1978 by gas tracers compare favorably when the large variation in flow and velocity are considered because the three radioactive-tracer coefficients and two gas coefficients lie on a line parallel to the line of equal coefficients.

Reach 2-3. This reach (fig. 8) yielded the closest agreement between coefficients obtained through propane and radioactive tracers.

Reach 3-4. This reach shows a slight disparity among measured coefficients. In this reach the hydrocarbon-tracer coefficients are slightly higher than the radioactive-tracer coefficients.

Some of the disparity among coefficients, as described above, may be attributed to procedural errors. Sources of error in sampling and in calculating reaeration coefficients might be as follows:

- The U.S. Geological Survey gage at Chapin was the sole source of discharge data used in the radioactive tracer studies. This gage has historically

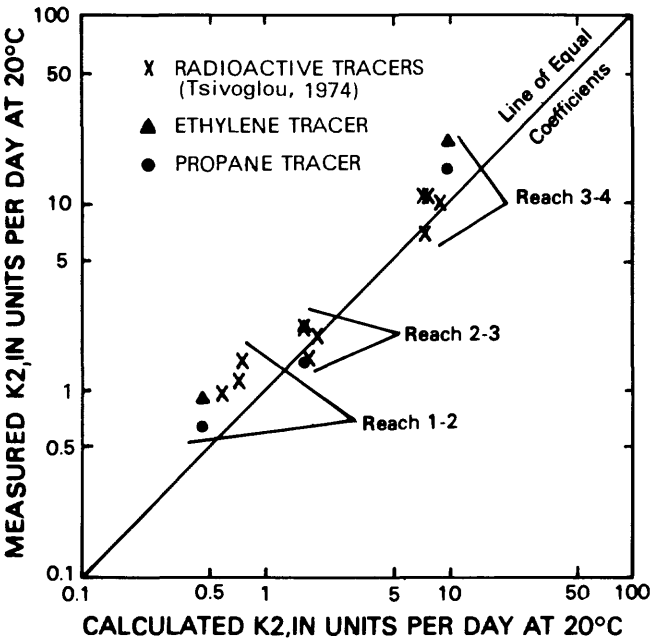



*Figure 8.*

*Reaeration coefficients calculated from measured field values in relation to those calculated from equation (1), Canandaigua Outlet, N.Y.*

had rating problems during low flow because extensive weed growth causes backwater conditions.

The stream slopes were calculated from contours on topographic maps, not actual water-surface elevations; therefore, changes in the relation of water-surface elevation to streamflow were not reflected in the calculations.

## Comparison With Results of Predictive Equations

The 10 predictive equations evaluated in this study were used to calculate the reaeration coefficients for the eight reaches that were free of man-made hydraulic structures such as dams or weirs. (The three reaches with man-made hydraulic structures were excluded because the equations being evaluated were designed only for unobstructed flow.) Although several predictive equations are available to calculate the amount of reaeration occuring over dams, none were evaluated because only three study reaches contained dams. The predicted and measured stream-reaeration coefficients for the eight reaches are given in table 3.

The accuracy of each of the predictive equations is given in terms of mean error. When the mean errors were being computed, it was noted that equations that yielded accurate values for small streams gave poor results for large streams and vice versa. Therefore, the mean error was also calculated for (1) the four small streams combined, and (2) the two large rivers combined, as well as all six streams combined; results are given in table 4. Only the two reaches on the Oswego and Hudson Rivers with flows greater than 1,000 $ft^3/s$ were used for the large rivers. All 10 equations underestimated the reaeration coefficients for the large river reaches; the reason may be related to the effects of wind on reaeration in large rivers. Also, the small number of large-river reaches evaluated may not be a representative sampling.

The mean errors of the predictive equations ranged from 51 to 103 percent among the eight stream reaches; all but one of these equations had mean errors less than 100 percent. The equation with the smallest mean error was that of Tsivoglou and Neal (1976); although this equation accurately predicted reaeration coefficients for small streams, it underestimated the large-stream values by 98 percent. The equation by Negulescu and Rojanski (1969) underestimated the large streams by only 51 percent but had a mean error of 68 percent for small streams. Equations that provided the best estimates for small streams gave the worst results for large rivers, and vice versa. No equation accurately predicted the reaeration coefficients for both small streams and large rivers.

*Table 3.--Measured and predicted reaeration coefficients for 11 stream reaches.*

(Reaeration coefficients are units per day at 20°C; equations are given on p. 6.)

| | River and reach (locations are shown in figs. 2-7. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Canandaigua Outlet | | | Oswego River | Hudson River | Cayadutta Creek | Chenango River | Payne Brook |
| Predictive Equation | 1-2 | 2-3 | 3-4 | 4-5 | 3-5 | 1-2 | 1-2 | 1-2 |
| Bennett and Rathbun (1972) | 3.1 | 5.2 | 12 | 0.53 | 0.73 | 51 | 21 | 1.2 |
| Churchill and others (1962) | .05 | .10 | .92 | .11 | .22 | 10 | .43 | .01 |
| Isaacs and Gaudy (1968) | .67 | 1.4 | 4.6 | .25 | .34 | 20 | 4.6 | .29 |
| Krenkel and Orlob (1963) | 2.7 | 7.2 | 16 | .61 | .69 | 58 | 18 | 3.6 |
| Langbein and Durion (1967) | .64 | 1.4 | 4.2 | .30 | .40 | 17 | 3.8 | .31 |
| Negulsecu and Rojanski (1969) | 1.5 | 2.8 | 6.9 | 1.2 | 1.4 | 18 | 5.2 | .95 |
| O'Conner and Dobbins (1958) | 2.5 | 3.9 | 7.8 | .50 | .66 | 28 | 13 | 1.0 |
| Padden and Gloyna (1971) | 1.1 | 2.0 | 4.4 | .56 | .70 | 13 | 4.4 | .63 |
| Parkhurst and Pomeroy (1972) | .68 | 1.7 | 4.0 | .10 | .12 | 15 | 5.7 | .69 |
| Tsivoglou and Neal (1976) | .32 | 1.7 | 9.4 | .05 | .05 | 49 | 8.0 | 1.6 |
| Measured | 0.77 | 1.8 | 18 | 6.0 | 1.8 | 52 | 12 | 3.7 |

*Table 4.--Accuracy of predictive equations for the four small streams, the two large rivers, and all streams combined.*

| Predictive equation | Mean error, in percent, and rank* Small streams | Large rivers | All streams studied |
|---|---|---|---|
| Bennett and Rathbun (1972) | 112 (10) | 75 (3) | 103 (10) |
| Churchill and others (1962) | 93 (8) | 93 (8) | 93 (8) |
| Isaacs and Gaudy (1968) | 54 (3) | 88 (7) | 63 (3) |
| Krenkel and Orlob (1963) | 104 (9) | 76 (3) | 97 (9) |
| Langbein and Durion (1967) | 57 (4) | 86 (6) | 64 (5) |
| Negulsecu and Rojanski (1969) | 68 (6) | 51 (1) | 64 (6) |
| O'Conner and Dobbins (1958) | 88 (7) | 78 (5) | 86 (7) |
| Padden and Gloyna (1971) | 58 (5) | 76 (4) | 63 (4) |
| Parkhurst and Pomeroy (1972) | 50 (2) | 96 (9) | 62 (2) |
| Tsivoglou and Neal (1976) | 35 (1) | 98 (10) | 51 (1) |

* Number in parentheses is ranking in terms of smallest mean error.

## SUMMARY AND CONCLUSIONS

Stream-reaeration measurements were made with fluorescent dye and hydrocarbon-gas tracers on six streams in New York State between 1978 and 1981. The locations were Canandaigua Outlet at Canandaigua, Oswego River at Fulton, Hudson River at Fort Miller, Cayadutta Creek near Johnstown, Chenango River near Morrisville, and Payne Brook near Hamilton. Multiple reaeration measurements were made on Canandaigua Outlet and the Hudson River. Reaeration coefficients calculated from results of these measurements were compared to reaeration coefficients measured by radioactive tracers on Canandaigua Outlet in 1973 and to those calculated from 10 predictive equations.

The reaeration coefficients obtained during this study were derived through gas-tracer methods described by Rathbun and Grant (1978). Of the two hydrocarbon tracer methods available, the "peak concentration" method was the only method used on all stream reaches. The "area" method, which requires many more gas samples, was used only on one short reach of the Hudson River. The Hudson River reaeration coefficients derived by these two methods were within 2 percent of each other. Final results of all measurements showed a range in log base e stream reaeration coefficients from 0.77 units per day on Canandaigua Outlet to 52 units per day on Cayadutta Creek. Dissolved-oxygen-deficit ratios were calculated for several reaches on the Oswego and Hudson Rivers. These ratios, which ranged from 1.4 to 2.1 on the Hudson River and from 1.6 to 7.6 on the Oswego River, were computed for stream reaches with one or more dams.

The reaeration coefficients measured on Canandaigua Outlet by hydrocarbon gas-tracer methods were compared with coefficients obtained through the radioactive-tracer technique on the same reach 10 years earlier. The coefficients obtained by both methods yielded values that were in close agreement for all three stream reaches. These results suggest that the hydrocarbon-gas-tracer method is a reasonable alternative to the use of radioactive tracers.

Comparison of reaeration coefficients calculated from ten predictive equations based on stream characteristics with those obtained by the hydrocarbon tracer measurements gave a wide range of results. The accuracy of each equation is reported in terms of mean error. Equations that yielded the closest agreement with the field-measured coefficients for small streams yielded the largest errors for large rivers, and vice versa. The equation with the smallest mean error (35 percent) for small streams was that of Tsivoglou and Neal (1976). All 10 equations underestimated the reaeration coefficients for the combination of two large river reaches; the smallest error (51 percent) was given by the equation of Negulescu and Rojanski (1969). No equation accurately predicted the stream-reaeration coefficients for both small and large rivers.

## REFERENCES CITED


Bansal, M. K, 1973, Atmospheric reaeration in natural streams: Water Research, Pergamon Press, Oxford, England, v. 7, no. 5, p. 769-782.

Buchanan, T. J., and Somers, W. P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water Resources Investigations, Book 3, Chapter A8, 65 p.

Cadwallader, T. E., and McDonnell, A. J., 1969, A multivariate analysis of reaeration data: Water Research, Pergamon Press, Oxford, England, v. 3, p. 731-742.

Churchill, M. A., Elmore, H. L., and Buckingham, R. A., 1962, The prediction of stream reaeration rates: American Society of Civil Engineers, Journal of the Sanitary Engineering Division, v. 88, no SA4, p. 1-46.

Dobbins, W. E., 1965, BOD and oxygen relationships in streams: Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, v. 91, no. SA5, Proceedings Paper 4442, p. 49-55.

Elmore, H. L., and West, W. F., 1961, Effect of water temperature on stream reaeration: Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, v. 87, no. SA6, p. 59-71.

Grant, R. S., and Skavroneck, Steven, 1981, Comparison of tracer methods and predictive equations for determination of stream reaeration on three small streams in Wisconsin: U.S. Geological Survey Water-Resources Investigations 80-19, 41 p.

House, L. B., and Skavroneck, Steven, 1981 Comparison of the propane-area tracer method and predictive equations for determination of stream reaeration coefficients on two small streams in Wisconsin: U.S. Geological Survey Water-Resources Investigations 80-105, 23 p.

## REFERENCES CITED (Continued)


Isaacs, W. P., and Gaudy, A. F., 1968, Atmospheric oxgenation in a simulated stream: Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, v. 94, no. SA2, Proceedings Paper 5905, p. 319-344.

Krenkel, P. A., and Orlob, G. T., 1963, Turbulent diffusion and the reaeration coefficient: Transactions of the American Society of Civil Engineers, v. 128, part III, Paper no. 3491, p. 293-334.

Langbein, W. B., and Durum, W. H., 1967, The aeration capacity of streams: U.S. Geological Survey Circular 542, 6 p.

Negulescu, M., and Rojanski, V., 1969, Recent research to determine reaeration coefficient: Water Research, v. 3, no. 3, p. 189-202.

O'Conner, D. J., and Dobbins, W. E., 1958, Mechanism of reaeration in natural streams: Transactions of the American Society of Civil Engineers, v. 123, p. 641-684.

Padden, T. J., and Gloyna, E. F., 1971, Simulation of stream processes in a model river: Austin, University of Texas, Report no. EHE-70-23, CRWR-72, 130 p.

Parkhurst, J. D., and Pomeroy, R. D., 1972, Oxygen absorption in streams: Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, v. 98, no. SA1, Proceedings Paper 8701, p. 101-124.

Rathbun, R. E., 1977, Reaeration coefficients of streams--state-of-the-art: Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, v. 103, no. H-Y4, p. 409-424.

Rathbun, R. E., Shultz, D. J., and Stephens, D. W., 1975, Preliminary experiments with a modified tracer technique for measuring stream reaeration coefficients: U.S. Geological Survey Open-File Report 75-256, 36 p.

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

Rathbun, R. E., Stephens, D. W., Shultz, D. J., and Tai, D. Y., 1978, Laboratory studies of gas tracers for reaeration: Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, v. 104, no. EE2, p. 215-229.

Shultz, D. J., Pankow, J. F., Tai, D. Y., Stephens, D. W., and Rathbun, R. E., 1976, Determination, storage, and preservation of low molecular weight hydrocarbon gases in aqueous solution: U.S. Geological Survey Journal of Research, v. 4, no. 2, p. 247-251.

## REFERENCES CITED (Continued)


Streeter, H. W., and Phelps, E. B., 1925, A study of the pollution and natural purification of the Ohio River. III, Factors concerned in the phenomena of oxidation and reaeration: U.S. Public Health Service, Bulletin 146, 1 v.

Thackston, E. L., and Krenkel, P. A., 1969, Reaeration prediction in natural streams: Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, v. 95, no. SA1, Proceedings Paper 6407, p. 65-94.

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

_______ 1974, The reaeration capacity of Canadaigua outlet, Canadaigua to Clifton Springs: New York State Department of Environmental Conservation, Project number C-5402, 79 p.

Tsivoglou, E. C., O'Connell, R. L., Walter, C. M., Godsil, P. J., and Logsdon, G. S., 1965, Laboratory studies, part I of Tracer measurements of atmospheric reaeration: Journal of the Water Pollution Control Federation, v. 37, no. 10, p. 1343-1362.

Tsivoglou, E. C., Cohen, J. B., Shearer, S. D., and Godsil, P. J., 1968, Field studies, part II of Tracer measurement of stream reaeration: Water Pollution Control Federation Journal, v. 40, no. 2, pt. II, p. 285-305.

Tsivoglou, E. C., and Neal, L. A., 1976, Predicting the reaeration capacity of inland streams, in Tracer measurement of reaeration, part III: Water Pollution Control Federation Journal, v. 48, no. 12, p. 2669-2688.

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