Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A9

MEASUREMENT OF TIME OF TRAVEL IN STREAMS BY DYE TRACING

By F.A. Kilpatrick and J.F. Wilson, Jr.

This manual is a revision of "Measurement of Time of Travel and Dispersion in Streams by Dye Tracing," by E.F. Hubbard, F.A. Kilpatrick, L.A. Martens, and J.F. Wilson, Jr., Book 3, Chapter A9, published in 1982.

Book 3

APPLICATIONS OF HYDRAULICS

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, Jr., ***Secretary***

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, ***Director***

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PREFACE

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The unit of publication, the chapter, is limited to a narrow field of subject matter. This format permits flexibility in revision and publication as the need arises. Chapter A9 deals with the application of dye tracers for the measurement of time of travel in streams.

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TWI 5-A3. Methods for the determination of organic substances in water and fluvial sediments, edited by R.L. Wershaw, M.J. Fishman, R.R. Grabbe, and L.E. Lowe. 1987. 80 pages. This manual is a revision of "Methods for Analysis of Organic Substances in Water" by Donald F. Goerlitz and Eugene Brown, Book 5, Chapter A3, published in 1972.

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TWI 8-B2. Calibration and maintenance of vertical-axis type current meters, by G.F. Smoot and C.E. Novak. 1968. 15 pages.

CONTENTS

FIGURES

TABLES

METRIC CONVERSION FACTORS

For readers who wish to convert measurements from the inch-pound system of units to the metric system of units, the conversion factors are listed below.

Multiply inch-pound unit	*By*	*To obtain metric unit*
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
gallon (gal)	3.785	liter (L)
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.589	square kilometer (km^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
foot per second (ft/s)	0.3048	meter per second (m/s)
square foot per second (ft^2/s)	0.0929	square meter per second (m^2/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile per hour (mi/h)	0.4470	meter per second (m/s)

Note: Micrograms per liter (μg/L) is approximately equal to parts per billion (ppb) in any like units of weight per weight.

SYMBOLS AND UNITS

Symbol	*Explanation*	*Unit*
B	Average width of stream	ft
C	Concentration	μg/L
C_p	Observed peak dye concentration	μg/L
d	Mean depth of stream	ft
E_z	Lateral or transverse mixing coefficient	ft^2/s
K	Mixing length coefficient	ft^2
L	Length of measurement reach	mi
L_o	Channel length required for optimum mixing; usually corresponds to about 95-percent mixing	ft
Q	Total stream discharge	ft^3/s
Q_m	Maximum discharge in test reach	ft^3/s
s	Water-surface slope	ft/ft
t	Time	h
t_b	Interval of time for dye concentrations to build up from the leading edge to the peak	h
$t_{c,L,t,p}$	Traveltime of centroid, leading edge, trailing edge, and peak, respectively, of dye-response curve	h
$T_{c,L,t,p}$	Elapsed time to centroid, leading edge, trailing edge, and peak, respectively, of dye-response curve	h or min
T_d	Duration in time for tracer cloud to pass any one point in a section	h or min
T_D	Duration in time for entire tracer cloud to pass a section	h or min
T_{D10}	Duration of abbreviated time-concentration curve to time when C=10 percent C_p	h
V_s	Volume of stock dye solution	L or mL
v	Mean stream velocity	ft/s or mi/h
v_p	Velocity of peak	ft/s or mi/h

MEASUREMENT OF TIME OF TRAVEL IN STREAMS BY DYE TRACING

By F.A. Kilpatrick and J.F. Wilson, Jr.

Abstract

The use of fluorescent dyes and tracing techniques provides a means of measuring the time of travel of solutes in steady and gradually varied flow in streams. This information is needed in waste transport studies, in particular to evaluate the behavior of soluble substances accidentally spilled in streams.

This manual describes methods of measuring time of travel of water and waterborne solutes by dye tracing. The fluorescent dyes, measuring equipment used, and field and laboratory procedures are also described. Methods of analysis and presentation to illustrate time of travel of streams are provided.

Introduction

General

Time of travel refers to the movement of water or waterborne solutes from point to point in a stream during steady or gradually varied flow conditions. The measurement or simulation of time of travel using dye tracers involves the slug injection of a dye at some location along the stream and the measurement of the resulting response, or dye cloud, at other locations downstream (Buchanan, 1964; Wilson, 1967). When a fluorescent dye is used as a tracer, the degree of fluorescence can be determined with a fluorometer. The concentration of dye in the sample is directly proportional to its fluorescence. A plot of concentration against time defines the dye-response curve at each sampling site. Time of travel is measured by observing the time required for movement of the dye cloud, as defined by the response curve, between sampling sites. Equally important, the dispersion characteristics of the stream can also be determined.

The purpose of this manual is to describe methods, procedures, dyes, and equipment used in planning and making time-of-travel measurements in streams and in analyzing and presenting such data.

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It is assumed that the reader is familiar with "Fluorometric Procedures for Dye Tracing," by Wilson and others (1986), which describes the general procedures for using and measuring dyes.

Purposes of tracer studies

As described in this manual, dye studies in streams usually are conducted to provide data for two purposes: to determine time of travel for use in water-quality models; and to define relations so that those charged with public safety, or others having interest in transient water-quality problems, can predict the time of arrival and passage time of a noxious substance released or spilled upstream.

Water-quality models are, typically, no better quantitatively than the travel time data used in their formation. Traveltimes estimated from low-flow discharge measurements from a few cross sections in a reach may be subject to large error. Thus, an accurate measurement of time of travel, such as can be made using dye tracers, is needed.

Newspaper headlines frequently report spills of hazardous materials into streams: a truck goes into a river; a barge sinks or starts leaking; a holding tank at a riverside facility ruptures; an industrial plant accidentally releases a dangerous substance into its normal effluent; or a pipeline ruptures near a river. Public-health officials often need to decide whether, when, and how long to suspend operations of public water-supply intakes in the reach downstream from the spill. Likewise, other users of the water need to decide on an appropriate course of action. On one hand, suspension of water use may result in economic penalties and, if it involves a public water supply, may cause widespread discomfort. On the other hand, public-health officials cannot afford to take risks when the safety of large numbers of people is involved. Clearly, accurate time-of-travel and dispersion informa- mation is needed, in advance of the spill, to provide a reasonable basis for such decisions.

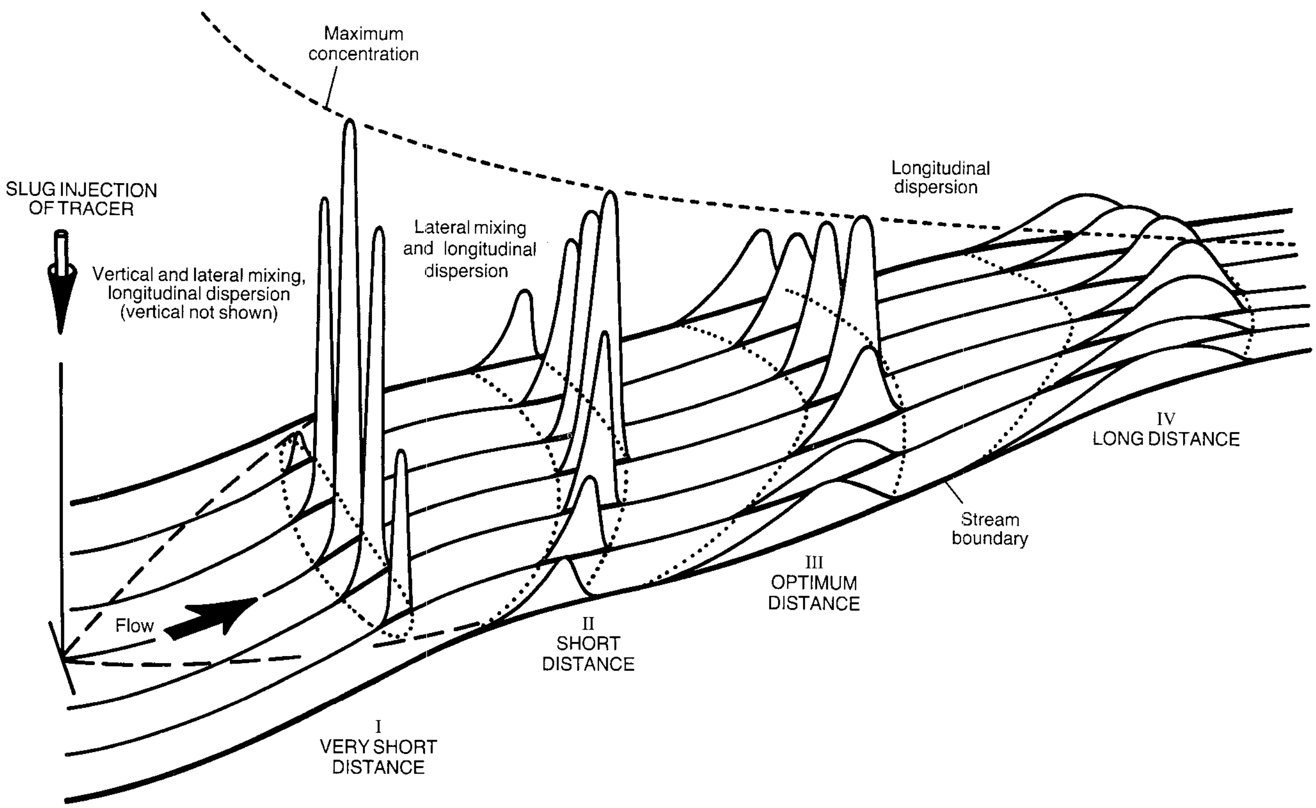

Figure 1.—Lateral mixing and longitudinal dispersion patterns and changes in distribution of concentration downstream from a single, center slug injection of tracer.

Stewart (1967) made such a study on short notice when a chlorine barge sank in the Mississippi River near Baton Rouge, La., causing officials to fear that the substance would leak into the river. Perhaps spurred by this incident, the Louisiana Department of Public Works has acquired, through its cooperative program with the U.S. Geological Survey, an extensive set of data on time of travel and dispersion on streams in the State (Shindel and others, 1977; Calandro, 1978).

Press releases

Because of increasing public awareness of stream pollution, it is highly desirable to provide press releases that describe dye tests in advance. A press release should emphasize the purpose of the test, for example, "to provide a means of predicting the movement of any harmful substances that might be spilled" or "to provide a means of understanding and monitoring the water quality of the stream." The press release should state that the dye is harmless; however, this should not be the main theme, and titles such as "Harmless red dye to be dumped into _____ River" should be avoided. The title should emphasize the *positive* aspects of the test, for example, "State and U.S. Geological Survey hydrologists to study transport characteristics of _____ River by use of dye tracers."

General Description of Dye Tracing

Theory

Dyes injected into a stream behave in the same manner as the water particles themselves. A measure of the movement of the tracer will in effect be a measure of the movement of an element of fluid in the stream and of its dispersion characteristics.

The dispersion and mixing of the tracer in the receiving stream takes place in all three dimensions of the channel (fig. 1). Vertical mixing is normally completed first, and lateral mixing later, depending on stream characteristics and velocity variations. Longitudinal dispersion, having no boundaries, continues indefinitely and is the dispersion component of primary interest.

In figure 1, the responses to a slug injection of tracer are shown *with distance* downstream along

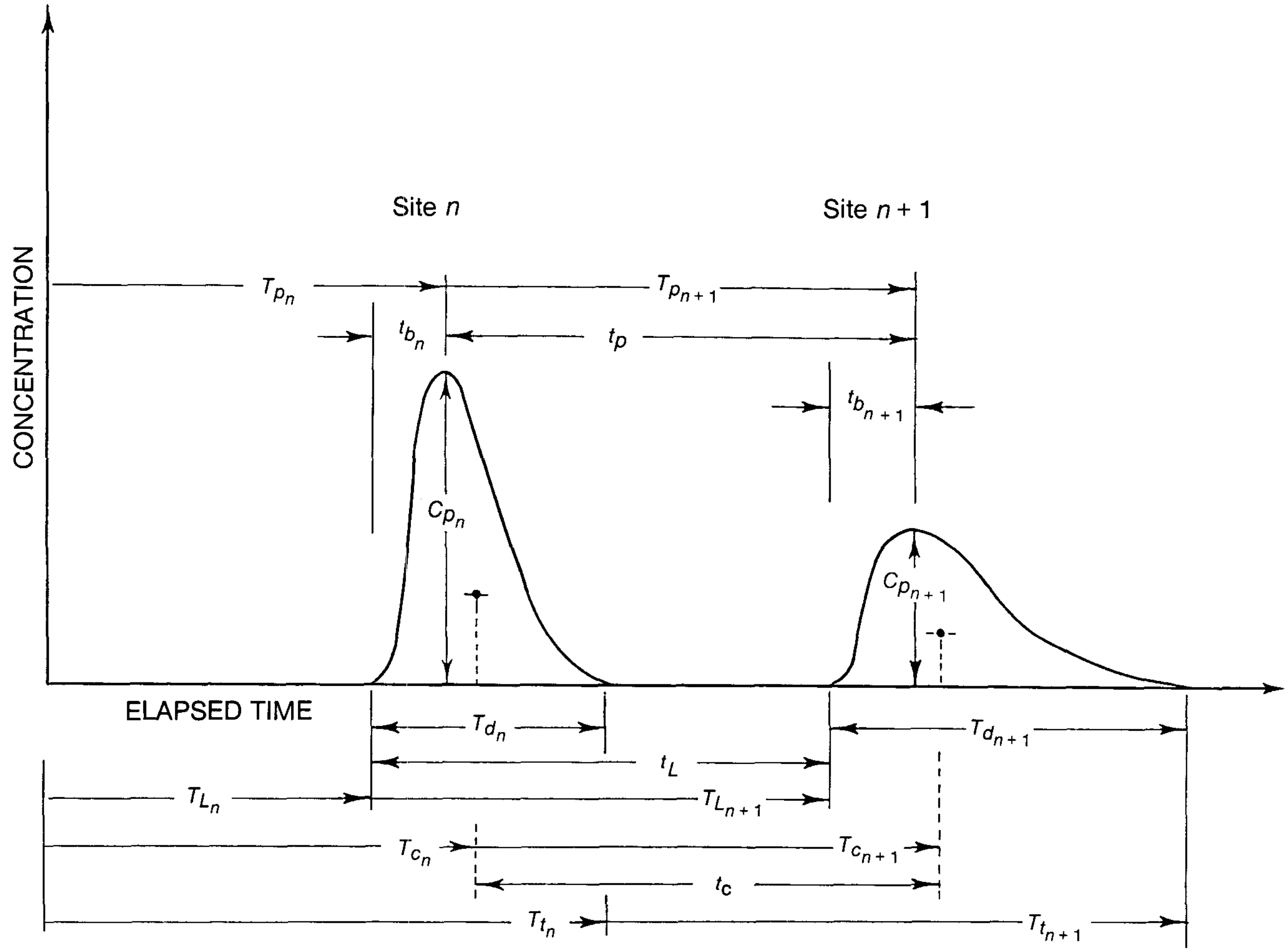

Figure 2.—Definition sketch of time-concentration curves along a selected streamline resulting from an instantaneous dye injection. (Abbreviations explained in section "Symbols and Units.")

selected imaginary streamlines. The response curve at any point downstream from an instantaneous dye injection is normally represented by plotting concentration against elapsed time (fig. 2). The time-concentration curves, or response curves, defined by the analysis of water samples taken at selected time intervals during the dye-cloud passage is the basis for determining time-of-travel and dispersion characteristics of streams.

The characteristics of the time-concentration curves *along a streamline* are shown in figure 2 and may be described in terms of elapsed time after an instantaneous dye injection. Characteristics pertinent to time-of-travel measurements are

T_L, elapsed time to the arrival of the leading edge of the response curve *at a sampling point*;

T_p, elapsed time to the peak concentration, C_p, of the response curve *at a point*;

T_c, elapsed time to the centroid of the response curve *at a point*; and

T_t, elapsed time to the trailing edge of the response curve *at a point*.

The mean traveltime for the flow along a streamline is the difference in elapsed time of the centroids of the time-concentration curves defined upstream and downstream *on the same streamline*:

$$t_c = T_{c(n+1)} - T_{c_n},$$

where n is the number of the sampling site.

Similarly, the traveltimes of the leading edge, peak concentration, and trailing edge *along a given streamline* are, respectively,

$$t_L = T_{L(n+1)} - T_{L_n}, \quad (1)$$

$$t_p = T_{p(n+1)} - T_{p_n}, \quad (2)$$

and

$$t_t = T_{t(n+1)} - T_{t_n}. \quad (3)$$

The time, T_d, necessary for the response to pass *a sampling point* in a section is

$$T_d = T_{t_n} - T_{L_n}. \tag{4}$$

As shown in figure 1, a typical dye cloud may travel faster in the center of the stream than along the banks, where it may also be more elongated. Complete definition of the response to a slug injection therefore may involve measurement at more than one point or streamline in the several sections involved. Fortunately, most time-of-travel measurements are made over long stream lengths, and elaborate measurement of the response curves laterally is not necessary. The exception is the measuring section nearest the injection point, where sampling at several points laterally is often advisable if the distance from the injection to this first section is short. Thus, in some uses the various times characterizing the response curves described above may best be averaged to represent the entire dye cloud at a section.

The duration or time of passage of a tracer response *at a section*, T_D, is the difference between the slowest trailing time along one bank and the fastest leading edge time, usually as observed in the center. The difference between the values of T_d and T_D can be significant. Unless otherwise indicated, further reference to the duration of the response curve will be to T_D, as in most time-of-travel studies $T_D \approx T_d$ for the long stream lengths involved.

Fluorometry

Fluorometers measure the luminescence of a fluorescent substance when the substance is subjected to a light source of a given wavelength. The higher the concentration of the fluorescent substance, the more emitted light the fluorometer will detect. The use of fluorometers in dye tracing has been described in detail by Wilson and others (1986).

Fluorescent dyes

Several dyes can be used as tracers in time-of-travel measurements. The basic characteristics of dyes now being used by the Geological Survey have been discussed by Wilson and others (1986). Properties to be considered in selecting a tracer include detectability, toxicity, solubility, cost, and sorption characteristics. Currently, rhodamine WT dye is the tracer recommended and the one involved in subsequent discussions.

Toxicity

Abidi (1982) reported on *laboratory* tests showing that when rhodamine WT dye is mixed with streamwater containing nitrites, diethylnitrosamine (DENA), a carcinogen, may be formed. Johnson and Steinheimer (1984) and Steinheimer and Johnson (1986) conducted a number of tests relative to DENA formation and persistence. They found that DENA in a simulated stream environment has a half-life of less than 3 hours. They also analyzed water samples from four streams taken during rhodamine WT tracer studies and could not detect DENA in any of the samples. Nitrite concentrations in the four streams varied from 2 to 46 micrograms per liter (μg/L).

Regrettably, Abidi's report influenced some agencies to suspend time-of-travel and related studies. Johnson and Steinheimer's reports need to be cited to emphasize that studies can be performed without harm if carefully performed. Similarly, it is important to adhere to the Geological Survey policy for the use of rhodamine dyes, which states that in a stream where *measured* nitrite is less than 50 μg/L, the maximum permissible concentration of the dye is 10 μg/L at any water intake that ultimately results in direct or indirect human consumption. Furthermore, should *measured* nitrite be greater than 50 μg/L, the maximum permissible concentration of rhodamine dye at an intake is 2 μg/L. Dye concentrations at water intakes can generally be kept well below this level; many dye studies are designed for maximum concentrations of 1 μg/L at such critical points as water intakes. Nitrite concentrations in excess of 50 μg/L seldom exist except with extreme river pollution.

In this regard, it is important to calibrate fluorometers with the dye used and to analyze samples so that the actual dye concentrations obtained in the stream are documented (Wilson and others, 1986). The test data and data on measured nitrite concentrations should be retained for any future legal needs, as well as for other types of analyses (Kilpatrick and Taylor, 1986).

Users of rhodamine WT dye need to take special precautions to avoid direct contact with the dye. Rubber or plastic gloves should be worn when handling concentrated dye solutions. When the dye does come in contact with the skin, it should be washed off immediately. Pipetting of dye solutions may be done with a squeeze bulb or by using a long piece of flexible tubing to prevent accidental ingestion of the dye.

Dye-Tracing Equipment and Supplies

Injection

Injections are usually made by pouring a measured amount of dye into the center of the flow. This is usually in the center of the stream. Graduated laboratory cylinders, as shown in figure 3, are recommended for measuring small quantities of dye. Large injections can be measured in terms of full dye containers; the net weight of dye is usually stamped on the container.

Injections at multiple points across the stream are sometimes used on wide or shallow streams to shorten the effective mixing length. The dye is measured, divided into a number of containers, and poured simultaneously at several points along the cross section. Special boat-mounted devices, such as those shown in figure 4, may be useful for line injections of very large doses. A line injection is made by pouring dye continuously while crossing the stream; in such instances, dye should not be injected at the immediate stream banks in dead water or in areas of slow-moving water. As a rule, dye should be injected in only about the central 75 percent of the flow.

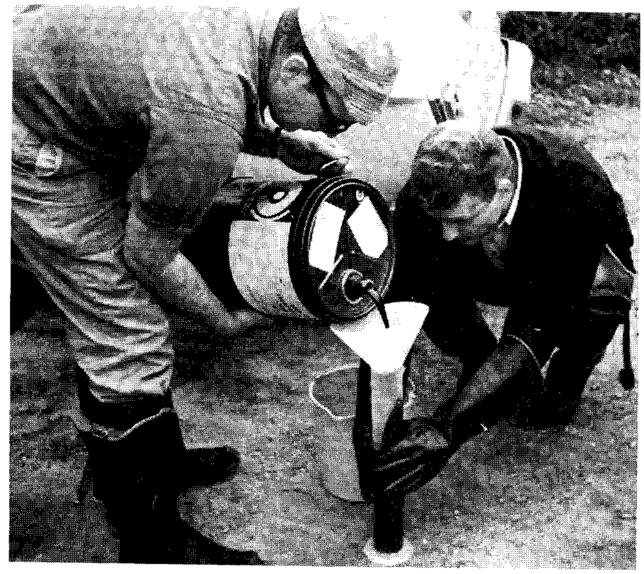

Figure 3.—Volumetric measuring of dye dosage in the field.

Sampling

Grab sampling is most commonly used in dye-tracing studies. Sampling may be done by wading into the stream, from a boat, or by lowering the sampling container by rope from a bridge. The 8-dram (approximately 32 milliliters (mL) or 1 ounce (oz)) polyseal-cap glass bottles shown in figure 5 are stock items. This bottle has sufficient volume for six to eight analyses on some fluorometers, is easy to clean and handle, and is compatible with temperature-bath control systems. If the Turner Designs model 10 fluorometer is used, a 100-mL sample is desirable. This fluorometer may also be equipped with a smaller cuvette holder which allows the smaller 1-oz bottle to be used. Excessively large samples require a longer time to come to the desired temperature when temperature-control apparatus is used. Glass bottles can be numbered so that the sample data can be kept on separate data sheets referred to only by sample number (see fig. 6). Permanent numbers can be placed on the glass with a vibrator-etcher tool, or temporary numbers can be added by writing on masking or transparent tape affixed to the bottle. Soap or acid cleansing of bottles is not recommended; flushing and then rinsing *twice* in plain water is sufficient.

The chest shown in figure 5 contains six trays of 50 bottles each and is sufficient for most tests.

Standard samplers, such as depth-integrating water-quality samplers, can be used for point sampling, although smaller, lighter samplers designed specifically for the size and type of sample bottle are best. The sample bottle holder for the standard glass bottle shown in figure 5 is intended for use from bridges. It is fabricated by mounting a utility clamp or a split section of rubber hose to angle iron or to some other support, which serves to hold and protect the bottle.

Hand sampling during dye studies is quite effective, but it frequently involves many people, and some of the sampling may need to be done during the night. Long hours with little relief is more the rule than the exception. Consequently, manpower costs are high. The automatic dye-sampling boat, shown in figure 7, has helped reduce the manpower required for dye studies (Kilpatrick, 1972). The sampler consists of a series of spring-activated 20-mL hypodermic syringes mounted vertically in a metal rack. When installed in the floating fiberglass boat, the tips of the syringes are immersed slightly in water. A worm gear, rotated by a small electric motor, advances a tripping mechanism, which releases the preset syringes one by one in sequence. As they are released, the syringes fill with water from the action of the spring that withdraws the plunger the necessary distance. Following use, the syringes need to be rinsed only with clear water; laboratory detergent will cause the syringes to stick during subsequent use. Bench-testing the timing mechanism to determine the sampling interval at various combinations of drive gears is recommended, as there may be some variation between units.

The use of dye-sampling boats can reduce the number of personnel required to do a fairly extensive dye study to just two. The first sampling site is usually sampled by hand because the dye passes quickly, and these data provide an opportunity to reestimate the

Figure 4.—Special boat-mounted apparatus for making a line injection of a large dosage of dye. (Photograph by Missouri district of U.S. Geological Survey.)

time of arrival of the dye cloud at downstream sampling points. Then the sampling boat is tied or anchored at the next sampling site and set to sample during a period of time that will ensure that the dye cloud is sampled when it passes. The frequency of sampling is set to obtain enough samples to define the dye cloud.

Although most investigators occasionally check the boats during the sampling process, they are typically left unattended for long periods to allow personnel time for meals and rest. There have been few reports of vandalism or theft. Some studies have been made with the sampler boats chained and locked to bridge pilings, but they are, of course, still subject to vandalism. Either way, the number of cases of vandalism and theft has been low nationwide.

It may be necessary to use two boats if the leading edge of the dye reaches a sampling site before the dye cloud has completely passed the next site upstream or if the dye cloud will pass two sites during the time set aside for the field crew to rest. When two sampling boats are used, they can be leapfrogged to alternate sites as the dye moves through the study reach.

In securing the boats by a bottom anchor in streams having swift velocities, enough anchor rope should be provided to prevent the boats from sinking. When tied at the front, where an eyebolt is installed for this purpose, the boats may be pulled under and sunk

Figure 5.—Sampling equipment for use in dye-tracer studies.

because the front end, affected by the force of the anchor rope, tends to float a little lower than the rear.

Although periodic grab sampling, either manually or with the automatic sampler described, has proved satisfactory for most applications, continuous sampling and recording may be accomplished by use of a flow-through device on the fluorometer and a strip-chart recorder, such as that shown in figure 8. Typically, the intake hose is attached to a small electrically operated pump, which pumps the sample through the flow-through fluorometer door and out the discharge hose.

Continuous sampling from a boat is particularly applicable to studies in which the dye-cloud movement is multidimensional. Depth sampling can be accomplished by traversing vertically with the intake hose. High pump rates and short hose lengths will minimize lag errors and dispersion taking place in the hose itself.

The strip-chart record of fluorescense plotted against time can be calibrated by periodically collecting bottle samples from the fluorometer discharge line and noting the collection time directly on the chart. Subsequently, these samples are analyzed, and concentrations are plotted against chart readings to define a calibration curve, as shown in figure 9.

Fluorometers

Fluorometers and accessory equipment, and their calibration and operation, are described by Wilson and others (1986). A modern fluorometer, such as the Turner Designs model 10 (see fig. 10), is battery operated and enclosed for field as well as laboratory use. It should be noted that the standard 1-oz bottle described earlier and the 20-mL syringe sample obtained with the boat sampler require the 13- by 100-millimeter cuvette holder to permit analysis on this fluorometer.

Fluorometer readings for samples are relative values of fluorescence intensity and cannot be directly converted into dye concentrations unless the fluorometer is one of the newer models designed to be read directly in concentration values. The actual concentrations of the samples can be determined by use of a fluorometer that has been calibrated by using a set of standard solutions of known concentration. The standard dye solutions should be made from the same dye lot used in the field test. Thus, the concentrations in samples for all tests using the same lot of dye can readily be determined.

Planning the Time-of-Travel Study

Test discharges

Time of travel varies inversely with discharge in a stream. To develop a method for predicting traveltimes that can be used over a range of discharges, it is necessary to relate the time of travel in some way to stream discharge. Over a long reach of river, stream discharge generally increases in the downstream direction as the area drained increases. These increases, however, do not occur uniformly with distance along the river. At the points where tributaries enter the river, stream discharge increases abruptly. Depending on the drainage area of the tributary, these increases can be substantial. Usually, however, the river channel has adjusted to these increases in flow, and an increase in velocity commensurate with the increase in flow does not occur. For this reason, except for very limited studies, absolute discharge in the river is not an ideal variable for determining the relation between traveltime and discharge (Taylor and others, 1984).

Flow duration is an index of river discharge that is nearly constant throughout a reach of stream, provided there is no flood wave moving through the system. This characteristic makes flow duration a useful index of stream discharge in developing a relationship with time of travel. Flow duration, expressed in percent, is the percentage of time that the historic mean-daily discharges equal or exceed a specified discharge.

Figure 11 is a map of the Shenandoah River and its tributaries in Virginia and West Virginia where an

TIME-OF-TRAVEL STUDY ON ____________________
SAMPLING SITE ____________________
Dye injected at ____________________ Time __________ Date __________
Amount injected __________ Type of dye __________ Conc. in % __________
Sampling section discharge __________ cfs; width __________; mean depth __________

Sample No.	Sample Point	Sample Time	Field Sampling and Analysis: Fluorometer Readings				Final Laboratory Analysis: Fluorometer Readings				Dye Conc. (μg/L)	
			1X	3X	10X	30X	1X	3X	10X	30X		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	

Column 1. Number on sample bottle.

2. When more than one point in section is sampled, indicate as "A," "B," "C," etc., from left to right bank.

3. Military time.

4-11. Fluorometer dial readings on scales used.

12. Based on fluorometer calibration--show dye concentration in microgram per liter in stream. If background has not been suppressed on the fluorometer, subtract background reading prior to using calibration curve.

Figure 6.—Form for recording dye-sample data.

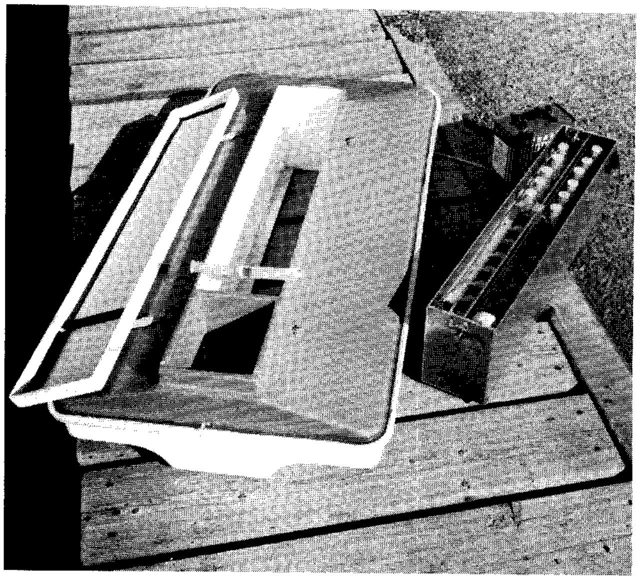

Figure 7.—Automatic dye-sampling boat, with the sampling mechanism and battery removed.

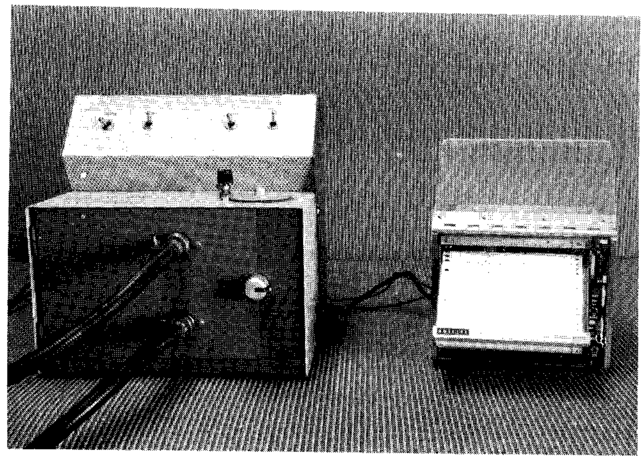

Figure 8.—Fluorometer equipped with a flow-through door and a strip-chart recorder for continuous sampling and recording.

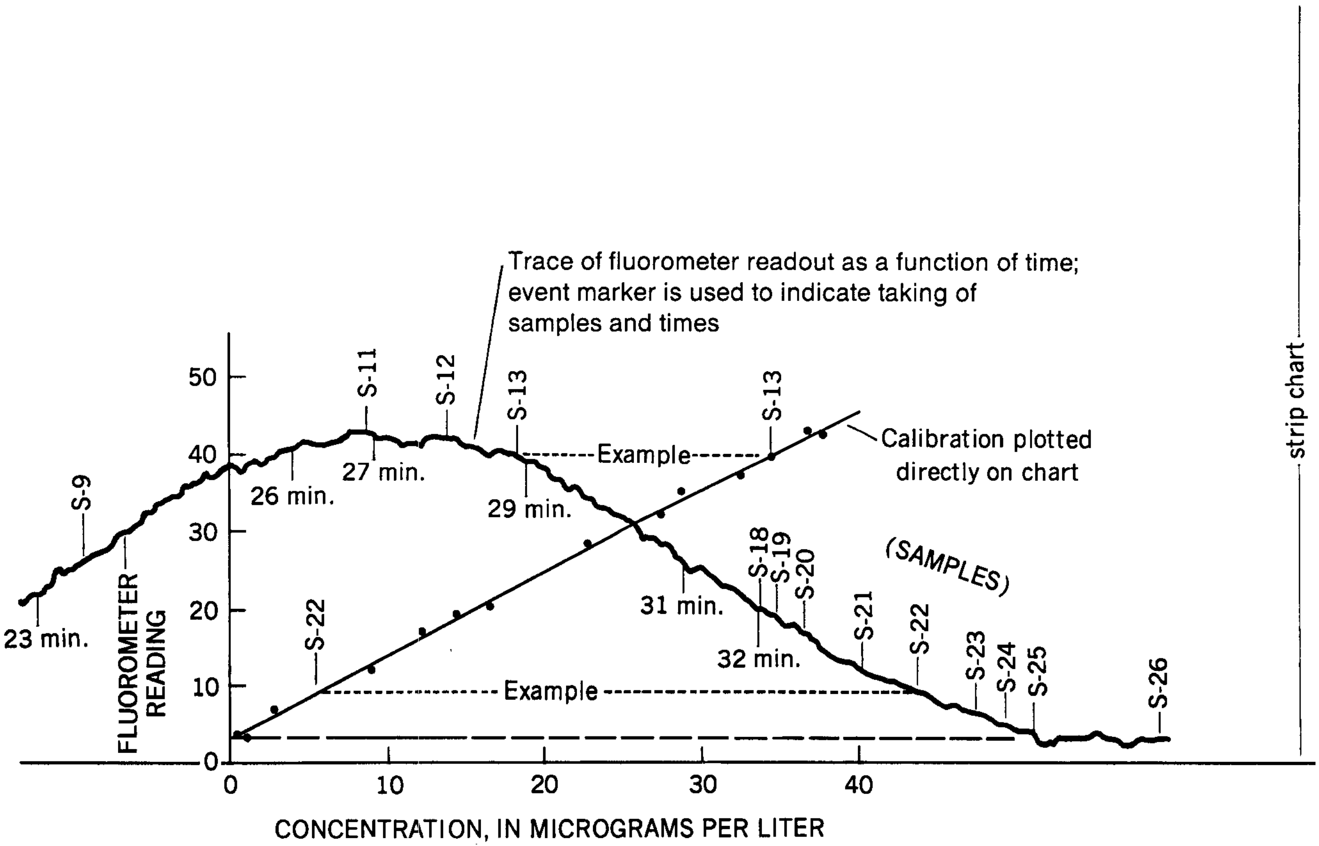

Figure 9.—Example of calibration of strip-chart trace. Selected samples from the fluorometer flow-through discharge are subsequently analyzed in the laboratory and concentrations are plotted against the strip-chart reading directly on the graph.

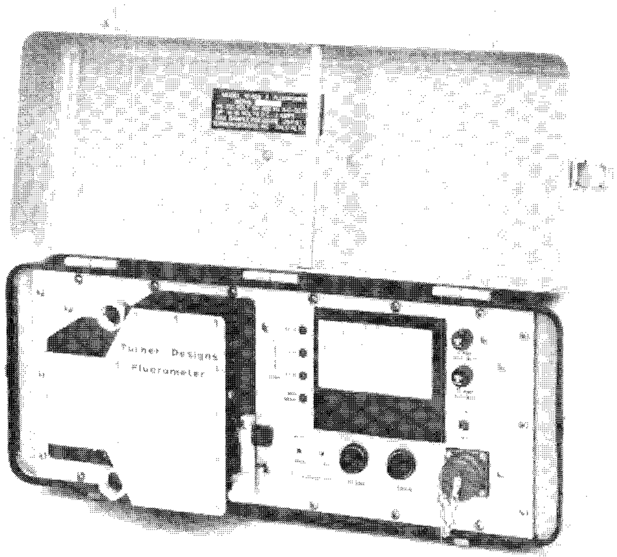

Figure 10.—A modern fluorometer, suitable for field use, having both flow-through and individual-sample analysis capability.

extensive series of time-of-travel tests was performed by Taylor and others (1986) during 1983 and 1984 at flows of 85 percent and 45 percent duration, respectively. The data and techniques used by Taylor and others are used selectively in this manual. Figure 12 shows the relation between flow duration and discharge for four gaging stations or locations on the South Fork Shenandoah River and its tributaries in Virginia. Taylor and others found that during September 1983 discharge on the Shenandoah River increased from 36 cubic feet per second (ft^3/s) at Waynesboro to 570 ft^3/s at Harpers Ferry, although flow duration was at approximately 85 percent throughout the reach. This information made possible comparisons with tests on the Potomac River, which were performed during the fall of 1981 at the flow duration of 90 percent; flow at this duration was 1,800 ft^3/s for the Potomac River at Washington, D.C. As mentioned previously, time of travel commonly varies inversely with discharge. The relation of time of travel to discharge is of the form

$$t=kQ^{-x}, \tag{5}$$

which is a straight line, logarithmically. The constant, k, and the exponent, x, need to be defined for each flow-control condition of interest, that is, pool-and-riffle or channel control. Thus, two or more time-of-travel measurements are usually required for any stream reach.

The first step in planning the time-of-travel study is to study existing streamflow records and to select the one or more flow durations to be sought for the tests. The lower flow (higher flow duration) is usually the most important, as traveltimes are long and the transport and behavior of potential wastes are the most critical. Fall is the most likely season for sufficiently long periods of stable low flows in a large river system. Stable high flows, having flow durations between 40 and 50 percent, sometimes occur during late spring. In either case, careful planning means being alert and ready for the desired periods of stable flows. Manpower may have to be concentrated for intense efforts when the flow "window" for the tests materialize. Plans and logistics need to be ready for implementation when the time comes.

Map and streamflow-data study

The next step in planning the time-of-travel measurement is to make a tentative evaluation of the stream reaches under consideration in terms of hydraulic characteristics and of constraints on the use of dyes. Topographic maps and available streamflow data should be examined to make the initial selection of sites where dye will be injected and sampled. Maps are useful in developing a generalized picture of the stream-channel system in terms of channel geometry, discharge and slope variations, manmade impoundments and diversions, and accessibility of the sites.

Examination of available streamflow data, discharge measurements, and gaging-station records and comparisons of hydrographs assist in selecting sampling and injection sites.

Reconnaissance of the stream

The reconnaissance of the stream will depend on the scope of the measurements being planned and should include the following activities:

1. Inspect the proposed injection site or sites to determine flow conditions, type of dye injection to use, and accessibility for injecting the dye.
2. Inspect the proposed sampling sites (minimum of two per injection is desirable) to determine accessibility and suitability. Decide whether more than one sampling point in the cross section will be necessary and where the sampling points will be located. Measure or estimate the channel width and depth and the mean velocity of the stream reach to the extent possible.
3. Estimate stream velocities to aid in planning sampling schedules. When making a visual reconnaissance of the stream, there is a tendency to give too much weight to the higher velocities observed in riffles compared with the slower