ESTIMATING REAERATION COEFFICIENTS FOR LOW-SLOPE STREAMS IN MASSACHUSETTS AND NEW YORK, 1985-88

By Gene W. Parker and Leslie A. DeSimone

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Flow	
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature

To convert degree Celsius (°C) to degree Fahrenheit (°F), use the following formula:

$$1.8 \times {}^{\circ}C + 32 = {}^{\circ}F.$$

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

Milligrams per liter (mg/L) is a unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water: 1 mg/L equals 1,000 micrograms per liter (µg/L).

Empirical Equation for Estimating Reaeration Coefficients for Low-Slope Streams in Massachusetts and New York, 1985-88

By Gene W. Parker and Leslie A. DeSimone

ABSTRACT

Multiple-regression techniques were used to develop the following empirical equation for estimating reaeration coefficients for low-slope streams in Massachusetts and New York: $K_2 = 3.83\ MBAS^{-0.41}\ SL^{0.20}\ D^{-0.76}$, *where* K_2 *is the depth-averaged reaeration coefficient at the standard temperature of 20 degrees Celsius, in base e units per day; MBAS is the concentration of methylene-blue-active substances, in milligrams per liter; SL is the water-surface slope, in foot per foot; and D is the mean depth, in feet. Multiple-regression analyses of measured reaeration coefficients and 14 hydraulic, physical, and water-quality characteristics of reaches from 29 tracer studies conducted on low-slope (water-surface slopes of less than 0.002 foot per foot) streams in Massachusetts and New York were used to develop the equation. Reaeration coefficients measured in 1985-88 for 29 stream tracer studies ranged from 0.16 to 10.99 base e units per day. Concentration of methylene-blue-active substances is significant because it is thought to be an indicator of the surfactants concentration, which could change the surface tension at the water-air interface.*

Reaeration coefficients and reach characteristics were determined from 29 stream tracer studies conducted on reaches in Massachusetts and New York. Hydraulic characteristics of reaches determined from each tracer study were (1) water-surface slope, (2) mean stream velocity, (3) average windspeed at the closest National Oceanic and Atmospheric Administration weather station, and (4) resultant wind velocity parallel to the channel azimuth and corrected for the mean sheltering angle. Physical characteristics of reaches determined from each tracer study were (1) mean depth, (2) mean width, (3) channel azimuth, (4) channel elevation, and (5) mean sheltering angle. Water-quality characteristics of reaches determined from each tracer study were (1) color, (2) concentration of total organic carbon, (3) concentration of methylene-blue-active substances, (4) specific conductance, and (5) concentration of suspended solids.

An error analysis technique was used to compare the measured reaeration coefficients with reaeration coefficients obtained from 19 commonly used equations. Equations were ranked in each of three groupings of 42 stream tracer studies according to their accuracy in terms of absolute average error and standard deviation of residuals. The three groupings are (1) unweighted, measured reaeration coefficients for 29 tracer studies conducted on streams having water surface slopes less than 0.002 foot per foot; (2) unweighted, measured reaeration coefficients for five tracer studies conducted on streams having water surface slopes greater than 0.002 foot per foot; and (3) unweighted, measured reaeration coefficients for eight tracer studies conducted on streams having water surface slopes less than 0.002 foot per foot and having a single, small impoundment. The error analysis indicates that the Parkhurst and Pomeroy (1972) equation has the best ranking, with an average error of 65 percent and a standard deviation of residuals of 2.23 for 29 low-slope stream studies. The error analysis indicates that the Smoot (1987) equation has the best ranking, with an average error of 40 percent and a standard deviation of residuals of 2.20 for the eight low-slope streams with single impoundment studies.

No single equation ranked in the top three for both average absolute error and standard deviation of residuals when considering the five tracer studies on streams with a water surface slope greater than 0.002 foot per foot.

The proposed equation improves the accuracy of estimating reaeration coefficients and can be used for predicting attenuation of volatile compounds released into streams. An example of application of the equation for predicting volatilization of a spilled contaminant from a low-slope stream is given.

INTRODUCTION

Reaeration coefficients are used in stream water-quality models to estimate dissolved-oxygen concentrations in reaches affected by organic loadings. State water-pollution-control agencies, such as the Massachusetts Department of Environmental Protection, Division of Water Pollution Control, and the New York State Department of Environmental Conservation, Bureau of Monitoring and Assessment, rely on stream dissolved-oxygen models to help make decisions concerning the maintenance of stream water-quality standards set by each State in conjunction with the U.S. Environmental Protection Agency (USEPA).

The self-cleaning capacity of a stream depends on the initial dissolved-oxygen concentration and on the capacity of the stream to replace oxygen removed by the oxidation of organic wastes. All major sources of and demands for dissolved oxygen are considered in modeling dissolved-oxygen concentrations in streams. Dissolved-oxygen sources include oxygen production by periphyton and phytoplankton, and reaeration through the water surface. Dissolved-oxygen demands include respiration of aquatic organisms, decay, and other biochemical demands. Dissolved-oxygen concentrations also can change because of dispersion. All of these processes can be measured or estimated.

Three-fourths of the large population centers in Massachusetts discharge treated sewage into low-slope (water-surface slopes of less than 0.002 ft/ft, or approximately 10 ft/mi) streams. Low-slope streams in Massachusetts and New York typically are characterized by forested, scrub/shrub, and (or) emergent wetland areas; slow water velocities; and large longitudinal-dispersion coefficients. Reaeration is an important source of oxygen in streams and an important component of the dissolved-oxygen balance of streams. However, because of cost considerations, reaeration coefficients rarely are measured and commonly are estimated from equations.

Before the 1970s, the two methods most commonly used to measure reaeration coefficients were the dissolved-oxygen-balance method and the disturbed-equilibrium method. Both methods consist of a summation of the rate of change in a stream's dissolved-oxygen content, the rate of oxygen production, the rate of oxygen utilization, and the rate of reaeration. The summation is solved for the unknown reaeration coefficient by trial and error. The methods differ in the use of natural stream-dissolved-oxygen content or artificially-reduced stream-dissolved-oxygen content. In the disturbed-equilibrium method, initial stream-dissolved-oxygen content is artificially reduced by the addition of sodium sulfite to a stream. In addition to being costly and time consuming, both methods are indirect determinations of reaeration coefficients that may be no more accurate than reaeration coefficients calculated from many estimating equations (Bennett and Rathbun, 1972).

The most recently accepted method used to measure reaeration coefficients is the gas-tracer method. In the gas-tracer method, reaeration coefficients are measured by the mass-transfer rate of a tracer gas. At a standard temperature, the mass-transfer rate of a tracer gas is directly proportional to the transfer rate of oxygen (reaeration). Constants associated with the direct relation of mass-transfer rates can be determined in the laboratory. Therefore, an organic gas, such as propane, can be used as a tracer to directly measure the transfer rate of oxygen. Recent advances in the gas-tracer method, such as the steady-state propane-gas-tracer method (Yotsukura and others, 1983, 1984; Kilpatrick and others, 1987), provide an economical, accurate, and reproducible method of determining reaeration coefficients along a reach. A further advantage of the gas-tracer method is that the use of a tracer not naturally present in the environment eliminates the necessity of accounting for other sources and demands. In contrast, the dissolved-oxygen balance and disturbed-equilibrium methods require accounting for photosynthetic oxygen production and for respiration of the suspended and attached aquatic plants, in addition to measuring dissolved oxygen (Rathbun and others, 1978; Rainwater and Holley, 1983).

In recent years, the need to evaluate the residence times in and transfer rates from surface-water systems of volatile-organic contaminants has increased substantially with the passage of many Federal and State environmental laws. Most volatile-organic compounds have transfer rates that are first-order processes like the reaeration process. Rathbun and Tai (1981) and Chiou and others (1983) reported that these volatilization coefficients can be estimated in relation to the reaeration coefficient using oxygen as a reference material. The determination of accurate reaeration coefficients has application beyond understanding oxygen transfer alone. It can be used to better understand the fate of other volatile gases within a stream system.

Predicting the effectiveness of waste-water practices in meeting the stringent water-quality standards imposed for streams in Massachusetts and New York require the use of accurate reaeration coefficients. However, the expense of measuring reaeration coefficients in nature, even when the steady-state propane-gas-tracer method is used, makes direct measurements for all reaches impractical. The U.S. Geological Survey (USGS), in cooperation with the Massachusetts Department of Environmental Protection, Division of Water Pollution Control, developed the following regionalized regression equation (Parker and Gay, 1987):

$$K_2 = 252.2\, D^{-0.76} V^{0.355} SL^{0.438} \qquad (1)$$

where K_2 is the reaeration coefficient, in base e units per day;
D is the mean depth, in ft;
V is the mean stream velocity, in ft/s; and
SL is the water surface slope, in ft/ft.

The Parker and Gay (1987) equation relates reaeration coefficients to hydraulic and physical characteristics of reaches. The equation, which was developed from a data base of 30 stream tracer studies, has a correlation coefficient of 0.85 and a standard error of estimate of 37.5 percent. The 30 stream tracer studies were conducted during periods of little or no wind at the water surface. Water-surface slopes were greater than 0.002 ft/ft for 20 of the stream tracer studies and at or less than 0.002 ft/ft for 10 of the stream tracer studies. For the 20 stream tracer studies conducted on streams having water-surface slopes greater than 0.002 ft/ft, the Parker and Gay (1987) equation has an average absolute error of 27 percent. For the 10 stream tracer studies conducted on streams having water-surface slopes at or less than 0.002 ft/ft, the equation has an average-absolute error of 177 percent. The large average-absolute error indicates that reach characteristics not included in the Parker and Gay (1987) equation are affecting the gas-transfer process in low-slope streams.

Reaeration and mass-transfer rates of gases are controlled by the processes that maintain an imbalance of gas concentration across the water-air interface (Yotsukura and others, 1983). Wind shear at the water surface is one of these processes. Wind shear can be affected by the sheltering angle of the basin caused by the vegetation along the riverbank and the hills surrounding the stream. Wind shear also can be affected by the azimuth of the basin in relation to the direction and speed of the prevailing winds. In the northeastern United States, wind shear at the water surface is reduced by the general north-south orientation of most river valleys and by the large percentage of stream channels bordered by forest.

In high-slope streams, the transport of gas away from or to the water-air interface is controlled primarily by turbulence in the water column and, to a lesser extent, by wind shear at the water surface. Turbulence in the water column can be affected by changes in hydraulic and physical characteristics of reaches, such as water-surface slope, mean stream velocity, mean depth, and mean width.

In low-slope streams, reaeration can be affected by less dynamic processes, such as changes in water quality. Water quality in a stream may be indicated by color as an indicator of humic and fulvic acid concentration, TOC (total organic carbon) concentration as an indicator of organic concentration, concentration of MBAS (methylene-blue-active substances) as an indicator of surfactants concentrations, specific conductance as an indicator of dissolved-solids concentration, and suspended-solids concentration as an indicator of suspended-inorganic concentration (Bennett and Rathbun, 1972). For streams having low-water-surface slopes and low-mean-stream velocities, turbulence in the water column is less pronounced, and the transport of gas across the water-air interface is controlled by the less dynamic processes.

Purpose and Scope

This report describes the equation development for estimating reaeration coefficients for low-slope streams using weighted, multiple, stepwise regression techniques. (P-STAT, Inc., 1989, p. 42.13-42.14). The new equation was developed by analysis of 14 measured physical, hydraulic, and water-quality characteristics of reaches (table 1). Twenty-nine stream tracer studies were conducted on 24 reaches of 18 naturally flowing low-slope streams in Massachusetts and New York (fig. 1 and table 2). The reaches represented most types of low-slope stream channels commonly occurring in Massachusetts and New York.

This report also describes the results of an error analysis of 19 commonly used reaeration-coefficient estimating equations. The error analysis was conducted on three groupings of 42 stream-tracer studies from 33 reaches of 22 streams in Massachusetts and New York (fig. 1). Twenty-nine of the 42 stream-tracer studies were conducted on naturally flowing low-slope reaches. Five of the 42 studies were conducted on reaches with slopes of more than 0.002 ft/ft (high-slope) and eight studies were performed on reaches having low slopes with a single, small impoundment. All impoundments had water residence times of less than 7 days. The results from the additional stream tracer studies were used to test the accuracy of the 19 equations for streams with reach characteristics close to but outside the range of reach characteristics determined for the 29 low-slope stream tracer studies. All stream tracer studies were conducted during medium- and low-flow periods from May 1985 through October 1988.

Approach

Based upon previous reaeration work in Massachusetts streams (Parker and Gay, 1987) and review of reaeration literature, 14 hydraulic, physical, and water-quality characteristics of reaches (table 1) were selected to be correlated with the measured reaeration coefficient. The reach characteristics were determined from 29 stream tracer studies (combined time of travel and reaeration) conducted on 24 reaches on 18 streams (fig. 1). The 24 reaches were selected for study on the basis of geographic distribution, consistency of reach characteristics within each reach, and accessibility. Reach locations and descriptions are given in Appendix 1 at the end of this report. When possible, adjacent reaches of a stream were studied concurrently, and studies were repeated on the same reach at different discharge rates. Hydraulic, physical, and water-quality characteristics of reaches were determined from each tracer study, and water-quality samples were collected for reach characteristics requiring laboratory analysis. Windspeed and wind direction data were obtained from reports published by the National Oceanic and Atmospheric Administration (1985; 1986a, b; 1987a, b, c, d; 1988a, b, c, d).

All tracer study data were analyzed to determine time-of-travel characteristics and initial propane-gas desorption coefficients as outlined by Yotsukura and others (1983) and Kilpatrick and others (1987). Final reaeration coefficients were determined using superposition techniques (Yotsukura and others, 1983; Kilpatrick and others, 1987). The measurement error for each tracer study was estimated using the technique outlined by Yotsukura and others (1983).

The new empirical equation for estimating reaeration coefficients was developed from measured reaeration coefficients and corresponding reach characteristics determined from the 29 tracer studies conducted on low-slope streams. Step-wise multiple-regression analyses (P-STAT, Inc., 1989, p. 42.13-42.14) were conducted to statistically relate weighted-measured reaeration coefficients to reach characteristics. Weights were determined from the estimated measurement error for each tracer study and from an estimated model error. Only reach characteristics significant at a 95-percent confidence level were retained.

Reaeration coefficients were estimated from the new empirical equation developed in this study and from 19 commonly used estimating equations. All equations were ranked in each of five groups of the 42 stream tracer studies according to the accuracy of their estimated reaeration coefficients. The equations were ranked for how well estimated reaeration coefficients compared with weighted and unweighted measured reaeration coefficients from all 42 stream tracer studies and with unweighted, measured reaeration coefficients from three subgroups of the 42 stream- tracer studies. The three subgroups are the 29 studies conducted on streams having water-surface slopes of less than 0.002 ft/ft; the five studies conducted on streams having water-surface slopes greater than 0.002 ft/ft; and the eight studies conducted on streams having water-surface slopes of less than 0.002 ft/ft and having a single, small impoundment.

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Table 1.--*Methods used to determine reach characteristics from 42 tracer studies conducted on low-slope streams in Massachusetts and New York*

Reach characteristic	Description of determination methods
Water-surface slope (foot/foot)	Determined as the change in water-surface elevation over the reach divided by the reach length (L). Water-surface elevation was determined by differential leveling from bench marks to the sampling sites. Reach lengths between sampling sites were measured from topographic maps.
Mean stream velocity (V) (foot per second)	Determined by dye tracer time-of-travel data by solving the equation: $V = \frac{L}{\bar{T}}$, where V is the mean streamflow velocity, in feet per second; L is the reach length, in feet; $\bar{T}$ is the centroid traveltime of a slug-injected dye-tracer response curve measured over a test reach [the slug injection method is explained in more detail by Hubbard and others (1982)];
Average windspeed (foot per second)	Determined by averaging the daily average windspeed as reported by NOAA (National Oceanic and Atmospheric Administration) at the closest NOAA weather station (Boston, Massachusetts; Worcester, Massachusetts; Hartford, Connecticut; or Albany, New York) for the duration of each tracer study (National Oceanic and Atmospheric Administration, 1985; 1986a,b; 1987a,b,c,d; 1988a,b,c,d).
Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (foot per second)	Determined in two steps. Initial wind velocity is reduced by multiplying the wind velocity component perpendicular to the channel azimuth by the sine of the sheltering angle. Next, the component of half of this adjusted wind velocity parallel to the channel azimuth is determined by the cosine of the smallest angle between the wind direction and the channel azimuth.
Mean width (W) (foot)	Determined by averaging widths at 10 to 30 evenly spaced locations along a reach. Widths were measured with a cloth tape or a calibrated optical rangefinder.

Table 1.--*Methods used to determine reach characteristics from 42 tracer studies conducted on low-slope streams in Massachusetts and New York*--Continued

Reach characteristic	Description of determination methods
Mean depth (D) (foot)	Determined by solving the continuity equation: $$D = \frac{Q}{W V},$$ where Q is the discharge determined by averaging measured discharge at each sampling site, in cubic feet per second. Discharge measurements were made using the methods outlined by Buchanan and Somes (1969) and confirmed using the dye-dilution-total-recovery method (Kilpatrick and Cobb, 1984).
Channel azimuth (degree)	Determined by measuring the angle formed by the reach from true north on topographic maps.
Channel elevation (foot)	Determined as the average water-surface elevation between the sampling sites at each end of a reach. Water-surface elevation was determined by differential leveling from bench marks.
Mean sheltering angle (degree)	Determined by measuring the angle between wind barriers on both sides of the river in a vertical plane perpendicular to the direction of streamflow. The reported sheltering angle is the average of measurements made at 10 to 30 locations along a reach. Examples of wind barriers are trees and hills.
Color (platinum-cobalt)	Measured in a water sample collected at the water-quality monitoring site during each study. Measured by comparison with calibrated colored glass disks according to the method outlined by Goerlitz and Brown (1972).
Total organic carbon concentration (milligram per liter)	Measured in a water sample collected at the water-quality monitoring site for each study. The sample was analyzed according to the method outlined by Goerlitz and Brown (1972).

Table 1.--*Methods used to determine reach characteristics from 42 tracer studies conducted on low-slope streams in Massachusetts and New York*--Continued

Reach characteristic	Description of determination methods
Concentration of methylene-blue-active substances (milligram per liter)	Measured in a water sample collected at the water-quality monitoring site during each study. The sample was analyzed spectrophotometrically according to the method outlined by Goerlitz and Brown (1972). The water-quality monitoring site for each study usually was established at the downstream end of a reach or, for concurrent reaches, at the junction of the reaches. If a water-quality change was expected between reaches, water samples were collected for analysis at the end of each reach. For Massachusetts studies, analyses were made at the U.S. Geological Survey's Central Laboratory in Arvada, Colo. For New York studies, analyses were made at the New York State Department of Health, Wadsworth Center for Laboratories and Research.
Specific conductance (SC) (microsiemen per centimeter at 25 degrees Celsius)	Measured at the water-quality monitoring site for each study with a continuous recording monitor or a conductance meter. Supplemental measurements of specific conductance also were made at all tracer study sampling sites.
Suspended-solids concentration (SS) (milligram per liter)	For Massachusetts studies, estimations were made by the equation: $SS = ROE - (0.54\ SC + 2.7)$ where ROE is the concentration of total dissolved solids, in milligrams per liter, as determined by evaporation at 105 degrees Celsius. Water samples were collected at the water-quality monitoring site for each study and analyzed according to the method outlined by Skougstad and others (1979). $(0.54SC + 2.7)$ is an equation to estimate the dissolved-solids concentration, in milligrams per liter, as outlined by Delaney and Gay (1980). A review of the literature indicates that the constant for a specific conductance to dissolved solids relation can range from 0.53 to 0.60 for Massachusetts rivers. The relation used to reflect an average for the State was developed for the Merrimac River, a large New England river basin, and was thought to be more transferable than a relation developed for a smaller basin. For New York studies, samples were collected at the water-quality monitoring site for each study and analyzed according to the method outlined by Skougstad and others (1979).

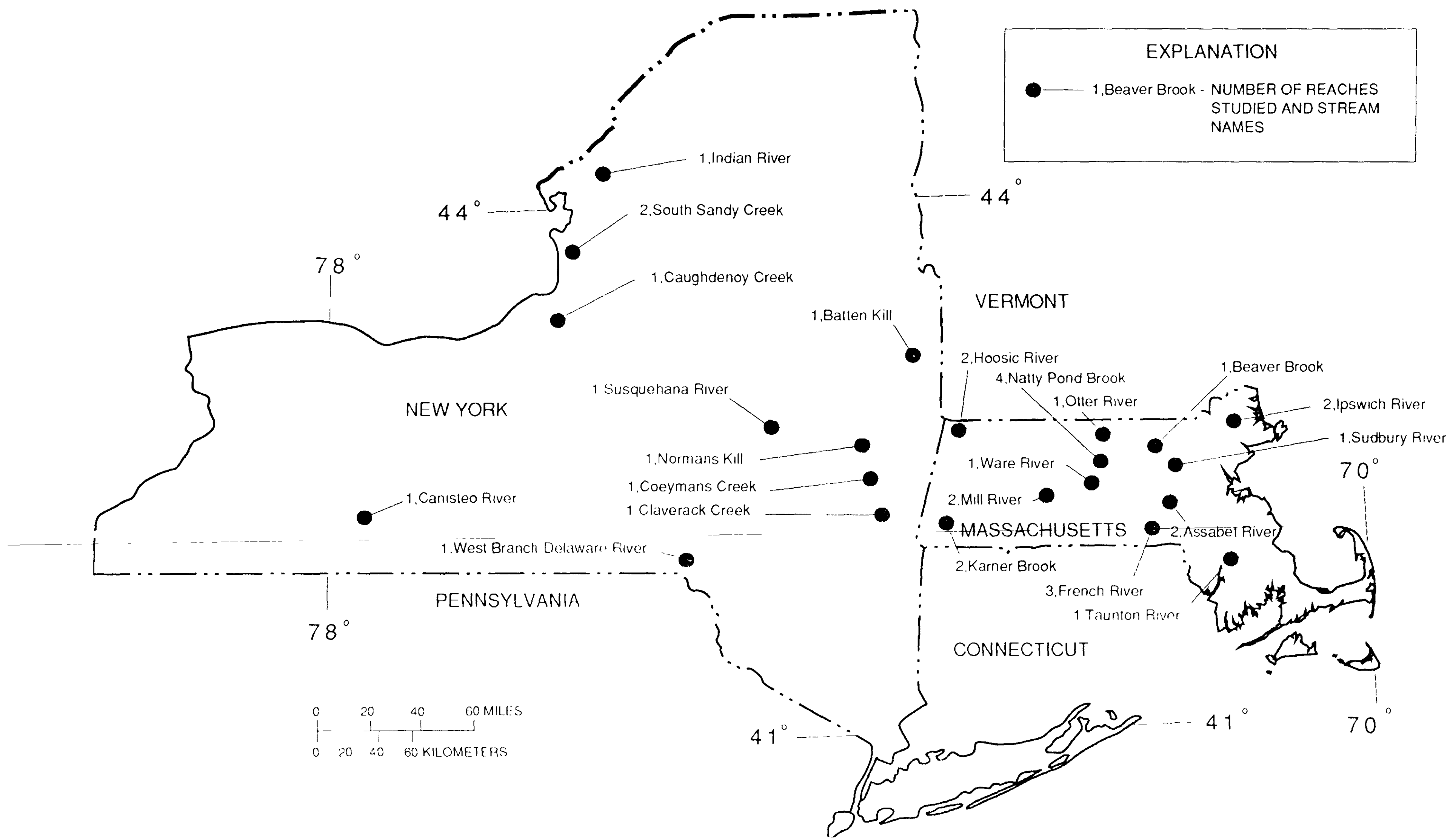

Figure 1.--Study-site locations.

Table 2.--*Tracer studies conducted on streams in Massachusetts and New York, 1985-88*

Stream name	Reach[1]	Number of tracer studies conducted	Reach descriptor[2]
Beaver Brook near Littleton, Mass.	A	1	Low-slope stream
Assabet River near Westborough, Mass.	A	3	Low-slope stream
	B	1	Low-slope stream
Sudbury River near Wayland, Mass.	A	1	Low-slope stream
Ipswich River near Topsfield, Mass.	A	1	Low-slope stream
	B	1	Impounded stream
Taunton River near Bridgewater, Mass.	A	2	Low-slope stream
French River near Oxford, Mass.	A	2	Low-slope stream
	B	1	Low-slope stream
	C	2	Impounded stream
Otter River near Gardner, Mass.	A	1	High-slope stream
Mill River near Amherst, Mass.	A	1	Low-slope stream
	B	1	Low-slope stream
Natty Pond Brook near Hubbardston, Mass.	A	1	Low-slope stream
	B	1	High-slope stream
	C	2	Low-slope stream
	D	1	Low-slope stream
Ware River near Barre, Mass.	A	1	Low-slope stream
Karner Brook at South Egremont, Mass.	A	1	Low-slope stream
	B	1	Impounded stream
Batten Kill near Greenwich, N.Y.	A	1	Impounded stream
Hoosic River near Adams, Mass.	A	3	High-slope stream
	B	2	Impounded stream
Normans Kill near Westmere, N.Y.	A	1	Low-slope stream
Coeymans Creek near Coeymans, N.Y.	A	1	Low-slope stream
Claverack Creek at Hudson, N.Y.	A	1	Impounded stream
West Branch Delaware River near Deposit, N.Y.	A	1	Low-slope stream

Table 2.--*Tracer studies conducted on streams in Massachusetts and New York, 1985-88*--Continued

Stream name	Reach[1]	Number of tracer studies conducted	Reach descriptor[2]
Susquehanna River at Phoenix Mills, N.Y.	A	1	Low-slope stream
Canisteo River at Hornell, N.Y.	A	1	Low-slope stream
Caughdenoy Creek near Caughdenoy, N.Y.	A	1	Low-slope stream
South Sandy Creek near Ellisburg, N.Y.	A	1	Low-slope stream
	B	1	Low-slope stream
Indian River at Kelsey Bridge, N.Y.	A	1	Low-slope stream

[1] A is the first reach of a river; B is the second reach; C is the third reach; D is the fourth reach.

[2] Low-slope stream is a stream reach having a water-surface slope of less than 0.002 foot per foot; impounded stream is a stream reach having a single, small impoundment at the downstream end; high-slope stream is a stream reach having a water-surface slope greater than 0.002 foot per foot.

nicipal officials who allowed day-and-night access through their property.

THEORY AND METHODOLOGY OF ESTIMATING REAERATION COEFFICIENTS

In order to evaluate the applicability of 19 commonly-used equations, the reach characteristics of 29 low-slope streams were measured. To further test these equations, reach characteristics at eight impounded low-slope streams, as well as five high-slope streams, were measured. Reaeration coefficients were then computed from the commonly-used equations and compared with measured reaeration coefficients at the high, low, and impounded stream systems.

If the results of the equations were not consistent in standard deviation of residuals and mean absolute error for all three groups of stream-tracer studies, other reach characteristics were deemed necessary to define the gas-transfer process in low-slope stream systems. The reaeration-process theory was reviewed in order to determine additional reach characteristics significant in low-energy environments.

Reaeration Process

Reaeration is oxygen transfer that occurs at the water-air interface. The rate of absorption of oxygen from air into water is controlled by the imbalance of oxygen concentration across the thin water-surface film. Rate of oxygen transfer across the water-air interface is a first-order process. Because vertical transfer of dissolved oxygen within the water column is rapid relative to transfer across the thin water-surface film, surface transfer of gases can be considered a first-order process for the entire depth of the water column (Yotsukura and others, 1983). The surface transfer of gases is described by the following equation (Rathbun and others, 1978, p. 218, eq. 2):

$$\frac{dC}{dT} = \pm K C \ (C_\infty - C), \qquad (2)$$

where C is the dissolved-gas concentration

C_∞ is the gas concentration in the air above the water surface, in micrograms per liter;

K is the absorption or desorption coefficient, in units per time; and

T is time.

The plus sign indicates that a gas (like oxygen) is being absorbed into the water. A negative sign indicates desorption of a gas from the water. The depth-averaged absorption or desorption coefficient (K) in equation 2 is directly proportional to the water-surface-film transfer coefficient (KL), as follows:

$$KL = K\,D, \qquad (3)$$

where KL is the water-surface-film transfer coefficient; and

D is the mean depth, in feet.

The absorption or desorption process is affected by wind shear at the water surface, turbulence in the water column, and water-quality characteristics. Wind shear disperses the gas that passes through the water-air interface and is affected by the sheltering angle along a reach, the azimuth of a reach relative to the prevailing winds, and the relative humidity of the air. Turbulence in the water column and at the stream surface enhances the dispersion process and is affected by changes in hydraulic- and physical-reach characteristics, such as water-surface slope, mean stream velocity, mean depth, and mean width. The absorption or desorption process also can be affected by high organic acids concentrations, surfactants concentrations, dissolved-solids concentrations, and suspended-solids concentrations that could affect surface tension, water density, gas solubility, or gas sorption to suspended particles.

Determination of Reach Characteristics

For each of the stream-tracer studies, the water-surface slope, mean stream velocity, average wind speed at the closest National Oceanic and Atmospheric Administration weather station, resultant wind velocity parallel to the channel azimuth as corrected for the mean sheltering angle, mean depth, mean width, channel azimuth, channel elevation, mean sheltering angle, color, TOC concentration, MBAS concentration, specific conductance, and suspended-solids concentration were determined. A description of determination methods for each reach characteristic is given in table 1. Values for the 14 reach characteristics listed as a reach characteristic in table 1 and measured reaeration coefficients from each of the tracer studies are given in Appendixes 2 and 3 at the end of this report. The minimum, median, mean, and maximum values of the

14 reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from the 29 low-slope stream-tracer studies, from the 8 low-slope tracer studies with a single impoundment and from the 5 high-slope tracer studies are given in tables 3, 4, and 5, respectively.

Determination of Time-of-Travel Characteristics

The slug-injection dye-tracer method (Hubbard and others, 1982) was used to determine time-of-travel and hence mean stream velocity through a reach. Steady streamflow conditions are required. A known volume of a 20-percent fluorescent-dye solution was slug injected far enough upstream from the test reach to ensure complete lateral mixing of the dye cloud before it entered the reach. Water samples were collected at the upstream and downstream ends of the reach to determine changes in dye concentration with time. Water-sample collection continued at each sampling site until the dye concentration dropped to 2 percent of the maximum concentration measured. Because dye samples do not require any special preservation, automatic samplers were used frequently for nighttime collection of water samples for dye-concentration analysis. For studies in Massachusetts, all water samples were retained at a constant temperature and reanalyzed in the USGS's office in Boston, Massachusetts. For studies in New York, only selected water samples were retained for reanalysis. Plots of changes in dye concentration over time since injection were used to define the dye-tracer response curve at each sampling site.

The mean stream velocity for a reach was determined with the following equation:

$$V = \frac{L}{(\bar{T}_d - \bar{T}_u)}, \tag{4}$$

where V is the mean stream velocity, in feet per second;

L is the reach length, in feet;

$\bar{T}$ is the centroid traveltime of a slug-injected dye-tracer response curve measured at a sampling site;

d is a subscript that designates the downstream sampling site; and

u is a subscript that designates the upstream sampling site.

The mean depth for a reach was determined with the continuity equation:

$$D = \frac{Q}{WV}, \tag{5}$$

where Q is the discharge determined by averaging measured discharge at each sampling site, in cubic feet per second; and

W is the mean width, in feet.

Measurement of Reaeration Coefficients

The steady-state propane-gas-tracer method described by Yotsukura and others (1983, 1984) and Kilpatrick and others (1987) directly measures the depth-averaged-desorption coefficient of propane gas. The steady-state method is a procedure involving the injection of both dye and gas tracers. The dye-tracer is injected as a slug. The gas-tracer is injected for a long duration, until steady-state conditions are reached throughout the test reach. Commercial-grade, propane-gas is the tracer injected through flat-plate porous-tile diffusers. Gas diffusers were placed on the river bottom within the middle 50 percent of the total streamflow for that cross section. The number of diffusers used in a study varied from two to eight depending on cross-section dimensions and flow conditions. The dye- and gas-tracer injections were made at identical upstream locations to ensure identical dispersion and dilution of both tracers, and to ensure complete lateral mixing of both tracers before they entered the reach.

The hydrocarbon gas, propane, was selected as a tracer because it is not naturally present in the environment, it is soluble in water, it is easily purchased locally, and the ratio of the transfer rates for propane gas and oxygen is known. Commercial-grade propane gas was injected from a 100-pound tank through a single-stage regulator and a carbon-dioxide- or air-calibrated flowmeter. A carbon-dioxide-calibrated flowmeter was used during all studies in Massachusetts to allow direct readings of the injection flow rate, inasmuch as the specific gravities of the propane and carbon-dioxide gases are nearly identical. An air-calibrated flowmeter was used during all studies in New York. Indicated airflow rates were corrected to propane-gas flow rates based on the ratio of their specific gravities. In

Table 3.--*Minimum, median, mean, and maximum values of reach characteristics and measured reaeration coefficients from 29 tracer studies conducted on naturally-flowing low-slope streams*

Reach characteristics	Minimum	Median	Mean	Maximum
Discharge (cubic foot per second)[1]	1.6	14.0	32.6	315.8
Water-surface slope (foot per foot)	.00001	.00023	.00040	.00170
Mean streamflow velocity (foot per second)	.01	.20	.23	.62
Average windspeed (foot per second)	7.3	13.0	13.4	21.7
Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (foot per second)	.1	6.0	7.9	21.7
Mean depth (foot)	.2	1.9	2.8	8.7
Mean width (foot)	19	31	46	201
Channel azimuth (degrees from true north)	6.0	76.0	136.3	339.5
Channel elevation (foot)	13	269	409	1,181
Mean sheltering angle (degree)	25.0	72.0	84.9	165.8
Color (platinum-cobalt)	5	20	46	300
Total organic carbon concentration (milligram per liter)	1.4	6.0	7.5	20
Concentration of methylene-blue-active substances (milligram per liter)	.02	.05	.07	.54
Specific conductance (microseimen per centimeter at 25 degrees Celsius)	37	211	245	647
Suspended-solids concentration (milligram per liter)	3	11	38	350
Measured reaeration coefficient (base e unit per day)	.16	1.50	2.62	11.0

[1] Reach characteristic not used in multiple-regression analysis.

Table 4.--*Minimum, median, mean, and maximum values of reach characteristics and measured reaeration coefficients from eight tracer studies conducted on naturally-flowing low-slope streams with a single impoundment*

Reach characteristics	Minimum	Median	Mean	Maximum
Discharge (cubic foot per second)	2.1	34.9	49.7	187
Water-surface slope (foot per foot)	.00020	.00040	.00050	.00092
Mean streamflow velocity (foot per second)	.01	.22	.27	.66
Average windspeed (foot per second)	10.1	13.8	14.1	20.7
Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (foot per second)	.1	7.9	6.7	12.1
Mean depth (foot)	.7	2.5	3.4	9.0
Mean width (foot)	29	64	93	246
Channel azimuth (degrees from true north)	42	310	234	358
Channel elevation	49	469	453	728
Mean sheltering angle (degree)	63	90	93	120
Color (platinum-cobalt)	2	19	21	44
Total organic carbon concentration (milligram per liter)	2.0	3.8	4.5	8.3
Concentration of methylene-blue-active substances (milligram per liter)	.02	.03	.03	.07
Specific conductance (microseimen per centimeter at 25 degrees Celsius)	137	260	256	376
Suspended-solids concentration (milligram per liter)	1	14	19	48
Measured reaeration coefficient (base e unit per day)	.21	1.20	2.80	9.20

Table 5.--*Minimum, median, mean, and maximum values of reach characteristics and measured reaeration coefficients from five tracer studies conducted on naturally-flowing high-slope streams*

Reach characteristics	Minimum	Median	Mean	Maximum
Discharge (cubic foot per second)	1.2	39.3	50.8	118.7
Water-surface slope (foot per foot)	.00325	.00340	.00390	.00601
Mean streamflow velocity (foot per second)	.09	.72	.66	1.34
Average windspeed (foot per second)	7.8	10.1	12.0	20.7
Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (foot per second)	.7	1.7	3.9	14.1
Mean depth (foot)	1.0	1.6	1.9	3.0
Mean width (foot)	13	35	32	42
Channel azimuth (degrees from true north)	3	7	65	302
Channel elevation (foot)	725	725	794	909
Mean sheltering angle (degree)	55	71	74	94
Color (platinum-cobalt)	2	4	29	110
Total organic carbon concentration (milligram per liter)	2.9	3.1	8.6	22.0
Concentration of methylene-blue-active substances (milligram per liter)	.03	.03	.04	.09
Specific conductance (microseimen per centimeter at 25 degrees Celsius)	35	240	208	307
Suspended-solids concentration (milligram per liter)	6	19	16	48
Measured reaeration coefficient (base e unit per day)	.8	6.7	6.3	10.2

most studies, the gas-tracer injection was started 30 minutes to 2 hours prior to the dye-tracer injection to allow the gas-tracer injection rate to stabilize. In all studies, there were no significant interruptions in the gas-tracer injection, which ranged from 1 to 10 days.

During steady streamflow conditions, the long-duration steady-state gas-tracer injection allows gas samples to be collected at any time after the gas-concentration plateau is fully formed. The time at which the dye cloud has completely passed a sampling site corresponds to the time at which the gas-concentration has reached a constant plateau (Yotsukura and Kilpatrick, 1973; Kilpatrick and Cobb, 1984). After the dye cloud had passed, gas samples were collected at each sampling site from the same parcel of water as it traveled down along the reach. The time of travel of the centroid of the dye clouds was used to determine the time required for a parcel of water to pass between sampling sites in a reach. To determine propane-gas concentrations, water samples were collected every 30 minutes for a 2-hour period with a volatile-gas sampler. To the extent possible, gas-sample collection at each sampling site was timed to occur during daylight and still be in the same water parcel. The gas-tracer-injection rate was maintained until after the water samples needed for propane-gas analysis were collected at all sampling sites. Water samples were preserved with 1 mL of a 37-percent solution of formaldehyde. The propane-gas concentration in each sample was determined by gas chromatography at the USGS laboratory in Arvada, Colo., or Ocala, Fla., as outlined by Shultz and others (1976).

The propane-gas depth-averaged desorption coefficient was calculated as outlined by Yotsukura and others (1983) with the average gas-concentration plateau and dye-tracer response curves determined for each tracer study. When transverse mixing was not complete at a sampling site, the average gas-concentration plateau was determined with a mass-flow weighting of the gas concentrations measured at various points in the cross section. An initial estimate of the propane-gas depth-averaged desorption coefficient (Kp′), in base e units per hour, was determined by the following equation:

$$Kp' = \frac{1}{\overline{T}_d - \overline{T}_u} \ln \frac{\overline{C}_u Q_u}{\overline{C}_d Q_d}, \qquad (6)$$

where $\overline{C}$ is the average propane-gas plateau concentration, in mg/L (micrograms per liter); and

Kp′ is the initial estimate of the propane-gas depth-averaged desorption coefficient, in base e units per hour.

Kp′ does not take into account the effects of longitudinal dispersion (Nobuhiro Yotsukura, U.S. Geological Survey, written commun., 1985). The actual propane-gas depth-averaged desorption coefficient (Kp), which does take into account longitudinal dispersion, was determined through iterative solution of the equation:

$$\frac{\overline{C}_u Q_u}{\overline{C}_d Q_d} = \frac{\Sigma(C_{c,i,u}/A_u)\exp(-KpT_{i,u})\,\Delta T_{i,u}}{\Sigma(C_{c,i,d}/A_d)\exp(-KpT_{i,d})\,\Delta T_{i,d}}, \qquad (7)$$

where $C_{c,i}$ is the dye concentration at the i[th] hour since the start of the injection, in micrograms per liter;

A is the area under the dye-tracer response curve, in micrograms-hours per liter;

Kp is the actual propane-gas depth-averaged desorption coefficient, in base e units per hour; and

T_i is the i[th] hour since the start of the injection.

The iterative process used Kp′ in equation 6 as an initial estimate of Kp in equation 7.

Kp was converted to the depth-averaged reaeration coefficient at the standard temperature of 20 °C (K_2) using the equation as represented by Kilpatrick and others (1987):

$$K_2 = 1.39\ Kp\ 1.024^{(20^\circ - t)}\ (24), \qquad (8)$$

where K_2 is the depth-averaged reaeration coefficient at the standard-temperature of 20 °C, in base e units per day;

t is the ambient water temperature, in °C; and

24 is the constant to convert hours to days; and

1.39 is the ratio of the absorption rate for oxygen to the desorption rate for propane based on mixing-tank experiments (Rathbun and others, 1978).

The transfer of error from measurement to calculation is controlled by the non-dimensional number,

$Kp\,(\bar{T}_d - \bar{T}_u)$ (Yotsukura and others, 1983). The measurement error (E) for a reaeration study can be estimated by the following equation:

$$E = \frac{E_r}{Kp\,(\bar{T}_d - \bar{T}_u)}, \qquad (9)$$

where E is the measurement error; and

E_r is the relative error of gas-concentration measurements and discharge measurements.

The relative error of gas-concentration measurements and discharge measurements (E_r) is estimated to be 10 percent for all studies.

Commonly Used Equations For Estimating Reaeration Coefficients

Physical and (or) hydraulic characteristics of a stream are used in most reaeration-coefficient estimating equations. With the exception of the Tsivoglou and Neal (1976) equation, 19 commonly used estimating equations require determination of mean stream velocity. The 19 commonly used reaeration coefficient estimating equations are as follow:

O'Connor and Dobbins (1958),

$$K_2 = 12.81\,\frac{V^{0.5}}{D^{1.5}}; \qquad (10)$$

Churchill and others (1962),

$$K_2 = 0.03453\,\frac{V^{2.695}}{D^{3.085}\,SL^{0.823}}; \qquad (11)$$

Churchill and others (1962),

$$K_2 = 11.57\,\frac{V^{0.969}}{D^{1.673}}; \qquad (12)$$

Krenkel and Orlob (1963),

$$K_2 = 234.5\,\frac{(V\,SL)^{0.404}}{D^{0.66}}; \qquad (13)$$

Owens and others (1964),

$$K_2 = 23.23\,\frac{V^{0.73}}{D^{1.75}}; \qquad (14)$$

Owens and others (1964),

$$K_2 = 21.73\,\frac{V^{0.67}}{D^{1.85}}; \qquad (15)$$

Dobbins (1965),

$$K_2 = 116.6\,\frac{1+F^2}{(0.9+F)^{1.5}}\,\frac{(V\,SL)^{0.375}}{D}\,\coth\left[\frac{4.10\,(V\,SL)^{0.125}}{(0.9+F)^{0.5}}\right], \qquad (16)$$

where coth is the hyperbolic cotangent of the angle, in radians; and

F is the Froude number, which is defined as the dimensionless ratio

$$F = \frac{V}{(g\,D)^{0.5}}, \qquad (17)$$

where g is the acceleration caused by gravity, in feet per second squared;

Langbein and Durum (1967),

$$K_2 = 7.61\,\frac{V}{D^{1.33}}; \qquad (18)$$

Isaac and Gaudy (1968),

$$K_2 = 8.62\,\frac{V}{D^{1.50}}; \qquad (19)$$

Cadwallader and McDonnell (1969),

$$K_2 = 336.8\,\frac{(V\,SL)^{0.5}}{D}; \qquad (20)$$

Negulescu and Rojanski (1969),

$$K_2 = 10.91\left(\frac{V}{D}\right)^{0.85}; \qquad (21)$$

Thackston and Krenkel (1969),

$$K_2 = 24.94\,\frac{(1+(F)^{0.5})\,u^*}{D}, \qquad (22)$$

where F is the Froude number (eq. 17);

u* is the average wind shear velocity, in feet per second, defined as

$$u^* = (g\;D\;SL)^{0.5}; \qquad (23)$$

Padden and Gloyna (1971),

$$K_2 = 6.87 \frac{V^{0.703}}{D^{1.054}}; \tag{24}$$

Bennett and Rathbun (1972),

$$K_2 = 106.10 \frac{V^{0.413} SL^{0.273}}{D^{1.408}}; \tag{25}$$

Bennett and Rathbun (1972),

$$K_2 = 20.19 \frac{V^{0.607}}{D^{1.689}}; \tag{26}$$

Parkhurst and Pomeroy (1972),

$$K_2 = 48.39 \frac{(1+0.17\ F^2)(V\ SL)^{0.375}}{D}; \tag{27}$$

Bansal (1973),

$$K_2 = 4.67 \frac{V^{0.6}}{D^{1.4}}; \tag{28}$$

Tsivoglou and Neal (1976),

$$K_2 = 1.296 \frac{dh}{dT}, \tag{29}$$

where dh is the change in water-surface elevation between the beginning and ending points of the reach, in feet; and

dT is the change in centroid traveltime between the beginning and ending points of the reach, in hours;

and Smoot (1987),

$$K_2 = 683.8 \frac{V^{0.5325} SL^{0.6236}}{D^{0.7258}}; \tag{30}$$

The 19 equations were converted to inch-pound units and the estimated reaeration coefficients are expressed in d^{-1} (base e units per day) corrected to 20 °C.

An error analysis comparing measured and estimated reaeration coefficients in percent can indicate the degree of uncertainty that is inherent in an individual estimating equation and define its application limits. Because several measured reaeration coefficients are small magnitude numbers, an equation can give consistently close estimates yet yield a high absolute error. This could bias evaluation of the accuracy of the equation. Additional error analysis of the standard deviation yielded a measure of the spread of residual error for each of the predicted and measured reaeration coefficients of an equation. Ideally, an equation will have both a low absolute error and a small standard deviation of residuals. The error analyses of the 19 commonly used reaeration-coefficient estimating equations were statistically summarized (table 6) for three groups of stream-tracer studies based on slope of water-surface and the presence of an impoundment within the study reach. The 3 groups consisted of the 29 low-slope stream-tracer studies, the 8 low-slope stream-tracer studies on streams with a single impoundment, and 5 high-slope stream-tracer studies.

The most reliable predictions of reaeration coefficients are obtained from equations consistently in the top rankings for lowest standard deviation of residuals and lowest mean absolute error. The unweighted error analyses of the 19 commonly used reaeration-coefficient estimating equations indicated that equation 27 (Parkhurst and Pomeroy, 1972) and equation 30 (Smoot, 1987) gave the more consistent estimate of the gas-transfer rate in all but the high-slope streams. Equation 27 was ranked first both for lowest average absolute error and standard deviation of residuals for the group of 29 low-slope stream-tracer studies with a single impoundment. Equation 30 was ranked first for the 8 single-impoundment stream-tracer studies (both average absolute error and standard deviation of residuals), and tied for first place for average absolute error in the 29 low-slope stream-tracer studies. No single equation ranked high for both average absolute error and standard deviation of residuals for the five high-slope stream-tracer studies. The top three ranking equations for each of the statistical groupings are marked in table 6 with superscripts. The reader should be aware that statistical analyses on the 2 groups of less than 10 stream-tracer studies are not conclusive but may be used to identify trends.

The individual study residuals and predictive errors for the 19 commonly used equations are given in Appendix 3 at the end of this report. The ranges for all the reach characteristics for each of the groups of stream-tracer studies are in tables 3, 4, and 5.

EMPIRICAL EQUATION FOR ESTIMATING REAERATION COEFFICIENTS

A multiple, stepwise-regression technique (P-STAT, Inc. 1989, p. 42.13-42.14) was used to describe the

Table 6.--*Statistical summary of error analyses of equations 10 through 30 (excluding equations 17 and 23)*

Group of tracer studies	Equation 10		Equation 11		Equation 12		Equation 13		Equation 14	
	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)
Unweighted measured reaeration coefficients from 29 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot	[1]2.55	126	361.80	2,946	11.63	159	3.08	88	30.45	355
Unweighted measured reaeration coefficients from 5 tracer studies conducted on streams having water-surface slopes greater than 0.002 foot per foot	3.95	299	3.44	95	2.92	48	[2]1.83	76	2.42	[3]40
Unweighted measured reaeration coefficients from 8 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot and having a single, small impoundment	[4]1.35	201	3.51	87	3.38	75	2.90	77	5.62	115

Table 6.--*Statistical summary of error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

	Equation 15		Equation 16		Equation 18		Equation 19		Equation 20	
	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)
Unweighted measured reaeration coefficients from 29 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot	34.26	384	3.08	88	4.92	100	6.81	116	2.91	[5]75
Unweighted measured reaeration coefficients from 5 tracer studies conducted on streams having water-surface slopes greater than 0.002 foot per foot	2.05	[6]33	21.83	76	3.13	56	3.06	56	2.19	103
Unweighted measured reaeration coefficients from 8 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot and having a single, small impoundment	6.02	125	2.90	77	3.09	67	3.18	71	2.48	[7]42

Table 6.--*Statistical summary of error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

Group of tracer studies	Equation 21		Equation 22		Equation 24		Equation 25		Equation 26	
	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)
Unweighted measured reaeration coefficients from 29 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot	3.98	119	[1]2.55	[8]68	3.82	96	7.21	152	26.42	323
Unweighted measured reaeration coefficients from 5 tracer studies conducted on streams having water-surface slopes greater than 0.002 foot per foot	3.50	52	2.47	135	3.05	52	[9]1.40	81	[10]2.01	[11]38
Unweighted measured reaeration coefficients from 8 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot and having a single, small impoundment	2.58	56	3.03	157	3.04	57	3.86	109	5.71	123

Table 6.--*Statistical summary of error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

Group of tracer studies	Equation 27		Equation 28		Equation 29		Equation 30	
	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)	Standard deviation of residuals	Mean absolute error (percent)
Unweighted measured reaeration coefficients from 29 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot	[12]2.23	[13]65	4.49	91	[14]2.29	81	2.59	[13]65
Unweighted measured reaeration coefficients from 5 tracer studies conducted on streams having water-surface slopes greater than 0.002 foot per foot	2.78	59	3.05	68	7.71	201	3.03	150
Unweighted measured reaeration coefficients from 8 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot and having a single, small impoundment	3.13	[15]54	3.34	63	[16]2.35	74	[17]2.20	[18]41

[1] Third rank equations for standard deviation of residuals for the indicated grouping of tracer studies.
[2] Second rank equation for standard deviation of residuals for the indicated grouping of tracer study.
[3] Third rank equation for mean absolute error for the indicated grouping of tracer studies.
[4] First rank equation for standard deviation of residuals for the indicated grouping of tracer studies.
[5] Third rank equations for mean absolute error for the indicated grouping of tracer studies.
[6] First rank equations for mean absolute error for the indicated grouping of tracer studies.
[7] Second rank equation for mean absolute error for the indicated grouping of tracer studies.
[8] Second rank equation for mean absolute error for the indicated grouping of tracer studies.
[9] First rank equation for standard deviation of residuals for the indicated grouping of tracer studies.
[10] Second rank equation for mean absolute error for the indicated grouping of tracer studies.
[11] Third rank equation for standard deviation of residuals for the indicated grouping of tracer studies.
[12] First rank equations for standard deviation of residuals for indicated grouping of tracer studies.
[13] First rank equations for mean absolute error for the indicated grouping of tracer studies.
[14] Second rank equation for standard deviation of residuals for the indicated grouping of tracer studies.
[15] Third rank equations for mean absolute error for the indicated grouping of tracer studies.
[16] Third rank equation for standard deviation of residuals for the indicated grouping of tracer studies.
[17] Second rank equation for standard deviation of residuals for the indicated grouping of tracer studies.
[18] First rank equation for mean absolute error for the indicated group of tracer studies.

relation between dependent variables (measured reaeration coefficients for 29 low-slope stream-tracer studies) and independent variables (14 reach characteristics determined for each of the tracer studies). At each step in this technique, an equation was derived by adding an independent variable with the highest absolute correlation to the dependent variable. After the variable was entered, its contribution to the equation was compared with those independent variables already in the equation. If the contribution of any independent variables weakened its correlation with the dependent variable below the confidence threshold (95 percentile), the independent variable was deleted. The potential contribution of variables that were not entered into the equation was recomputed; the independent variable with the next highest partial correlation that exceeded the confidence threshold was entered into the equation. The process continued until all variables that could meet the threshold requirements were compared.

The general form of a linear-relation equation involving dependent and independent variables is:

$$\log Y = \log h + i \log(H) + j \log(I) + k \log(J) + \ldots, \quad (31)$$

where Y is the dependent variable;

h is a regression constant;

i, j, and k are regression coefficients; and

H, I, and J are independent variables.

When not transformed, the linear-relation equation is:

$$Y = h H^i I^j J^k \ldots, \quad (32)$$

Measured reaeration coefficients from each of the 29 stream-tracer studies conducted on low-slope streams were used as the dependent variables in the regression analyses. Each measured reaeration coefficient used as a dependent variable was weighted with the following equation:

$$\text{weight} = 29 \frac{(L_{me}^2 + L_e^2)^{-1}}{\Sigma (L_{me}^2 + L_e^2)^{-1}}, \quad (33)$$

where 29 is the number of stream-tracer studies conducted on naturally-flowing, low-slope streams;

L_{me} is the log model error for the resulting regression equation; and

L_e is the log measurement error of each tracer study.

The model error in equation 32 was estimated as 34 percent with a convergence technique for the depth-averaged reaeration-coefficient analysis.

The correlation matrix of independent variables indicated potential colinearity between color and TOC concentration (table 7). The correlation matrix also indicated potential colinearity between the resultant wind velocity parallel to the channel azimuth and corrected for mean sheltering angle and average windspeed, channel azimuth, and mean sheltering angle. Many step-regression analyses were conducted on groups of reach characteristics to account for the potential correlated variables.

The depth-averaged reaeration coefficient may be estimated by the new empirical equation:

$$K_2 = 3.83 \frac{SL^{0.20}}{MBAS^{0.41} D^{0.76}}, \quad (34)$$

where SL is the water-surface slope, in foot per foot; and MBAS is the methylene-blue-active substances concentration, in milligrams per liter.

The empirical equation has an adjusted r^2 (coefficient of determination) value of 0.66 and a standard error of estimate of 71 percent. A plot relating measured and estimated reaeration coefficients is shown in figure 2.

Although many regression analyses were conducted on variations and groups of independent variables, none of the variations or groups improved the results of the regression analyses. Average windspeed, channel azimuth, mean sheltering angle, color, and suspended-solids concentration were not included in the final analyses because the sign of their regression coefficients did not make physical or hydrological sense. Resultant wind velocity parallel to the channel azimuth and corrected for mean sheltering angle had an insufficient degree of freedom to be included in the empirical equation at the 95-percent confidence level. Because mean stream velocity, mean width, channel elevation, TOC concentration, and specific conductance were very sensitive to sample size and model error, they were eliminated in the final analysis.

Table 7.--*Weighted correlation coefficient matrix used in the reaeration-coefficient regression analysis*

Variables	Independent variables													Variable
	Log of water-surface slope	Log of mean stream velocity	Log of wind speed	Log of resultant wind velocity vector	Log of mean depth	Log of mean width	Log of channel azimuth	Log of channel elevation	Log of color	Log of total organic carbon	Log of methylene blue active substances	Log of specific conductance	Log of suspended solids	Log of reaeration coefficient
Independent log of:														
Water-surface slope	1.000	0.309	-0.235	-0.200	-0.437	0.047	0.389	0.338	-0.191	-0.542	-0.390	0.118	-0.175	0.634
Mean stream veloocity	0.309	1.000	0.237	-0.017	-0.137	0.267	0.195	-0.248	-0.174	-0.381	0.130	0.200	-0.199	0.064
Wind speed	-0.235	0.237	1.000	0.579	0.476	0.162	-0.493	-0.655	0.199	0.141	0.369	0.230	0.348	-0.571
Resultant wind velocity vector	-0.200	-0.017	0.579	1.000	0.537	0.367	-0.486	-0.341	0.086	-0.160	0.005	0.106	0.514	-0.364
Mean depth	-0.437	-0.137	0.476	0.537	1.000	0.272	-0.573	-0.416	0.248	0.129	0.000	-0.141	0.321	-0.684
Mean width	0.047	0.267	0.162	0.367	0.272	1.000	-0.279	-0.132	0.023	-0.288	-0.046	-0.120	-0.099	-0.231
Channel azimuth	0.389	0.195	-0.493	-0.486	-0.573	-0.279	1.000	0.201	-0.324	-0.152	-0.173	0.240	-0.292	0.538
Channel elevation	0.338	-0.248	-0.655	-0.341	-0.416	-0.132	0.201	1.000	-0.198	-0.370	-0.317	-0.436	-0.192	0.553
Color	-0.191	-0.174	0.199	0.086	0.248	0.023	-0.324	-0.198	1.000	0.537	0.529	-0.379	0.040	-0.212
Total organic carbon	0.542	-0.381	0.141	-0.160	0.129	-0.288	-0.152	-0.370	0.537	1.000	0.513	0.004	0.182	-0.371
Methylene blue active substances	0.390	0.130	0.369	0.005	0.000	-0.046	-0.173	-0.317	0.529	0.513	1.000	-0.223	0.190	-0.432
Specific conductance	0.118	0.200	0.230	0.106	-0.141	-0.120	0.240	-0.436	-0.379	0.004	-0.223	1.000	0.089	-0.000
Suspended solids	-0.175	-0.199	0.348	0.514	0.321	-0.099	-0.292	-0.192	0.040	0.182	0.190	0.089	1.000	-0.258
Dependent log of:														
Reaeration coefficient	0.634	0.064	-0.571	-0.364	-0.684	-0.231	0.538	0.553	-0.212	-0.371	-0.432	-0.000	-0.258	1.000

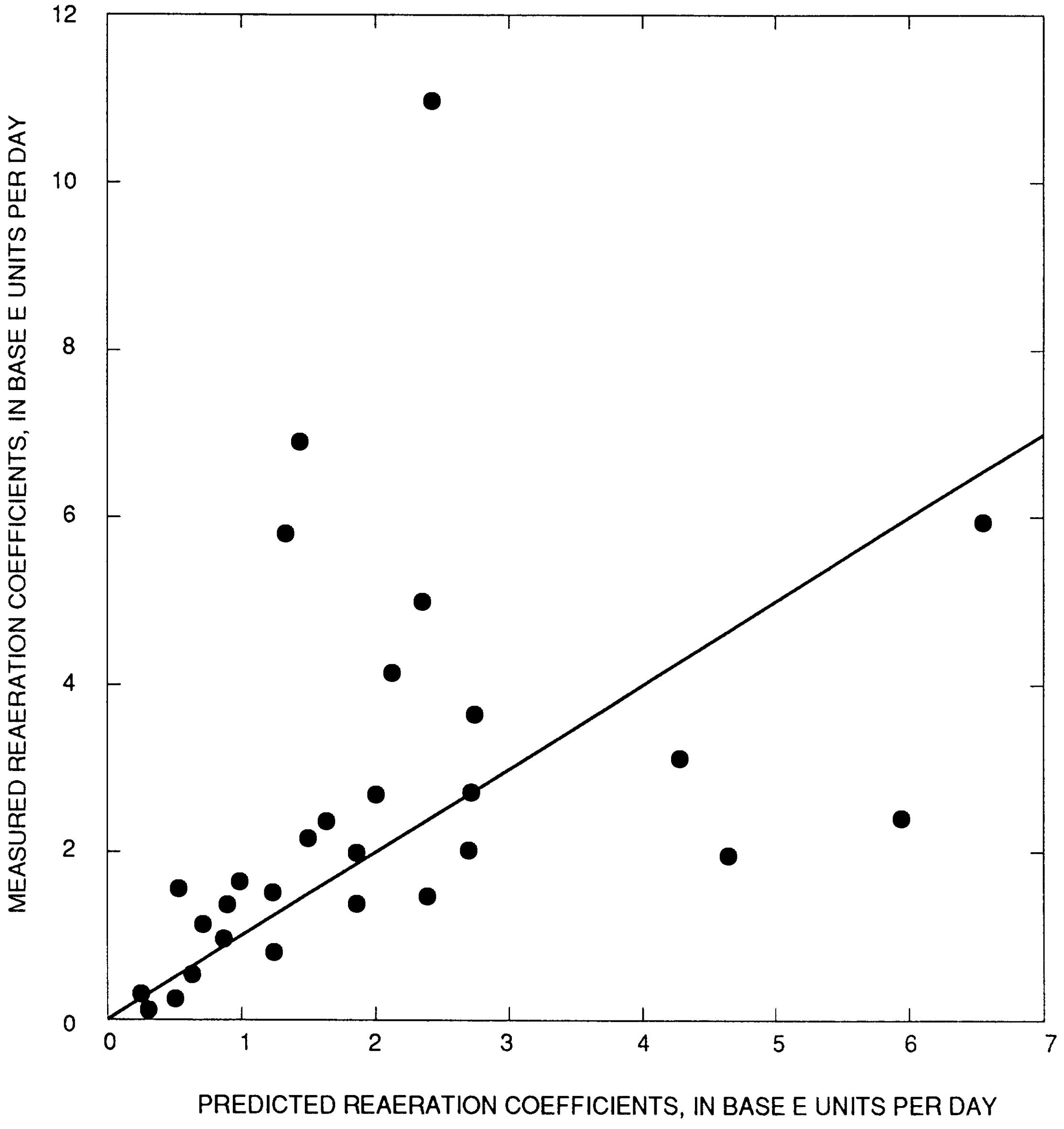

Figure 2.--Relation of measured and estimated reaeration coefficients from 29 tracer studies conducted on low-slope streams in Massachusetts and New York, 1985-88.

MBAS concentration and mean depth were not sensitive in any of the regression analyses. The negative coefficients for these two reach characteristics (eq. 34) are to be expected if a surfactant, as indicated by MBAS concentration, decreases surface tension and if increased depth in a stream channel reduces dynamic in-channel mixing forces caused by flow, bottom roughness, and gradual bends. The positive coefficient for the water-surface slope (eq. 34) would be expected because water-surface slope is an indication of the energy being released along a reach. The positive coefficient (eq. 34) indicates that water-surface slope is still important in understanding the gas-transfer process, even when the process is restricted to low-slope stream environments.

Two reach characteristics, water-surface slope and mean depth, are common to both equation 34 and equation 1 reported by Parker and Gay (1987) for high-slope streams. The 0.20 regression coefficient for water-surface slope in equation 34 is less than half the 0.438 regression coefficient reported for the Parker and Gay (1987) equation (eq. 1). This is because mean depth and MBAS concentration are accountable for more of the variability in the dependent variable for the data base of low-slope stream-tracer studies. The results support the Parker and Gay (1987) hypothesis that additional nonenergy reach characteristics, such as MBAS concentration, significantly affect the gas-transfer process at the water-air interface in low-slope stream environments.

Limitations of New Empirical Equation

Equation 34 may be used to estimate reaeration coefficients for streams in Massachusetts and New York where reach characteristics fall within the range of minimum and maximum values given in table 3 for the 29 tracer

studies conducted on naturally-flowing low-slope streams. Particular attention should be given to the reach characteristics that are included in equation 34 --water-surface slope, mean depth, and MBAS concentration. Reaeration coefficients estimated using equation 34 are for streams during steady-flow conditions.

Error Analysis of New Empirical Equation

Results from an error analysis of equation 34 are given in Appendix 4 at the end of this report. The individual study residuals and predictive errors are summarized in table 8 in two groups of stream-tracer studies. The two groups consisted of 29 tracer studies of low-slope streams and eight tracer studies on low-slope streams with a single impoundment. With a standard deviation of 2.55 and a mean absolute error of 56 percent, equation 34 is a significantly better predictor of reaeration rates for the subgroup of 29 low-slope stream studies than the eight tracer studies for low-slope streams with single impoundments. The standard deviation and mean absolute error of equation 34 for this second group was 3.73 and 152 percent, respectively. This difference in error indicates that while the single impoundment reaches are within the range of low-slope stream reach characteristics (see tables 4 and 8), the relation defined by equation 34 does not adequately reflect the gas transfer process in an impounded system.

APPLICATION OF EMPIRICAL EQUATION TO A REACH

The following example describes the application of the new empirical reaeration-coefficient equation to an unstudied reach in the study area to estimate a volatile-organic-compound transfer coefficient. For the purposes of this study, the reach is considered to be unstudied.

The following steps were used to estimate reaeration coefficients and show their application for estimating final concentration from a hypothetical toluene spill on Normans Kill near Westmere, New York (fig. 3):

1. From the Voorheesville, New York topographic map (U.S. Geological Survey, 1954; photorevised 1980), a reach was chosen from which estimations would be made. For convenient field identification, Normans Kill between the bridge on State Farm Road and the bridge on Krumkill Road was selected.

2. From the topographic map, the length of the reach was determined. The reach selected in the study was 2.4 miles or 12,700 ft.

3. Site visits to the stream reach were made to measure the reach characteristics used in solving the estimating equation. Discharge

Table 8.--*Statistical summary of error analysis for new empirical equation*

[d, day]

Group of tracer studies	Standard deviation of residuals (base e unit/d)	Mean absolute error (percent)
Unweighted measured reaeration coefficients from 29 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot	2.55	56
Unweighted measured reaeration coefficients from 8 tracer studies conducted on streams having water-surface slopes of less than 0.002 foot per foot and having a single, small impoundment	3.73	152

was measured at each end of the study reach and the width of the channel was measured in at least 20 places at evenly spaced intervals along the length of the reach. Change in water surface elevation was measured between the extremes of the study reach by differential leveling although this can most easily be completed using a total-station-laser theodolite. Water samples were collected at both ends of the study reach to determine its MBAS concentration. For the purpose of this example, assume the discharge measured at the State Farm Road bridge is 15.4 ft^3/s and at the Krumkill Road bridge is 16.5 ft^2/s for an average discharge of 16 ft^3/s. Assume the average channel width is 50 feet and the change in water-surface elevation is 15 ft. Assume the average MBAS concentration is 0.02 mg/L and the water temperature is 20 °C.

4. For greatest accuracy, two methods were available for determining the mean velocity for the study reach. The easiest method would be to use the results of a previously completed time-of-travel study. This information may be available from local, State, or Federal agencies. If this historic information were available, a dye-tracer time-of-travel study could be conducted to determine mean velocity. In this study, assume historic time-of-travel data indicated centroid time of travel was 9.4 hours and that mean velocity was 0.38 ft/s for the flow duration of interest.

5. Equation 4 was used to calculate a reach mean depth, D:

$$D = \frac{16}{(0.38)\ (50)} = 0.84 \text{ feet}$$

6. Channel slope was calculated by dividing the change in water-surface elevation at the extremes of the reach by the reach length. The calculated channel slope is 0.0012 ft/ft.

7. Equation 34 was used to estimate the reaeration coefficient:

$$K_2 = 3.83 \frac{(0.0012)^{0.20}}{(0.02)^{0.41}\ (0.84)^{0.76}}$$

$$= 5.7 \text{ per day}.$$

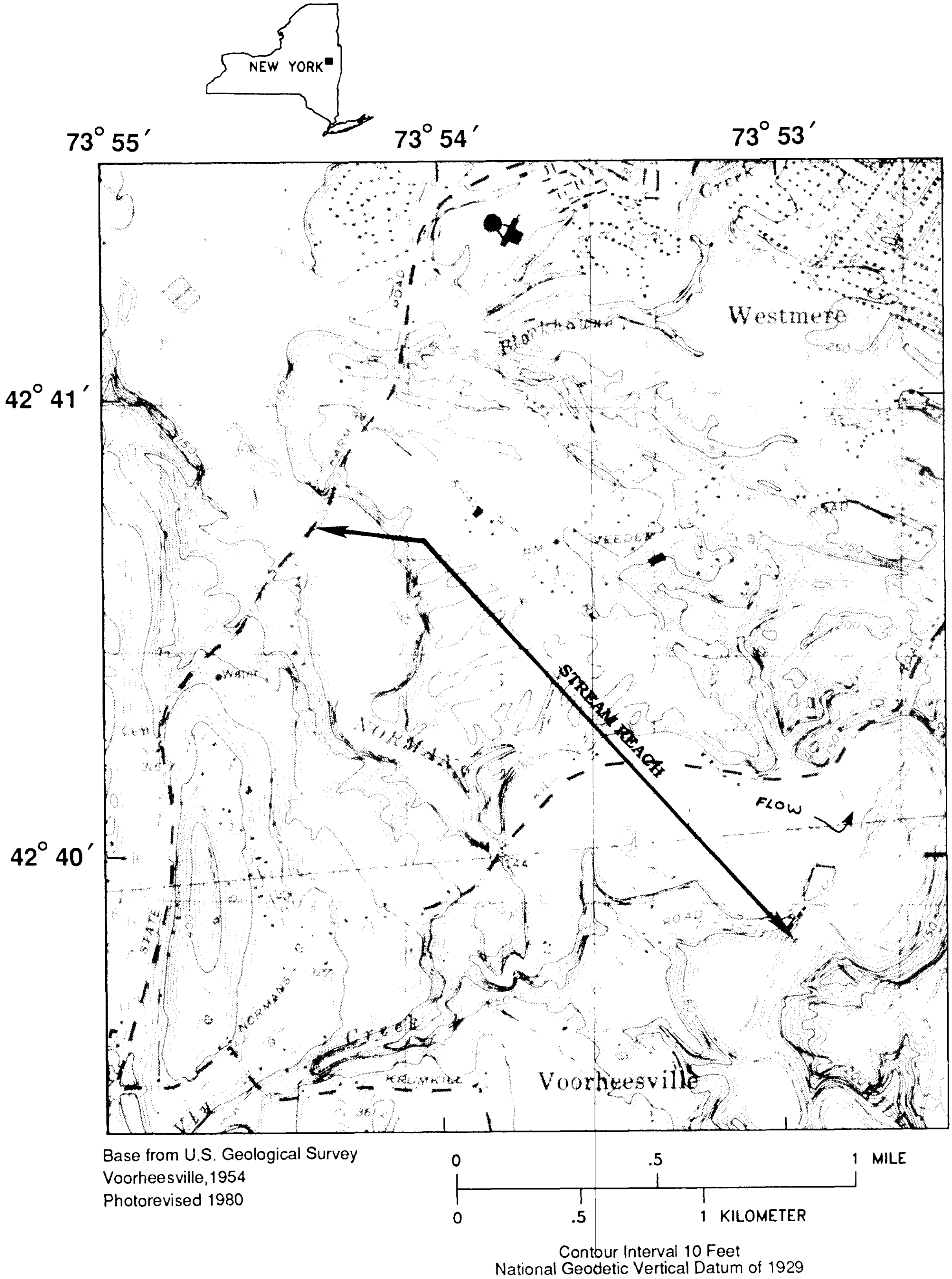

Figure 3.--Location of stream reach on Normans Kill near Westmere, New York.

Because the ambient water temperature is already at the base temperature of 20 °C, no temperature correction needs to be made.

8. Toluene is a volatile-organic compound on the USEPA list of priority pollutants (Keith and Telliard, 1979). Rathbun and Tai (1981) reported that the volatilization coefficient for toluene can be estimated with the following relation:

$$K_{toluene} = 0.655\ K_2 \qquad (35)$$

Rathbun and Tai (1981) limited the application of this estimating technique to toluene, benzene, chloroform, and methylene chloride because all have Henry's law constants larger than 10^{-3}atm-m^{3}mol/g (atmospheres-cubic meters-moles per gram) and therefore, are in the range of conditions where the liquid film is the controlling resistance to the mass-transfer process. The toluene concentration ($C_{toluene}$) at the downstream end of the example reach, assuming a toluene concentration ($C_{o,toluene}$) of 100 mg/L at the upstream end of the reach, can be estimated with equation 1 and 35:

$$C_{toluene} = (100) \exp[-(5.7)(0.655)(9.4/24)]$$

=23 mg/L at the end of the reach or a 78 percent reduction in concentration.

SUMMARY

The steady-state propane-gas-tracer method was used to measure reaeration coefficients from 42 stream-tracer studies conducted on 33 reaches of 22 streams in Massachusetts and New York. The stream-tracer studies were conducted during medium- and low-flow periods from May 1985 through October 1988. Also determined from each tracer study were 14 hydraulic, physical, and water-quality reach characteristics. The hydraulic and physical characteristics of the reaches were: water-surface slope, mean stream velocity, average windspeed reported at the closest NOAA weather station, resultant wind velocity parallel to the channel azimuth (and corrected for the mean sheltering angle), mean depth, mean width, channel azimuth, channel elevation, and mean sheltering angle. The water-quality reach characteristics were color, concentration of total organic carbon, concentration of methylene-blue-active substances, specific conductance, and concentration of suspended-solids.

Multiple-regression techniques were applied to data from 29 stream-tracer studies conducted on naturally-flowing low-slope streams without impoundments. The regression analyses, which related dependent variables (measured reaeration coefficients) to independent variables (14 reach characteristics), yielded the following empirical equation for estimating reaeration coefficients:

$$K_2 = 3.83\ \frac{SL^{0.20}}{MBAS^{0.41}\ D^{0.76}}$$

where the equation has a standard error of estimate of 71 percent. Only those variables significant at the 95-percent confidence level were retained in the final equation.

For 19 commonly used equations for estimating reaeration coefficients, the most reliable estimations of measured reaeration coefficients from the 29 low-slope stream-tracer studies were obtained from equation 27 (Parkhurst and Pomeroy, 1972):

$$K_2 = 48.39\ \frac{(1 + 0.17\ F^2)\ (V\ SL)^{0.375}}{D}$$

The Parkhurst and Pomeroy (1972) equation ranked first for both average absolute error and standard deviation of residuals for the group of 29 low-slope stream-tracer studies and third for average absolute error for the eight low-slope tracer studies on streams with a single impoundment. The most reliable estimations of measured reaeration coefficients from the eight low-slope stream-tracer studies with a single impoundment were obtained by equation 30 (Smoot, 1987):

$$K_2 = 683.8\ \frac{V^{0.5325}\ SL^{0.6236}}{D^{0.7258}}$$

The Smoot (1987) equation ranked first for eight tracer studies on low-slope streams with a single impoundment for both average absolute error and standard deviation of residuals, and tied for first place in rank for the average absolute error for the 29 low-slope stream-tracer studies.

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GLOSSARY OF TERMS

A, area under dye-tracer response curve, in microgram per liter hour.

coth, hyperbolic cotangent of angle, in radians.

C, dissolved-gas concentration, in micrograms per liter.

$C_{c,i}$, dye concentration at i^{th} hour since start of injection, in micrograms per liter.

d, subscript that designates downstream sampling site.

dh, change in water-surface elevation between beginning and ending points of reach, in feet.

dT, change in centroid traveltime between beginning and ending points of reach, in hours.

D, mean depth, feet.

E, measurement error.

E_r, relative error of gas-concentration measurements and discharge measurements.

F, Froude number.

g, acceleration caused by gravity, in feet per second squared.

h, regression constant.

H, independent variable.

i, regression coefficient.

I, independent variable.

j, regression coefficient.

J, independent variable.

k, regression coefficient.

K, absorption or desorption coefficient, in units per time.

K_2, depth-averaged reaeration coefficient at standard temperature of 20 degrees Celsius, in base e units per day.

KL, water-surface-film transfer coefficient.

Kp, actual propane-gas depth-averaged desorption coefficient, in base e units per hour.

Kp′, initial estimate of propane-gas depth-averaged desorption coefficient, in base e units per hour.

L, reach length, in feet.

L_e, log measurement error of each tracer study.

L_{me}, log model error for resulting regression equation.

MBAS, methylene-blue active-substances concentration, in milligrams per liter.

Q, discharge determined by averaging measured discharge at each sampling site, in cubic feet per second.

r^2, coefficient of determination.

ROE, total dissolved-solids concentration, in milligrams per liter.

SC, specific conductance, microsiemens per centimeter at 25 degrees Celsius.

SL, water-surface slope, in foot per foot.

SS, suspended-solids concentration, in milligrams per liter.

t, ambient water temperature, in degrees Celsius.

T, time.

$\bar{T}$**,** centroid traveltime of a slug-injected dye-tracer response curve measured at a sampling site.

T_i**,** i^{th} hour since start of injection.

u, subscript that designates upstream sampling site.

u*, average wind shear velocity, in feet per second.

V, mean streamflow velocity, in feet per second.

W, mean width, in feet.

Y, dependent variable.

24, constant to convert hours to days.

29, number of tracer studies conducted on naturally-flowing low-sloped streams used in error analysis.

APPENDIXES

Appendix 1.--*Study-reach location and descriptions*

Stream name	Sampling site	Location and description	Study date
Beaver Brook near Littleton, Mass.	Site 1 near Littleton	Lat. 42°31′00″ N., long. 71°31′24″ E., Middlesex County, 0.7 miles upstream of State Highway 2 bridge, 1.6 miles southwest of Littleton, Mass.	6-17-86
	Site 2 near Littleton	Lat. 42°31′32″ N., long. 71°31′08″ E., Middlesex County, upstream of State Highway 2 bridge, 1.0 miles southwest of Littleton, Mass.	6-17-86
		Reach: A - Site 1 to site 2 Reach length: 0.7 mile Wetland vegetation: Forested, scrub/shrub, and emergent	
Assabet River near Westborough, Mass.	Site 1 near Westborough	Lat. 42°16′46″ N., long. 71°38′19″ E., Worcester County, 1,400 feet upstream of State Highway 9 bridge, 1.5 miles northwest of Westborough, Mass.	5-13-86 8-05-86 10-28-86
	Site 2 near Westborough	Lat. 42°17′16″ N., long. 71°38′35″ E., Worcester County, at town line, 2,000 feet downstream from State Highway 9 bridge, 2.0 miles northwest of Westborough, Mass.	5-13-86 8-05-86 10-28-86
	Site 3 near Northborough	Lat. 42°10′16″ N., long. 71°37′44″ E., Worcester County, upstream side School Street Bridge, 1.3 miles southeast of Northborough, Mass.	8-05-86
		Reach: A - Site 1 to site 2 Reach length: 0.7 mile Reach: B - Site 2 to site 3 Reach length: 1.8 miles Wetland vegetation: Forested and scrub/shrub	

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Sudbury River near Wayland, Mass.	Site 1 near Wayland	Lat. 42°22′27″ N., long. 71°22′56″ E., Middlesex County, upstream side State Highway 27 bridge, 1.3 miles northwest of Wayland, Mass.	11-16-87
	Site 2 near Wayland	Lat. 42°23′41″ N., long. 71°21′55″ E., Middlesex County, upstream side Sherman Bridge, 2.3 miles north of Wayland, Mass.	11-16-87
		Reach: A - Site 1 to site 2 Reach length: 2.8 miles Wetland vegetation: Scrub/shrub and emergent	
Ipswich River near Topsfield, Mass.	Site 1 near Topsfield	Lat. 42°37′41″ N., long. 70°55′02″ E., Essex County, at Bunker Meadows, 1.7 miles downstream from mouth of Salem-Beverly Waterway Canal, 1.9 miles west of Topsfield, Mass.	6-23-87
	Site 2 near Topsfield	Lat. 42°39′13″ N., long. 70°54′44″ E., Essex County, at Hamilton Road Bridge, 2.3 miles northwest of Topsfield, Mass.	6-23-87
	Site 3 near Ipswich	Lat. 42°39′34″ N., long. 70°53′41″ E., Essex County, at Willowdale Dam, 2.9 miles northwest of Topsfield, Mass.	6-23-87
		Reach: A - Site 1 to site 2 Reach length: 4.1 miles Reach: B - Site 2 to site 3 Reach length: 1.4 miles Wetland vegetation: Scrub/shrub and emergent	

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Taunton River near Bridgewater, Mass.	Site 1 near Bridgewater	Lat. 41°57′47″ N., long. 70°54′46″ E., Plymouth County, at bridge on Auburn Street, 3.7 miles southeast of Bridgewater, Mass.	5-03-88 8-23-88
	Site 2 at South Bridgewater	Lat. 41°57′47″ N., long. 70°54′46″ E., Plymouth County, at Woodward Bridge on Summer Street, 0.7 miles east of South Bridgewater, Mass.	5-03-88 8-23-88
		Reach: A - Site 1 to site 2 Reach length: 2.4 miles Wetland vegetation: Forested	
French River near Oxford, Mass.	Site 1 near Oxford	Lat. 42°08′48″ N., long. 71°52′31″ E., Worcester County, 0.3 miles upstream of Wellington Brook, 2.1 miles northwest of Oxford, Mass.	10-21-87 6-21-88 9-23-88
	Site 2 near Oxford	Lat. 42°08′14″ N., long. 71°53′03″ E., Worcester County, at end of Charlton Road, 1.8 miles northwest of Oxford, Mass.	10-21-87 6-21-88 9-23-88
	Site 3 at Oxford	Lat. 42°07′52″ N., long. 71°52′50″ E., Worcester County, at pipeline crossing, 0.8 miles west of Oxford, Mass.	9-23-88
	Site 4 at Oxford	Lat. 42°07′06″ N., long. 71°52′54″ E., Worcester County, on right bank at Hodges Village, 240 feet downstream from Hodges Village Dam, 0.8 miles west of Oxford, Mass.	10-21-87 6-21-88

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
French River near Oxford, Mass.--Continued		Reach: A - Site 1 to site 2 Reach length: 1.0 miles Wetland vegetation: Forested Reach: B - Site 2 to site 3 Reach length: 0.7 mile Wetland vegetation: Forested and scrub/shrub Reach: C - Site 2 to site 4 Reach length: 1.8 miles Wetland vegetation: Forested, scrub/shrub, and emergent	
Otter River near Gardner, Mass.	Site 1 near Gardner	Lat. 42°34′29″ N., long. 72°01′22″ E., Worcester County, at bridge on town road, 3,900 feet downstream from Gardner sewage treatment plant, 1.2 miles west of Gardner, Mass.	5-19-87
	Site 2 near Gardner	Lat. 42°35′02″ N., long. 72°02′33″ E., Worcester County, at Boston and Maine Railroad bridge, 2.4 miles west of Gardner, Mass.	5-19-87
		Reach: A - Site 1 to site 2 Reach length: 2.0 miles Wetland vegetation: Forested, scrub/shrub, and emergent	
Mill River near Amherst, Mass.	Site 1 near Amherst	Lat. 42°23′18″ N., long. 72°32′24″ E., Hampshire County, 500 feet upstream from bridge on State Highway 116, 1.5 miles northwest of Amherst, Mass.	8-03-87
	Site 2 near Amherst	Lat. 42°23′10″ N., long. 72°33′03″ E., Hampshire County, at bridge on Maple Street, 1.6 miles east of North Hadley, Mass.	8-03-87

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Mill River near Amherst, Mass.--Continued	Site 3 at North Hadley	Lat. 42°23′27″ N., long. 72°33′46″ E., Hampshire County, 1.1 miles downstream from bridge on Maple Street, 0.5 miles east of North Hadley, Mass.	8-03-87
		Reach: A - Site 1 to site 2 Reach length: 0.7 mile Wetland vegetation: Forested Reach: B - Site 2 to site 3 Reach length: 1.1 miles Wetland vegetation: Forested, scrub/shrub, and emergent	
Natty Pond Brook near Hubbardston, Mass.	Site 1 near Hubbardston	Lat. 42°29′44″ N., long. 72°01′24″ E., Worcester County, on right bank at upstream side of culvert on New Templeton Road, 1.7 miles northwest of Hubbardston, Mass.	6-25-86
	Site 2 near Hubbardston	Lat. 42°29′24″ N., long. 72°01′30″ E., Worcester County, 2,200 feet downstream from culvert on New Templeton Road, 1.4 miles northwest of Hubbardston, Mass.	9-17-85 6-25-86
	Site 3 at Hubbardston	Lat. 42°28′52″ N., long. 72°01′38″ E., Worcester County, 1,000 feet upstream from bridge on Williamsville Road, 1.0 miles west of Hubbardston, Mass.	9-17-85
	Site 4 at Hubbardston	Lat. 42°28′05″ N., long. 72°01′14″ E., Worcester County, 1,200 feet downstream from bridge on Parson Road, 0.8 miles southwest of Hubbardston, Mass.	5-22-85 8-20-85

Stream name	Sampling site	Location and description	Study date
Natty Pond Brook near Hubbardston, Mass.--Continued	Site 5 at Hubbardston	Lat. 42°27′52″ N., long. 72°00′49″ E., Worcester County, at dirt road crossing, 770 feet west of Barre Road, 0.8 miles south of Hubbardston, Mass.	5-22-85 8-20-85
	Site 6 at Hubbardston	Lat. 42°27′29″ N., long. 72°01′07″ E., Worcester County, 5,000 feet upstream from Hale Road, 1.3 miles south of Hubbardston, Mass.	5-22-85
		Reach: A - Site 1 to site 2 Reach length: 0.4 mile Wetland vegetation: Scrub/shrub and emergent Reach: B - Site 2 to site 3 Reach length: 0.8 mile Wetland vegetation: Forested Reach: C - Site 4 to site 5 Reach length: 0.8 mile Wetland vegetation: Scrub/shrub Reach: D - Site 5 to site 6 Reach length: 0.8 mile Wetland vegetation: Forested, scrub/shrub, and emergent	
Ware River near Barre, Mass.	Site 1 near Barre	Lat. 42°25′16″ N., long. 72°02′52″ E., Worcester County, 30 feet upstream from mouth of Burnshirt River, 3.0 miles east of Barre, Mass.	6-28-88
	Site 2 near Barre	Lat. 42°23′41″ N., long. 72°03′02″ E., Worcester County, at bridge on State Highway 122, 3.0 miles east of Barre, Mass.	6-28-88

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Ware River near Barre, Mass.--Continued		Reach: A - Site 1 to site 2 Reach length: 2.2 miles Wetland vegetation: Scrub/shrub and emergent	
Karner Brook at South Egremont, Mass.	Site 1 at South Egremont	Lat. 42°09′19″ N., long. 73°25′51″ E., Berkshire County, at most easterly bridge on Mount Washington Road, 0.8 miles southwest of South Egremont, Mass.	10-14-88
	Site 2 at South Egremont	Lat. 42°09′24″ N., long. 73°25′45″ E., Berkshire County, 0.2 miles upstream of Mill Pond, 0.7 miles southwest of South Egremont, Mass.	10-14-88
	Site 3 at South Egremont	Lat. 42°09′30″ N., long. 73°25′20″ E., Berkshire County, at outlet of Mill Pond, 0.4 miles southwest of South Egremont, Mass.	10-14-88
		Reach: A - Site 1 to site 2 Reach length: 0.2 mile Wetland vegetation: Forested Reach: B - Site 2 to site 3 Reach length: 0.5 mile Wetland vegetation: Scrub/shrub and emergent	
Batten Kill near Greenwich, N.Y.	Site 1 near Greenwich	Lat. 43°05′30″ N., long. 73°27′59″ E., Washington County, 0.4 miles downstream from bridge at Center Falls, 1.5 miles northeast of Greenwich, N.Y.	8-24-87
	Site 2 at Greenwich	Lat. 43°05′27″ N., long. 73°29′45″ E., Washington County, at upper dam at Greenwich, N.Y.	8-24-87
		Reach: A - Site 1 to site 2 Reach length: 1.7 miles	

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Hoosic River near Adams, Mass.	Site 1 near Adams	Lat. 42°38′38″ N., long. 73°06′29″ E., Berkshire County, 0.3 miles downstream from bridge on Lime Street, 1.2 miles north of Adams, Mass.	6-09-87 6-02-88 8-17-88
	Site 2 near Adams	Lat. 42°39′54″ N., long. 73°06′16″ E., Berkshire County, at bridge on State Highway 8A, 2.9 miles north of Adams, Mass.	6-09-87 6-02-88 8-17-88
	Site 3 near Adams	Lat. 42°41′08″ N., long. 73°06′21″ E., Berkshire County, at entrance of North Adams flood control channel, 1.0 miles south of North Adams, Mass.	6-09-87 8-17-88
		Reach: A - Site 1 to site 2 Reach length: 2.1 miles Reach: B - Site 2 to site 3 Reach length: 1.7 miles Wetland vegetation: Forested	
Normans Kill near Westmere, N.Y.	Site 1 near Westmere	Lat. 42°40′43″ N., long. 73°54′25″ E., Albany County, 100 feet upstream from bridge on State Highway 155, 1.6 miles southwest of Westmere, N.Y., 0.5 miles southeast of Guilderland, N.Y.	6-08-88
	Site 2 near Voorheesville	Lat. 42°40′02″ N., long. 73°53′48″ E., Albany County, at bridge on Normans Kill Road, 0.1 miles upstream from Vly Creek, and 1.2 miles northeast of Voorheesville, N.Y.	6-08-88
		Reach: A - Site 1 to site 2 Reach length: 1.3 miles	

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Coeymans Creek near Coeymans, N.Y.	Site 1 near Selkirk	Lat. 42°30′47″ N., long. 73°48′31″ E., Albany County, at bridge on Pictovia Road, 1.4 miles southwest of Selkirk, N.Y.	9-29-87
	Site 2 near Coeymans	Lat. 42°29′33″ N., long. 73°48′08″ E., Albany County, just downstream from bridge on the Thomas E. Dewey Thruway, 1.3 miles northwest of Coeymans, N.Y.	9-29-87
		Reach: A - Site 1 to site 2 Reach length: 2.5 miles	
Claverack Creek at Hudson, N.Y.	Site 1 at Hudson	Lat. 42°15′17″ N., long. 73°45′17″ E., Columbus County, at bridge on State Highway 66, at Hudson, N.Y.	6-28-88
	Site 2 at Stattville	Lat. 42°17′12″ N., long. 73°44′14″ E., Columbus County, just upstream from dam at State Highway 401 at Stattville, N.Y.	6-28-88
		Reach: A - Site 1 to site 2 Reach length: 2.5 miles	
West Branch Delaware River at Deposit, N.Y.	Site 1 at Deposit	Lat. 42°02′49″ N., long. 75°25′16″ E., Delaware County, 0.7 miles downstream from Oquaga Creek, 1.0 miles south of Deposit, N.Y.	10-22-86
	Site 2 at Hale Eddy	Lat. 42°00′10″ N., long. 75°23′02″ E., Delaware County, 9.0 miles upstream from confluence of East and West Branches of Delaware River near Hancock, at Highway Bridge at Hale Eddy, N.Y.	10-22-86

Stream name	Sampling site	Location and description	Study date
West Branch Delaware River at Deposit, N.Y.--Continued		Reach: A - Site 1 to site 2 Reach length: 3.9 miles Wetland vegetation: Forested	
Susquehanna River at Phoenix Mills, N.Y.	Site 1 near Cooperstown	Lat. 42°40′43″ N., long. 74°56′16″ E., Otsego County, at bridge on private dirt road, 0.7 miles downstream from Red Creek, 0.9 miles south of Cooperstown, N.Y., Corporate boundary	8-09-88
	Site 2 at Phoenix Mills	Lat. 42°40′02″ N., long. 74°56′45″ E., Otsego County, at bridge on road 0.1 miles west of Phoenix Mills, N.Y., 0.8 miles northwest of Hyde Park, N.Y.	8-09-88
		Reach: A - Site 1 to site 2 Reach length: 1.3 miles	
Canisteo River at Hornell, N.Y.	Site 1 at Hornell	Lat. 42°18′20″ N., long. 77°39′18″ E., Steuben County, at bridge on East Street, 0.9 miles south of Hornell, N.Y.	9-26-88
	Site 2 at Canisteo	Lat. 42°17′10″ N., long. 77°37′29″ E., Steuben County, at bridge on town road, 0.3 miles west upstream of Cunningham Creek, 1.5 miles northwest of Canisteo, N.Y.	9-26-88
		Reach: A - Site 1 to site 2 Reach length: 2.4 miles	

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Caughdenoy Creek near Caughdenoy, N.Y.--Continued	Site 1 near Caughdenoy	Lat. 43°17′54″ N., long. 76°12′19″ E., Oswego County, 0.2 miles downstream of bridge on State Highway 49, 0.3 miles southeast of McMahon Corners, 1.3 miles north of Caughdenoy, N.Y.	6-13-88
	Site 2 near Caughdenoy	Lat. 43°16′42″ N., long. 76°11′39″ E., Oswego County, at culvert on Fuller Road, 0.7 miles northwest of Caughdenoy, N.Y.	6-13-88
		Reach: A - Site 1 to site 2 Reach length: 0.7 mile	
South Sandy Creek near Ellisburg, N.Y.	Site 1 near Ellisburg	Lat. 43°43′17″ N., long. 76°09′25″ E., Jefferson County, 1.0 miles upstream from Kibling Creek, 1.3 miles southeast of Ellisburg, N.Y.	6-15-88
	Site 2 near Ellisburg	Lat. 43°42′55″ N., long. 76°10′04″ E., Jefferson County, 500 feet upstream from Kibling Creek, 2.0 miles southeast of Ellisburg, N.Y.	6-15-88
	Site 3 near Ellisburg	Lat. 43°42′55″ N., long. 76°10′04″ E., Jefferson County, 0.7 miles downstream from Kibling Creek, 2.6 miles southeast of Ellisburg, N.Y.	6-15-88
		Reach: A - Site 1 to site 2 Reach length: 1.0 mile Reach: B - Site 2 to site 3 Reach length: 0.7 mile	

Appendix 1.--*Study-reach location and descriptions*--Continued

Stream name	Sampling site	Location and description	Study date
Indian River at Kelsey Bridge, N.Y.	Site 1 near Evans Mills	Lat. 44°08′41″ N., long. 75°47′22″ E., Jefferson County, 0.1 miles downstream from Joachin Bridge, 0.1 miles northeast of River Road, 4.0 miles northeast of Evans Mills, N.Y.	6-02-87
	Site 2 at Kelsey Bridge	Lat. 44°10′29″ N., long. 75°47′00″ E., Jefferson County, at bridge on River Road at Kelsey Bridge, 2.9 miles south of Theresa, N.Y.	6-02-87
		Reach: A - Site 1 to site 2	
		Reach length: 1.8 miles	

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*

[ft, foot; ft/s, foot per second; ft^3/s, cubic foot per second; ft/ft, foot per foot; channel elevation is in feet above sea level]

Reach	Study date	Reach descriptor[1]	Discharge (ft^3/s)	Water-surface slope (ft/ft)	Mean streamflow velocity (ft/s)	Average wind-speed (ft/s)	Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (ft/s)	Mean depth (ft)	Mean width (ft)
				Beaver Brook near Littleton, Mass.					
A	6-17-86	L	5.6	0.00035	0.03	13.5	11.8	3.3	65
				Assabet River near Westborough, Mass.					
A	5-13-86	L	8.3	.00023	.29	10.6	.1	1.4	20
A	8-05-86	L	3.0	.00020	.12	14.2	13.9	1.2	20
A	10-28-86	L	1.6	.00012	.08	14.8	3.2	1.0	20
B	8-05-86	L	3.0	.00003	.50	13.2	2.5	.2	25
				Sudbury River near Wayland, Mass.					
A	11-16-87	L	76.3	.00005	.31	21.7	21.7	5.0	98
				Ipswich River near Topsfield, Mass.					
A	6-23-87	L	33.7	.00009	.23	19.8	5.6	4.7	31
B	6-23-87	I	37.4	.00034	.05	19.2	8.0	9.0	81
				Taunton River near Bridgewater, Mass.					
A	5-03-88	L	315.8	.00006	.62	19.2	17.6	8.7	59
A	8-23-88	L	45.5	.00003	.15	18.8	18.4	4.9	61

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Discharge (ft^3/s)	Water-surface slope (ft/ft)	Mean streamflow velocity (ft/s)	Average wind-speed (ft/s)	Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (ft/s)	Mean depth (ft)	Mean width (ft)
French River near Oxford, Mass.									
A	6-21-88	L	6.6	.00073	.19	13.8	7.5	1.6	22
A	9-23-88	L	2.0	.00070	.06	14.1	1.2	1.9	19
B	9-23-88	L	2.0	.00033	.01	15.8	6.8	7.0	28
C	10-21-87	I	20.7	.00020	.20	14.2	.1	2.3	46
C	6-21-88	I	8.0	.00021	.24	13.5	7.9	.7	46
Otter River near Gardner, Mass.									
A	5-19-87	H	33.3	.00336	.32	9.4	2.0	3.0	35
Mill River near Amherst, Mass.									
A	8-03-87	L	14.4	.00020	.30	12.5	10.5	2.0	25
B	8-03-87	L	14.4	.00026	.48	12.5	11.5	1.1	28
Natty Pond Brook near Hubbardston, Mass.									
A	6-25-86	L	2.0	.00001	.03	13.8	2.0	3.6	19
B	9-17-85	H	1.1	.00601	.09	10.1	1.7	1.0	13
C	5-22-85	L	12.0	.00053	.25	12.6	1.0	2.1	23
C	8-20-85	L	3.2	.00005	.08	7.3	4.0	1.6	24
D	5-22-85	L	12.4	.00087	.17	11.0	10.6	2.4	31

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Discharge (ft^3/s)	Water-surface slope (ft/ft)	Mean streamflow velocity (ft/s)	Average wind-speed (ft/s)	Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (ft/s)	Mean depth (ft)	Mean width (ft)
				Ware River near Barre, Mass.					
A	6-28-88	L	27.4	0.00003	0.07	13.5	13.5	4.5	91
				Karner Brook at South Egremont, Mass.					
A	10-14-88	L	1.9	.00170	.10	9.4	5.2	.9	22
B	10-14-88	I	2.0	.00067	.01	10.9	10.3	.8	246
				Batten Kill near Greenwich, N.Y.					
A	8-24-87	I	181.1	.00026	.37	10.1	9.0	3.8	128
				Hoosic River near Adams, Mass.					
A	6-09-87	H	58.5	.00371	.86	20.7	14.1	1.6	42
A	6-02-88	H	114.9	.00325	1.34	12.0	.9	2.4	36
A	8-17-88	H	38.1	.00326	.72	7.8	.7	1.5	35
B	6-09-87	I	61.6	.00092	.66	20.7	12.1	2.5	37
B	8-17-88	I	44.8	.00092	.60	10.3	.8	2.6	29
				Normans Kill near Westmere, N.Y.					
A	6-08-88	L	15.9	.00124	.38	12.9	1.4	.8	50
				Coeymans Creek near Coeymans, N.Y.					
A	9-29-87	L	19.8	.00061	.39	20.2	18.7	1.6	31
				Claverack Creek at Hudson, N.Y.					
A	6-28-88	I	30.0	.00049	.05	14.1	5.1	5.2	128

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Discharge (ft^3/s)	Water-surface slope (ft/ft)	Mean streamflow velocity (ft/s)	Average wind-speed (ft/s)	Resultant wind velocity parallel to channel azimuth and corrected for mean sheltering angle (ft/s)	Mean depth (ft)	Mean width (ft)
				West Branch Delaware River near Deposit, N.Y.					
A	10-22-86	L	104.5	.00108	.56	11.0	5.7	.9	201
				Susquehanna River at Phoenix Mills, N.Y.					
A	8-09-88	L	24.1	.00041	.25	7.3	3.3	2.5	39
				Canisteo River at Hornell, N.Y.					
A	9-26-88	L	20.2	.00040	.22	13.6	13.5	2.7	34
				Caughdenoy Creek near Caughdenoy, N.Y.					
A	6-13-88	L	2.1	.00003	.04	8.1	2.4	1.6	29
				South Sandy Creek near Ellisburg, N.Y.					
A	6-15-88	L	14.9	.00116	.31	9.3	.5	.7	48
B	6-15-88	L	15.1	.00010	.14	8.7	2.7	1.6	67
				Indian River at Kelsey Bridge, N.Y.					
A	6-02-87	L	137.3	.00006	.17	15.6	11.8	8.2	97

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

[Pt-Co, platinum-cobalt; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius]

Reach	Study date	Reach descriptor[1]	Channel azimuth (degree)	Channel elevation (ft)	Mean sheltering angle (degree)	Color (Pt-Co)	Total organic carbon concentration (mg/L)	Methylene-blue active-substances concentration (mg/L)	Specific conductance (µS/cm at 25 °C)
				Beaver Brook near Littleton, Mass.					
A	6-17-86	L	22.5	220	71.9	160	20	0.07	183
				Assabet River near Westborough, Mass.					
A	5-13-86	L	339.5	269	67.0	30	15	.13	234
A	8-05-86	L	339.5	269	67.0	50	13	.12	277
A	10-28-86	L	339.5	269	67.0	35	9.4	.13	360
B	8-05-86	L	58.0	269	111.5	60	19	.54	336
				Sudbury River near Wayland, Mass.					
A	11-16-87	L	29.5	112	165.8	8	5.9	.05	390
				Ipswich River near Topsfield, Mass.					
A	6-23-87	L	9.5	49	74.2	44	6.7	.07	227
B	6-23-87	I	68.0	49	85.7	44	6.7	.07	227
				Taunton River near Bridgewater, Mass.					
A	5-03-88	L	41.5	13	72.2	58	10	.13	190
A	8-23-88	L	41.5	13	75.0	51	9.5	.14	357

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Channel azimuth (degree)	Channel elevation (ft)	Mean sheltering angle (degree)	Color (Pt-Co)	Total organic carbon concentration (mg/L)	Methylene-blue active-substances concentration (mg/L)	Specific conductance (µS/cm at 25 °C)
				French River near Oxford, Mass.					
A	6-21-88	L	35.5	472	43.8	35	5.6	.04	153
A	9-23-88	L	35.5	472	50.7	16	6.2	.04	157
B	9-23-88	L	339.0	469	98.9	16	6.2	.04	153
C	10-21-87	I	354.5	469	86.4	37	8.3	.03	137
C	6-21-88	I	354.5	469	110.8	35	5.6	.04	155
				Otter River near Gardner, Mass.					
A	5-19-87	H	302.0	896	78.5	110	22	.09	165
				Mill River near Amherst, Mass.					
A	8-03-87	L	75.5	135	45.0	13	5.9	.06	187
B	8-03-87	L	297.0	131	39.6	13	5.9	.06	187
				Natty Pond Brook near Hubbardston, Mass.					
A	6-25-86	L	14.0	922	131.3	20	3.1	.05	37
B	9-17-85	H	3.0	909	55.0	25	12	.03	35
C	5-22-85	L	60.0	879	137.3	75	6	.05	45
C	8-20-85	L	60.0	876	137.3	300	6.5	.06	49
D	5-22-85	L	305.0	876	138.5	75	6	.05	45

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Channel azimuth (degree)	Channel elevation (ft)	Mean sheltering angle (degree)	Color (Pt-Co)	Total organic carbon concentration (mg/L)	Methylene-blue active-substances concentration (mg/L)	Specific conductance (µS/cm at 25 °C)
				Ware River near Barre					
A	6-28-88	L	6.0	686	120.0	100	11	0.04	58
				Karner Brook at South Egremont, Mass.					
A	10-14-88	L	42.0	732	125.0	5	2	.02	320
B	10-14-88	I	69.0	728	120.0	5	2	.02	320
				Batten Kill near Greenwich, N.Y.					
A	8-24-87	I	266.5	341	101.0	18	2.8	.02	226
				Hoosic River near Adams, Mass.					
A	6-09-87	H	7.0	725	70.6	4	3	.03	294
A	6-02-88	H	7.0	725	70.0	4	2.9	.04	240
A	8-17-88	H	7.0	725	93.8	2	3.1	.03	307
B	6-09-87	I	358.5	702	63.0	4	3	.03	294
B	8-17-88	I	358.5	702	86.9	2	3.1	.03	376
				Normans Kill near Westmere, N.Y.					
A	6-08-88	L	149.0	131	44.0	20	4.8	.02	603
				Coeymans Creek near Coeymans, N.Y.					
A	9-29-87	L	166.0	98	25.0	15	3	.02	647

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Channel azimuth (degree)	Channel elevation (ft)	Mean sheltering angle (degree)	Color (Pt-Co)	Total organic carbon concentration (mg/L)	Methylene-blue active-substances concentration (mg/L)	Specific conductance (µS/cm at 25 °C)
				Claverack Creek at Hudson, N.Y.					
A	6-28-88	I	42.0	151	93.0	20	4.6	.02	317
				West Branch Delaware River near Deposit, N.Y.					
A	10-22-86	L	148.0	981	140.0	18	1.4	.07	81
				Susquehanna River at Phoenix Mills, N.Y.					
A	8-09-88	L	206.0	1,181	53.0	15	2.4	.02	287
				Canisteo River at Hornell, N.Y.					
A	9-26-88	L	130.0	203	44.0	20	3.4	.02	617
				Caughdenoy Creek near Caughdenoy, N.Y.					
A	6-13-88	L	180.0	381	126.0	11	15.3	.02	211
				South Sandy Creek near Ellisburg, N.Y.					
A	6-15-88	L	234.5	180	31.0	20	5	.02	287
B	6-15-88	L	241.0	177	41.0	20	5	.02	287
				Indian River at Kelsey Bridge, N.Y.					
A	6-02-87	L	8.0	390	120.0	45	5.6	.02	154

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

[d, day; h, hours]

Reach	Study date	Reach descriptor[1]	Suspended-solids concentration (mg/L)	Measured reaeration coefficient (base e unit/d)	Measurement error	Travel time to: Leading edge (h)	Peak (h)	Centroid (h)	Trailing edge (h)
				Beaver Brook near Littleton, Mass.					
A	6-17-86	L	46	1.62	0.14	10.7	15.7	37.8	123.7
				Assabet River near Westborough, Mass.					
A	5-13-86	L	3	1.46	.15	2.4	2.9	3.4	5.6
A	8-05-86	L	7	5.78	1.17	5.7	6.8	8.2	17.1
A	10-28-86	L	24	.79	.26	3.5	4.6	12.5	45.6
B	8-05-86	L	8	2.35	.33	3.3	4.8	5.4	6.8
				Sudbury River near Wayland, Mass.					
A	11-16-87	L	48	.19	.18	8.6	10.1	13.4	24.3
				Ipswich River near Topsfield, Mass.					
A	6-23-87	L	39	1.50	1.14	20.3	24.2	26.0	43.0
B	6-23-87	I	39	.38	.39	18.0	22.6	38.8	162.0
				Taunton River near Bridgewater, Mass.					
A	5-03-88	L	19	.23	.05	5.3	5.5	5.8	6.9
A	8-23-88	L	11	.16	.11	21.8	23.0	23.2	25.1

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Suspended-solids concentration (mg/L)	Measured reaeration coefficient (base e unit/d)	Measurement error	Travel time to Leading edge (h)	Travel time to Peak (h)	Travel time to Centroid (h)	Travel time to Trailing edge (h)
French River near Oxford, Mass.									
A	6-21-88	L	25	3.67	.86	5.3	7.4	8.0	13.0
A	9-23-88	L	13	1.43	1.19	16.6	24.0	25.9	40.6
B	9-23-88	L	15	1.08	2.25	35.8	57.0	100.0	101.7
C	10-21-87	I	0	.66	.35	9.7	12.5	13.7	20.1
C	6-21-88	I	24	2.63	.22	28.8	30.8	33.6	41.6
Otter River near Gardner, Mass.									
A	5-19-87	H	19	.78	.25	6.4	8.3	9.1	21.9
Mill River near Amherst, Mass.									
A	8-03-87	L	350	6.85	.69	2.5	3.0	3.5	5.5
B	8-03-87	L	350	10.99	1.00	2.1	2.5	3.4	6.0
Natty Pond Brook near Hubbardston, Mass.									
A	6-25-86	L	14	.91	.51	8.5	14.1	17.3	41.9
B	9-17-85	H	17	8.22	.36	8.7	11.1	14.1	33.9
C	5-22-85	L	8	2.74	.39	3.1	3.9	4.4	7.6
C	8-20-85	L	6	1.94	.78	5.0	13.1	13.4	26.2
D	5-22-85	L	8	2.05	.46	5.0	6.2	6.9	13.2

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Suspended-solids concentration (mg/L)	Measured reaeration coefficient (base e unit/d)	Measurement error	Travel time to Leading edge (h)	Travel time to Peak (h)	Travel time to Centroid (h)	Travel time to Trailing edge (h)
				Ware River near Barre, Mass.					
A	6-28-88	L	17	1.31	1.72	23.2	29.9	48.7	92.0
				Karner Brook at South Egremont, Mass.					
A	10-14-88	L	9	2.40	.32	1.9	2.8	3.5	6.8
B	10-14-88	I	9	1.02	.28	36.0	63.5	67.3	234.4
				Batten Kill near Greenwich, N.Y.					
A	8-24-87	I	18	1.34	.28	4.4	5.5	6.8	9.1
				Hoosic River near Adams, Mass.					
A	6-09-87	H	48	6.74	.73	2.9	3.4	3.6	4.7
A	6-02-88	H	6	5.60	.45	1.9	2.2	2.3	2.9
A	8-17-88	H	35	10.16	1.25	3.3	4.1	4.3	5.5
B	6-09-87	I	48	7.33	.72	2.7	3.2	3.7	4.9
B	8-17-88	I	0	9.20	1.05	3.1	3.8	4.1	4.9
				Normans Kill near Westmere, N.Y.					
A	6-08-88	L	8	1.92	.11	5.7	7.4	9.4	16.9
				Coeymans Creek near Coeymans, N.Y.					
A	9-29-87	L	6	4.96	.06	6.1	9.0	9.3	12.2

Appendix 2.--*Reach characteristics, time-of-travel characteristics, and measured reaeration coefficients from 42 tracer studies*--Continued

Reach	Study date	Reach descriptor[1]	Suspended-solids concentration (mg/L)	Measured reaeration coefficient (base e unit/d)	Measurement error	Travel time to: Leading edge (h)	Peak (h)	Centroid (h)	Trailing edge (h)
				Claverack Creek at Hudson, N.Y.					
A	6-28-88	I	10	.21	.16	32.3	48.4	55.2	85.5
				West Branch Delaware River near Deposit, N.Y.					
A	10-22-86	L	5	3.10	.07	7.5	8.9	10.3	17.2
				Susquehanna River at Phoenix Mills, N.Y.					
A	8-09-88	L	13	2.66	.08	3.5	7.1	7.8	11.2
				Canisteo River at Hornell, N.Y.					
A	9-26-88	L	29	2.13	.06	11.1	14.9	15.6	18.8
				Caughdenoy Creek near Caughdenoy, N.Y.					
A	6-13-88	L	11	1.33	.06	15.2	21.6	24.5	40.0
				South Sandy Creek near Ellisburg, N.Y.					
A	6-15-88	L	3	5.89	.07	3.2	4.3	4.5	8.7
B	6-15-88	L	3	4.09	.07	5.8	7.1	7.3	8.9
				Indian River at Kelsey Bridge, N.Y.					
A	6-02-87	L	3	.51	.24	12.5	14.9	15.3	19.6

[1] L, low-slope stream; H, high-slope stream; I, impounded stream

Appendix 3.--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*

[ft/ft, foot per foot; d, day]

					Equation 10			Equation 11		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.35	1.27	-78	0	1.62	-100
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	4.10	-2.64	181	.43	1.03	-71
A	8-05-86	L	.00020	5.78	3.20	2.58	-45	.06	5.72	-99
A	10-28-86	L	.00012	.79	3.54	-2.75	348	.06	.73	-92
B	8-05-86	L	.00003	2.35	75.40	-73.05	3,109	1,948.35	-1,946.00	82,809
				Sudbury River near Wayland, Mass.						
A	11-16-87	L	.00005	.19	.64	-.45	237	.03	.16	-84
				Ipswich River near Topsfield, Mass.						
A	6-23-87	L	.00009	1.50	.60	.90	-60	.01	1.49	-99
B	6-23-87	I	.00034	.38	.11	.27	-71	0	.38	-100
				Taunton River near Bridgewater, Mass.						
A	5-03-88	L	.00006	.23	.39	-.16	70	.03	.20	-87
A	8-23-88	L	.00003	.16	.46	-.30	188	.01	.15	-94

Appendix 3.--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 10			Equation 11		
					Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
French River near Oxford, Mass.										
A	6-21-88	L	.00073	3.67	2.71	.96	-26	.03	3.64	-99
A	9-23-88	L	.00070	1.43	1.18	.25	-17	0	1.43	-100
B	9-23-88	L	.00033	1.08	.07	1.01	-94	0	1.08	-100
C	10-21-87	I	.00020	.66	1.64	-.98	148	.04	.62	-94
C	6-21-88	I	.00021	2.63	10.91	-8.28	315	2.42	.21	-8
Otter River near Gardner, Mass.										
A	5-19-87	H	.00336	.78	1.41	-.63	81	.01	.77	-99
Mill River near Amherst, Mass.										
A	8-03-87	L	.00020	6.85	2.55	4.30	-63	.19	6.66	-97
B	8-03-87	L	.00026	10.99	7.66	3.33	-30	3.07	7.92	-72
Natty Pond Brook near Hubbardston, Mass.										
A	6-25-86	L	.00001	.91	.32	.59	-65	0	.91	-100
B	9-17-85	H	.00601	8.22	4.04	4.18	-51	0	8.22	-100
C	5-22-85	L	.00053	2.74	2.11	.63	-23	.04	2.70	-98
C	8-20-85	L	.00005	1.94	1.76	.18	-9	.03	1.91	-98
D	5-22-85	L	.00087	2.05	1.45	.60	-29	.01	2.04	-100

Appendix 3 .--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 10			Equation 11		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.34	0.97	-74	0	1.31	-100
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	5.12	-2.72	113	.02	2.38	-99
B	10-14-88	I	.00067	1.02	1.76	-.74	73	0	1.02	-100
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	1.04	.30	-22	.03	1.31	-98
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	5.76	.98	-15	.52	6.22	-92
A	6-02-88	H	.00325	5.60	3.97	1.63	-29	.56	5.04	-90
A	8-17-88	H	.00326	10.16	5.64	4.52	-44	.41	9.75	-96
B	6-09-87	I	.00092	7.33	2.60	4.73	-65	.20	7.13	-97
B	8-17-88	I	.00092	9.20	2.44	6.76	-73	.15	9.05	-98
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	8.15	-6.23	324	1.01	.91	-47
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	3.81	1.15	-23	.27	4.69	-95

Appendix 3.--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 10: Estimated reaeration coefficient (base e unit/d)	Equation 10: Residuals (base e unit/d)	Equation 10: Error (percent)	Equation 11: Estimated reaeration coefficient (base e unit/d)	Equation 11: Residuals (base e unit/d)	Equation 11: Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.23	-.02	10	0	.21	-100
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	10.67	-7.57	244	2.49	.61	-20
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	1.64	1.02	-38	.03	2.63	-99
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	1.40	.73	-34	.02	2.11	-99
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	1.31	.02	-2	.01	1.32	-99
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	11.63	-5.74	97	1.05	4.84	-82
B	6-15-88	L	.00010	4.09	2.27	1.82	-44	.07	4.02	-98
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.22	.29	-57	0	.51	-100

Appendix 3.--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 12			Equation 13		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.05	1.57	-97	0.95	0.67	-41
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	1.96	-.50	34	3.67	-2.21	151
A	8-05-86	L	.00020	5.78	1.03	4.75	-82	2.65	3.13	-54
A	10-28-86	L	.00012	.79	.97	-.18	23	2.07	-1.28	162
B	8-05-86	L	.00003	2.35	62.60	-60.25	2,564	6.74	-4.39	187
				Sudbury River near Wayland, Mass.						
A	11-16-87	L	.00005	.19	.25	-.06	32	.91	-.72	379
				Ipswich River near Topsfield, Mass.						
A	6-23-87	L	.00009	1.50	.21	1.29	-86	1.02	.48	-32
B	6-23-87	I	.00034	.38	.02	.36	-95	.63	-.25	66
				Taunton River near Bridgewater, Mass.						
A	5-03-88	L	.00006	.23	.20	.03	-13	.90	-.67	291
A	8-23-88	L	.00003	.16	.13	.03	-19	.55	-.39	244

Appendix 3.--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 12 Estimated reaeration coefficient (base e unit/d)	Equation 12 Residuals (base e unit/d)	Equation 12 Error (percent)	Equation 13 Estimated reaeration coefficient (base e unit/d)	Equation 13 Residuals (base e unit/d)	Equation 13 Error (percent)
				French River near Oxford, Mass.						
A	6-21-88	L	.00073	3.67	1.02	2.65	-72	4.52	-.85	23
A	9-23-88	L	.00070	1.43	.25	1.18	-83	2.47	-1.04	73
B	9-23-88	L	.00033	1.08	.01	1.07	-99	.38	.70	-65
C	10-21-87	I	.00020	.66	.60	.06	-9	2.17	-1.51	229
C	6-21-88	I	.00021	2.63	5.39	-2.76	105	5.33	-2.70	103
				Otter River near Gardner, Mass.						
A	5-19-87	H	.00336	.78	.62	.16	-21	7.02	-6.24	800
				Mill River near Amherst, Mass.						
A	8-03-87	L	.00020	6.85	1.17	5.68	-83	2.84	4.01	-59
B	8-03-87	L	.00026	10.99	4.80	6.19	-56	5.62	5.37	-49
				Natty Pond Brook near Hubbardston, Mass.						
A	6-25-86	L	.00001	.91	.04	.87	-96	.21	.70	-77
B	9-17-85	H	.00601	8.22	1.17	7.05	-86	11.09	-2.87	35
C	5-22-85	L	.00053	2.74	.88	1.86	-68	3.76	-1.02	37
C	8-20-85	L	.00005	1.94	.45	1.49	-77	1.06	.88	-45
D	5-22-85	L	.00087	2.05	.49	1.56	-76	3.63	-1.58	77

Appendix 3.--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 12 Estimated reaeration coefficient (base e unit/d)	Equation 12 Residuals (base e unit/d)	Equation 12 Error (percent)	Equation 13 Estimated reaeration coefficient (base e unit/d)	Equation 13 Residuals (base e unit/d)	Equation 13 Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.07	1.24	-95	0.41	0.90	-69
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	1.62	.78	-33	7.55	-5.15	215
B	10-14-88	I	.00067	1.02	.19	.83	-81	2.09	-1.07	105
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	.47	.87	-65	2.21	-.87	65
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	4.45	2.29	-34	16.34	-9.60	142
A	6-02-88	H	.00325	5.60	3.53	2.07	-37	14.29	-8.69	155
A	8-17-88	H	.00326	10.16	4.04	6.12	-60	14.85	-4.69	46
B	6-09-87	I	.00092	7.33	1.65	5.68	-77	6.21	1.12	-15
B	8-17-88	I	.00092	9.20	1.48	7.72	-84	5.93	3.27	-36
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	5.90	-3.98	207	8.45	-6.53	340
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	2.04	2.92	-59	5.63	-.67	14

Appendix 3.--*Results from error analyses of equations 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 12			Equation 13		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.04	.17	-81	1.00	-.79	376
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	7.44	-4.34	140	11.98	-8.88	286
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	.66	2.00	-75	3.03	-.37	14
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	.53	1.60	-75	2.75	-.62	29
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	.25	1.08	-81	.66	.67	-50
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	6.42	-.53	9	11.44	-5.55	94
B	6-15-88	L	.00010	4.09	.74	3.35	-82	1.79	2.30	-56
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.06	.45	-88	.55	-.04	8

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 14: Estimated reaeration coefficient (base e unit/d)	Equation 14: Residuals (base e unit/d)	Equation 14: Error (percent)	Equation 15: Estimated reaeration coefficient (base e unit/d)	Equation 15: Residuals (base e unit/d)	Equation 15: Error (percent)
Beaver Brook near Littleton, Mass.										
A	6-17-86	L	0.00035	1.62	0.21	1.41	-87	0.21	1.41	-87
Assabet River near Westborough, Mass.										
A	5-13-86	L	.00023	1.46	5.14	-3.68	252	5.00	-3.54	242
A	8-05-86	L	.00020	5.78	3.37	2.41	-42	3.51	2.27	-39
A	10-28-86	L	.00012	.79	165.75	-164.96	20,881	186.39	-185.60	23,494
B	8-05-86	L	.00003	2.35	3.57	-1.22	52	3.88	-1.53	65
Sudbury River near Wayland, Mass.										
A	11-16-87	L	.00005	.19	.59	-.40	211	.51	-.32	168
Ipswich River near Topsfield, Mass.										
A	6-23-87	L	.00009	1.50	.52	.98	-65	.46	1.04	-69
B	6-23-87	I	.00034	.38	.06	.32	-84	.05	.33	-87
Taunton River near Bridgewater, Mass.										
A	5-03-88	L	.00006	.23	.37	-.14	61	.29	-.06	26
A	8-23-88	L	.00003	.16	.37	-.21	131	.33	-.17	106

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 14: Estimated reaeration coefficient (base e unit/d)	Equation 14: Residuals (base e unit/d)	Equation 14: Error (percent)	Equation 15: Estimated reaeration coefficient (base e unit/d)	Equation 15: Residuals (base e unit/d)	Equation 15: Error (percent)
French River near Oxford, Mass.										
A	6-21-88	L	.00073	3.67	1.66	2.01	-55	1.58	2.09	-57
A	9-23-88	L	.00070	1.43	2.96	-1.53	107	2.92	-1.49	104
B	9-23-88	L	.00033	1.08	15.64	-14.56	1,348	16.54	-15.46	1,431
C	10-21-87	I	.00020	.66	.94	-.28	42	.98	-.32	48
C	6-21-88	I	.00021	2.63	.03	2.60	-99	.03	2.60	-99
Otter River near Gardner, Mass.										
A	5-19-87	H	.00336	.78	1.50	-.72	92	1.34	-.56	72
Mill River near Amherst, Mass.										
A	8-03-87	L	.00020	6.85	2.96	3.89	-57	2.79	4.06	-59
A	8-03-87	L	.00026	10.99	11.44	-.45	4	11.09	-.10	1
Natty Pond Brook near Hubbardston, Mass.										
A	6-25-86	L	.00001	.91	4.23	-3.32	365	4.60	3.69	-405
B	9-17-85	H	.00601	8.22	.19	8.03	-98	.19	8.03	-98
C	5-22-85	L	.00053	2.74	2.31	.43	-16	2.18	.56	-20
C	8-20-85	L	.00005	1.94	1.41	.53	-27	1.34	.60	-31
D	5-22-85	L	.00087	2.05	1.59	.46	-22	1.65	.40	-20

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 14 Estimated reaeration coefficient (base e unit/d)	Equation 14 Residuals (base e unit/d)	Equation 14 Error (percent)	Equation 15 Estimated reaeration coefficient (base e unit/d)	Equation 15 Residuals (base e unit/d)	Equation 15 Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.23	1.08	-82	0.22	1.09	-83
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	5.69	-3.29	137	6.21	-3.81	159
B	10-14-88	I	.00067	1.02	1.17	-.15	15	1.47	-.45	44
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	1.07	.27	-20	.93	.41	-31
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	8.94	-2.20	33	8.05	-1.31	19
A	6-02-88	H	.00325	5.60	6.18	-.58	10	5.21	.39	-7
A	8-17-88	H	.00326	10.16	8.50	1.66	-16	7.77	2.39	-24
B	6-09-87	I	.00092	7.33	3.40	3.93	-54	2.98	4.35	-59
B	8-17-88	I	.00092	9.20	3.11	6.09	-66	2.74	6.46	-70
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	15.15	-13.23	689	15.28	-13.36	696
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	4.92	.04	-1	4.63	.33	-7

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 14			Equation 15		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.13	.08	-38	.13	.08	-38
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	17.24	-14.14	456	16.82	-13.72	443
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	1.72	.94	-35	1.60	1.06	-40
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	1.41	.72	-34	1.30	.83	-39
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	1.03	.30	-23	1.10	.23	-17
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	17.48	-11.59	197	18.13	-12.24	208
B	6-15-88	L	.00010	4.09	2.31	1.78	-44	2.31	1.78	-44
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.16	.35	-69	.14	.37	-73

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 16 Estimated reaeration coefficient (base e unit/d)	Equation 16 Residuals (base e unit/d)	Equation 16 Error (percent)	Equation 18 Estimated reaeration coefficient (base e unit/d)	Equation 18 Residuals (base e unit/d)	Equation 18 Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.60	1.02	-63	0.04	1.58	-98
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	2.61	-1.15	79	1.40	.06	-4
A	8-05-86	L	.00020	5.78	2.14	3.64	-63	.69	5.09	-88
A	10-28-86	L	.00012	.79	1.96	-1.17	148	.59	.20	-25
B	8-05-86	L	.00003	2.35	10.53	-8.18	348	24.79	-22.44	955
				Sudbury River near Wayland, Mass.						
A	11-16-87	L	.00005	.19	.48	-.29	153	.28	-.09	47
				Ipswich River near Topsfield, Mass.						
A	6-23-87	L	.00009	1.50	.53	.97	-65	.22	1.28	-85
B	6-23-87	I	.00034	.38	.27	.11	-29	.02	.36	-9[illegible]
				Taunton River near Bridgewater, Mass.						
A	5-03-88	L	.00006	.23	.36	-.13	57	.27	-.04	17
A	8-23-88	L	.00003	.16	.33	-.17	106	[illegible]	.02	-12

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 16 Estimated reaeration coefficient (base e unit/d)	Equation 16 Residuals (base e unit/d)	Equation 16 Error (percent)	Equation 18 Estimated reaeration coefficient (base e unit/d)	Equation 18 Residuals (base e unit/d)	Equation 18 Error (percent)
				French River near Oxford, Mass.						
A	6-21-88	L	.00073	3.67	2.90	.77	-21	.75	2.92	-80
A	9-23-88	L	.00070	1.43	1.65	-.22	15	.19	1.24	-87
B	9-23-88	L	.00033	1.08	.21	.87	-81	.01	1.07	-99
C	10-21-87	I	.00020	.66	1.36	-.70	106	.50	.16	-24
C	6-21-88	I	.00021	2.63	4.96	-2.33	89	2.99	-.36	14
				Otter River near Gardner, Mass.						
A	5-19-87	H	.00336	.78	3.19	-2.41	309	.57	.21	-27
				Mill River near Amherst, Mass.						
A	8-03-87	L	.00020	6.85	1.82	5.03	-73	.93	5.92	-86
B	8-03-87	L	.00026	10.99	4.20	6.79	-62	3.19	7.80	-71
				Natty Pond Brook near Hubbardston, Mass.						
A	6-25-86	L	.00001	.91	.19	.72	-79	.04	.87	-96
B	9-17-85	H	.00601	8.22	7.71	.51	-6	.71	7.51	-91
C	5-22-85	L	.00053	2.74	2.21	.53	-19	.71	2.03	-74
C	8-20-85	L	.00005	1.94	.93	1.01	-52	.33	1.61	-83
D	5-22-85	L	.00087	2.05	2.03	.02	-1	.41	1.64	-80

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 16			Equation 18		
					Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.27	1.04	-79	0.07	1.24	-95
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	5.89	-3.49	145	.94	1.46	-61
B	10-14-88	I	.00067	1.02	2.20	-1.18	116	.10	.92	-90
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	1.09	.25	-19	.47	.87	-65
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	8.78	-2.04	30	3.44	3.30	-49
A	6-02-88	H	.00325	5.60	6.67	-1.07	19	3.17	2.43	-43
A	8-17-88	H	.00326	10.16	8.20	1.96	-19	3.05	7.11	-70
B	6-09-87	I	.00092	7.33	3.12	4.21	-57	1.47	5.86	-80
B	8-17-88	I	.00092	9.20	2.98	6.22	-68	1.32	7.88	-86
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	8.45	-6.53	340	3.56	-1.64	85
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	3.46	1.50	-30	1.55	3.41	-69

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 16 Estimated reaeration coefficient (base e unit/d)	Equation 16 Residuals (base e unit/d)	Equation 16 Error (percent)	Equation 18 Estimated reaeration coefficient (base e unit/d)	Equation 18 Residuals (base e unit/d)	Equation 18 Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.50	-.29	138	.04	.17	-81
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	8.51	-5.41	175	4.69	-1.59	51
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	1.72	.94	-35	.57	2.09	-79
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	1.53	.60	-28	.46	1.67	-78
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	.67	.66	-50	.18	1.15	-86
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	9.07	-3.18	54	3.64	2.25	-38
B	6-15-88	L	.00010	4.09	1.38	2.71	-66	.55	3.54	-87
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.25	.26	-51	.08	.43	-84

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 19: Estimated reaeration coefficient (base e unit/d)	Equation 19: Residuals (base e unit/d)	Equation 19: Error (percent)	Equation 20: Estimated reaeration coefficient (base e unit/d)	Equation 20: Residuals (base e unit/d)	Equation 20: Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.04	1.58	-98	0.31	1.31	-81
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	1.49	-.03	2	1.93	-.47	32
A	8-05-86	L	.00020	5.78	.75	5.03	-87	1.33	4.45	-77
A	10-28-86	L	.00012	.79	.67	.12	-15	1.02	-.23	29
B	8-05-86	L	.00003	2.35	35.72	-33.37	1,420	5.70	-3.35	143
				Sudbury River near Wayland, Mass.,						
A	11-16-87	L	.00005	.19	.24	-.05	26	.27	-.08	42
				Ipswich River near Topsfield, Mass.,						
A	6-23-87	L	.00009	1.50	.19	1.31	-87	.32	1.18	-79
B	6-23-87	I	.00034	.38	.02	.36	-95	.16	.22	-58
				Taunton River near Bridgewater, Mass.,						
A	5-03-88	L	.00006	.23	.21	.02	-9	.25	-.02	9
A	8-23-88	L	.00003	.16	.12	.04	-25	.15	.01	-6

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 19			Equation 20		
					Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				French River near Oxford, Mass.,						
A	6-21-88	L	.00073	3.67	.78	2.89	-79	2.44	1.23	-34
A	9-23-88	L	.00070	1.43	.19	1.24	-87	1.12	.31	-22
B	9-23-88	L	.00033	1.08	0	1.08	-100	.09	.99	-92
C	10-21-87	I	.00020	.66	.49	.17	-26	.93	-.27	41
C	6-21-88	I	.00021	2.63	3.60	-.97	37	3.50	-.87	33
				Otter River near Gardner, Mass.,						
A	5-19-87	H	.00336	.78	.54	.24	-31	3.71	-2.93	376
				Mill River near Amherst, Mass.,						
A	8-03-87	L	.00020	6.85	.94	5.91	-86	1.33	5.52	-81
B	8-03-87	L	.00026	10.99	3.55	7.44	-68	3.42	7.57	-69
				Natty Pond Brook near Hubbardston, Mass.						
A	6-25-86	L	.00001	.91	.04	.87	-96	.05	.86	-95
B	9-17-85	H	.00601	8.22	.81	7.41	-90	8.07	.15	-2
C	5-22-85	L	.00053	2.74	.71	2.03	-74	1.84	.90	-33
C	8-20-85	L	.00005	1.94	.34	1.60	-82	.41	1.53	-79
D	5-22-85	L	.00087	2.05	.40	1.65	-80	1.73	.32	-16

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 19			Equation 20		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.06	1.25	-95	0.11	1.20	-92
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	1.09	1.31	-55	5.14	-2.74	114
B	10-14-88	I	.00067	1.02	.12	.90	-88	1.08	-.06	6
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	.43	.91	-68	.86	.48	-36
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	3.59	3.15	-47	11.74	-5.00	74
A	6-02-88	H	.00325	5.60	3.09	2.51	-45	9.24	-3.64	65
A	8-17-88	H	.00326	10.16	3.21	6.95	-68	10.53	-.37	4
B	6-09-87	I	.00092	7.33	1.42	5.91	-81	3.30	4.03	-55
B	8-17-88	I	.00092	9.20	1.27	7.93	-86	3.11	6.09	-66
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	4.15	-2.23	116	8.58	-6.66	347
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	1.61	3.35	-68	3.17	1.79	-36

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 19: Estimated reaeration coefficient (base e unit/d)	Equation 19: Residuals (base e unit/d)	Equation 19: Error (percent)	Equation 20: Estimated reaeration coefficient (base e unit/d)	Equation 20: Residuals (base e unit/d)	Equation 20: Error (percent)
Claverack Creek at Hudson, N.Y.										
A	6-28-88	I	.00049	.21	.03	.18	-86	.30	-.09	43
West Branch Delaware River near Deposit, N.Y.										
A	10-22-86	L	.00108	3.10	5.38	-2.28	74	8.92	-5.82	188
Susquehanna River at Phoenix Mills, N.Y.										
A	8-09-88	L	.00041	2.66	.55	2.11	-79	1.37	1.29	-48
Canisteo River at Hornell, N.Y.										
A	9-26-88	L	.00040	2.13	.45	1.68	-79	1.20	.93	-44
Caughdenoy Creek near Caughdenoy, N.Y.										
A	6-13-88	L	.00003	1.33	.19	1.14	-86	.23	1.10	-83
South Sandy Creek near Ellisburg, N.Y.										
A	6-15-88	L	.00116	5.89	4.36	1.53	-26	8.85	-2.96	50
B	6-15-88	L	.00010	4.09	.57	3.52	-86	.78	3.31	-81
Indian River at Kelsey Bridge, N.Y.										
A	6-02-87	L	.00006	.51	.06	.45	-88	.13	.38	-75

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 21			Equation 22		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.18	1.44	-89	1.46	0.16	-10
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	2.86	-1.40	96	2.01	-.55	38
A	8-05-86	L	.00020	5.78	1.50	4.28	-74	1.93	3.85	-67
A	10-28-86	L	.00012	.79	1.25	-.46	58	1.63	-.84	106
B	8-05-86	L	.00003	2.35	20.03	-17.68	752	2.36	-.01	0
				Sudbury River near Wayland, Mass.						
A	11-16-87	L	.00005	.19	1.02	-.83	437	.51	-.32	168
				Ipswich River near Topsfield, Mass.						
A	6-23-87	L	.00009	1.50	.84	.66	-44	.60	.90	-60
B	6-23-87	I	.00034	.38	.14	.24	-63	.83	-.45	118
				Taunton River near Bridgewater, Mass.						
A	5-03-88	L	.00006	.23	1.16	-.93	404	.40	-.17	74
A	8-23-88	L	.00003	.16	.58	-.42	262	.36	-.20	125

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 21 Estimated reaeration coefficient (base e unit/d)	Equation 21 Residuals (base e unit/d)	Equation 21 Error (percent)	Equation 22 Estimated reaeration coefficient (base e unit/d)	Equation 22 Residuals (base e unit/d)	Equation 22 Error (percent)
				French River near Oxford, Mass.						
A	6-21-88	L	.00073	3.67	1.74	1.93	-53	3.27	.40	-11
A	9-23-88	L	.00070	1.43	.56	.87	-61	2.69	-1.26	88
B	9-23-88	L	.00033	1.08	.04	1.04	-96	.81	.27	-25
C	10-21-87	I	.00020	.66	1.35	-.69	105	1.46	-.80	121
C	6-21-88	I	.00021	2.63	4.45	-1.82	69	3.01	-.38	14
				Otter River near Gardner, Mass.						
A	5-19-87	H	.00336	.78	1.65	-.87	112	5.18	-4.40	564
				Mill River near Amherst, Mass.						
A	8-03-87	L	.00020	6.85	2.21	4.64	-68	1.58	5.27	-77
B	8-03-87	L	.00026	10.99	5.35	5.64	-51	2.70	8.29	-75
				Natty Pond Brook near Hubbardston, Mass.						
A	6-25-86	L	.00001	.91	.18	.73	-80	.20	.71	-78
B	9-17-85	H	.00601	8.22	1.43	6.79	-83	11.80	-3.58	44
C	5-22-85	L	.00053	2.74	1.80	.94	-34	2.42	.32	-12
C	8-20-85	L	.00005	1.94	.87	1.07	-55	.79	1.15	-59
D	5-22-85	L	.00087	2.05	1.16	.89	-43	2.88	-.83	40

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 21 Estimated reaeration coefficient (base e unit/d)	Equation 21 Residuals (base e unit/d)	Equation 21 Error (percent)	Equation 22 Estimated reaeration coefficient (base e unit/d)	Equation 22 Residuals (base e unit/d)	Equation 22 Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.30	1.01	-77	0.37	0.94	-72
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	1.77	.63	-26	6.92	-4.52	188
B	10-14-88	I	.00067	1.02	.26	.76	-74	4.23	-3.21	315
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	1.50	-.16	12	1.33	.01	-1
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	6.36	.38	-6	8.79	-2.05	30
A	6-02-88	H	.00325	5.60	6.64	-1.04	19	6.79	-1.19	21
A	8-17-88	H	.00326	10.16	5.68	4.48	-44	8.21	1.95	-19
B	6-09-87	I	.00092	7.33	3.49	3.84	-52	3.23	4.10	-56
B	8-17-88	I	.00092	9.20	3.20	6.00	-65	3.12	6.08	-66
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	5.47	-3.55	185	6.75	-4.83	252
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	3.24	1.72	-35	3.19	1.77	-36

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 21 Estimated reaeration coefficient (base e unit/d)	Equation 21 Residuals (base e unit/d)	Equation 21 Error (percent)	Equation 22 Estimated reaeration coefficient (base e unit/d)	Equation 22 Residuals (base e unit/d)	Equation 22 Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.19	.02	-10	1.40	-1.19	567
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	7.09	-3.99	129	6.34	-3.24	105
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	1.55	1.11	-42	2.00	.66	-25
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	1.33	.80	-38	1.87	.26	-12
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	.51	.82	-62	.60	.73	-55
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	5.32	.57	-10	7.01	-1.12	19
B	6-15-88	L	.00010	4.09	1.34	2.75	-67	1.25	2.84	-69
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.41	.10	-20	.40	.11	-22

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 24			Equation 25		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.15	1.47	-91	0.51	1.11	-69
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	2.01	-.55	38	3.94	-2.48	170
A	8-05-86	L	.00020	5.78	1.23	4.55	-79	3.18	2.60	-45
A	10-28-86	L	.00012	.79	1.14	-.35	44	3.10	-2.31	292
B	8-05-86	L	.00003	2.35	18.65	-16.30	694	35.17	-32.82	1,397
				Sudbury River near Wayland, Mass.						
A	11-16-87	L	.00005	.19	.55	-.36	189	.46	-.27	142
				Ipswich River near Topsfield, Mass.						
A	6-23-87	L	.00009	1.50	.48	1.02	-68	.51	.99	-66
B	6-23-87	I	.00034	.38	.08	.30	-79	.16	.22	-58
				Taunton River near Bridgewater, Mass.						
A	5-03-88	L	.00006	.23	.50	-.27	117	.30	-.07	30
A	8-23-88	L	.00003	.16	.34	-.18	112	.30	-.14	88

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 24			Equation 25		
					Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				French River near Oxford, Mass.						
A	6-21-88	L	.00073	3.67	1.27	2.40	-65	3.78	-.11	3
A	9-23-88	L	.00070	1.43	.47	.96	-67	1.83	-.40	28
B	9-23-88	L	.00033	1.08	.04	1.04	-96	.12	.96	-89
C	10-21-87	I	.00020	.66	.91	-.25	38	1.66	-1.00	152
C	6-21-88	I	.00021	2.63	3.72	-1.09	41	9.86	-7.23	275
				Otter River near Gardner, Mass.						
A	5-19-87	H	.00336	.78	.98	-.20	26	3.01	-2.23	286
				Mill River near Amherst, Mass.						
A	8-03-87	L	.00020	6.85	1.45	5.40	-79	2.44	4.41	-64
B	8-03-87	L	.00026	10.99	3.69	7.30	-66	7.19	3.80	-35
				Natty Pond Brook near Hubbardston, Mass.						
A	6-25-86	L	.00001	.91	.15	.76	-84	.17	.74	-81
B	9-17-85	H	.00601	8.22	1.30	6.92	-84	10.21	-1.99	24
C	5-22-85	L	.00053	2.74	1.19	1.55	-57	2.69	.05	-2
C	8-20-85	L	.00005	1.94	.71	1.23	-63	1.25	.69	-36
D	5-22-85	L	.00087	2.05	.79	1.26	-61	2.22	-.17	8

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 24 Estimated reaeration coefficient (base e unit/d)	Equation 24 Residuals (base e unit/d)	Equation 24 Error (percent)	Equation 25 Estimated reaeration coefficient (base e unit/d)	Equation 25 Residuals (base e unit/d)	Equation 25 Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.21	1.10	-84	0.24	1.07	-82
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	1.61	.79	-33	8.97	-6.57	274
B	10-14-88	I	.00067	1.02	.34	.68	-67	2.90	-1.88	184
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	.83	.51	-38	1.11	.23	-17
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	3.71	3.03	-45	10.98	-4.24	63
A	6-02-88	H	.00325	5.60	3.34	2.26	-40	7.28	-1.68	30
A	8-17-88	H	.00326	10.16	3.43	6.73	-66	10.50	-.34	3
B	6-09-87	I	.00092	7.33	1.94	5.39	-74	3.61	3.72	-51
B	8-17-88	I	.00092	9.20	1.79	7.41	-81	3.42	5.78	-63
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	4.11	-2.19	114	14.36	-12.44	648
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	2.11	2.85	-57	4.74	.22	-4

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 24			Equation 25		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.14	.07	-33	.36	-.15	71
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	4.93	-1.83	59	14.33	-11.23	362
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	.99	1.67	-63	1.98	.68	-26
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	.86	1.27	-60	1.71	.42	-20
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	.46	.87	-65	.85	.48	-36
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	4.25	1.64	-28	16.36	-10.47	178
B	6-15-88	L	.00010	4.09	1.02	3.07	-75	1.91	2.18	-53
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.22	.29	-57	.19	.32	-63

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 26			Equation 27		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.30	1.32	-81	0.19	1.43	-88
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	5.30	-3.84	263	.92	.54	-37
A	8-05-86	L	.00020	5.78	3.86	1.92	-33	.72	5.06	-88
A	10-28-86	L	.00012	.79	4.24	-3.45	437	.62	.17	-22
B	8-05-86	L	.00003	2.35	144.05	-141.70	6,030	3.25	-.90	38
				Sudbury River near Wayland, Mass.						
A	11-16-87	L	.00005	.19	.65	-.46	242	.16	.03	-16
				Ipswich River near Topsfield, Mass.						
A	6-23-87	L	.00009	1.50	.60	.90	-60	.18	1.32	-88
B	6-23-87	I	.00034	.38	.08	.30	-79	.09	.29	-76
				Taunton River near Bridgewater, Mass.						
A	5-03-88	L	.00006	.23	.39	-.16	70	.13	.10	-43
A	8-23-88	L	.00003	.16	.44	-.28	175	.10	.06	-38

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 26: Estimated reaeration coefficient (base e unit/d)	Equation 26: Residuals (base e unit/d)	Equation 26: Error (percent)	Equation 27: Estimated reaeration coefficient (base e unit/d)	Equation 27: Residuals (base e unit/d)	Equation 27: Error (percent)
French River near Oxford, Mass.										
A	6-21-88	L	.00073	3.67	3.26	.41	-11	1.07	2.60	-71
A	9-23-88	L	.00070	1.43	1.21	.22	-15	.57	.86	-60
B	9-23-88	L	.00033	1.08	.05	1.03	-95	.06	1.02	-94
C	10-21-87	I	.00020	.66	1.86	-1.20	182	.47	.19	-29
C	6-21-88	I	.00021	2.63	15.83	-13.20	502	1.73	.90	-34
Otter River near Gardner, Mass.										
A	5-19-87	H	.00336	.78	1.60	-.82	105	1.25	-.47	60
Mill River near Amherst, Mass.										
A	8-03-87	L	.00020	6.85	3.11	3.74	-55	.64	6.21	-91
B	8-03-87	L	.00026	10.99	10.96	.03	0	1.51	9.48	-86
Natty Pond Brook near Hubbardston, Mass.										
A	6-25-86	L	.00001	.91	.27	.64	-70	.05	.86	-95
B	9-17-85	H	.00601	8.22	4.95	3.27	-40	2.98	5.24	-64
C	5-22-85	L	.00053	2.74	2.49	.25	-9	.81	1.93	-70
C	8-20-85	L	.00005	1.94	1.94	0	0	.28	1.66	-86
D	5-22-85	L	.00087	2.05	1.60	.45	-22	.75	1.30	-63

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 26			Equation 27		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.30	1.01	-77	0.08	1.23	-94
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	6.50	-4.10	171	2.19	.21	-9
B	10-14-88	I	.00067	1.02	1.77	-.75	74	.69	.33	-32
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	1.14	.20	-15	.39	.95	-71
				Hoosic River near Adams, Mass.,						
A	6-09-87	H	.00371	6.74	8.16	-1.42	21	3.47	3.27	-49
A	6-02-88	H	.00325	5.60	5.47	.13	-2	2.63	2.97	-53
A	8-17-88	H	.00326	10.16	7.90	2.26	-22	3.23	6.93	-68
B	6-09-87	I	.00092	7.33	3.30	4.03	-55	1.20	6.13	-84
B	8-17-88	I	.00092	9.20	3.05	6.15	-67	1.14	8.06	-88
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	14.70	-12.78	666	3.22	-1.30	68
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	4.94	.02	0	1.29	3.67	-74

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 26: Estimated reaeration coefficient (base e unit/d)	Equation 26: Residuals (base e unit/d)	Equation 26: Error (percent)	Equation 27: Estimated reaeration coefficient (base e unit/d)	Equation 27: Residuals (base e unit/d)	Equation 27: Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.19	.02	-10	.17	.04	-19
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	16.02	-12.92	417	3.24	-.14	5
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	1.87	.79	-30	.62	2.04	-77
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	1.56	.57	-27	.55	1.58	-74
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	1.35	-.02	2	.18	1.15	-86
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	17.20	-11.31	192	3.43	2.46	-42
B	6-15-88	L	.00010	4.09	2.64	1.45	-35	.45	3.64	-89
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.20	.31	-61	.08	.43	-84

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 28 Estimated reaeration coefficient (base e unit/d)	Equation 28 Residuals (base e unit/d)	Equation 28 Error (percent)	Equation 29 Estimated reaeration coefficient (base e unit/d)	Equation 29 Residuals (base e unit/d)	Equation 29 Error (percent)
				Beaver Brook near Littleton, Mass.						
A	6-17-86	L	0.00035	1.62	0.10	1.52	-94	0.04	1.58	-98
				Assabet River near Westborough, Mass.						
A	5-13-86	L	.00023	1.46	1.37	.09	-6	.31	1.15	-79
A	8-05-86	L	.00020	5.78	.96	4.82	-83	.11	5.67	-98
A	10-28-86	L	.00012	.79	1.00	-.21	27	.04	.75	-95
B	8-05-86	L	.00003	2.35	22.24	-19.89	846	.08	2.27	-97
				Sudbury River near Wayland, Mass.						
A	11-16-87	L	.00005	.19	.24	-.05	26	.08	.11	-58
				Ipswich River near Topsfield, Mass.						
A	6-23-87	L	.00009	1.50	.22	1.28	-85	.09	1.41	-94
B	6-23-87	I	.00034	.38	.04	.34	-89	.08	.30	-79
				Taunton River near Bridgewater, Mass.						
A	5-03-88	L	.00006	.23	.17	.06	-26	.19	.04	-17
A	8-23-88	L	.00003	.16	.16	0	0	.02	.14	-88

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 28			Equation 29		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				French River near Oxford, Mass.						
A	6-21-88	L	.00073	3.67	.87	2.80	-76	.63	3.04	-83
A	9-23-88	L	.00070	1.43	.34	1.09	-76	.19	1.24	-87
B	9-23-88	L	.00033	1.08	.02	1.06	-98	.02	1.06	-98
C	10-21-87	I	.00020	.66	.55	.11	-17	.18	.48	-73
C	6-21-88	I	.00021	2.63	3.33	-.70	27	.08	2.55	-97
				Otter River near Gardner, Mass.						
A	5-19-87	H	.00336	.78	.51	.27	-35	5.06	-4.28	549
				Mill River near Amherst, Mass.						
A	8-03-87	L	.00020	6.85	.88	5.97	-87	.28	6.57	-96
B	8-03-87	L	.00026	10.99	2.62	8.37	-76	.58	10.41	-95
				Natty Pond Brook near Hubbardston, Mass.						
A	6-25-86	L	.00001	.91	.09	.82	-90	0	.91	-100
B	9-17-85	H	.00601	8.22	1.15	7.07	-86	2.46	5.76	-70
C	5-22-85	L	.00053	2.74	.72	2.02	-74	.06	2.68	-98
C	8-20-85	L	.00005	1.94	.53	1.41	-73	.02	1.92	-99
D	5-22-85	L	.00087	2.05	.48	1.57	-77	.68	1.37	-67

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 28 Estimated reaeration coefficient (base e unit/d)	Equation 28 Residuals (base e unit/d)	Equation 28 Error (percent)	Equation 29 Estimated reaeration coefficient (base e unit/d)	Equation 29 Residuals (base e unit/d)	Equation 29 Error (percent)
				Ware River near Barre, Mass.						
A	6-28-88	L	0.00003	1.31	0.11	1.20	-92	0.01	1.30	-99
				Karner Brook at South Egremont, Mass.						
A	10-14-88	L	.00170	2.40	1.46	.94	-39	.87	1.53	-64
B	10-14-88	I	.00067	1.02	.40	.62	-61	.03	.99	-97
				Batten Kill near Greenwich, N.Y.						
A	8-24-87	I	.00026	1.34	.39	.95	-71	.45	.89	-66
				Hoosic River near Adams, Mass.						
A	6-09-87	H	.00371	6.74	2.17	4.57	-68	14.83	-8.09	120
A	6-02-88	H	.00325	5.60	1.63	3.97	-71	20.35	-14.75	263
A	8-17-88	H	.00326	10.16	2.08	8.08	-80	10.89	-.73	7
B	6-09-87	I	.00092	7.33	1.00	6.33	-86	2.83	4.50	-61
B	8-17-88	I	.00092	9.20	.93	8.27	-90	2.59	6.61	-72
				Normans Kill near Westmere, N.Y.						
A	6-08-88	L	.00124	1.92	3.27	-1.35	70	2.19	-.27	14
				Coeymans Creek near Coeymans, N.Y.						
A	9-29-87	L	.00061	4.96	1.33	3.63	-73	1.12	3.84	-77

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

					Equation 28			Equation 29		
Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
				Claverack Creek at Hudson, N.Y.						
A	6-28-88	I	.00049	.21	.07	.14	-67	.10	.11	-52
				West Branch Delaware River near Deposit, N.Y.						
A	10-22-86	L	.00108	3.10	3.64	-.54	17	2.84	.26	-8
				Susquehanna River at Phoenix Mills, N.Y.						
A	8-09-88	L	.00041	2.66	.57	2.09	-79	.48	2.18	-82
				Canisteo River at Hornell, N.Y.						
A	9-26-88	L	.00040	2.13	.48	1.65	-77	.43	1.70	-80
				Caughdenoy Creek near Caughdenoy, N.Y.						
A	6-13-88	L	.00003	1.33	.37	.96	-72	.01	1.32	-99
				South Sandy Creek near Ellisburg, N.Y.						
A	6-15-88	L	.00116	5.89	3.65	2.24	-38	1.68	4.21	-71
B	6-15-88	L	.00010	4.09	.71	3.38	-83	.07	4.02	-98
				Indian River at Kelsey Bridge, N.Y.						
A	6-02-87	L	.00006	.51	.08	.43	-84	.03	.48	-94

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 30		
					Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
			Beaver Brook near Littleton, Mass.				
A	6-17-86	L	0.00035	1.62	0.29	1.33	-82
			Assabet River near Westborough, Mass.				
A	5-13-86	L	.00023	1.46	1.47	-.01	1
A	8-05-86	L	.00020	5.78	.93	4.85	-84
A	10-28-86	L	.00012	.79	.62	.17	-22
B	8-05-86	L	.00003	2.35	2.15	.20	-9
			Sudbury River near Wayland, Mass.				
A	11-16-87	L	.00005	.19	.25	-.06	32
			Ipswich River near Topsfield, Mass.				
A	6-23-87	L	.00009	1.50	.30	1.20	-80
B	6-23-87	I	.00034	.38	.20	.18	-47
			Taunton River near Bridgewater, Mass.				
A	5-03-88	L	.00006	.23	.27	-.04	17
A	8-23-88	L	.00003	.16	.12	.04	-25

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 30: Estimated reaeration coefficient (base e unit/d)	Equation 30: Residuals (base e unit/d)	Equation 30: Error (percent)
			French River near Oxford, Mass.				
A	6-21-88	L	.00073	3.67	2.18	1.49	-41
A	9-23-88	L	.00070	1.43	1.01	.42	-29
B	9-23-88	L	.00033	1.08	.10	.98	-91
C	10-21-87	I	.00020	.66	.78	-.12	18
C	6-21-88	I	.00021	2.63	2.16	.47	-18
			Otter River near Gardner, Mass.				
A	5-19-87	H	.00336	.78	4.85	-4.07	522
			Mill River near Amherst, Mass.				
A	8-03-87	L	.00020	6.85	1.09	5.76	-84
B	8-03-87	L	.00026	10.99	2.51	8.48	-77
			Natty Pond Brook near Hubbardston, Mass.				
A	6-25-86	L	.00001	.91	.03	.88	-97
B	9-17-85	H	.00601	8.22	7.95	.27	-3
C	5-22-85	L	.00053	2.74	1.72	1.02	-37
C	8-20-85	L	.00005	1.94	.26	1.68	-87
D	5-22-85	L	.00087	2.05	1.75	.30	-15

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 30		
					Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
			Ware River near Barre, Mass.				
A	6-28-88	L	0.00003	1.31	0.08	1.23	-94
			Karner Brook at South Egremont, Mass.				
A	10-14-88	L	.00170	2.40	4.22	-1.82	76
B	10-14-88	I	.00067	1.02	.72	.30	-29
			Batten Kill near Greenwich, N.Y.				
A	8-24-87	I	.00026	1.34	.88	.46	-34
			Hoosic River near Adams, Mass.				
A	6-09-87	H	.00371	6.74	13.55	-6.81	101
A	6-02-88	H	.00325	5.60	11.87	-6.27	112
A	8-17-88	H	.00326	10.16	11.74	-1.58	16
B	6-09-87	I	.00092	7.33	3.58	3.75	-51
B	8-17-88	I	.00092	9.20	3.38	5.82	-63
			Normans Kill near Westmere, N.Y.				
A	6-08-88	L	.00124	1.92	7.06	-5.14	268
			Coeymans Creek near Coeymans, N.Y.				
A	9-29-87	L	.00061	4.96	2.87	2.09	-42

Appendix 3.--*Results from error analyses of equation 10 through 30 (excluding equations 17 and 23)*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Equation 30: Estimated reaeration coefficient (base e unit/d)	Equation 30: Residuals (base e unit/d)	Equation 30: Error (percent)
			Claverack Creek at Hudson, N.Y.				
A	6-28-88	I	.00049	.21	.34	-.13	62
			West Branch Delaware River near Deposit, N.Y.				
A	10-22-86	L	.00108	3.10	7.49	-4.39	142
			Susquehanna River at Phoenix Mills, N.Y.				
A	8-09-88	L	.00041	2.66	1.30	1.36	-51
			Canisteo River at Hornell, N.Y.				
A	9-26-88	L	.00040	2.13	1.16	.97	-46
			Caughdenoy Creek near Caughdenoy, N.Y.				
A	6-13-88	L	.00003	1.33	.13	1.20	-90
			South Sandy Creek near Ellisburg, N.Y.				
A	6-15-88	L	.00116	5.89	6.86	-.97	16
B	6-15-88	L	.00010	4.09	.55	3.54	-87
			Indian River at Kelsey Bridge, N.Y.				
A	6-02-87	L	.00006	.51	.14	.37	-73

[1] L, low-slope stream; I, impounded stream; H, high-slope stream

Appendix 4.--*Results from error analysis of new empirical equation*

[ft/ft, foot per foot; d, day]

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
			Beaver Brook near Littleton, Mass.				
A	6-17-86	L	0.00035	1.62	0.94	0.68	-42
			Assabet River near Westborough, Mass.				
A	5-13-86	L	.00023	1.46	1.27	.19	-13
A	8-05-86	L	.00020	5.78	1.42	4.36	-75
A	10-28-86	L	.00012	.79	1.45	-.66	84
B	8-05-86	L	.00003	2.35	1.87	.48	-20
			Sudbury River near Wayland, Mass.				
A	11-16-87	L	.00005	.19	.54	-.35	184
			Ipswich River near Topsfield, Mass.				
A	6-23-87	L	.00009	1.50	.54	.96	-64
B	6-23-87	I	.00034	.38	.44	-.06	16
			Taunton River near Bridgewater, Mass.				
A	5-03-88	L	.00006	.23	.25	-.02	9
A	8-23-88	L	.00003	.16	.32	-.16	100

Appendix 4.--*Results from error analysis of new empirical equation*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
			French River near Oxford, Mass.				
A	6-21-88	L	.00073	3.67	2.37	1.30	-35
A	9-23-88	L	.00070	1.43	2.08	-.65	45
B	9-23-88	L	.00033	1.08	.66	.42	-39
C	10-21-87	I	.00020	.66	1.58	-.92	139
C	6-21-88	I	.00021	2.63	3.53	-.90	34
			Mill River near Amherst, Mass.				
A	8-03-87	L	.00020	6.85	1.33	5.52	-81
B	8-03-87	L	.00026	10.99	2.19	8.80	-80
			Natty Pond Brook near Hubbardston, Mass.				
A	6-25-86	L	.00001	.91	.49	.42	-46
C	5-22-85	L	.00053	2.74	1.65	1.09	-40
C	8-20-85	L	.00005	1.94	1.15	.79	-41
D	5-22-85	L	.00087	2.05	1.67	.38	-19

Appendix 4.--*Results from error analysis of new empirical equation*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
			Ware River near Barre, Mass.				
A	6-28-88	L	0.00003	1.31	0.57	0.74	-56
			Karner Brook at South Egremont, Mass.				
A	10-14-88	L	.00170	2.40	6.03	-3.63	151
B	10-14-88	I	.00067	1.02	5.22	-4.20	412
			Batten Kill near Greenwich, N.Y.				
A	8-24-87	I	.00026	1.34	1.32	.02	-1
			Hoosic River near Adams, Mass.				
B	6-09-87	I	.00092	7.33	1.99	5.34	-73
B	8-17-88	I	.00092	9.20	1.97	7.23	-79
			Normans Kill near Westmere, N.Y.				
A	6-08-88	L	.00124	1.92	5.69	-3.77	196
			Coeymans Creek near Coeymans, N.Y.				
A	9-29-87	L	.00061	4.96	2.98	1.98	-40
			Claverack Creek at Hudson, N.Y.				
A	6-28-88	I	.00049	.21	1.19	-.98	467

Appendix 4.--*Results from error analysis of new empirical equation*--Continued

Reach	Study date	Reach descriptor[1]	Water-surface slope (ft/ft)	Measured reaeration coefficient (base e unit/d)	Estimated reaeration coefficient (base e unit/d)	Residuals (base e unit/d)	Error (percent)
			West Branch Delaware River near Deposit, N.Y.				
A	10-22-86	L	.00108	3.10	3.09	.01	0
			Susquehanna River at Phoenix Mills, N.Y.				
A	8-09-88	L	.00041	2.66	2.02	.64	-24
			Canisteo River at Hornell, N.Y.				
A	9-26-88	L	.00040	2.13	1.91	.22	-10
			Caughdenoy Creek near Caughdenoy, N.Y.				
A	6-13-88	L	.00003	1.33	1.64	-.31	23
			South Sandy Creek near Ellisburg, N.Y.				
A	6-15-88	L	.00116	5.89	6.36	-.47	8
B	6-15-88	L	.00010	4.09	2.11	1.98	-48
			Indian River at Kelsey Bridge, N.Y.				
A	6-02-87	L	.00006	.51	.56	-.05	10

[1] L, low-slope stream; I, impounded stream

*U.S. Government Printing Office: 1992 — 601-070