TIME OF TRAVEL AND DISPERSION IN THE

JONES FALLS, BALTIMORE, MARYLAND

By R. W. James, Jr., and B. M. Helinsky

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4203

Towson, Maryland

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

CONVERSION OF MEASUREMENT UNITS

The following factors may be used by readers who wish to convert inch-pound units to metric (System International or SI) units.

Multiply inch-pound units	by	To obtain SI units
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Mass		
pound, avoirdupois (lb)	453.6	gram (g)
Volume		
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow		
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Miscellaneous		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

TIME OF TRAVEL AND DISPERSION IN THE

JONES FALLS, BALTIMORE, MARYLAND

By R. W. James, Jr., and B. M. Helinsky

ABSTRACT

Three dye studies were done on the Jones Falls between Lake Roland Dam and a point 4.5 miles downstream at Baltimore, Maryland. Flow during the three studies was at the 91, 40, and 14 percent flow-duration levels.

Methods were developed to predict traveltimes and concentrations resulting from a spill of a water-soluble substance into the Falls, at a relatively steady streamflow of from 10 to 60 cubic feet per second at the index gage--Jones Falls at Sorrento, Maryland. The three sets of data obtained were used to develop these methods.

A sample problem is solved for a hypothetical situation in which 100 pounds of a contaminant is spilled at a point 9 miles above the mouth of the Falls. A combination graphical and tabular solution is used to provide the user with an insight into the transport, dispersion, and dilution of a soluble material.

1

INTRODUCTION

Jones Falls below Lake Roland Dam at Baltimore, Md. (fig. 1), flows through a highly urbanized area and was the primary focus of a recent study to examine the water-quality characteristics of urban runoff in Baltimore. The Jones Falls study was one of many studies conducted throughout the country under the Nationwide Urban Runoff Program (NURP).

Although not a part of the original design of the NURP study, the project described in this report was subsequently initiated as a complementary study to satisfy a need for information on the rate of movement of the water, the longitudinal dispersive characteristics of the stream, and the dilution capacity of the flow in the Jones Falls.

The purpose of this report is to describe the transport, dispersion, and dilution of a soluble material in a 4.5-mi reach of the Jones Falls below Lake Roland Dam. Dye-tracing techniques were used to measure these properties. A total of three studies were done--one each in 1981, 1982, and 1983.

DESCRIPTION OF THE STUDY REACH

The Jones Falls (fig. 1) begins in Baltimore County about 3 mi northwest of Baltimore City. It flows in an easterly direction for approximately 4.5 mi and then turns to the south and flows into Lake Roland, which is located in Baltimore County just upstream from the Baltimore City line. From Lake Roland Dam, the Falls flows southeasterly about 10.5 mi through the city of Baltimore to the harbor, the last 1.7 mi in a tunnel. The reach selected for this study is the 4.5-mi reach below Lake Roland, which is an unregulated recreational lake.

The land use along the study reach is primarily high-density residential in the outlying areas, with light industry along the flood plain. Channel slope in the study reach averages about 18 ft/mi. The banks of the stream have been built up over the years to protect the industries situated in the flood plain. Channel width is fairly uniform with a slight tendency to narrow in the downstream direction. Due to the steep gradient of the channel, water depths are relatively shallow and ranged from 1 to 2 ft during the three studies.
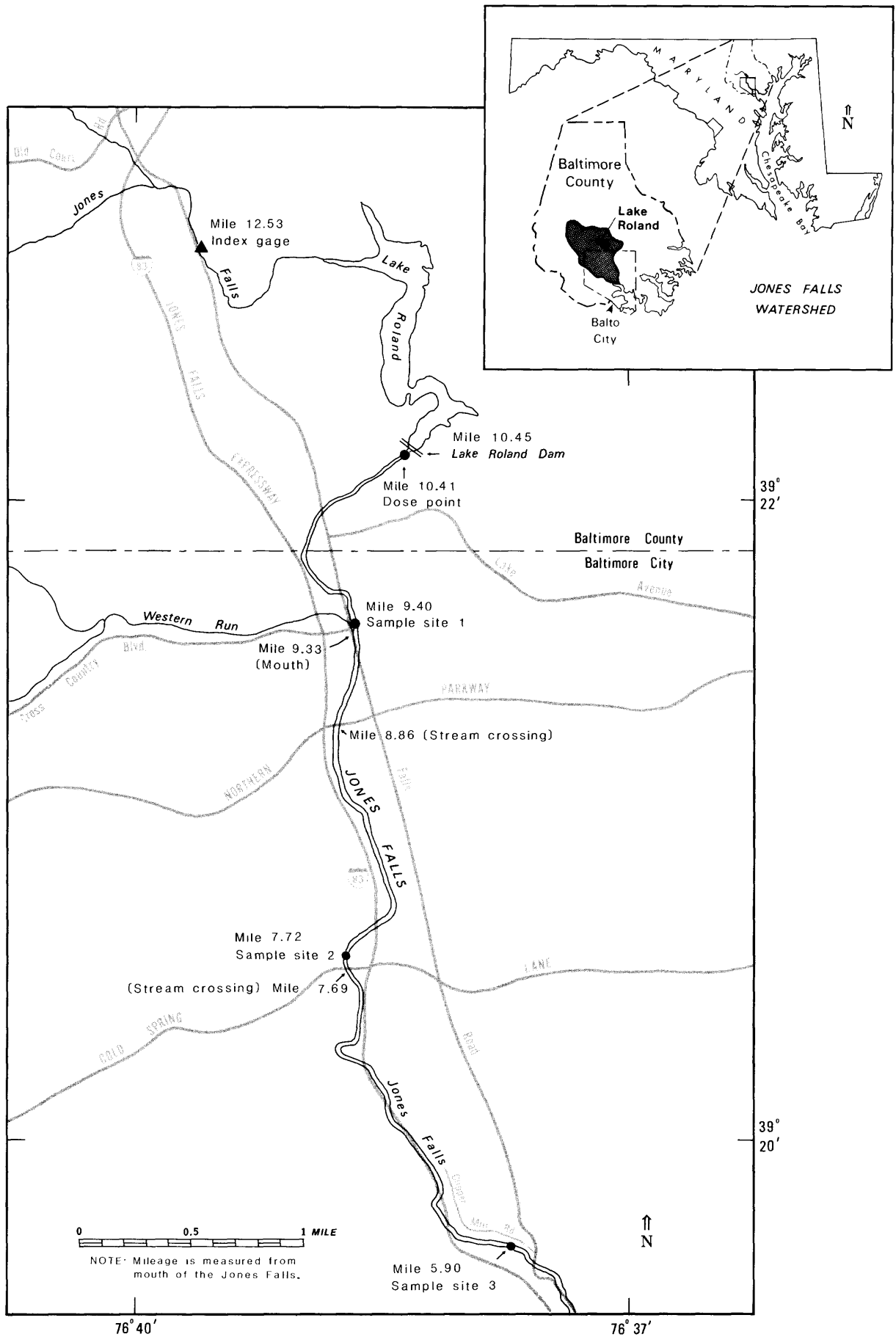
2

Figure 1.-- Location of study reach.

A U.S. Geological Survey continuous-record gaging station--Jones Falls at Sorrento--is located about 2.1 mi upstream from Lake Roland Dam. Discharge data at this gage were used as an index of flow conditions in the basin during the study.

FIELD PROCEDURES

Field procedures for conducting traveltime and dispersion studies using dye-tracing techniques have been well documented by Hubbard and others, 1982. In general, those procedures were followed in this study.

On July 17, 1981, January 5, 1982, and May 18, 1983, a fluorescent dye was injected at multiple points at the head of the study reach below Lake Roland Dam. Once vertical and lateral mixing was complete (Yotsukura and Cobb, 1972; Fischer and others, 1979), the dye cloud was sampled at the midpoint of the stream at three locations (fig. 1) as it moved downstream through the study reach. A fluorometer was used at each site to measure the relative fluorescence of each sample. The rate of change of relative fluorescence was used to select the sampling frequency necessary to define the time-concentration curve at each site. Sampling included background samples prior to arrival of the dye, and sampling was continued until dye concentrations dropped to 10 percent of the measured peak fluorescence. All field samples were retained for final processing in the office. Definition of the time-concentration curves obtained during each study is considered excellent.

Flows at the index station for the three studies were 10.7 ft^3/s for the 1981 study, 29.5 ft^3/s for the 1982 study, and 50.2 ft^3/s for the 1983 study. These flows were at the levels that have historically been exceeded 91, 40, and 14 percent of the time, respectively. Thus, the three studies cover a large range of the flows expected on the Jones Falls.

Discharge measurements were made at each sampling site during each of the three studies. The measurements were made using standard U.S. Geological Survey procedures (Buchanan and Somer, 1969). Discharge data at the sampling sites were necessary for several calculations and are explained in the following section.

DATA ANALYSIS

Traveltimes

Samples collected in the field were returned to the office where dye concentrations were determined using a fluorometer. Sample temperatures were controlled by use of a circulating water bath. The fluorometer was calibrated using standard solutions prepared from the same dye lots used in the studies.

For each sampling site, the observed dye concentrations (C_{obs}) were plotted versus elapsed time since injection of the dye. Figures 2, 3, and 4 show the observed and conservative time-concentration curves for the July 17, 1981, January 5, 1982, and May 18, 1983 studies, respectively. The conservative (C_{con}) curves represent the concentrations that would have been obtained had the tracer been conservative. A tracer is conservative if the recovered weight at a downstream point is equal to the weight of the tracer injected upstream. The dye used in this study is not conservative. However, the ratio of the amount of dye passing a sampling point to the amount of dye injected can be used to adjust the curve to represent a conservative tracer. For rhodamine WT dye (20-percent solution) having a specific gravity of 1.19, this recovery ratio (R_R) can be computed by the following formula:

$$R_R = 0.000428 \frac{QA_c}{V} \tag{1}$$

where

R_R = recovery ratio;

Q = discharge at the point of sampling, in cubic feet per second;

A_c = area of the time-concentration curve, in micrograms per liter times hours; and
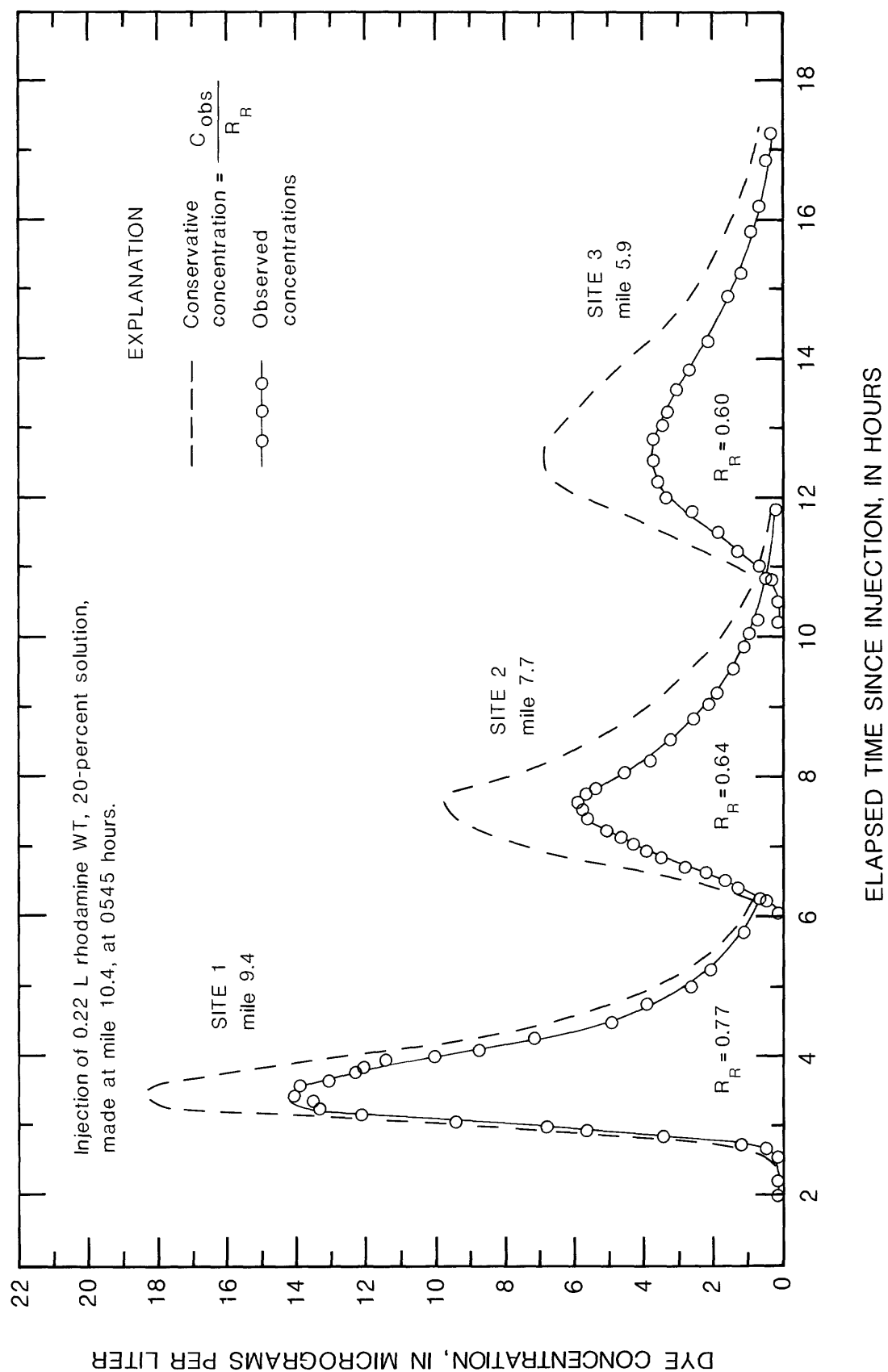
V = volume of dye solution, in liters.

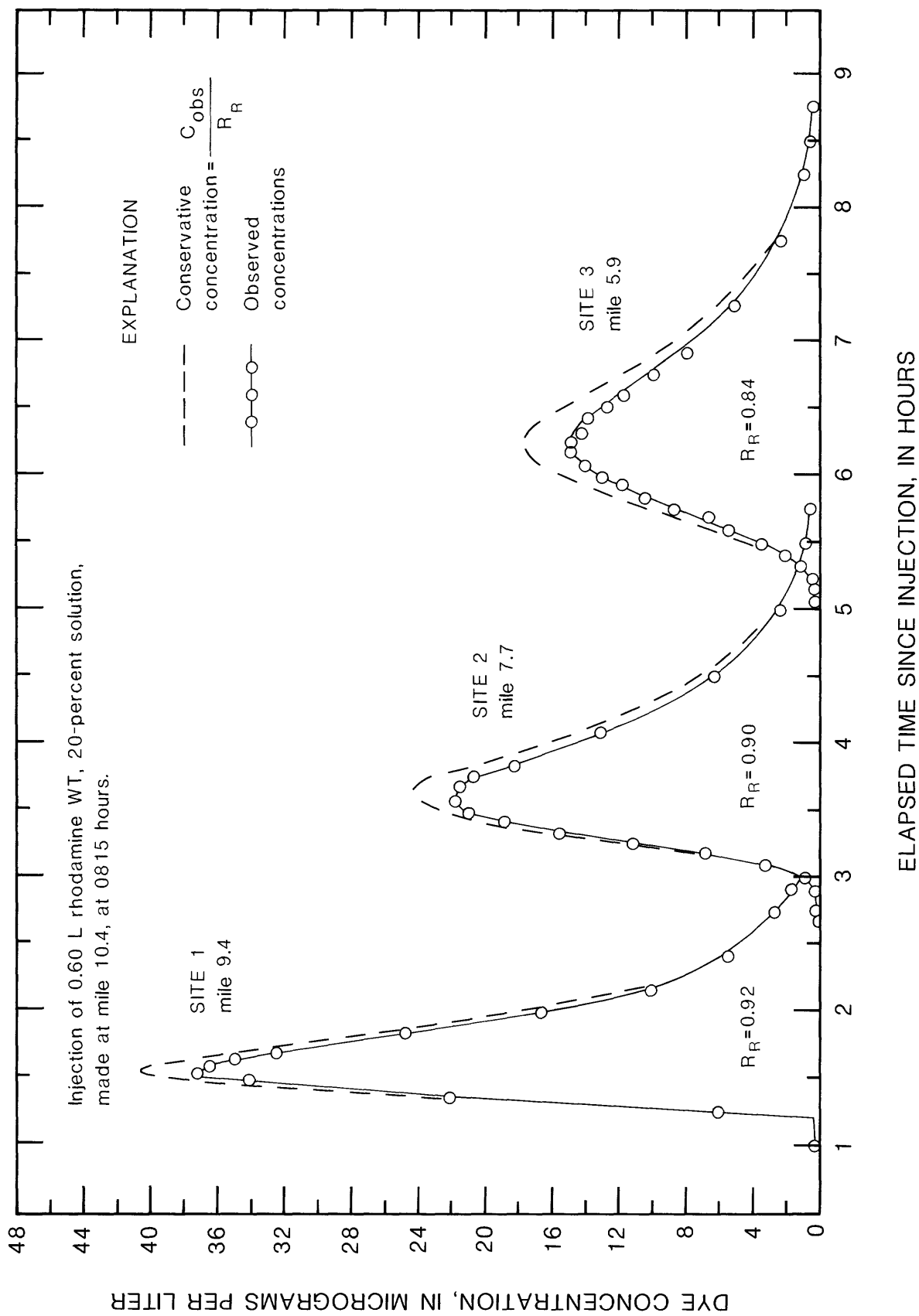Figure 2.-- Observed and conservative time-concentration curves for the July 17, 1981 study.

6

Figure 3.-- Observed and conservative time-concentration curves for the January 5, 1982 study.
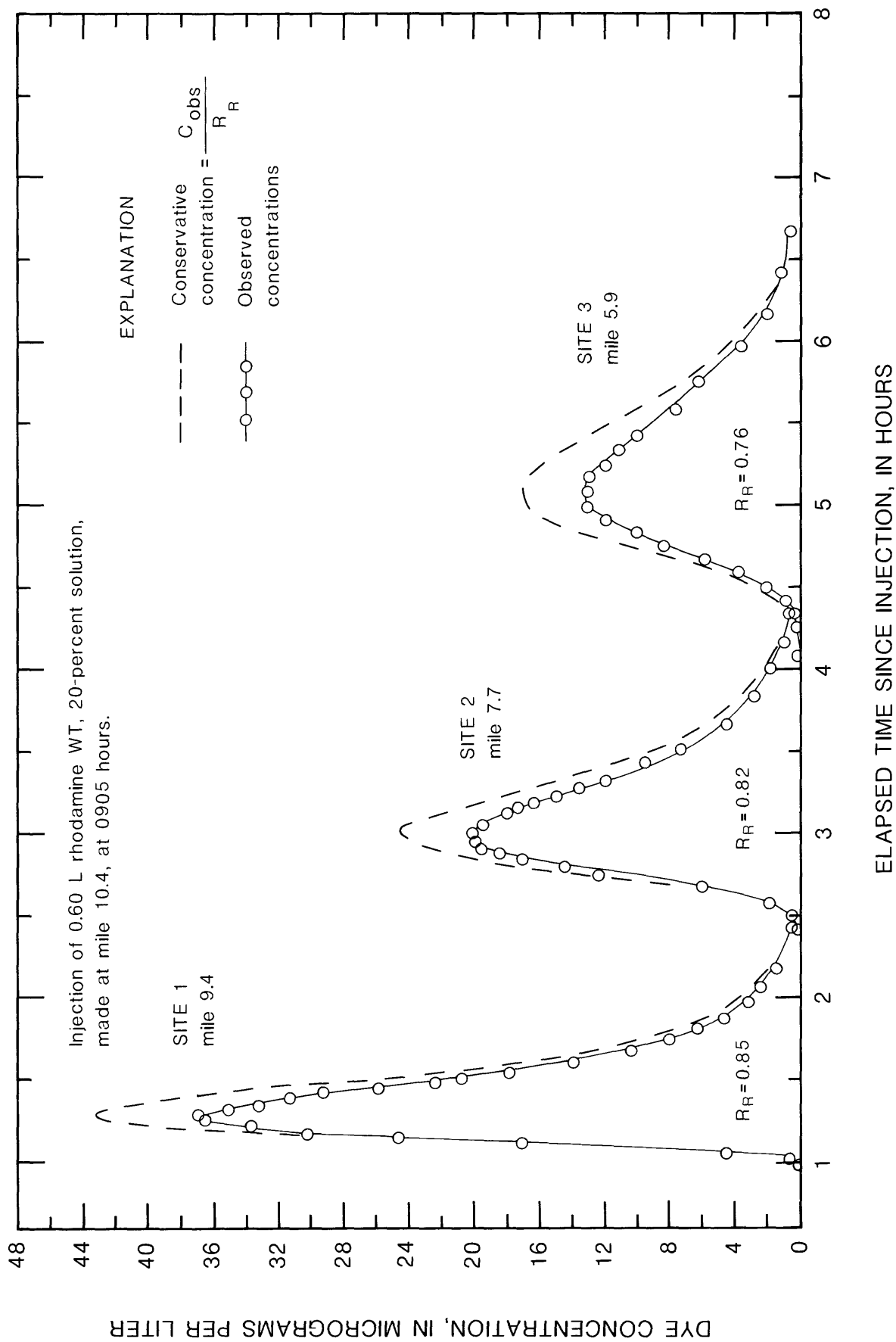
Figure 4.-- Observed and conservative time-concentration curves for the May 18, 1983 study

8

Using the time-concentration curve for each sampling site, the traveltime of the leading edge, peak, and trailing edge of the dye cloud was determined. The trailing edge of the dye cloud, as used in this report, is defined as the time after the peak at which the dye concentration is 10 percent of the peak concentration at a sampling site. Table 1 gives the sampling sites, traveltimes, and other pertinent data for the three studies.

The traveltime data summarized in table 1 are presented graphically in figure 5 for each of the three studies. Figure 5 shows that traveltime is inversely related to the discharge in the river (traveltimes are longer at lower river discharge). In order to generalize the traveltime data from the three studies into a relation covering a range of river discharges, traveltimes between sites were converted to velocities and plotted against the discharge at the index gage at the time of the study. Figure 6 shows the velocity-index discharge relations developed for the three subreaches.

From figure 6, velocities at selected discharges at the index gage were determined for each of the three subreaches. Traveltimes for each subreach for the selected discharge were computed by dividing the subreach length by the corresponding velocity. These traveltimes were accumulated for each of the three subreaches at each selected discharge. Table 2 presents the traveltime data computed for the leading edge, peak, and trailing edge at 11 selected discharges at the index gage. Traveltime of the trailing edge may be affected by the initial dispersive effects and the truncation at 10 percent of the peak concentration. Therefore, traveltimes for the trailing edge should be considered as a good estimate of the expected pattern. Figures 7, 8, and 9 show these traveltime-distance relations for selected discharges at the index gage. The selected discharges range in flow from 10 to 60 ft^3/s, which covers a range in flow duration from 92 to 9.6 percent.

Dispersion

In addition to providing information on traveltimes, dye studies can provide considerable insight into the ability of a stream to disperse and dilute a slug of soluble material that is spilled into the stream. As soon as the soluble substance

9

Table 1.--Traveltime, dispersion, and related data from the dye studies of July 1981, January 1982, and May 1983 on the Jones Falls, Maryland

Site No.	Distance — Upstream from mouth (mi)	Distance — Sub-reach length (mi)	Distance — From point of injection (mi)	Leading edge (LE) — Time since injection (h)	LE — Travel-time between sites (h)	LE — Velocity between sites (mi/h)	Peak concentration (C_p) — Time since injection (h)	Peak — Travel-time between sites (h)	Peak — Velocity between sites (mi/h)	Trailing edge (TE) at 0.1 C_p — Time since injection (h)	TE — Travel-time between sites (h)	TE — Velocity between sites (mi/h)	Discharge at site, Q (ft^3/s)	Observed peak concentration, C ($\mu g/L$)	Calculated dye recovery, R_R (percent)	Conservative peak concentration, $C_p(con)$ ($\mu g/L$)	Unit peak concentration, C_{up} [1]	Time of passage of dye cloud (h)
						July 17, 1981												
				Injected 0.22 liters of 20-percent rhodamine WT dye at mile 10.4 at 0545. Index gage discharge: 10.7 ft^3/s.														
0	10.4	-	0	0	-	-	0	-	-	0	-	-	17.0	-	-	-	-	-
1	9.4	1.0	1.0	2.5	2.5	0.40	3.4	3.4	0.29	5.6	5.6	0.18	18.0	14.1	77	18.3	2,860	3.1
2	7.7	1.7	2.7	6.0	3.5	0.49	7.6	4.2	0.40	10.6	5.0	0.34	22.8	6.0	64	9.4	1,860	4.6
3	5.9	1.8	4.5	10.3	4.3	0.42	12.6	5.0	0.36	16.7	6.1	0.29	24.6	3.8	60	6.3	1,350	6.4
						January 5, 1982												
				Injected 0.60 liters of 20-percent rhodamine WT dye at mile 10.4 at 0815. Index gage discharge: 29.5 ft^3/s.														
0	10.4	-	0	0	-	-	0	-	-	0	-	-	51.9	-	-	-	-	-
1	9.4	1.0	1.0	1.20	1.20	0.83	1.55	1.55	0.64	2.6	2.6	0.38	51.1	37.4	92	40.7	6,620	1.40
2	7.7	1.7	2.7	2.95	1.75	0.97	3.60	2.05	0.83	5.1	2.5	0.68	55.9	21.9	90	24.3	4,320	2.15
3	5.9	1.8	4.5	5.15	2.20	0.82	6.20	2.60	0.69	8.1	3.0	0.60	56.1	14.9	84	17.7	3,160	2.95
						May 18, 1983												
				Injected 0.60 liters of 20-percent rhodamine WT dye at mile 10.4 at 0905. Index gage discharge: 50.2 ft^3/s.														
0	10.4	-	0	0	-	-	0	-	-	0	-	-	71.8	-	-	-	-	-
1	9.4	1.0	1.0	0.96	0.96	1.04	1.26	1.26	0.79	1.96	1.96	0.51	74.0	36.9	85	43.4	10,200	1.00
2	7.7	1.7	2.7	2.43	1.47	1.16	3.00	1.74	0.98	4.00	2.04	0.83	81.1	20.0	82	24.4	6,290	1.57
3	5.9	1.8	4.5	4.30	1.87	0.96	5.10	2.10	0.86	6.40	2.40	0.75	80.0	12.9	76	17.0	4,330	2.10

[1] $C_{up} = \dfrac{C_{p(con)} Q}{w_d}$, in micrograms per liter times cubic feet per second per pound.
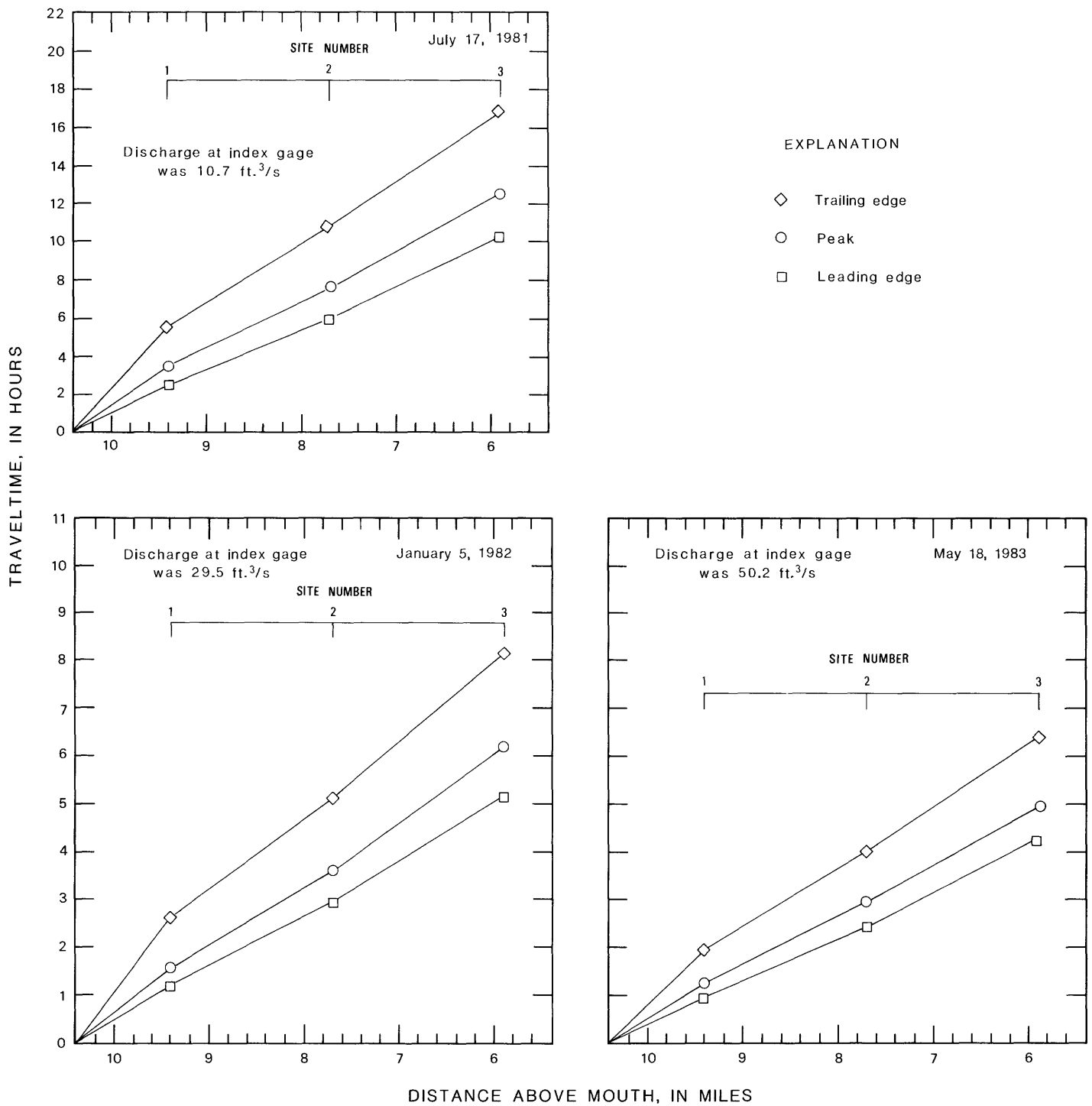
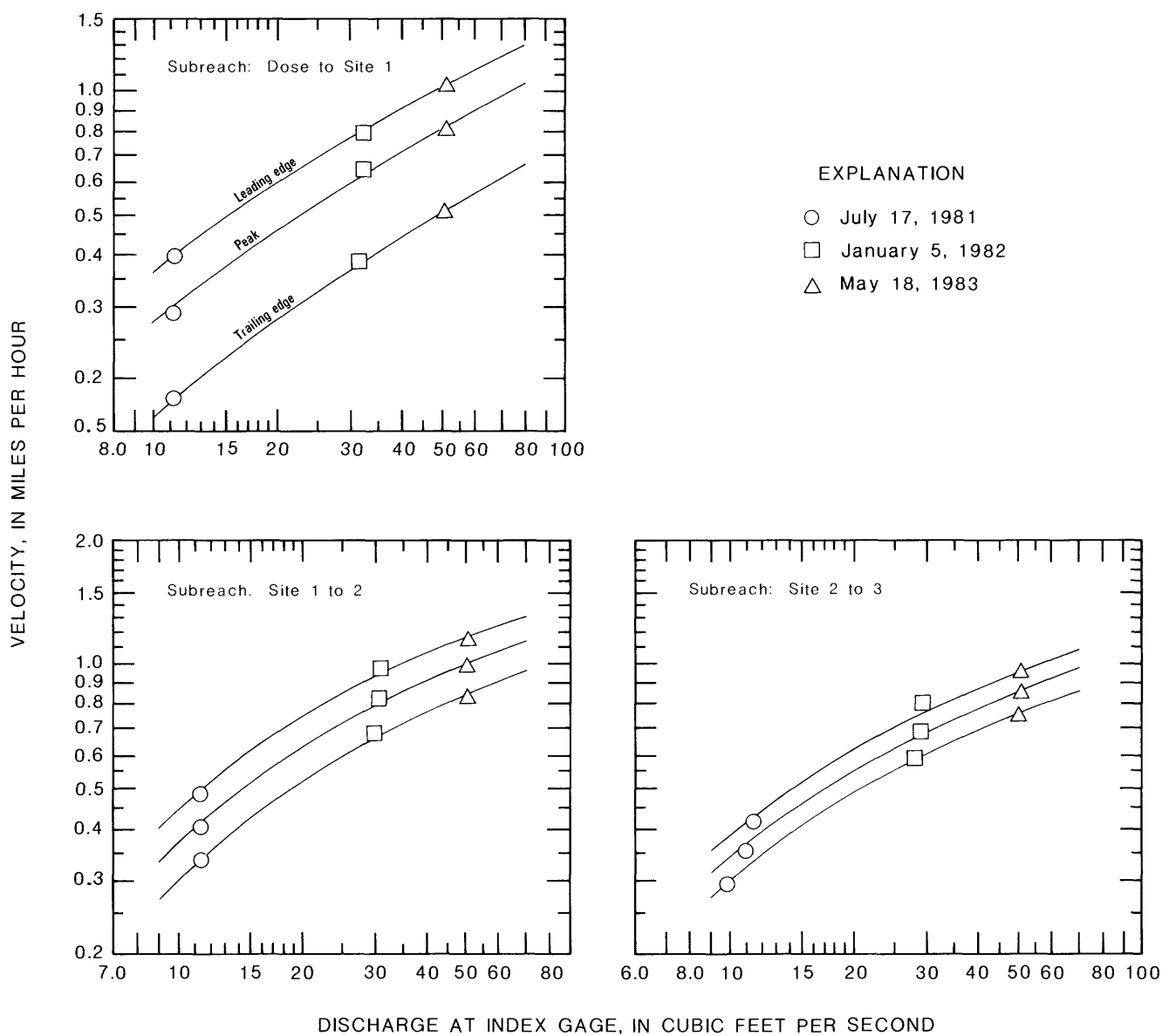Figure 5.-- Relation between traveltime and distance.

Figure 6.-- Relation between velocity in subreach and discharge at the index gage.

12

Table 2.--Traveltimes for leading edge, peak concentration, and trailing edge of dye cloud for selected discharges at the index gage

| Site No.	Miles upstream from mouth	Sub-reach length (miles)	Traveltime of dye cloud, in hours, for indicated discharges, in cubic feet per second										
			10	12	14	16	18	20	25	30	40	50	60
LEADING EDGE													
0	10.4	-	-	-	-	-	-	-	-	-	-	-	-
1	9.4	1.0	2.74	2.33	2.13	1.94	1.79	1.67	1.45	1.28	1.10	0.97	0.88
2	7.7	1.7	6.56	5.60	5.01	4.56	4.22	3.94	3.43	3.09	2.69	2.44	2.24
3	5.9	1.8	11.24	9.64	8.61	7.83	7.25	6.80	5.97	5.40	4.76	4.32	3.99
PEAK CONCENTRATION													
0	10.4	-	-	-	-	-	-	-	-	-	-	-	-
1	9.4	1.0	3.64	3.13	2.78	2.53	2.33	2.17	1.87	1.67	1.41	1.23	1.12
2	7.7	1.7	8.23	7.04	6.25	5.68	5.21	4.87	4.23	3.80	3.26	2.91	2.69
3	5.9	1.8	13.45	11.54	10.29	9.39	8.64	8.08	7.09	6.41	5.54	5.00	4.63
TRAILING EDGE													
0	10.4	-	-	-	-	-	-	-	-	-	-	-	-
1	9.4	1.0	6.25	5.32	4.69	4.22	3.89	3.57	3.08	2.70	2.25	1.98	1.79
2	7.7	1.7	11.92	10.04	8.89	8.00	7.26	6.81	5.90	5.24	4.46	3.98	3.66
3	5.9	1.8	17.92	15.18	13.51	12.19	11.13	10.48	9.11	8.17	7.03	6.35	5.88
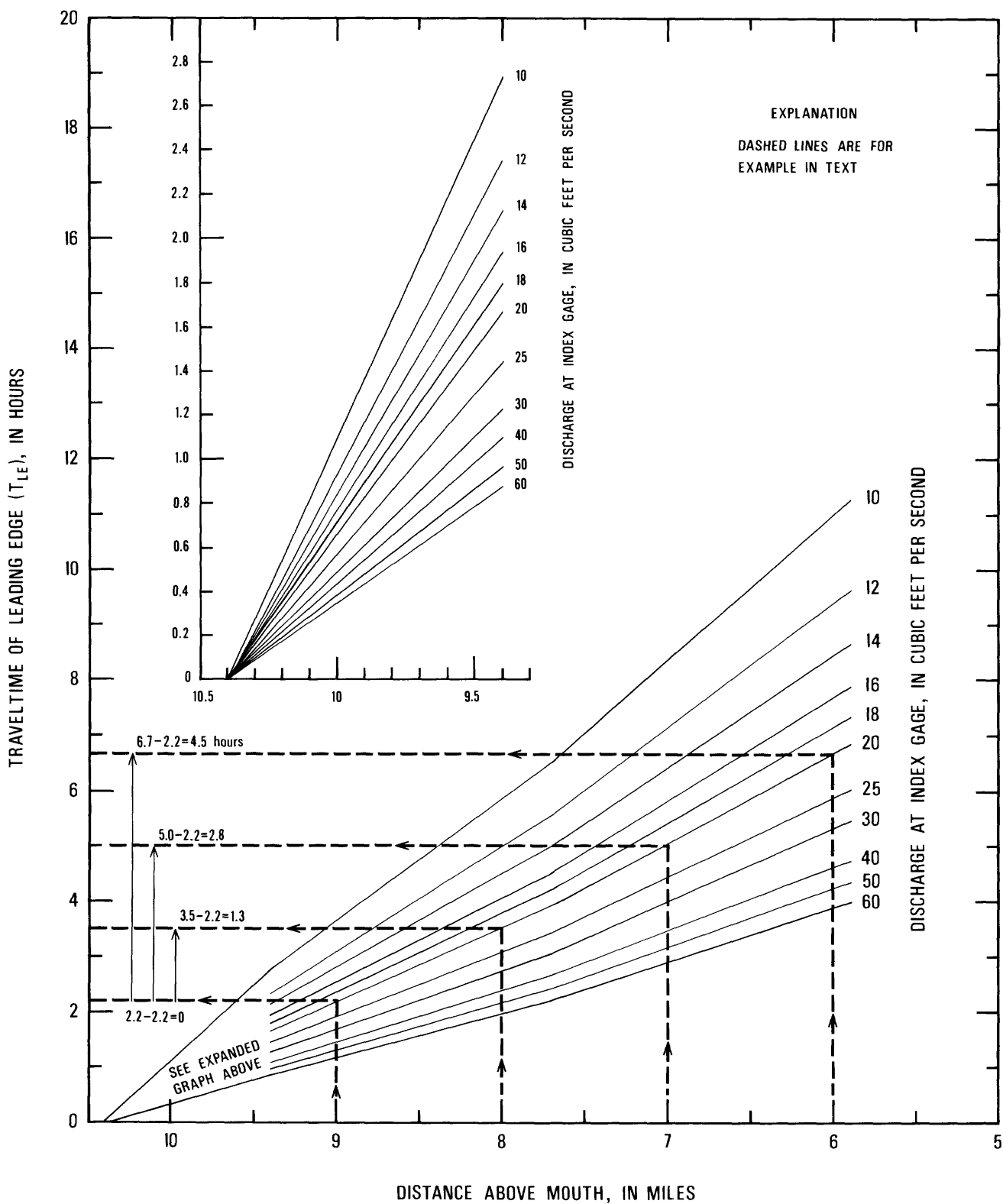
Figure 7.-- Relation among traveltime, distance , and selected discharges at index gage for leading edge of the dye cloud.
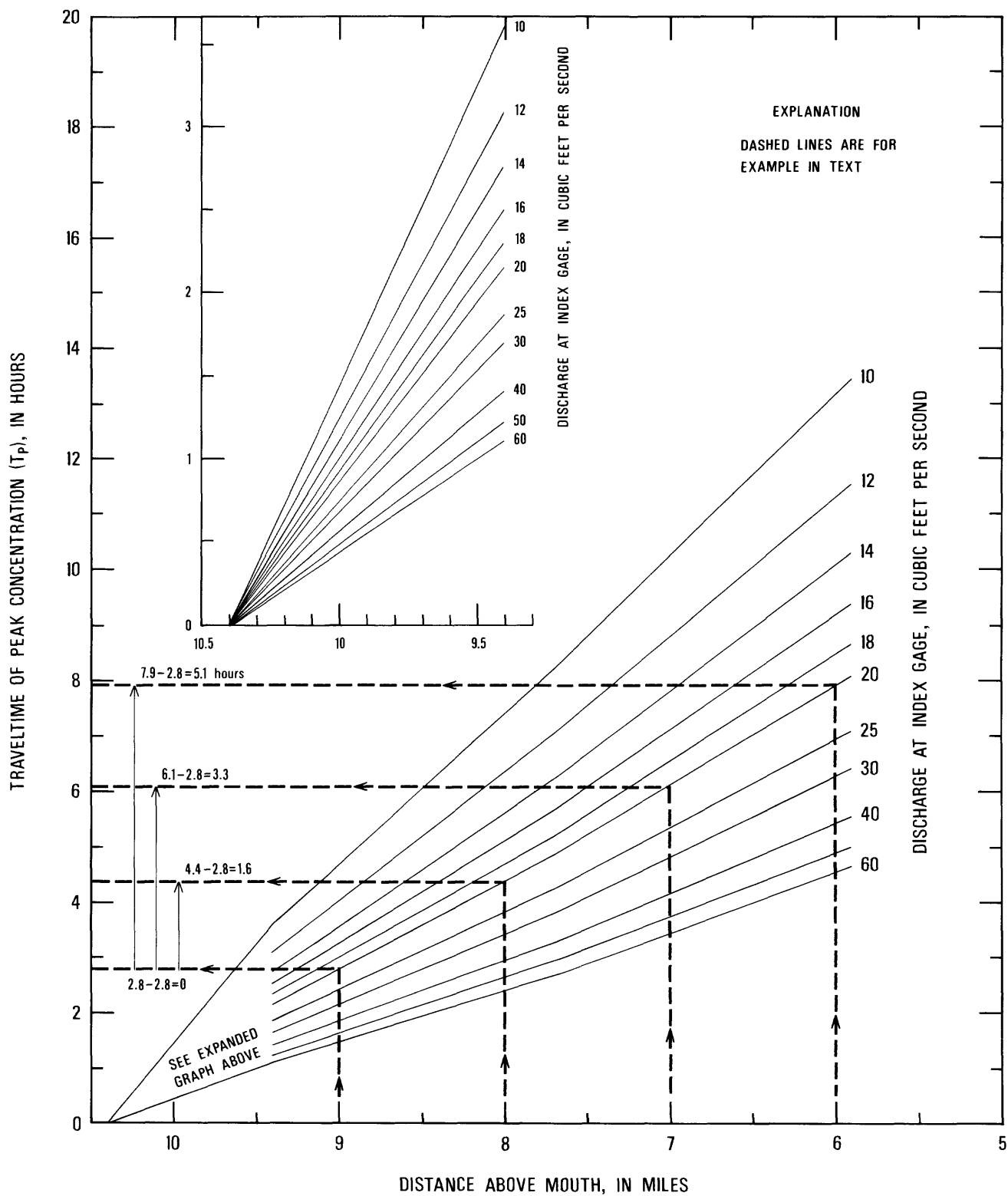
14

Figure 8.-- Relation among traveltime, distance , and selected discharges at index gage for peak concentration of the dye cloud.
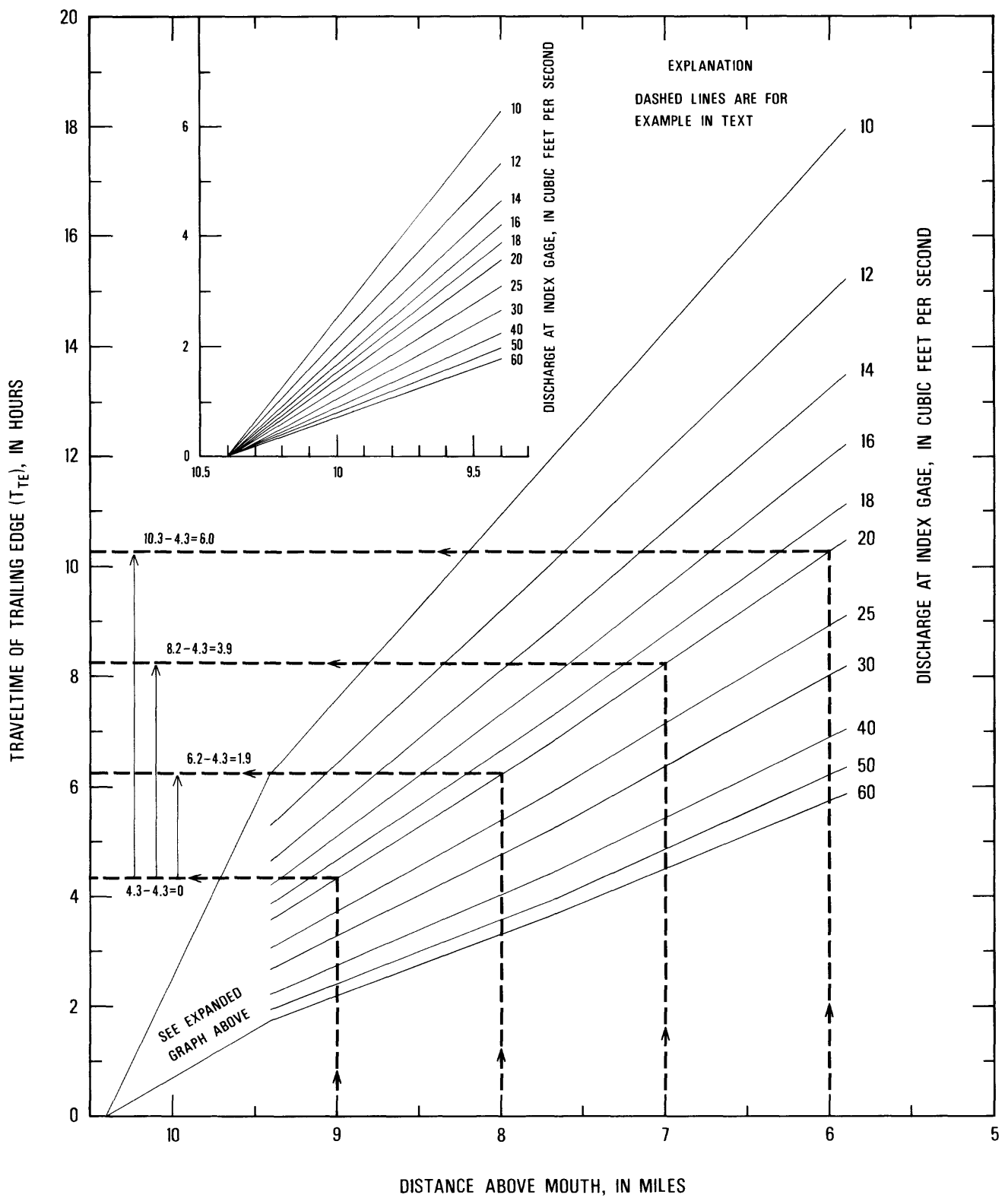
Figure 9.-- Relation among traveltime, distance, and selected discharges at index gage for trailing edge of the dye cloud.

16

is spilled into the stream, it begins to disperse vertically, laterally, and longitudinally as it moves downstream with the flowing water. In a small stream like the Jones Falls, complete vertical and lateral mixing are accomplished within a relatively short distance downstream from the spill or injection site. Longitudinal mixing, or lengthening of a cloud in time, is a continuous process because the cloud has no definable physical boundaries.

To illustrate the concept of longitudinal dispersion, figures 2, 3, and 4 show that the peak concentration is lower and the time for the dye cloud to pass is longer at each successive downstream sampling point. Figure 5 shows that, for the July 17, 1981 study, the time required for the dye cloud to pass mile 8 was 4.5 hours; therefore, the dye is mixing in all the water that flows past mile 8 during those 4.5 hours. This illustration also shows that 8 hours after the injection, the dye is mixing in all the water in a 1.7-mi reach of river. However, the concentration of the dye-water mixture is not uniform during either the 4.5-hour passage time at mile 8, or at any point over the 1.7-mi reach.

F. A. Kilpatrick (in Hubbard and others, 1982) developed the concept of unit peak concentration as a measure of the longitudinal dispersive characteristics of a stream. Unit peak concentration can be defined as the peak concentration produced by one unit weight of conservative solute in one unit of flow rate. Unit peak concentration (C_{up}) can be formulated as:

$$C_{up} = \frac{C_{p(con)}Q}{W_d} \qquad (2)$$

where

C_{up} = unit peak concentration;

$C_{p(con)}$ = conservative peak concentration of the time-concentration curve, in micrograms per liter;

Q = discharge at the sampling site, in cubic feet per second; and

W_d = weight of pure dye injected, in pounds.

The calculation of unit peak concentration by equation 2 requires that the observed peak concentration at a sample site be adjusted to a conservative peak concentration as was discussed earlier in the report. After unit peak concentration values are computed from observations of dye dispersion in a study, equation 2 can be rearranged to calculate the conservative peak concentration of a conservative soluble contaminant spilled into the stream. The rearranged equation is:

$$C_{p(con)} = \frac{C_{up} W_s}{Q} \tag{3}$$

where

W_s = weight of the spilled substance.

The unit peak-concentration values determined for the three studies on the Jones Falls are plotted as a function of the traveltimes of the peak concentrations in figure 10. This illustration shows that unit peak concentration is inversely related to the traveltime of the peak and directly related to the discharge in the stream. The slope of the lines in figure 10 is a measure of the dispersive capability of the stream. For inbank discharges, the slope of the lines for each study would be approximately parallel if the channel throughout the reach is fairly uniform with regard to geometry and roughness. A steeper slope would indicate more dispersive capability. The data in figure 11 were interpolated and extrapolated from figure 10 to cover a range of selected discharges at the index gage.

The use of equation 3 requires knowledge of the flow in the stream at the point of interest. As this information is not readily available at all points along the stream, the discharge measurements made at the sampling points during the three studies were related to the discharge at the index gage. These relations were generalized to provide a method for estimating discharge at any point along the stream if the discharge is known at the index gage. The relation between discharge at the index gage and discharge at selected mile points upstream from the mouth is shown in figure 12. This relation is an approximation and is only applicable during non-storm flow conditions similar to those observed.
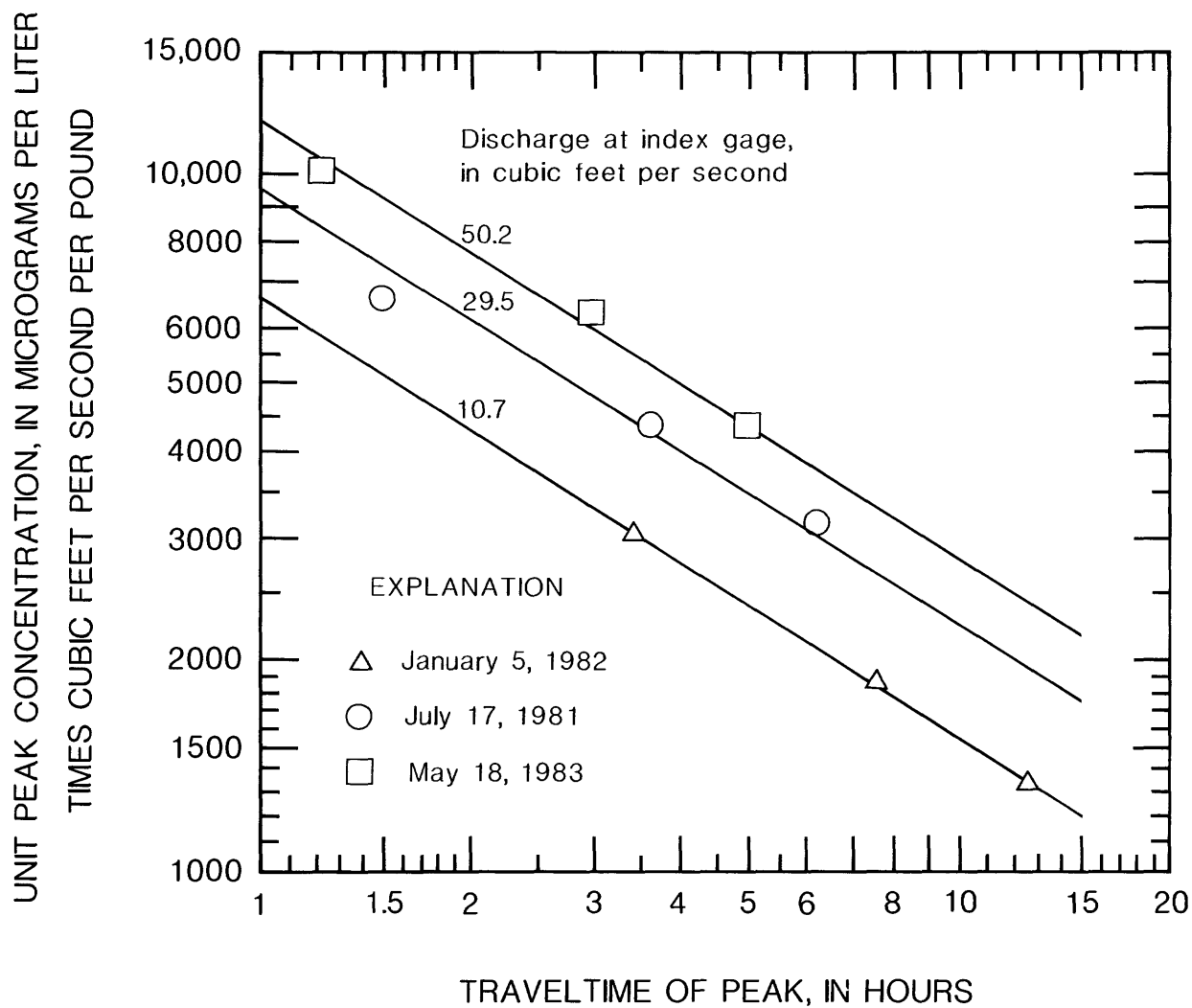
18

Figure 10.-- Relation between unit peak concentration and traveltime of peak concentration for three studies.
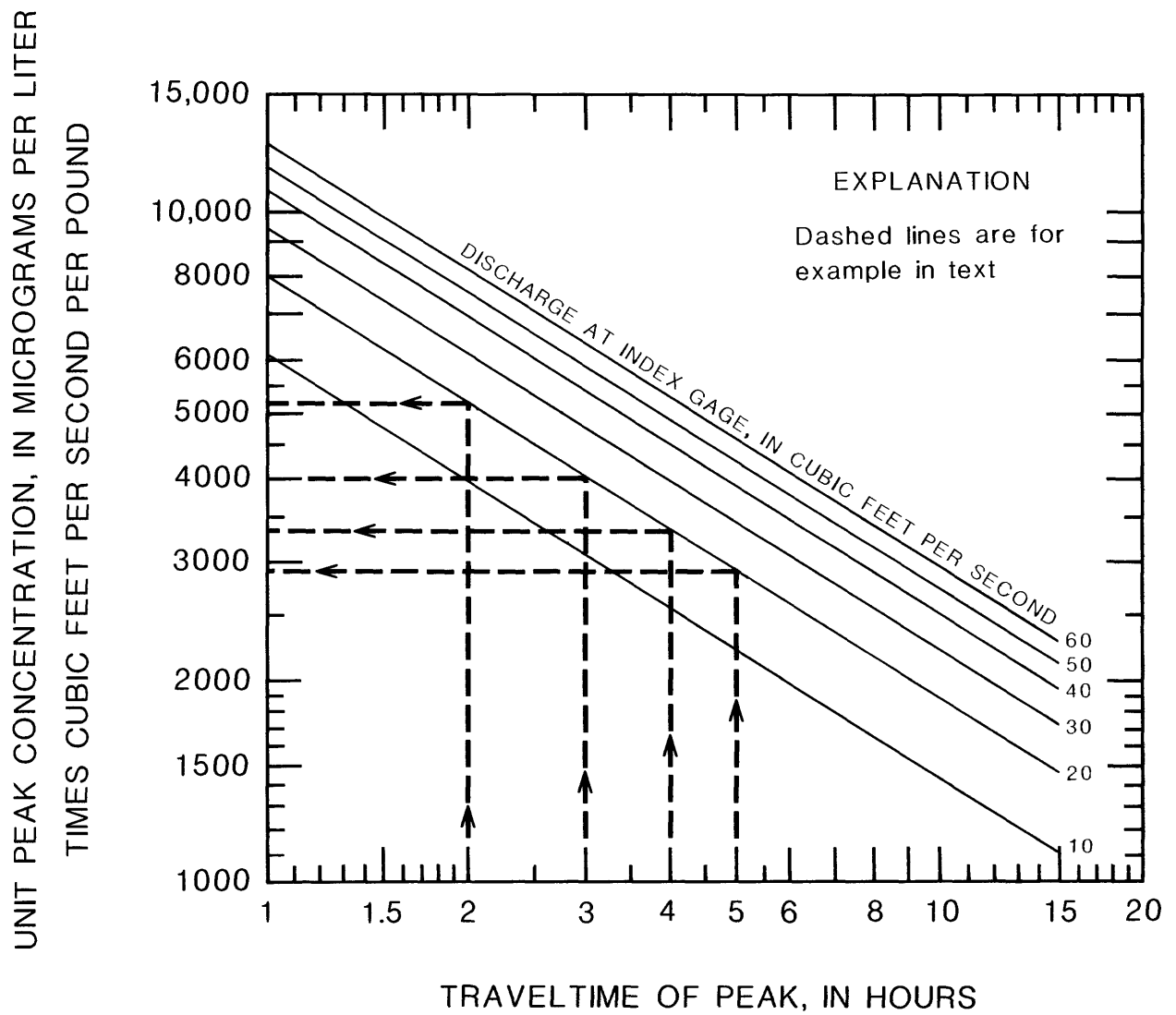
Figure 11.-- Relation between unit peak concentration and traveltime of peak concentration for selected discharges at the index gage.
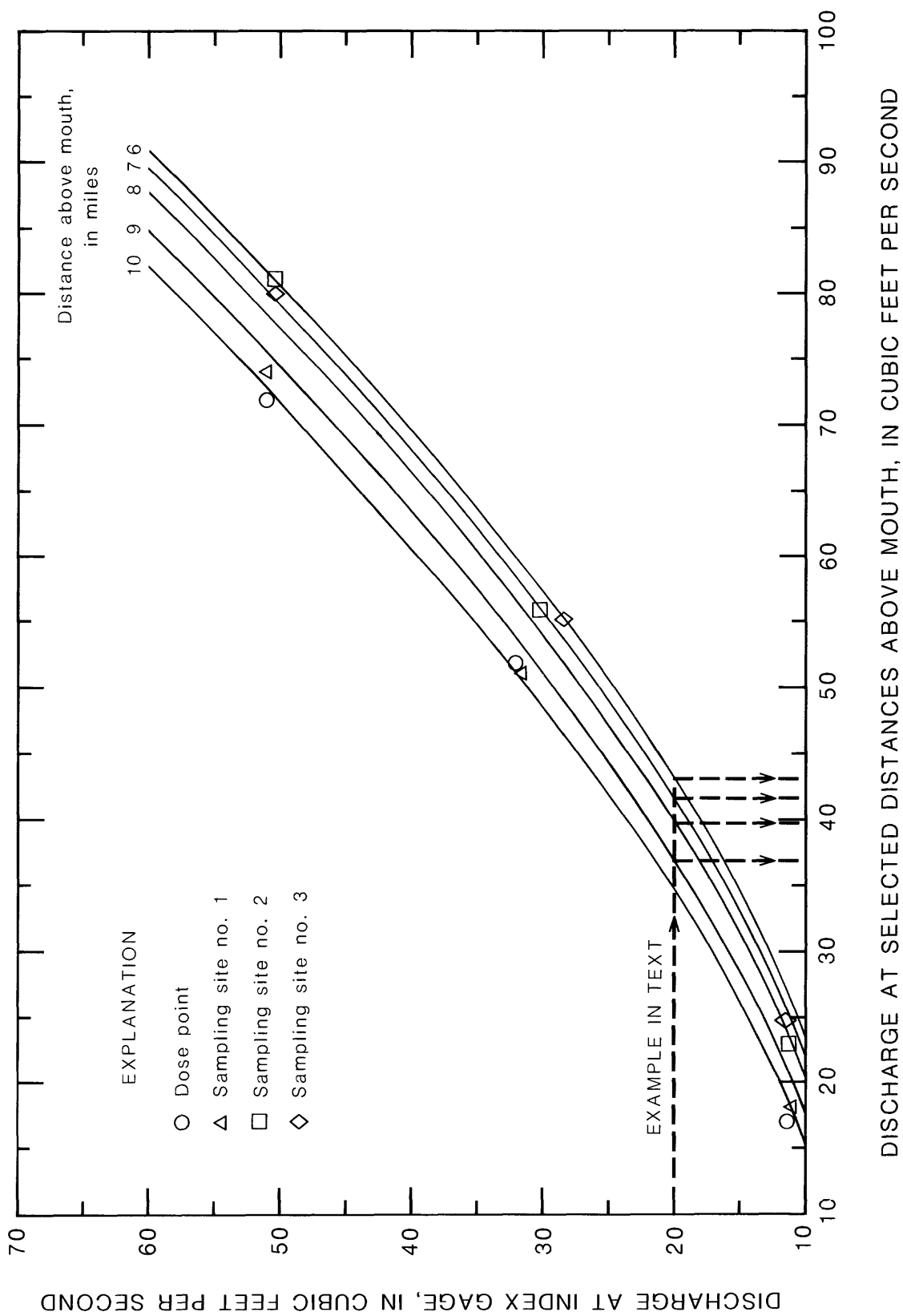
Figure 12.-- Relation between discharge at index gage and discharge at selected distances upstream from the mouth.
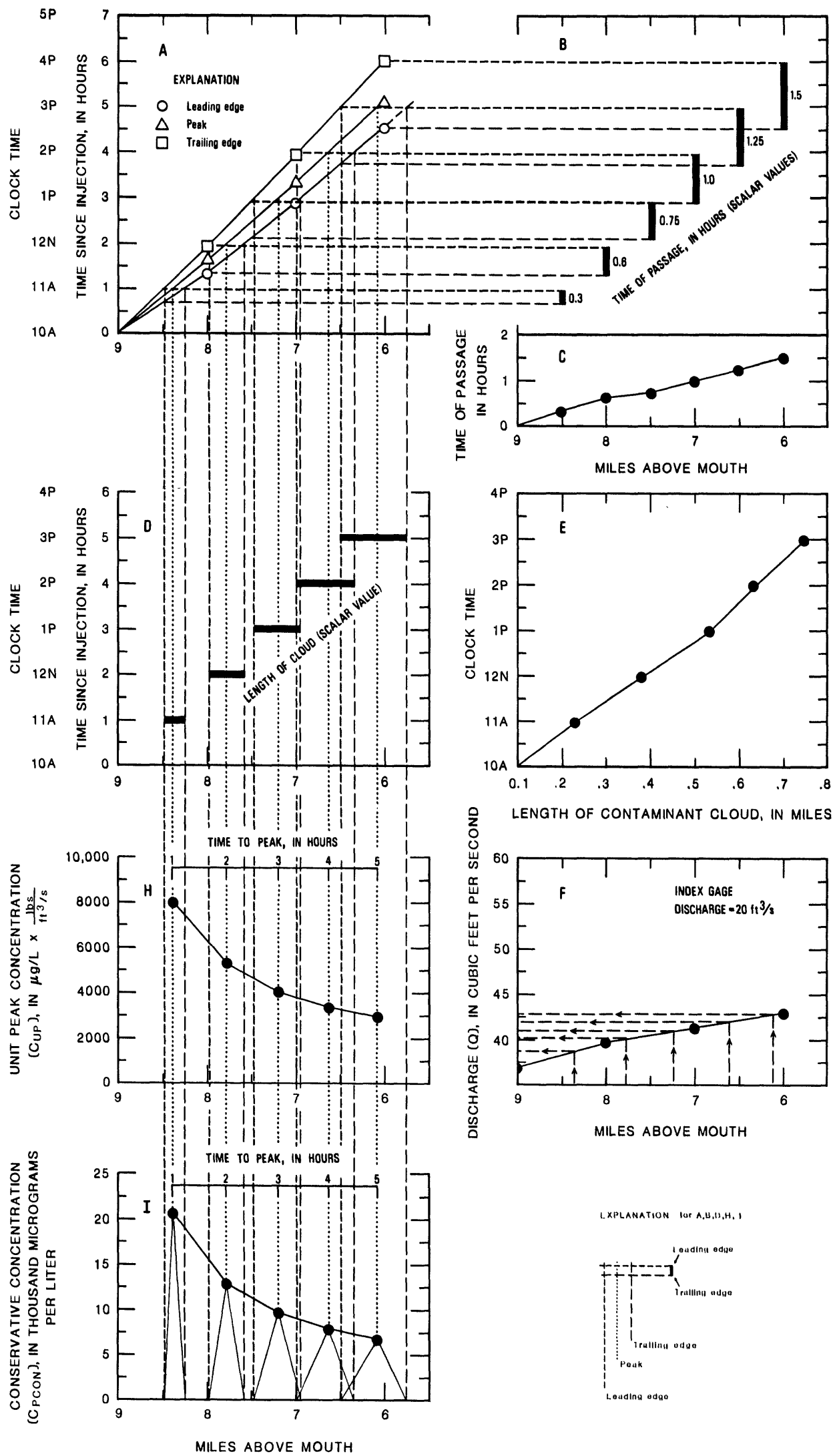
21

USE OF DATA

Example Problem

The stated purpose of this study was to describe the transport, dispersion, and dilution of a soluble material that might be introduced into the stream. The application of the results of this study can best be demonstrated by solving a sample problem. Assume, for example, 100 pounds of a conservative water-soluble substance was spilled into the Jones Falls at 10 a.m., at a point 9 mi upstream from the mouth. A further assumption is that the flow at the index gage at the time of the spill is steady at the rate of 20 ft^3/s. The problem is to describe the behavior of the contaminant as it moves downstream through the study reach.

Most of the questions one might want answered about the described problem would be related to time, distance, and/or concentration. Each of the above parameters is constantly changing after the time of the spill (Time = 0 = 10 a.m.). The user could make the calculations necessary to answer almost any question relating to time, distance, and/or concentration using the illustrations given in the report. However, the calculations and bookkeeping might become somewhat tedious and confusing.

In order to solve the problem in a way that will provide the user insight into what is happening, a combination graphical and tabular solution is used (see fig. 13).

The first step in the solution of the problem is to determine the traveltimes of the leading edge (T_{LE}), peak (T_p), and trailing edge (T_{TE}) of the contaminant cloud as it moves downstream. This can be accomplished by initializing (set equal to zero) the traveltimes in figures 7, 8, and 9 to the conditions of the problem—that is, T_{LE}, T_p, T_{TE} = 0 at mile 9 (point of spill); figure 7 is used to initialize the traveltimes for the leading edge. Determine the traveltimes at miles 9, 8, 7, and 6, using the line for a discharge of 20 ft^3/s at the index gage. Subtract from each of these values the value determined for mile 9. Table 3 shows the complete set of calculations necessary to initialize T_{LE}, T_p, and T_{TE} to zero at mile 9 for the hypothetical spill. Plot the initialized traveltimes for the leading edge, peak, and trailing edge versus river miles upstream from mouth as shown in figure 13A. This graph is similar to the ones shown in figure 5 for the dye studies. For convenience, times are shown both in clock time and time since the spill $(T_o = 10$ a.m.).

22

A

EXPLANATION

○ Leading edge
△ Peak
□ Trailing edge

B

TIME OF PASSAGE, IN HOURS (SCALAR VALUES)

1.5
1.25
1.0
0.75
0.6
0.3

CLOCK TIME — TIME SINCE INJECTION, IN HOURS

C

TIME OF PASSAGE IN HOURS

MILES ABOVE MOUTH

D

LENGTH OF CLOUD (SCALAR VALUE)

CLOCK TIME — TIME SINCE INJECTION, IN HOURS

E

CLOCK TIME

LENGTH OF CONTAMINANT CLOUD, IN MILES

H

TIME TO PEAK, IN HOURS

UNIT PEAK CONCENTRATION (C_{up}), IN $\mu g/L \times \frac{lbs}{ft^3/s}$

F

INDEX GAGE
DISCHARGE = 20 ft³/s

DISCHARGE (Q), IN CUBIC FEET PER SECOND

MILES ABOVE MOUTH

I

TIME TO PEAK, IN HOURS

CONSERVATIVE CONCENTRATION (C_{Pcon}), IN THOUSAND MICROGRAMS PER LITER

MILES ABOVE MOUTH

EXPLANATION for A,B,D,H, I

Leading edge
Trailing edge
Trailing edge
Peak
Leading edge

Location of peak (River mile)	Time to peak (H)	Unit peak Concentration (μg/L/lb/ft³/s)	Discharge (ft³/s)	Weight of Contaminant (lb)	Conservative Concentration Peak (μg/L)
8.35	1.0	8,000	38.8	100	20,600
7.75	2.0	5,200	40.4	100	12,900
7.2	3.0	4,000	41.0	100	9,760
6.6	4.0	3,350	42.0	100	7,980
6.1	5.0	2,950	42.8	100	6,890

$$C_{p(con)} = \frac{C_{up} W_s}{Q}$$

23 (p. 25 follows)

Figure 13.--Steps in solution of example problem.

Table 3.—Calculations to initialize traveltimes for sample problem

LEADING EDGE (use fig. 7)

$$T_{LE(mile\ 9)} = T_{LE(mile\ 9)} - T_{LE(mile\ 9)} = 2.2 - 2.2 = 0$$

$$T_{LE(mile\ 8)} = T_{LE(mile\ 8)} - T_{LE(mile\ 9)} = 3.5 - 2.2 = 1.3$$

$$T_{LE(mile\ 7)} = T_{LE(mile\ 7)} - T_{LE(mile\ 9)} = 5.0 - 2.2 = 2.8$$

$$T_{LE(mile\ 6)} = T_{LE(mile\ 6)} - T_{LE(mile\ 9)} = 6.7 - 2.2 = 4.5$$

PEAK (use fig. 8)

$$T_{P(mile\ 9)} = T_{P(mile\ 9)} - T_{P(mile\ 9)} = 2.8 - 2.8 = 0$$

$$T_{P(mile\ 8)} = T_{P(mile\ 8)} - T_{P(mile\ 9)} = 4.4 - 2.8 = 1.6$$

$$T_{P(mile\ 7)} = T_{P(mile\ 7)} - T_{P(mile\ 9)} = 6.1 - 2.8 = 3.3$$

$$T_{P(mile\ 6)} = T_{P(mile\ 6)} - T_{P(mile\ 9)} = 7.9 - 2.8 = 5.1$$

TRAILING EDGE (use fig. 9)

$$T_{TE(mile\ 9)} = T_{TE(mile\ 9)} - T_{TE(mile\ 9)} = 4.3 - 4.3 = 0$$

$$T_{TE(mile\ 8)} = T_{TE(mile\ 8)} - T_{TE(mile\ 9)} = 6.2 - 4.3 = 1.9$$

$$T_{TE(mile\ 7)} = T_{TE(mile\ 7)} - T_{TE(mile\ 9)} = 8.2 - 4.3 = 3.9$$

$$T_{TE(mile\ 6)} = T_{TE(mile\ 6)} - T_{TE(mile\ 9)} = 10.3 - 4.3 = 6.0$$

If the user is interested in how the contaminant cloud is spreading out as it moves downstream, this can be determined by projecting T_{LE} and T_{TE} at each half-mile increment of distance as shown in figure 13B. The scalar difference between T_{LE} and T_{TE} at any point is the time required for the contaminant cloud to pass that point. These scalar values can be plotted against distance above mouth (fig. 13C) to demonstrate more clearly how the time of passage is increasing at each successive downstream point.

If the user is interested in the position of the contaminant cloud in the reach relative to time since the spill, it can be determined by projecting the leading edge and trailing edge of the contaminant cloud at 1-hour increments of time as shown in figure 13D. The scalar lengths of the contaminant cloud, determined from figure 13D, can be shown relative to clock time as illustrated in figure 13E.

Even though the location of the contaminant cloud and its dispersion in the reach is known, the user may still need to predict concentrations within the cloud. Any computation concerning concentration requires a knowledge of the discharge in the stream. Figure 13F was developed from figure 12 for an index-gage discharge of 20 ft³/s to show how discharge varies with distance along the study reach.

Knowledge of the location of the peak concentration of the contaminant cloud also is necessary for predicting concentration. In order to determine this location relative to the location of the entire cloud, the peak line in figure 13A is projected down at 1-hour increments. This fixes the location of the peak concentration of the contaminant spill (figs. 13H and 13I) relative to distance above mouth for the different hourly increments of time since the spill. These values are tabulated in the first two columns of figure 13G.

The magnitude of the unit peak concentrations is determined from figure 11 for an index-gage discharge of 20 ft³/s and hourly intervals of traveltime to the peak. These values of unit peak concentration are plotted on figure 13H at the appropriate time and position and tabulated in the third column of figure 13G.

The discharge at the location of the peak concentration for each time interval can be estimated from figure 13F by entering the graph with the appropriate river-mile location of the peak. The discharges are tabulated in the fourth column of figure 13G.

The conservative peak concentration can now be predicted using the data in figure 13G and equation 3. The magnitude of the peak concentration is plotted in figure 13I at the associated time and distance above the mouth. A generalized shape of the conservative time-concentration curve can be constructed as shown in figure 13I assuming zero concentration at the leading and trailing edges of the contaminant cloud (Taylor and others, in press).

DISCUSSION

In developing the procedures used in this report, several assumptions were made to help expand upon and present the data in a format most readily usable by the reader. It is up to the user to make adjustments for any dissimilarities between the following assumptions and actual field conditions.

The flow of the Falls during the three dye studies was generally one of steady or decreasing flow. No precipitation occurred during the studies. Relations developed from dye studies cannot be used to predict with any reliable accuracy the concentration or the passage time of a solute when flow conditions are unsteady.

All calculations and procedures relative to concentration assume that the dye, contaminant, or toxic substance is conservative (is not lost for any reason as it moves downstream). In actual field conditions, there are processes other than dilution that would cause a decreasing concentration. Substances such as nutrients, dissolved gases, and other materials can be physically, biologically, or chemically degraded. In these instances, the user's calculation of concentration is likely to be higher than observed concentrations. The user will have to make adjustments to predicted values based on the characteristics of the material spilled.

Once vertical and lateral mixing takes place, dispersion data represents the rate at which a stream dilutes and disperses a soluble substance by mixing it into increasing volumes of water as the solute cloud moves downstream. Predictions for an insoluble or immiscible substance cannot be made using this technique.

The studies measured the results of a direct slug injection of dye at multiple points in the stream cross section. The probability of an actual spill occurring in such a manner is very small. It is more likely that the spill will enter the stream as a side injection over some length in time. A side injection of a conservative soluble substance would result in higher peak concentrations than predicted by this report. This is due to the fact that an injection for any length of time would sustain concentrations at a higher value. It is also due to the fact that complete lateral mixing would need several times as much channel length before occurring (Yotsukura and Cobb, 1972; Fischer and others, 1979). As a result, concentrations would remain higher in the contaminant cloud throughout the study reach.

The methods presented in this report to predict traveltime and concentration on the Jones Falls apply only to the reach studied. Extrapolation of the methods to other reaches could give erroneous results.

SUMMARY

Time-of-travel studies on the Jones Falls at flow durations of approximately 91, 40, and 14 percent were used to define time-distance relations for a range of discharges from 10 to 60 ft^3/s at the index gage--Jones Falls at Sorrento, Maryland. These relations can be used to estimate the traveltimes of the leading edge, peak, and trailing edge of water-soluble materials spilled into the stream. Graphs using the unit-concentration method can be used to predict the conservative peak concentration expected to occur at any point resulting from a contaminant spill. All of the procedures are intended for use during periods of nearly steady or slowly decreasing flow.

Field data were collected, following multiple-point injection, under conditions of steady or decreasing flow and no precipitation. All interpretation of data assumed that a conservative substance was involved and that both vertical and lateral dispersion were complete throughout the sampled length of the reach

28

studied. The procedures described will have a larger uncertainty if used during periods of unsteady flow, periods of active precipitation, or on other reaches than the one studied.

Many subjective decisions will be required to adjust predicted results to actual field conditions at the time a problem occurs. Allowances must be made for nonconservative substances that decrease in concentration because of processes other than dilution, and for insoluble or immiscible substances that are affected very little, or not at all, by dilution. Depending on the substance, actual concentrations may be greater or less than those predicted. Allowances must also be made if a spill occurs from the bank as a slug injection, or enters the stream continuously over a period of time. In either case, traveltimes and concentrations will be greater than those predicted.

SELECTED REFERENCES

Collings, M. R., 1968, Selection of dye-injection and measuring sites for time-of-travel studies, in Chase, E. B., and Payne, F. N., compilers, Selected techniques in water-resources investigations, 1966-67: U.S. Geological Survey Water-Supply Paper 1892, p. 23-29.

Fischer, H. B., and others, 1979, Mixing in island and coastal waters: New York, Academic Press, 483 p.

Hubbard, E. F., Kilpatrick, F. A., Martens, L. A., and Wilson, J. R., Jr., 1982, Measurement of time of travel and dispersion in streams by dye tracing: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A9, 44 p.

Taylor, K. R., James, R. W., Jr., Helinsky, B. M., 1983, Traveltime and dispersion in the Potomac River, Cumberland, Maryland, to Washington, D.C.: U.S. Geological Survey Water-Supply Paper 2257 [in press].

Yotsukura, Nobuhiro, and Cobb, E. D., 1972, Transverse diffusion of solutes in natural streams: U.S. Geological Survey Professional Paper 582-C, 19 p.