Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge

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River at Delaware Memorial Bridge all indicated coefficients that lie in the narrow range of 0.90 to 0.92 for adjusting the subsurface velocity to the mean velocity. Carter and Anderson (1963) present a table of velocity ratios and standard deviations for various relative depths. That table indicates that for depths of 10 ft (3 m) or more, an average coefficient of 0.90 is satisfactory for adjusting velocities obtained 4 ft (1.2 m) below the surface to mean velocity. The sample from which the data in that table were obtained consisted of 100 stream sites at each of which 25 to 30 verticals had been used. Similar conclusions concerning subsurface velocity coefficients can be drawn from table 2 (p. 132).

APPLICATION OF VELOCITY ADJUSTMENT TO COMPUTED DISCHARGE

Application of the vertical-velocity adjustment factor is made immediately after the width-area adjustment has been applied to the computed discharge. In other words, after the computed discharge has been multiplied by the width-area adjustment factor, the resulting product is multiplied by the vertical-velocity adjustment factor. The final product is the adjusted, or "true," discharge for the measurement. (See fig. 113.)

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CHAPTER 7.—MEASUREMENT OF DISCHARGE BY TRACER DILUTION

GENERAL

The measurement of stream discharge by dilution methods depends on the determination of the degree to which an added tracer is diluted by the flowing water. Any substance can be used as a tracer if it meets the following criteria:

1. It dissolves readily in water at ordinary temperatures.
2. It is either absent in the water of the stream or present only in very low concentrations.
3. It is not decomposed in the water of the stream and is not retained or absorbed in significant quantity by sediments, plants, or other organisms.
4. It can be detected in extremely low concentrations by simple methods.

5. It is harmless to man and animals in the concentration it assumes in the stream.

Until recent years chemical salts, primarily common salt (NaCl), were usually used as the tracers injected into the streams. The use of salt tracers, on all but the smallest streams, was limited, however, to the sudden-injection method, because of the difficulty of handling the large quantities of salt solution required by the usually more accurate constant-rate-injection method. In recent years, and particularly in the U.S.A., the use of dye tracers in the constant-rate-injection method has become the most popular method of discharge measurement by tracer dilution. That has resulted from the development of fluorescent dyes and fluorometers that can detect those dyes at very low concentrations. The use of fluorescent dyes is not as popular in Europe as in the U.S.A. There, colorimetric analysis, using sodium dichromate as the tracer dye, is the most widely used means of measuring discharge by the constant-rate-injection method. However, where the sudden-injection method is to be used, the use of common salt as a tracer is still preferred, particularly on the smaller streams, because of the greater ease in handling salt and in determining concentrations. Radioactive elements, such as gold 198 and sodium 24, have also been used in recent years as the tracers in the sudden-injection method, but the use of such elements is still (1980) considered experimental.

The tracer-dilution methods of measuring discharge are more difficult to use than the conventional current-meter method, and under most conditions the results are less reliable. Dilution methods should therefore not be used when conditions are favorable for a current-meter measurement of discharge. Tracer-dilution methods of measuring discharge in open channels can be used advantageously in rough channels that carry highly turbulent flow.

THEORY OF TRACER-DILUTION METHODS

In the tracer-dilution methods of measuring discharge, a tracer solution is injected into the stream to be diluted by the discharge of the stream. From measurements of the rate of injection, the concentration of the tracer in the injected solution, and the concentrations of the tracer at a sampling cross section downstream from the injection site, the stream discharge can be computed.

Either of two methods may be used for determining the discharge of a stream by tracer dilution. The first method, the constant-rate-injection method, requires that the tracer solution be injected into the stream at a constant flow rate for a period sufficiently long to achieve a constant concentration of the tracer in the streamflow at the downstream sampling cross section. The second method, the sudden-injection method, requires the instantaneous injection of a slug of tracer solution and an accounting of the total mass of tracer at the sampling cross section. Another use is often made of the sudden-injection method that is not concerned with degree of dilution. Where the cross-sectional area of the flow is constant, as in pressure conduit, the sudden-injection method may be used to determine the velocity of flow; discharge can then be computed by using that velocity and the known cross-sectional area. (See p. 533.)

THEORY OF THE CONSTANT-RATE-INJECTION METHOD

A constant-rate-injection system is shown schematically in figure 115. If the tracer is injected for a sufficiently long period, sampling of the stream at the downstream sampling cross section will produce a concentration-time curve similar to that shown in figure 116. The stream discharge is computed from the equation for the conservation of mass, which follows:

$$QC_b + qC_1 = (Q + q)C_2$$

or

$$Q = \left[\frac{C_1 - C_2}{C_2 - C_b}\right] q, \tag{24}$$

where

q is the rate of flow of the injected tracer solution,

Q is the discharge of the stream,

C_b is the background concentration of the stream,

C_1 is the concentration of the tracer solution injected into the stream, and

C_2 is the measured concentration of the plateau of the concentration-time curve (fig. 116).

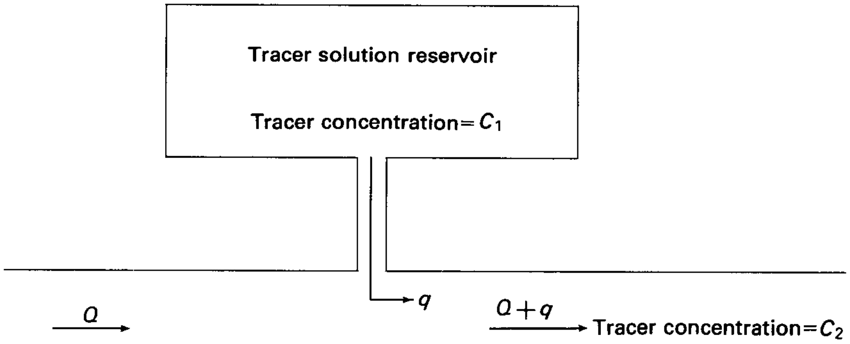


FIGURE 115.—Constant-rate-injection system.

THEORY OF THE SUDDEN-INJECTION METHOD

If a slug of tracer solution is instantaneously injected into a stream, sampling of the stream at the downstream sampling cross section will produce a concentration-time curve similar to that shown in figure 117. The equation for computing stream discharge, which is again based on the principle of the conservation of mass, is

$$Q = \frac{V_1 C_1}{\int_0^\infty (C - C_b)dt}, \qquad (25)$$

where

Q is the discharge of the stream,
V_1 is the volume of the tracer solution introduced into the stream,
C_1 is the concentration of the tracer solution injected into the stream,
C is the measured tracer concentration at a given time at the downstream sampling site,
C_b is the background concentration of the stream, and
t is time.

The term $\int_0^\infty (C - C_b)\, dt$ is the total area under the concentration-time curve. In practice the term $\int_0^\infty (C - C_b)dt$ can be approximated by the term

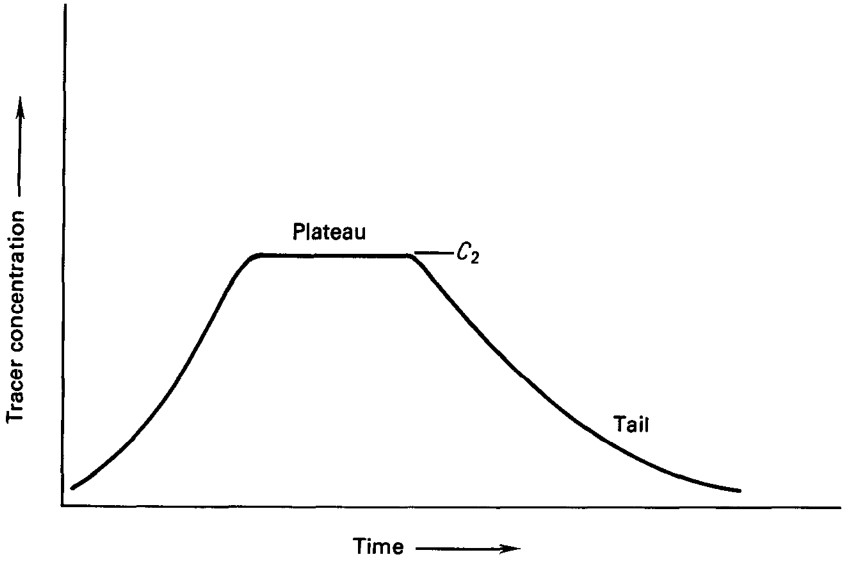


FIGURE 116.—Concentration-time curve at downstream sampling site for constant-rate injection.

$$\sum_{i=1}^{N} (C_i - C_b)(t_{i+1}-t_{i-1})/2,$$

where

i is the sequence number of a sample,
N is the total number of samples, and
t_i is time when a sample, C_i, is obtained.

FACTORS AFFECTING THE ACCURACY OF TRACER-DILUTION METHODS

Even if it is assumed that measurements of concentrations and of the injection rate are error free, there still remain three factors that affect the accuracy of tracer-dilution methods of measuring discharge. Those factors are stream turbidity, loss of tracer between the injection site and the downstream sampling site, and incomplete mixing throughout the stream cross section before the downstream sampling section is reached.

TURBIDITY

Turbidity may either increase or decrease the recorded tracer fluorescence depending upon the relative concentrations of tracer and turbidity (Feuerstein and Selleck, 1963). To minimize the effect of turbidity, samples should be permitted to stand long enough to allow

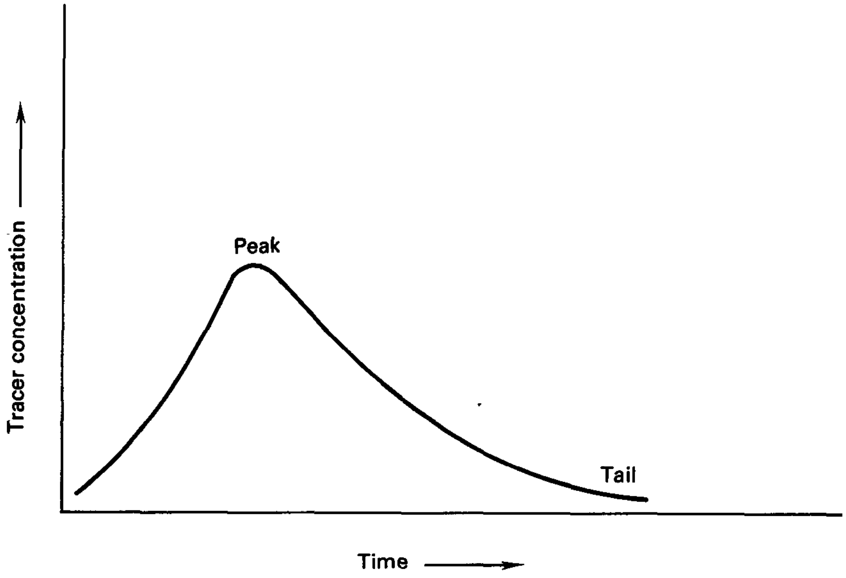


FIGURE 117.—Concentration-time curve at downstream sampling site for sudden injection.

suspended solids to settle prior to fluorometric analysis (p. 231, 240). Use of a centrifuge for the purpose of separating the suspended solids is even more effective, but a centrifuge is seldom used for that purpose in stream-gaging work.

LOSS OF TRACER

The computation of stream discharge, as mentioned earlier, is based on equations for the conservation of mass. Consequently, the accuracy of the computed discharge will be adversely affected if some of the tracer is lost in the reach of channel between the injection site and the downstream sampling site. Tracer losses are primarily due to sorption and chemical reaction between the tracer and one or more of the following: streambed material, suspended sediments, dissolved material in the river water, plants, and other organisms. For most of the tracers used, chemical reaction is a minor factor in comparison with sorption. The degree of tracer loss by sorption for a particular tracer varies primarily with the type and concentration of suspended and dissolved solids in the water. In routine stream gaging by the tracer-dilution method no attempt is made to quantify tracer loss by sorption; instead, the "best" tracer available from the standpoint of being least affected by sorption is used.

Photochemical decay is also a source of tracer loss which varies with the tracer material used and its residence time in direct sunlight. Loss from that source is usually negligible, even with fluorescent dyes, if the proper dye is used and if residence time in direct sunlight is limited to only a few hours, as it usually is in stream-gaging work.

Equations 24 and 25 show that loss of tracer will result in a computed discharge that exceeds the true stream discharge.

CRITERIA FOR SATISFACTORY MIXING

Tracer-dilution measurements require complete vertical and lateral mixing at the sampling site. Vertical mixing is usually accomplished very rapidly compared to lateral mixing; therefore, the distance required for lateral mixing is the primary consideration. Frequently, long reaches are needed for complete lateral mixing of the tracer. The mixing distance will vary with the hydraulic characteristics of the reach. Engmann and Kellerhals (1974) have demonstrated that ice cover significantly reduces the mixing capacity of a reach of river.

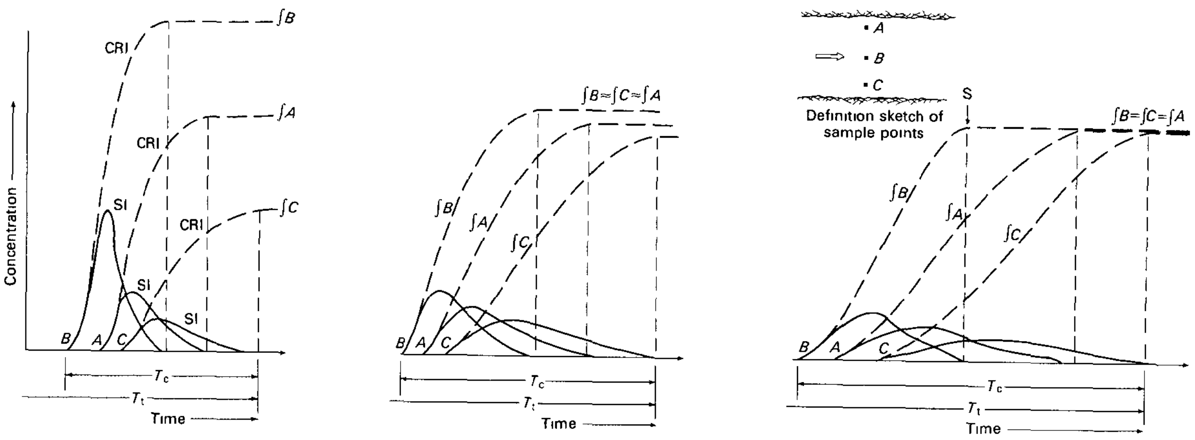
When the constant-rate-injection method is used, complete mixing is known to have occured when the concentration C_2, shown in figure 116, has the same value at all points in the downstream sampling cross section. When the sudden-injection method is used, complete mixing is considered to have occurred when the area under the concentration-time curve, shown in figure 117, has the same value at all points in the downstream sampling section.

For a reach of channel of given geometry and stream discharge, the length of reach required for adequate mixing of the tracer is the same for either of the two methods of tracer injection. Several formulas are available for estimating the required mixing length for a particular set of conditions, but these formulas, while useful as guides, are too simplistic to give adequate consideration to the degree of mixing desired. Perfect mixing is seldom the optimum goal (see below) because perfect mixing usually requires an extremely long reach of channel, along with a correspondingly long period of injection in the constant-rate-injection (CRI) method and a correspondingly long period of sampling in the sudden-injection (SI) method.

Figures 116 and 117 are only rudimentary illustrations of the two methods. For either method to be successful an understanding is needed of the interrelations among mixing length and injection and sampling times. Figure 118 attempts to illustrate those interrelations for both types of injection. It is important to realize that unless adequate mixing is known to exist at a given sampling site, the tracer cloud in the SI method must be sampled for its entire time of passage at several locations laterally in the channel, such as at A, B, and C in figure 118. Similarly, in the CRI method the plateau concentration must be sampled at several locations laterally in the channel. Experience indicates that regardless of method or stream size, at least three lateral sampling points should be used at each sampling site.

Figure 118 indicates that there is an optimum mixing length for a given stream reach and discharge. Use of too short a distance will result in an inaccurate accounting of the tracer mass passing the sampling site. Use of too great a distance will yield excellent results, but only *if it is feasible to inject the tracer for a long enough period* (CRI method) or to sample for a long enough period (SI method). An optimum mixing length is one that produces mixing adequate for an accurate discharge measurement but does not require an excessively long duration of injection or sampling.

As mentioned earlier, figure 118 shows that the tracer cloud resulting from a sudden injection must be sampled at the sampling site from the time of its first appearance there until the time (T_t) of its disappearance at all points in the sampling cross section. For the same mixing reach and discharge, if the CRI method is used, a plateau will first be reached at all points in the sampling cross section at time T_t after injection starts at the injection site. Thus, it is seen that for the CRI method the duration of injection must at least be equal to T_t and injection should continue long enough thereafter to



I. Short Sampling Reach

1 Areas under curves differ considerably in the SI method, lateral mixing incomplete

2 Rapid buildup to concentration plateaus of different levels in the CRI method

3 Discharge results will usually be poor, even by the use of such expedients as velocity-integrated sampling or discharge-weighting of the concentration data.

II Optimum Sampling Reach

1 Areas under the curves nearly equal in the SI method, lateral mixing nearly complete

2 Fast buildup to plateaus of nearly equal concentration in the CRI method, lateral mixing adequate

3 Reliable discharge measurement can be made by the CRI method using a moderate injection time that exceeds T_c

III. Excessively Long Sampling Reach

1 Areas under the curves are identical in the SI method, perfect mixing

2 Slow buildup to plateaus of equal concentration in the CRI method but only after a long period of injection

3 Minimum duration of constant injection is equal to total time, T_c, that slug dye cloud is present

4 Reliable discharge measurement can be made by CRI method if injection period is long enough to exceed T_c

5 Results by CRI method will be poor if injection time is too short or sampling is discontinued too soon Samples taken at time S would give impression that mixing is poor, as well as suggesting loss of dye

FIGURE 118.—Comparison of concentration-time curves obtained by SI and CRI methods, observed at three points in sampling cross section, for sampling reaches of three different lengths.

insure adequate sampling of the plateau. It should be noted that a stable condition of mixing is usually first attained in midchannel. Tracer lag along the streambanks will generally prolong the time required for complete lateral mixing.

The CRI method has become increasingly popular because reliable injection apparatus is available and the sampling process is relatively simple. If an injection period well in excess of T_c is used, the sampling can be done leisurely at several points in the sampling cross section. In the SI method the injection is simple, but the sampling process is much more demanding. More reliable results are usually obtained by the CRI method.

Figure 118 indicates that a satisfactory discharge measurement requires "nearly equal" areas under the concentration-time curves for the sampling points in the SI method and "nearly equal" concentration plateaus for the sampling points in the CRI method. A numerical criterion—P_m, the percentage of mixing—is often used as a quantitative index of the consistency of sampling results for the sampling cross section. A satisfactory discharge measurement can usually be obtained if the value of P_m is 95 percent or greater. The computation of P_m is discussed in the paragraphs that follow.

Percentage of mixing, P_m, is defined in this manual by the equation

$$P_m = 100 - \{|X_A - X_m|Q_A + |X_B - X_m|Q_B + |X_C - X_m|Q_C + \ldots\}\frac{50}{X_m Q}, \qquad (26)$$

where

$X_A, X_B, X_C, \ldots$ are the areas under the concentration-time curves or, for constant-rate injection, the C_2 concentrations at the points A, B, $C, \ldots$ across the sampling section;

X_m is the mean area under the concentration-time curves or, for constant-rate injection, the mean C_2 concentration for points A, B, $C, \ldots$ across the sampling section;

$Q_A, Q_B, Q_C, \ldots$ are the subsection discharges applicable to the points, A, B, $C, \ldots$;

Q is the total stream discharge.

If the distribution of discharge is unknown at the sampling section, the cross-sectional subareas applicable to each point should be used in place of Q_A, Q_B, Q_C; total cross-sectional area should be used in place of Q. If both discharge and area distribution are unknown, as will often be the case, the appropriate widths may be used. Terms $|X_A - X_m|$, $|X_B - X_m|$, $|X_C - X_m|, \ldots$ are absolute values.

The percentage of mixing can also be determined graphically, as shown in figure 119. Values of C_2 or $\int_0^\infty (C - C_b)dt$, depending on the injection method used, are plotted for each sampling point against the distance from an initial point at water's edge. The mean value C_2 or $\int_0^\infty (C - C_b)dt$ is determined by dividing the area under the distribution curve for C_2 or $\int_0^\infty (C - C_b)dt$ by the total width of the section. The percentage of mixing, P_m, is then given as

$$P_m = \left(\frac{A}{A + B}\right) 100 \tag{27}$$

where

A is the area under the C_2 distribution and mean C_2 curves, or the area under the $\int_0^\infty (C - C_b)dt$ distribution and mean $\int_0^\infty (C - C_b)dt$ curves;

B is the area above the C_2 distribution and under the mean C_2 curves or the area above the $\int_0^\infty (C - C_b)dt$ distribution and under the mean $\int_0^\infty (C - C_b)dt$ curves.

The graphical technique illustrated in figure 119 can also be used if the distribution of discharge or area is known. The only change in the procedure that is required is a change in the abscissa of figure 119. In place of "distance from edge of water" either cumulative discharge or cumulative area from edge of water is substituted.

CALIBRATION OF MEASUREMENT REACH

Several theoretical studies have been made by the U.S. Geological Survey (for example, Yotsukura and Cobb, 1972) in which equations have been derived for determining the length of measurement reach required for satisfactory or complete mixing. However, the derived equations cannot be applied in the field without detailed information

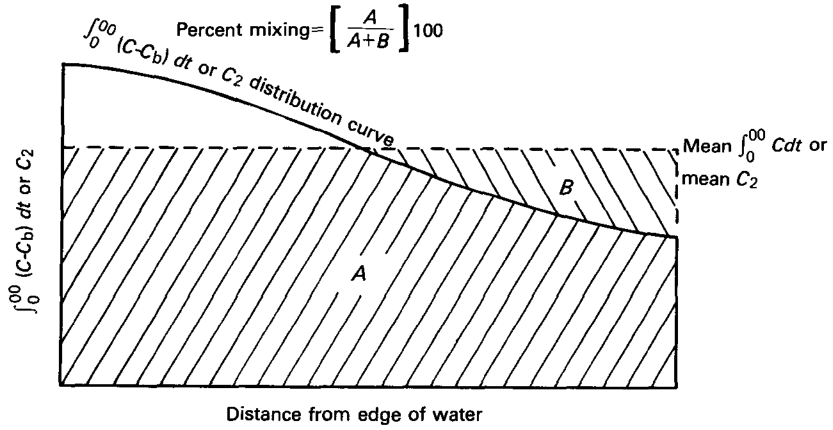


FIGURE 119.—Concentration-distribution curve illustrating the graphical method of determining the percentage of mixing.

on channel geometry and velocity distribution for the reach of channel. Consequently several gross formulas have been developed from the theoretical equations strictly for use as guides in determining a satisfactory length of measurement reach. Some of the simplified formulas follow:

a. Point injection at midchannel (English units)—

1.
$$L=0.25\frac{V}{(gDS)^{1/2}}\frac{W^2}{D}, \tag{28}$$

where

L is distance downstream from the injection point,
V is mean velocity,
g is acceleration of gravity,
D is mean depth,
S is gradient of water surface or streambed, and
W is stream width.

2.
$$L=0.6\frac{R^{1/6}}{ng^{1/2}}\frac{W^2}{D}, \tag{29}$$

where R is the hydraulic radius and n is the Manning roughness coefficient.

3.
$$L=2V\frac{(W^2)}{D}\cdot \tag{30}$$

b. Point injection at bankside (English units)—

$$L=8V\frac{W^2}{D}\cdot \tag{31}$$

Studies indicate that if more than one injection point is used, the mixing distance will vary inversely with the square of the number of injection points, provided that the injection points are located so that the dye will disperse equal distances both to the left and right of the injection points. This statement may seldom hold true for natural stream conditions, but it does indicate that the mixing length may be shortened considerably by using additional injection points.

In Europe the formula commonly used as a guide for determining the required length, L, between the injection site and sampling section is

$$L=0.13C\ \frac{(0.7C+6)}{g}\ \frac{b^2}{h}\text{(metric units)}, \tag{32}$$

where

b is the average width of the wetted cross section,
h is the average depth of flow,
C is the Chezy coefficient for the reach ($15<C<50$), and
g is acceleration of gravity.

Equation 32 is intended for use where injection is made at a single point in midstream.

Before making a discharge measurement by the tracer-dilution method, the proposed measurement reach should be calibrated to determine the length required for adequate mixing and the possibility of significant tracer loss. If repeated tracer-dilution measurements of the stream are to be made, it will be especially advantageous to make the calibration study comprehensive. One of the equations, 28 to 32, may be used as a guide in selecting a length of reach for the calibration tests; the quantity of tracer to be used for any given discharge is discussed later on pages 235–237. Instructions for calibration testing follow.

Select an injection site on the stream, and on the basis of one of the equations, 28 to 32, select several downstream sampling sites. Inject the tracer and then sample the water at three or more points in the cross section at each of the selected sampling sites. Take adequate samples at each point to define the plateau of the concentration-time curve if the constant-rate-injection method is used, or to define the entire concentration-time curve if the sudden-injection method is used. Analyze the samples and determine the percentage of mixing by use of equation 26. As mentioned earlier, for a satisfactory measurement of discharge the percentage of mixing should be at least 95. Mixing distances and losses may vary with discharge, and the reach may therefore have to be calibrated at more than one discharge. The quantity of tracer lost, if any, between successive sampling sites can be determined by a comparison of the values of C_2 (constant-rate-injection method) or of $\int_0^\infty (C - C_b)dt$ (sudden-injection method) obtained at each site. That determination provides a basis for the final selection of a sampling site from the several sites tested.

EFFECT OF INFLOW OR OUTFLOW BETWEEN INJECTION AND SAMPLING SITES

A satisfactory tracer-dilution measurement of discharge made in a reach that has no inflow or outflow between the injection and sampling sites will give the discharge occurring at all cross sections in the reach.

If tributary inflow enters the reach and if the tributary inflow is well mixed with the water in the main stream, the discharge measured will be that at the sampling site. If the tributary inflow is not well mixed, that fact may be evident from the difference in concentrations at the various sampling points in the sampling cross section; a low percentage of mixing would indicate that the particular sampling site could not be used for a satisfactory measurement of discharge.

If outflow occurs between the injection and sampling sites and if the tracer becomes completely mixed anywhere upstream from the outflow channel, the discharge measured at the sampling site will be that for the reach upstream from the outflow channel. If the tracer does not become completely mixed upstream from the outflow channel, the discharge measured at the sampling site will be indeterminate; the magnitude of the "measured" discharge will be dependent on the quantities of both tracer and water that are carried off in the outflow.

MEASUREMENT OF DISCHARGE BY FLUORESCENT DYE DILUTION

As mentioned earlier, the most popular type of tracer for the measurement of streamflow in the U.S.A. is fluorescent dye. The cost of the dye is relatively small because the quantity of dye needed for a discharge measurement is small; modern fluorometers are capable of accurately measuring dye concentrations of less than 1 μg/L (microgram per liter) and can detect concentrations as low as 0.02 μg/L.

FLUORESCENT DYES

Fluorescence occurs when a substance absorbs light at one wavelength and emits it at another, and usually longer, wavelength. The dyes commonly used as tracers are strongly fluorescent. They are organic dyes of the rhodamine family and are commercially available.

Dyes selected for use as tracers should (1) have a high detectability range, (2) have little effect on flora or fauna, (3) have a low sorption tendency, (4) have a low photochemical decay rate, (5) be soluble and disperse readily in water, (6) be chemically stable, (7) be inexpensive, (8) be easily separated from common background fluorescence, and (9) be easy to handle.

On the basis of recent studies in the U.S.A. on the adsorption potential and detectability of dyes, Rhodamine WT dye is recommended as the best dye available for use in dye-dilution measurements of discharge. Formerly used at times, but no longer recommended are Rhodamine B, BA, and Fluorescein.

FLUOROMETER

The fluorometer is an instrument that gives a measure of the strength of the light emitted by a fluorescent substance. Figure 120 is a schematic diagram of a fluorometer. The flurometer briefly described in this manual is the Turner model 111 fluorometer, and it is discussed because it is the instrument that is in general use by the U.S. Geological Survey. However, there are many satisfactory fluorometers that are commercially available, and for detailed instructions concerning any particular fluorometer it is necessary that the hydrographer consult the service manual prepared by the manufacturer of that instrument. The fluorometry techniques described in this manual are oriented toward use of the Turner fluorometer, but those techniques are applicable to most types of fluorometer. (Note.—The use of brand names in this manual is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.)

DESCRIPTION OF FLUOROMETER

The principle of the operation of the Turner model 111 fluorometer is described in the operating manual (1963, p. 12) as follows:

> This fluorometer is basically an optical bridge which is analogous to the accurate Wheatstone Bridge used in measuring electrical resistance. The optical bridge measures the difference between light emitted by the sample and that from a calibrated rear light path. A single photomultiplier surrounded by a mechanical light interrupter sees light alternately from the sample and the rear light path. Photomultiplier output is alternating current, permitting a drift-free A-C amplifier to be used for the first electronic stages. The second stage is a phase-sensitive detector whose output is either positive or negative, depending on whether there is an excess of light in the forward (sample) or rear light path, respectively. Output of the phase detector drives a servo amplifier which is in turn connected to a servo motor. The servo motor drives the light cam (and the "fluorescence" dial) until equal amounts of light reach the photomultiplier from the sample and from the rear light path. The quantity of light required in the rear path to balance that from the sample is indicated by the "fluorescence" dial. Each of this dial's 100 divisions add equal increments of light to the rear path by means of a light cam.

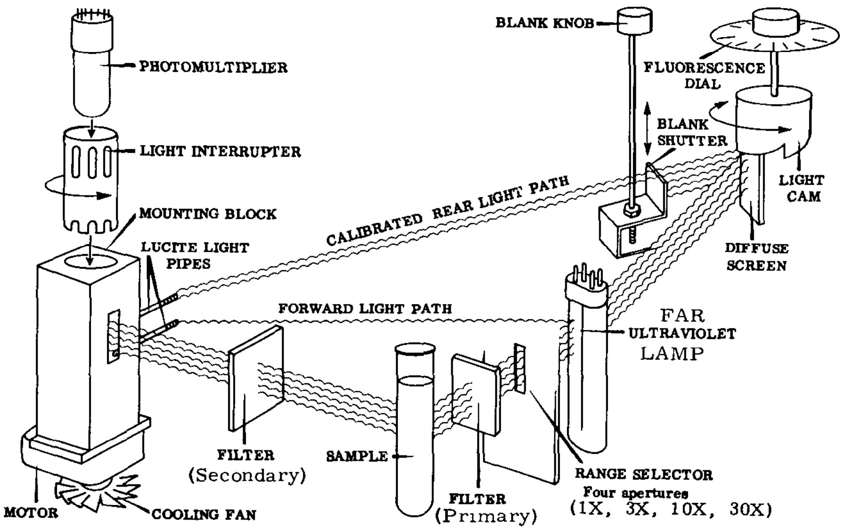


FIGURE 120.—Schematic diagram of the fluorometer (from G. K. Turner Associates, 1963, p.13).

Lamps.—At least three different lamps can be used as a light source for the fluorometer when the fluorescence of rhodamine dyes is tested. They are the general purpose ultraviolet lamp, the far ultraviolet lamp, and the green T–5 lamp. Although all three lamps work well, the far ultraviolet and green T–5 lamps are recommended as a light source because their outputs are compatible with the fluorescent properties of the dyes. Sensitivity of the fluorometer is increased approximately twofold to tenfold when the far ultraviolet and green T–5 lamps, respectively, are substituted for the general purpose ultraviolet lamp.

Filters.—The sensitivity of the fluorometer is directly related to the filter system employed. Light having undesirable wavelengths may be screened out by placing filters at two points in the fluorometer: (1) between the source light and the water sample and (2) between the water sample and the photomultiplier.

The filter (primary) recommended for use with rhodamine dyes for the absorbed light has a peak color specification of 546 mμ (millimicrons); that is, the greatest amount of light passed through the filter is at a wavelength of 546 mμ. Light at other wavelengths is subdued or eliminated. The recommended filter (secondary) for the emitted light has a peak color specification of 590 mμ. The peak color specifications for these filters are near the peak excitation and emittance wavelengths of the rhodamine dyes and will eliminate most natural background fluorescence. The filters may be used regardless of the type of lamp that is installed.

Doors.—Three main types of doors available for use with the fluorometer are the standard-cuvette (test tube) door, the temperature-stabilizing door, and flow-through door. All three doors are easily interchanged.

The standard-cuvette door is the easiest to use in the field for intermittent sampling and should be used with the green T–5 lamp. If the far ultraviolet lamp is used, a high-sensitivity kit should be installed on this door because it will increase the overall sensitivity of the fluorometer about tenfold. It is important to note that excessive sensitivity will be obtained if the high-sensitivity kit and green T–5 lamp are used together.

The temperature-stabilizing door is recommended for the final testing of samples. This door is similar to the standard-cuvette door with the high sensitivity kit but has, in addition, a water-cooled, copper block that surrounds the cuvette. Cooling water may be pumped or tap water of constant, or near-constant, temperature may be run through the door to stablize the sample temperature. Only round 12×75-mm cuvettes can be used with this door.

The flow through door permits continuous sampling which can be recorded. A pump is used to circulate water from the stream through the cuvette in the door. The results may be recorded on any recorder with a 0 to 1 milliamp or 0 to 10 millivolt readout. The intake hose used with the flow-through door should be made of plastic or other nonabsorptive material. Different fittings and cuvette sizes are available for this door. The sensitivity of the flow-through door is about the same as that of the standard-cuvette door with the high sensitivity kit. That is so because of the larger cuvette used in the flow-through door.

Normally dye concentrations are not determined in the field because it is difficult to attain sufficient accuracy under such conditions. The flow-through door arrangement may be used for preliminary calibration of a reach, however. As a rule, bottle samples are collected and transferred to the laboratory for accurate fluorometric analysis.

EFFECT OF TEMPERATURE ON FLUOROMETRY

Accurate dilution discharge measurements require accurate fluorometry, and accurate fluorometry can only be attained in the laboratory where operating conditions are favorable. Temperature has a significant effect upon the fluorescence intensity of dyes. Fluorescence decreases with increasing temperature. This characteristic of the dyes has been investigated by several researchers, among them Feuerstein and Selleck (1963). For best results, all samples, including background and standard solutions, should be placed in a laboratory temperature bath and kept at constant temperature prior to fluorometric analysis. If the same temperature is used for all samples, no temperature corrections will be needed. If temperatures cannot be held constant, temperature corrections, as given in table 13 for Rhodamine WT dye, should be applied to dial readings or to concentrations.

Dunn and Vaupel (1965) point out the need for corrections to fluorometer dial readings as a result of changing compartment temperatures. However, tests by the U.S. Geological Survey showed that these corrections were needed only during the warmup period. A 1½-to 2-hr warmup will usually eliminate the need for this type of correction, although minor changes may still be observed thereafter. The warmup characteristics of each fluorometer should be determined. If possible, the fluorometer should not be operated where large temperature changes can occur rapidly.

CALIBRATION CHARACTERISTICS OF THE FLUOROMETER

Most fluorometers have a linear calibration ratio, meaning that dye concentration is directly proportional to the dial reading on the fluorometer and is related by the equation