Designation: D5613 – 94(Reapproved 2008)

Standard Test Method for
Open-Channel Measurement of Time of Travel Using Dye Tracers[1]

This standard is issued under the fixed designation D5613; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a means of measuring the time-of-travel of water and waterborne solutes by the use of dye tracers and tracing techniques. This test method is similar to methods developed by the U.S. Geological Survey and described in other referenced documents.

1.2 This test method describes the dye tracers, measuring equipment used, and field and laboratory procedures customarily used.

1.3 This test method describes the methods of tracer study analysis and data presentation.

1.4 The user of this test method should address the following concerns regarding the use of tracers in water bodies:

1.4.1 Determine whether the chemical has clearance or approval or has potential or preceived impacts relating to potable, industrial, irrigation, or fish and wildlife use.

1.4.2 Determine whether approvals are required by involved agencies.

1.4.3 Document contacts regarding notification.

1.5 The values stated in inch-pound units except for chemical concentrations and liquid volumes for step dilutions, which are stated in SI units, are to be regarded as the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazards statements, see Section 9.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1192 Guide for Equipment for Sampling Water and Steam in Closed Conduits (Withdrawn 2003)[3]

D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water

D3370 Practices for Sampling Water from Closed Conduits

D3858 Test Method for Open-Channel Flow Measurement of Water by Velocity-Area Method

D4411 Guide for Sampling Fluvial Sediment in Motion

2.2 *ISO Standard:*[4]

ISO 555/2-1974 Liquid Flow Measurement in Open Channels—Dilution Methods for Measurement of Steady Flow, Part 2: Integration (Sudden Injection) Method.

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *automatic programmable sampler*—a portable device designed to collect sequential, discrete water samples representative of the water mixture moving in the river in the vicinity of the sampler at a single point in a cross section. Depending on the make and model of the device, water samples can be collected at equal or variable time intervals.

3.1.2 *centroid*—the center of mass of the dye response curve calculated as outlined by Parker and Hunt (**1**)[5].

3.1.3 *depth-integrated sample*—a water sample collected in such a manner as to be representative of the water mixture moving in the river in the vicinity of the sampler at a single vertical in a cross section.

3.1.4 *dispersion*—the three-dimensional process of disseminating the dye within a river's waters.

3.1.5 *flow duration*—the percentage of time during which a specific discharge is equalled or exceeded.

3.1.6 *fluorometer*—an instrument that measures the luminescence of a fluorescent substance when subjected to a light source of a given wave length.

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[1] This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] The boldface numbers in parentheses refer to the list of references at the end of this test method.

3.1.7 *injection site*—a study site where the tracer is to be introduced into a parcel of river water. This study site is usually a sufficient distance upstream of the study reach such that complete vertical and lateral mixing of the tracer in a parcel of river water has occurred before the water parcel's entry into the study reach.

3.1.8 *lateral dispersion*—the process of disseminating the dye within a river water's horizontal axis perpendicular to its longitudinal axis. The completion of this process is dependent on the width of the river and velocity variations.

3.1.9 *leading edge*—the first detectable dye concentration observed at a sampling site.

3.1.10 *longitudinal dispersion*—the process of disseminating the dye within a river's waters along its upstream-downstream axis. This component of the dispersion process continues downstream indefinitely.

3.1.11 *mixing*—the blending of two or more substances into one uniform mass.

3.1.12 *peak*—the maximum dye concentration observed at a sampling site.

3.1.13 *point sample*—a water sample collected in such a manner as to be representative of the water mixture moving in the river in the vicinity of the sampler at a single point in a cross section.

3.1.14 *sample site*—a study site where water samples are collected for determination of the tracer-concentration response curve.

3.1.15 *standard integrated depth sampler*—a device designed to accumulate a water sample from a stream vertical at such a rate that the velocity in the nozzle at the point of intake is always as nearly as possible identical with the immediate stream velocity.

3.1.16 *study reach*—the section of a river's length that is to be studied.

3.1.17 *study site*—sections of a river where data are to be determined, monitored, measured, and where tracer is to be introduced into the river.

3.1.18 *tracer response curve*—at each sampling site, the plots of tracer concentration versus time after the tracer injection.

3.1.19 *trailing edge*—the point of the falling limb of the dye response curve that is equal to approximately 2 % of the peak concentration observed at a sampling site.

3.1.20 *vertical dispersion*—the process of disseminating the dye within a river's water's vertical axis perpendicular to its upstream-downstream axis. This dispersion process is usually completed first.

4. Summary of Test Method

4.1 Dye tracers injected into a stream are assumed to behave in the same manner as the water molecules themselves. A measure of the longitudinal movement of a tracer along a given streamline will be a measure of the movement of an element of fluid in the stream and of its dispersion characteristics for that streamline.

4.2 The initial planning of a dye tracer time-of-travel study involves the estimation of stream velocities and the required tracer injection volume. The information necessary for these estimations is obtained by reviewing historical flow data and topographic maps and by making a reconnaissance of the proposed study reach.

4.3 The time-of-travel for a given flow is determined by observing the passage of a slug-injected dye tracer cloud at previously identified locations along the study reach. The dye cloud response curve is defined at each reach location (study site) by measuring the dye concentration in collected water samples and noting the time that each sample was collected since the tracer injection.

4.4 After tracer studies have been conducted at two or more flow durations on the study reach, estimation of the time-of-travel and dispersion of a solute can be made at any flow between those studied. Tracer studies are typically performed at 40 to 90 % flow duration ranges.

5. Significance and Use

5.1 *Purpose:*

5.1.1 This test method covers the use of fluorescent dye tracers in streams to determine the rate that a solute moves along a streamline for a given river reach and the rate at which a solute disperses as it moves downstream.

5.1.2 Accurate measurements of a stream's velocity and dispersion coefficient that can be determined by a tracer study are important parameters for water-quality models.

5.1.3 Determined in advance to potential spilled or released noxious substances, velocity and dispersion rates are used to predict the time of arrival, passage time, and maximum concentration. Public health officials need this information to decide whether, when, and how long to suspend operations of public water-supply intakes in the reach downstream of a spill.

5.2 *Assumptions:*

5.2.1 This test method assumes that the dye tracer behaves in the same manner as the water in which it is injected. Dispersion and mixing of the tracer in the receiving river occur in all three dimensions of the channel. Longitudinal mixing is unending since boundaries do not exist in this direction.

5.2.2 The tracer response curve at a point downstream from the point of tracer injection can be represented by plotting the tracer concentration against elapsed time since the injection (Fig. 1).

5.2.3 A tracer response curve has four important characteristics: the elapsed time to the response curve's leading edge; elapsed time to the response curve's peak concentration; elapsed time to the response curve's centroid; and elapsed time to response curve trailing edge at 2 % of the peak concentration.

5.2.4 Between two monitoring locations separated by a long stream length, the time-of-travel for individual response curve characteristics is the difference in the elapsed times since injection for that characteristic at the two locations.

5.2.5 The duration or time of passage of a tracer response curve at a particular river location is the difference between the

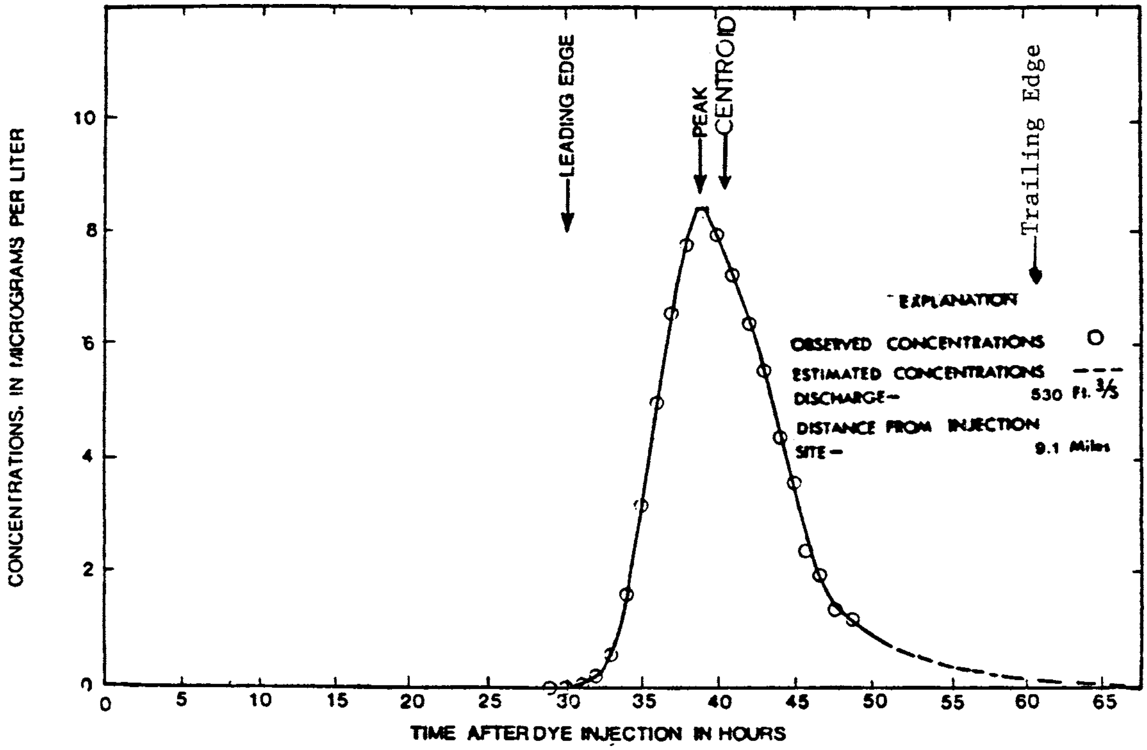

FIG. 1 Travel Time from Burnham Versus Concentration at Clinton, Maine, Sept. 18–20, 1979 (from Parker) (2)

slowest trailing edge elapsed time since injection and the earliest leading edge elapsed time since injection determined in the cross section.

5.3 *Tracers:*

5.3.1 Conservative tracers used to investigate fluid motion are generally extrinsic, artificial, and chemical substances and are usually classified according to the methods of detection used and chemical composition.

5.3.2 Properties to be considered when selecting a tracer for a study include detectability, toxicity, solubility, cost, natural background concentration, and sorption characteristics.

5.3.3 Fluorescent dye tracers such as Rhodamine WT, pontacyl pink, and acid yellow 7 are generally good chemical tracers. Rhodamine WT has the most numerous qualities preferred by many state and federal agencies for open-channel studies.

5.3.4 Other tracers can be used when water-quality or physical conditions are not suitable for the use of fluorescent dyes in a proposed study reach. These include salt-based chemical tracers such as sodium chloride, radioactive tracers such as tritium, and tracers determined with neutron activation analysis such as bromine and lithium (**3**).

5.3.5 These tracers are considered to be generally conservative and, in terms of this test method, differ primarily in the apparatus required to measure the concentrations in the study reach. Discussions in subsequent sections will be limited to fluorescent dye because of the simplicity of fluorometric analysis.

5.3.6 Different tracers require varied levels of permits before being introduced into the environment. For example, radioactive tracers require permits from the Nuclear Regulatory Commission (NRC) and usually state and local permits. Fluorescent dye tracers do not usually require formal permits for use in a study.

6. Interferences

6.1 Natural water may exhibit background fluorescence that is not the result of a fluorescent dye tracer. This background fluorescence may result from scattered light, fluorescence of natural materials or pollutants, or other causes (**4**).

6.2 The fluorescence of Rhodamine WT is stable in solutions having a pH in the range from 5 to 10, which is within the range of most streams. Rhodamine WT fluorescent decreases when in solutions having a pH below 5 (**5**).

6.3 Dye tracer fluorescence may be quenched by the action of other chemicals in the streamwater. The quenching agent may cause any of the following to occur (**6**): absorption of exciting light, absorption of light emitted by the dye, degradation of the excited-state energy, and chemically changing the fluorescent compound of the dye tracer.

6.4 The permanent reduction of Rhodamine dye tracer fluorescence can be caused by photochemical decay as a result of exposure to sunlight (**7**). Sunlight degradation half-lives for the dye at the water surface to a depth of 0.03 ft ranged from 15 to 30 days at 30° North latitude, depending on the season of the year. The degradation half-lives ranged from 15 to 44 days at 40° North latitude, depending on the season of the year. The photochemical decay half-life increases with increased water depth and decreasing light intensity; it is therefore not a concern for most practical problems.