UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TIME-OF-TRAVEL STUDY IN THE PRESUMPSCOT RIVER BASIN, MAINE

By Gene W. Parker

Open-File Report 80-570

Prepared in cooperation with the
Maine Department of Environmental Protection

Augusta, Maine

July 1980

TABLE OF CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

FACTORS FOR CONVERTING INCH-POUND TO INTERNATIONAL SYSTEM (SI) UNITS

To convert from	To	Multiply by
	Length	
Foot (ft)	Meter (m)	0.3048
Mile (mi)	Kilometer (km)	1.609
	Area	
Square mile (mi^2)	Square kilometer (km^2)	2.590
	Flow	
Cubic foot per second (ft^3/s)	Liter per second (L/s)	28.32
Cubic foot per second (ft^3/s)	Cubic meter per second (m^3/s)	0.02832
	Velocity	
Foot per second (ft/s)	Meter per second (m/s)	0.3048

TIME-OF-TRAVEL STUDY IN THE PRESUMPSCOT RIVER BASIN, MAINE

By Gene W. Parker

ABSTRACT

Time of travel was determined for a 6-mile reach of the Presumpscot River, starting from a short distance downstream from Cumberland Mill Dam at Westbrook to Presumpscot Falls near Falmouth, Maine. A 20-percent solution of rhodamine WT was used. Dye-tracer runs were made at discharges of 134, 500, and 800 cubic feet per second. Water samples were collected at three sites: the U.S. Route 302 bridge near Westbrook; the U.S. Geological Survey gaging station near West Falmouth (station number 01064140); and Presumpscot Falls near Falmouth, Maine. The samples were then analyzed for dye concentrations.

Time-of-travel data for each subreach are depicted in a series of illustrations and summarized in tabular form. Examples are given to illustrate the use of the data presented.

INTRODUCTION

The time needed to transport dissolved or suspended materials through a reach of a river is called time of travel. Time of travel is a function of both stream discharge and channel geometry. Time-of-travel data have many applications. One of the most important uses is to estimate the time required for a pollutant spilled into a river at one point to arrive at a specific site downstream.

In October 1977, the USGS (U.S. Geological Survey) entered into a 3-year joint funded project with the MDEP (Maine Department of Environmental Protection). The purposes of the project were to evaluate and describe flow characteristics of selected streams with known or potential water quality problems; to define time-of-travel rates of those streams; and to use this information to calibrate and verify a stream water-quality model used by MDEP. During the open water period of 1979, a time-of-travel study was carried out on the Presumpscot River between Westbrook and Falmouth, Maine.

ACKNOWLEDGMENTS

The author would like to acknowledge Gardner Hunt and James Jones of MDEP, who significantly contributed to the success of this study.

DESCRIPTION OF STUDY REACH

The Presumpscot River originates at the outlet of Sebago Lake and flows generally eastward to the ocean at Falmouth, 3 miles north of Portland. Although the Presumpscot River is only 26 miles long, it is impounded by eight operating dams. The USGS publishes flow data from two sites on the river, at the outlet of Sebago Lake (station number 01064000), and near West Falmouth (station number 01064140). The West Falmouth gage is also equipped with a four-parameter water-quality monitor to collect dissolved-oxygen, pH, specific conductance, and water-temperature data. These are also published annually by the USGS.

The reach of the Presumpscot River studied during this project extends from a point just downstream from Cumberland Mill Dam in Westbrook, 6 miles downstream to Presumpscot Falls. See fig. 1. Cumberland Mill Dam is the most downstream dam on the river still in operation. Although no longer operated, an old, deteriorating dam still impounds water at Presumpscot Falls. Presumpscot Falls is at the upstream limit of tidal influence.

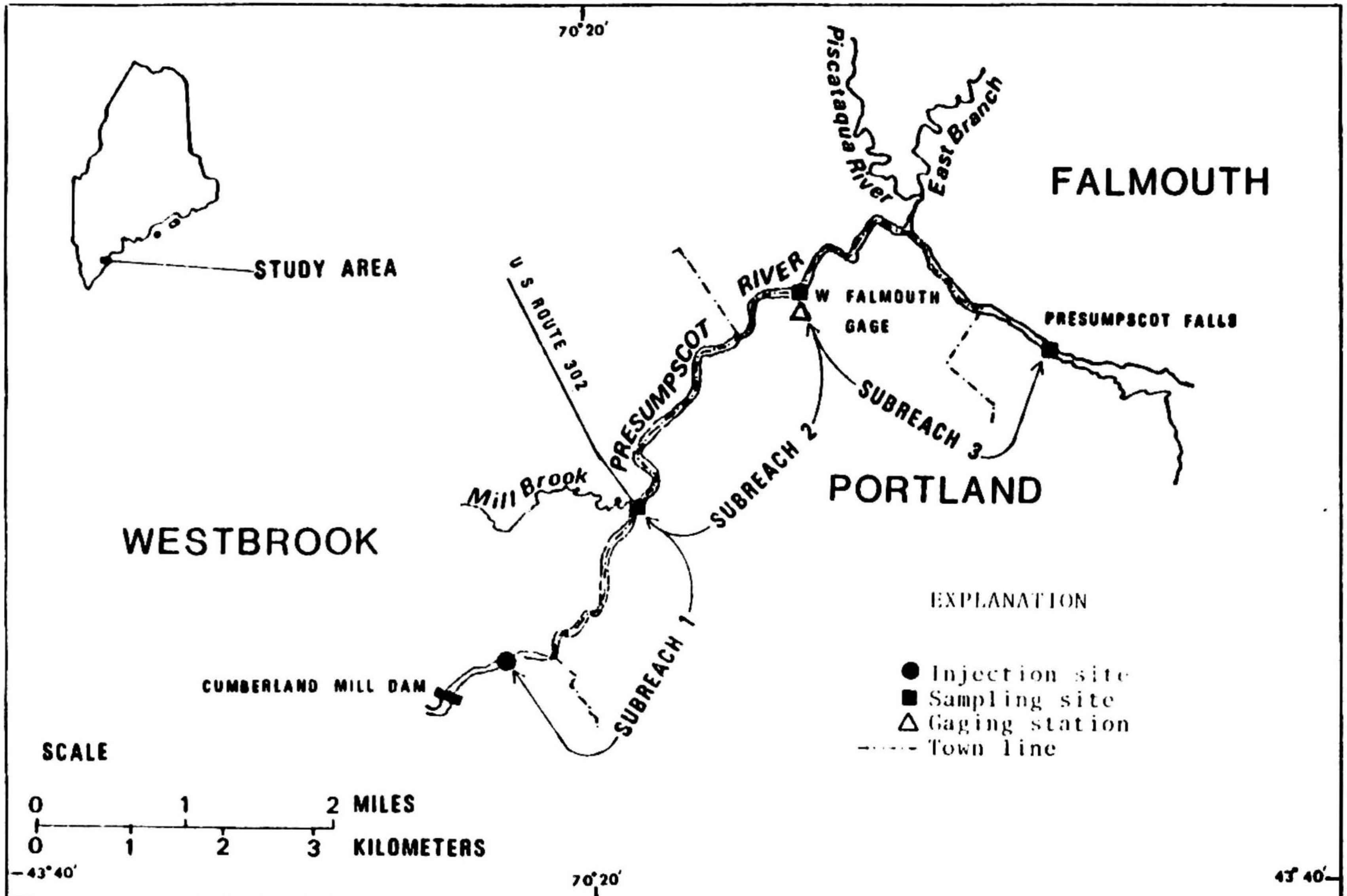

Figure 1.--Map of Presumpscot River time-of-travel study area.

METHODS

The dye injection and sampling sites for the Presumpscot River study area were identified on topographic maps. These sites were used to divide the study reach into the three sub-reaches shown in figure 1.

A reconnaissance was made to inspect the dye-injection and sampling sites, to confirm the existance of impoundments shown on the topographic maps, and to locate suitable discharge measuring sites.

Desirable discharges for tracer-dye studies agreed upon by USGS and MDEP were at the 50-, 85-, and 90-percent (or greater) duration levels, as determined from a flow-duration curve developed for a gaging station in the study area.

The West Falmouth gage had been in operation for too short a time before the study to provide sufficient data to develop a flow-duration curve. Instead, the flow-duration curve for the USGS gaging station at the outlet of Sebago Lake was used, and flows were adjusted for drainage area, as needed.

Data Collection

The West Falmouth gage was used as the index gage. During each of the dye tracer studies, discharge was measured at the West Falmouth gage to verify the stage-discharge relation. Discharge was also measured of the three major tributaries that flow into the study reach, namely, Mill Brook, Piscataqua River, and East Branch Piscataqua River.

Discharge at each of the sampling sites was computed from discharge at the West Falmouth gage. Adjustments for difference in drainage area were based on runoff per square mile computed from discharge measurements of the three major tributaries.

The discharge at the West Falmouth gage for the three dye studies was 134, 500, and 830 ft^3/s (cubic feet per second), respectively.

A 20-percent solution of the fluorescent dye, rhodamine WT, was used as the tracer. MDEP personnel injected the dye, collected water samples at the designated sampling sites, and determined the dye concentration of the samples collected. The appropriate volume of dye to be injected for each of the three dye runs was computed based on estimates of mean stream velocity at the time of the dye studies.

During the first two runs, a recording flow-through fluorometer was used to determine dye concentrations at the West Falmouth gaging station. During all three runs, an automatic sampler at each sampling site collected water at set time intervals. Samples were later analyzed for dye concentration by a fluorometer, as outlined by Wilson (1968).

A fluorometer gives a relative measure of the intensity of fluorescent light emitted by a sample containing a fluorescent dye. This measured intensity is directly proportional to the amount of fluorescent dye in the sample.

Problems

During the July 5-7 run, the automatic sampler set to operate at the U.S. Route 302 bridge malfunctioned before the dye cloud arrived at the site. During subsequent runs, the sampler operated correctly.

Data Analysis

Time-Concentration Curves

Measured dye concentrations at each sampling site were plotted against time after injection for each dye study. See figs. 2-9. A smooth curve was drawn through the plotted points, taking into consideration possible background fluorescence and occasional erroneous analyses of dye concentrations.

From the time-concentration curves, the arrival time to the important features of the dye cloud were determined. The four features considered to be most important (Buchanan, 1964) are:

> Leading edge.--The arrival at the sampling site of the first dye particle.
>
> Peak.--The maximum dye concentration.
>
> Centroid.--The center of mass of the dye cloud.
>
> Trailing edge.--The point at which the dye concentration recedes to 10 percent of the peak concentration.

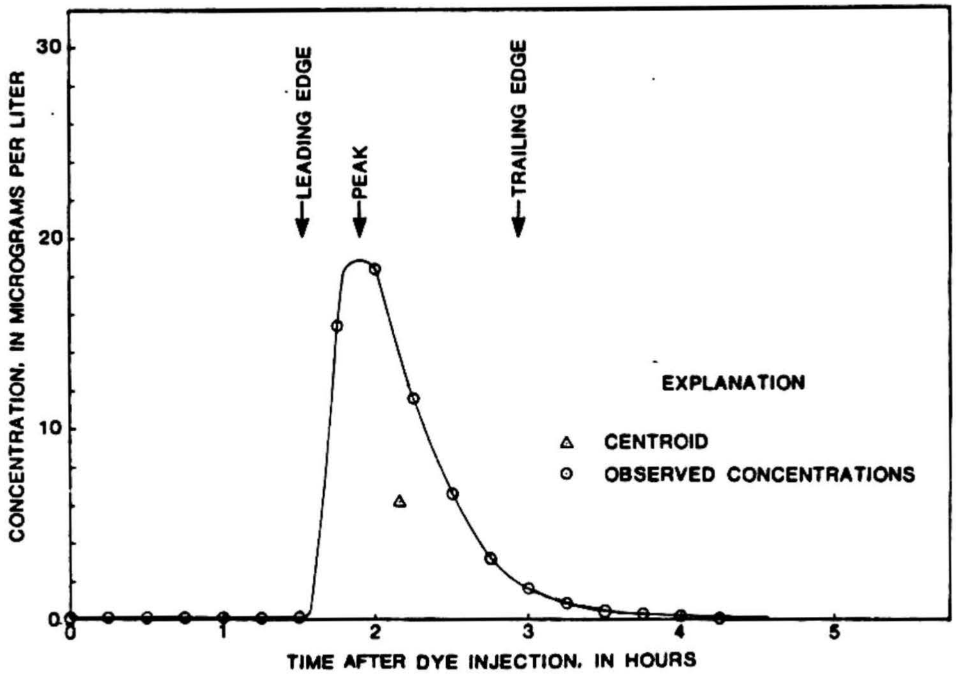

Figure 2.--Traveltime versus concentration at U.S. Route 302 bridge near Westbrook, Maine, August 8, 1979.

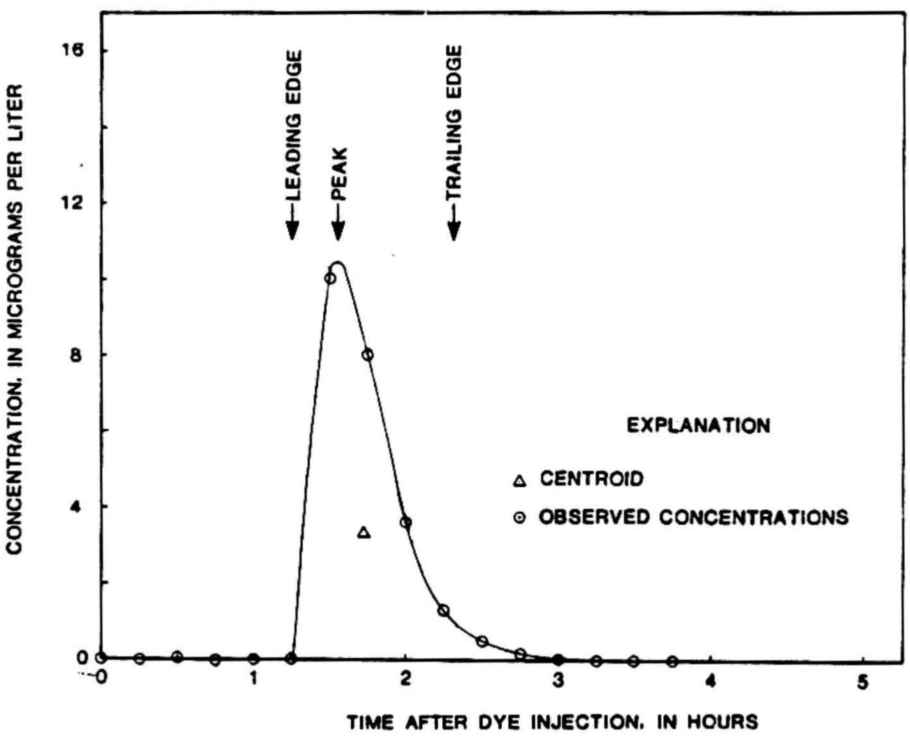

Figure 3.--Traveltime versus concentration at U.S. Route 302 bridge near Westbrook, Maine, September 5, 1979.

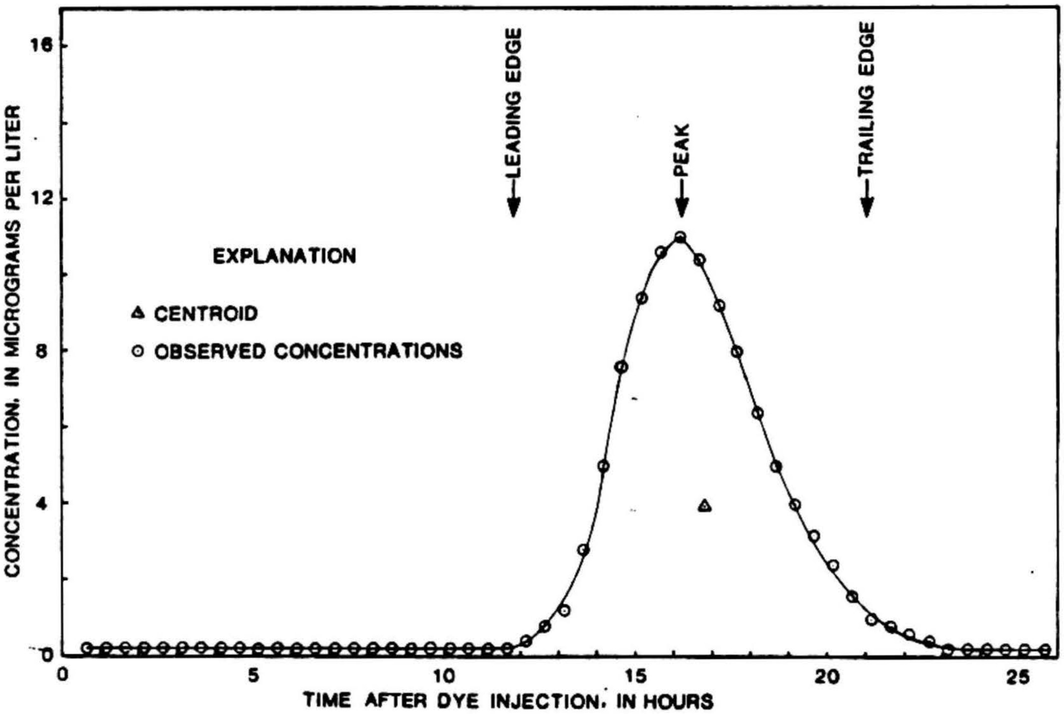

Figure 4.--Traveltime versus concentration at West Falmouth gage, July 5-6, 1979.

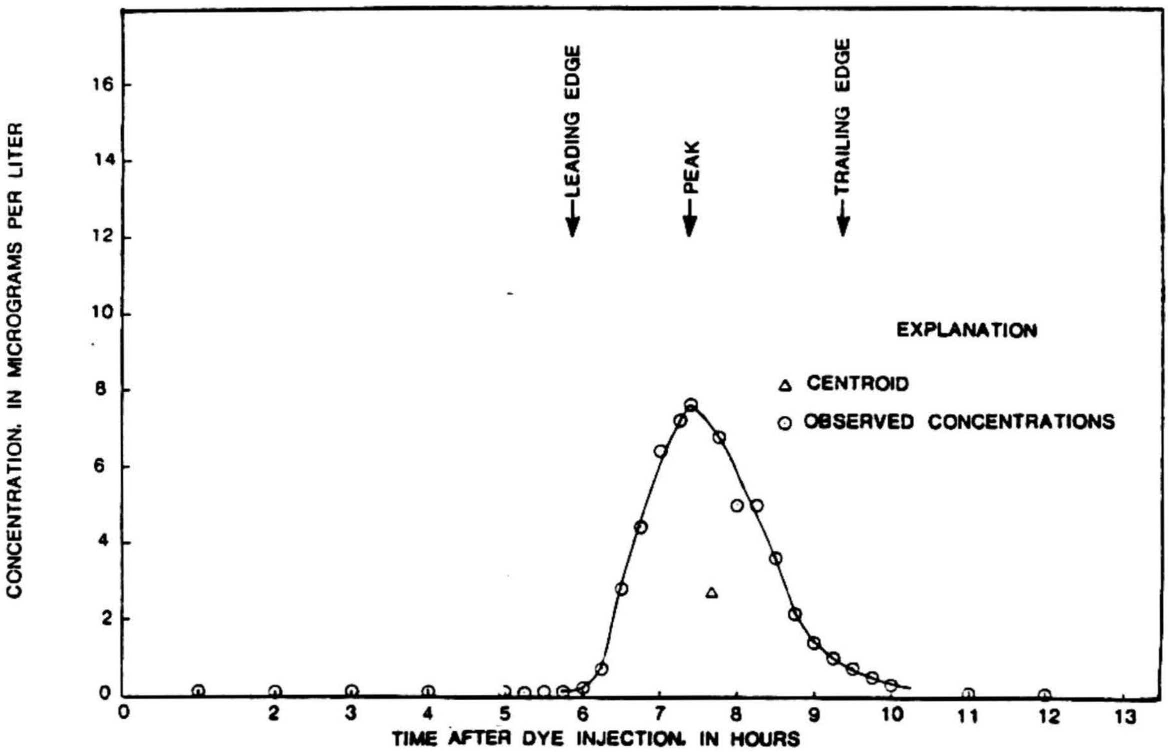

Figure 5.--Traveltime versus concentration at West Falmouth gage, August 8, 1979.

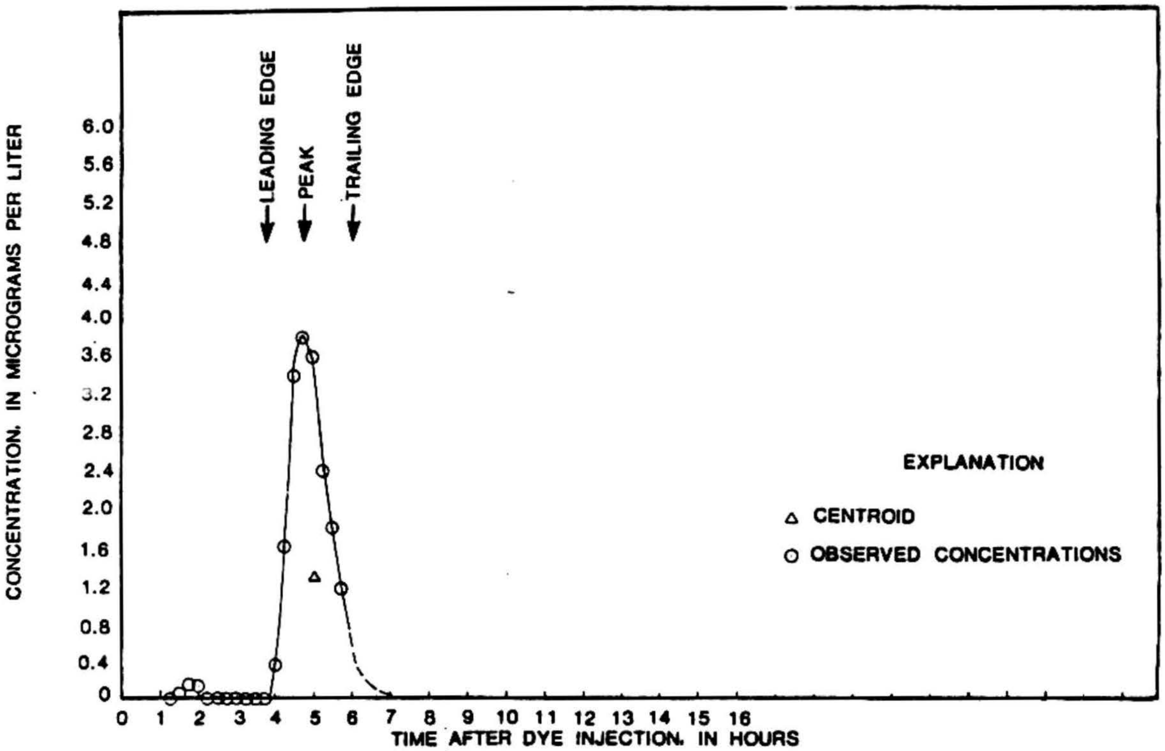

Figure 6.--Traveltime versus concentration at West Falmouth gage, September 5-6, 1979.

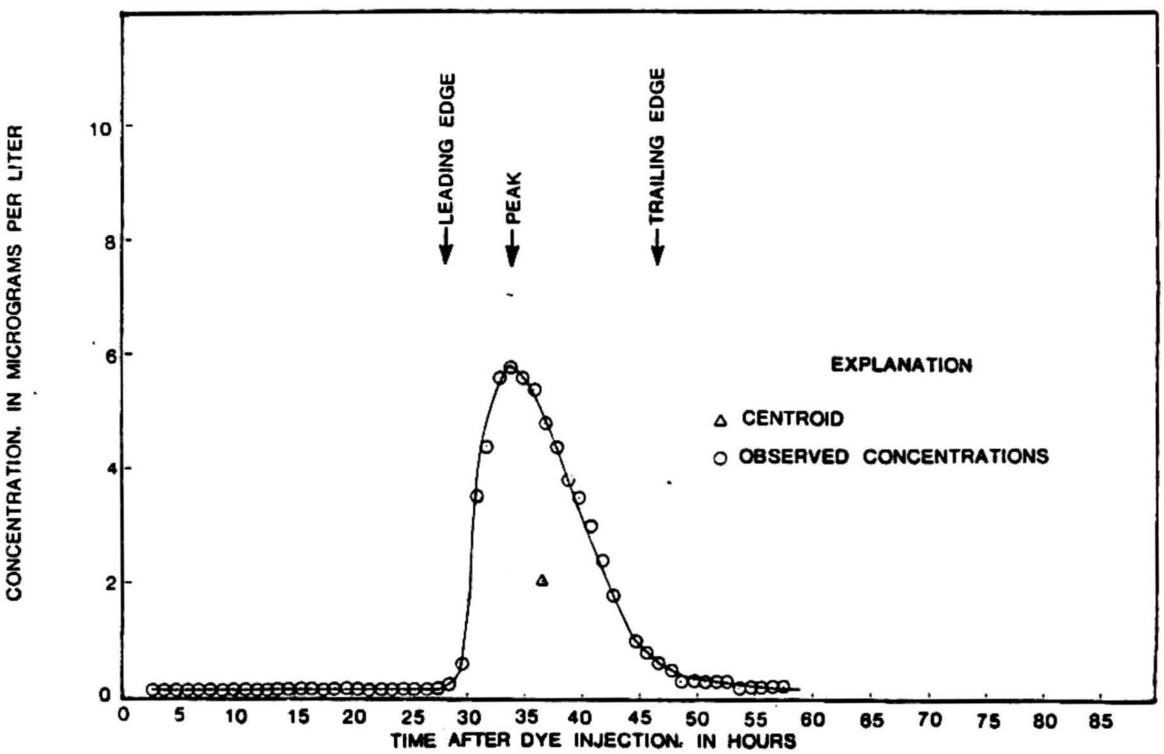

Figure 7.--Traveltime versus concentration at Presumpscot Falls, Maine, July 5-7, 1979.

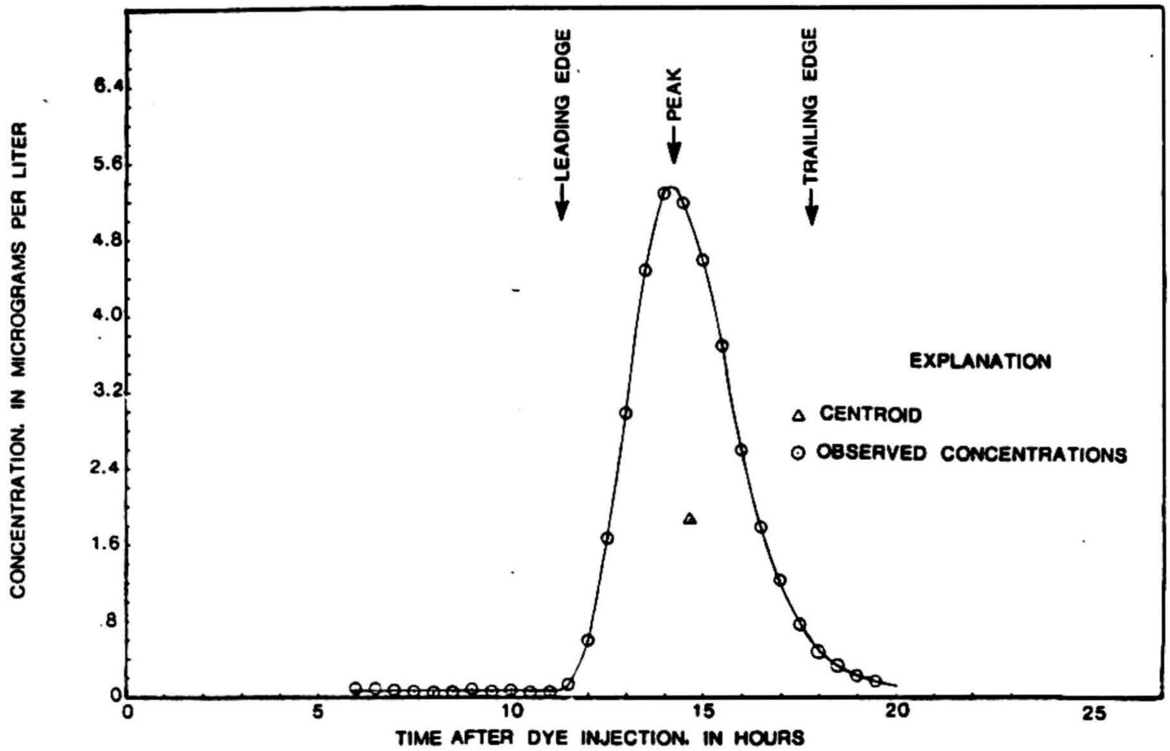

Figure 8.--Traveltime versus concentration at Presumpscot Falls, Maine, August 8-9, 1979.

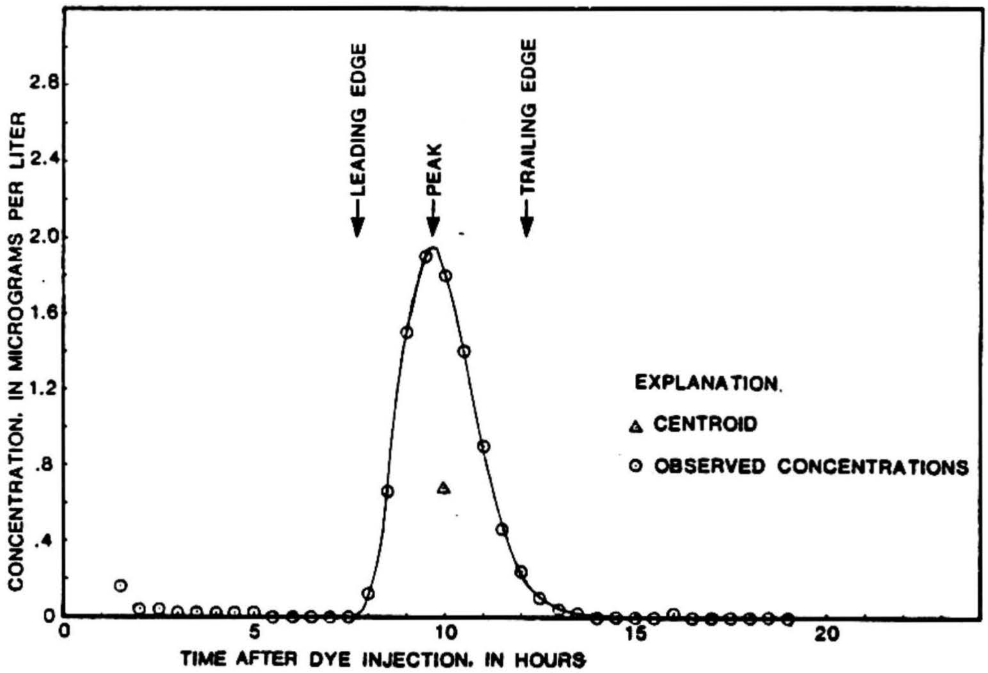

Figure 9.--Traveltime versus concentration at Presumpscot Falls, Maine, September 5-6, 1979.

Leading edge, peak, and trailing edge are determined by inspecting the time-concentration curves. The centroid, on the other hand, is computed by the formulas:

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i c_i \Delta_i t}{\sum_{i=1}^{n} c_i \Delta_i t}$$

and

$$c = \frac{\sum_{i=1}^{n} (1/2) c_i^2 \Delta_i t}{\sum_{i=1}^{n} c_i \Delta_i t}$$

Where:

$\bar{t}$ = the average time for the geometric region under the time-dye concentration curve.

$\bar{c}$ = the average concentration value for the geometric region under the time-dye concentration curve.

t_i = the elapsed time since the dye injection.

c_i = the dye concentration at time t_i.

$\Delta_i t$ = the interval of time determined by $(t_{i+1} - t_i)/2)$ $+(t_i - t_{i-1})/2)$.

The area under the curve represents the dye cloud mass. A summary of time-of-travel data for all subreaches is presented in table 1.

Table 1.--Time-of-travel data for all subreaches

Sub-reach No.	Dye run No.	Distance from injection site (miles)	Date of injection	Discharge (ft³/s)	Time-of-travel leading edge (h)	Time-of-travel peak (h)	Peak velocity (ft/s)	Time-of-travel centroid (h)	Centroid velocity (ft/s)	Time-of-travel trailing edge (h)
1	1	1.4	7/5/79	133	*	*	*	*	*	*
	2		8/8/79	500	1.5	1.9	1.1	2.2	1.0	2.9
	3		9/5/79	830	1.2	1.5	1.3	1.7	1.2	2.3
2	1	3.5	7/5/79	134	11.8	16.2	0.3	16.7	0.3	21.0
	2		8/8/79	500	5.8	7.4	0.7	7.7	0.7	7.4
	3		9/5/79	830	3.8	4.8	1.1	3.0	1.0	6.0
3	1	6.0	7/5/79	150	28.0	33.7	0.3	36.8	0.2	46.3
	2		8/8/79	510	11.3	14.2	0.6	14.7	0.6	17.8
	3		9/5/79	840	7.7	9.7	0.9	9.9	0.9	12.1

* Automatic sampler malfunctioned.

Time-Discharge Curves

The traveltimes to each of the four features of the dye cloud described earlier were plotted against the discharge of the Presumpscot River during each of the dye studies. The relations are presented in figures 10-12. The relationship between time of travel and discharge is generally linear on log-log paper. Note that the time-discharge curves on each of figures 10-12 converge as discharge increases. This convergence indicates that the dye cloud will pass a point on the river more rapidly as discharge increases. These relations can be used to estimate the arrival time of each of the important features of a dye or pollutant cloud for a wide range of flows.

Time-Distance Relation

Graphical relationships of time-of-travel data can be presented by plotting the traveltime of the centroid of the dye cloud versus distance between the injection site and the sampling points (see figure 13) at each of the discharge levels. From these relations, traveltime of the centroid can be estimated to any point in the study reach. Also, traveltimes at flows other than those during the study can be estimated. The discharge values shown in figure 13 are for the West Falmouth gage.

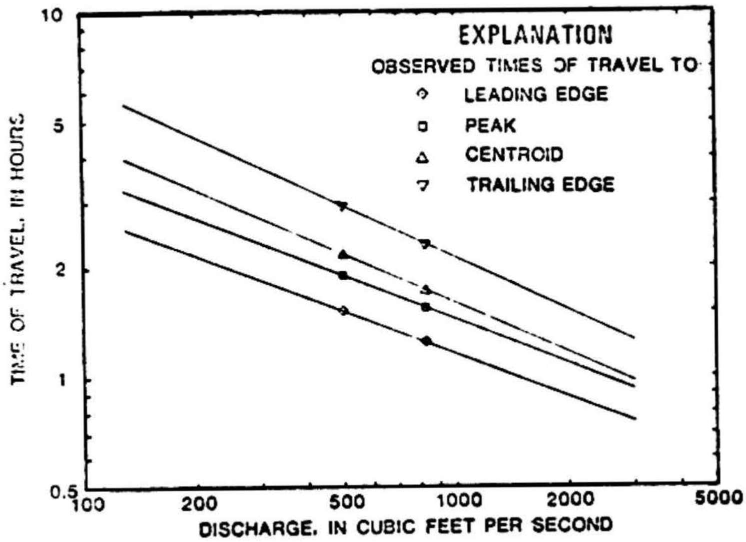

Figure 10.--Time of travel versus discharge Cumberland Mill Dam to U.S. Route 302 bridge near Westbrook, Maine.

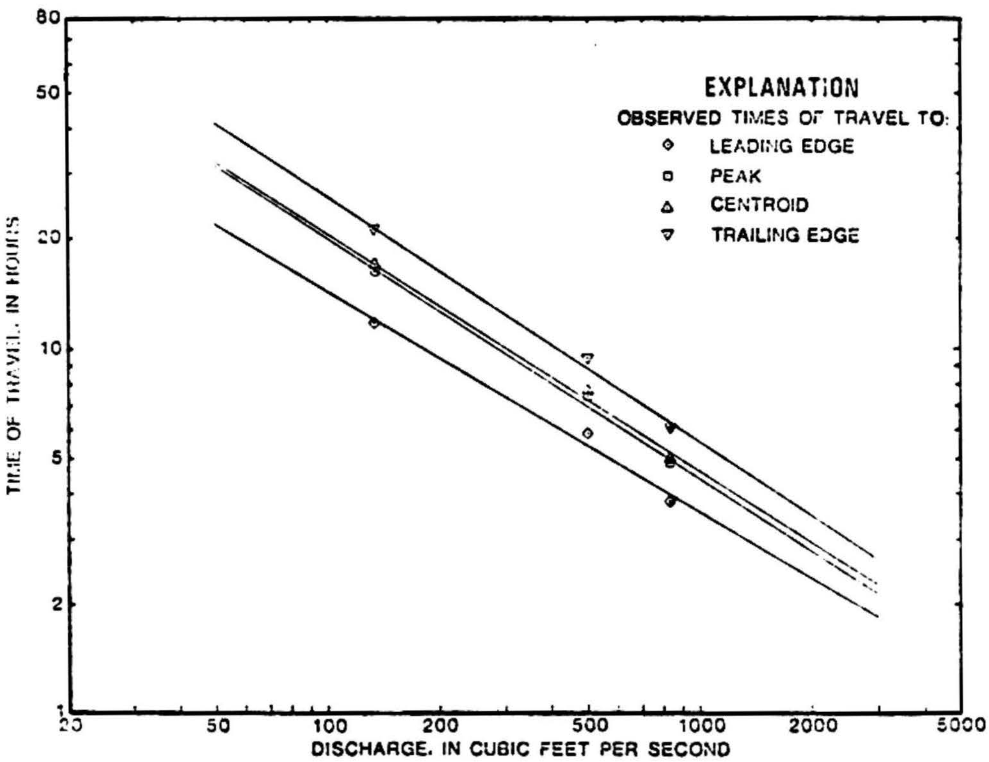

Figure 11.--Time of travel versus discharge Cumberland Mill Dam to West Falmouth gage.

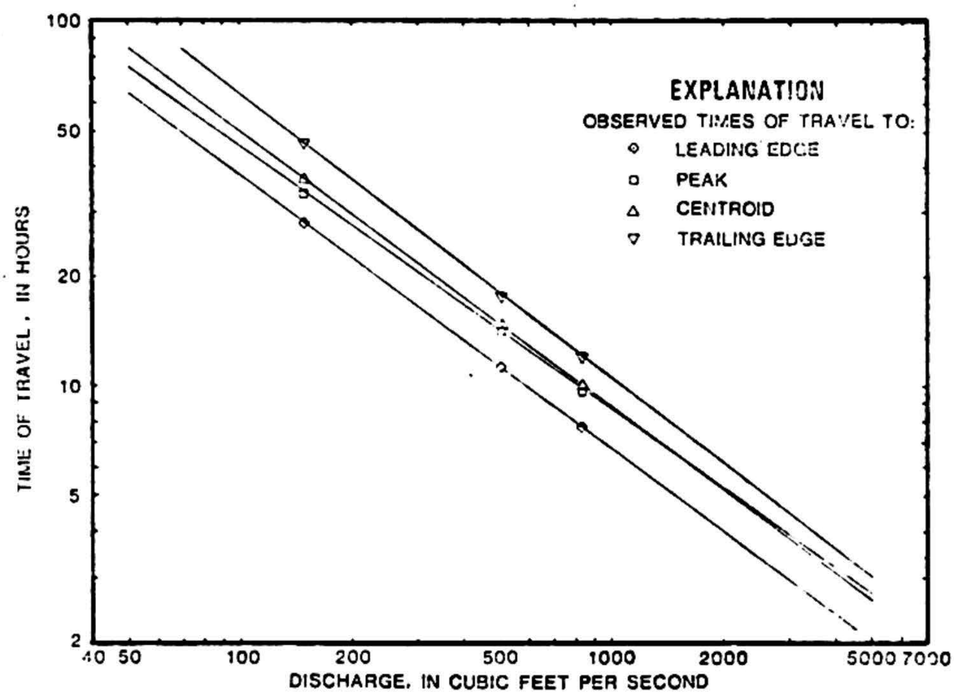

Figure 12.--Time of travel versus discharge Cumberland Mill Dam to Presumpscot Falls, Maine.

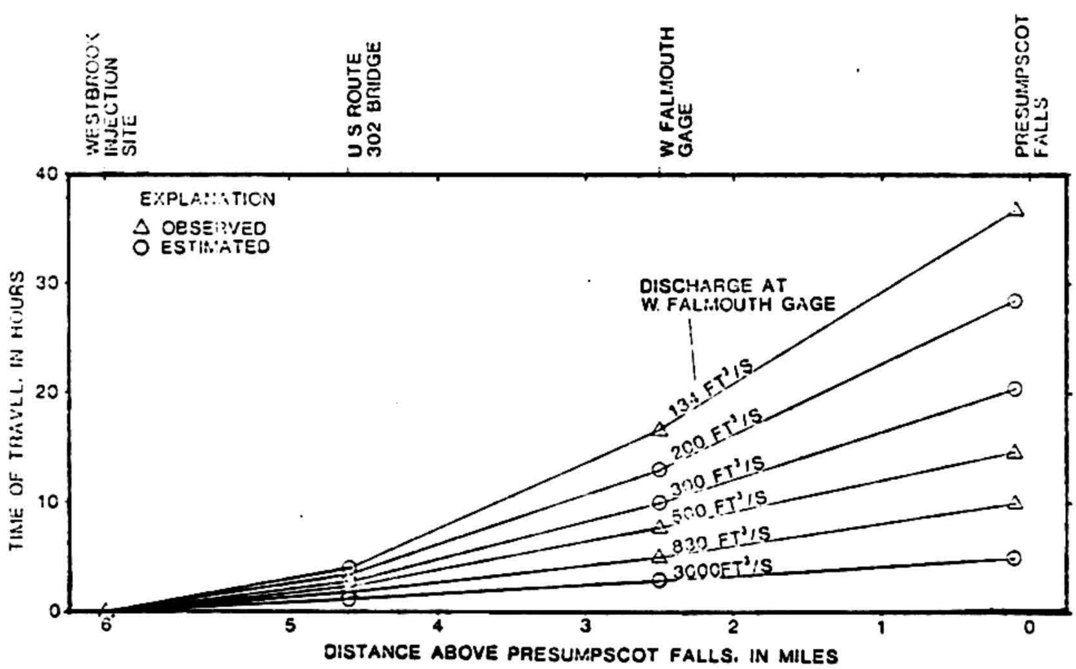

Figure 13.--Centroid time of travel versus distance above Presumpscot Falls, Maine.

USE OF TIME-OF-TRAVEL DATA

To illustrate the use of time-of-travel data, two examples will be discussed. For both examples, it will be assumed that a pollutant has been instantaneously injected into the Presumpscot River at a point just below Cumberland Mill Dam. Example A will show how to estimate the time necessary for the pollutant to completely pass one of the sampling sites. The procedures outlined in example B provide a guide for estimating the time needed for the centroid or center of mass of the pollutant cloud to reach a site between sampling locations.

Example A

The discharge of the Presumpscot River at the USGS gage near West Falmouth is 295 ft^3/s. If a pollutant is spilled into the Presumpscot River at 1:45 a.m. just downstream from Cumberland Mill Dam, what time would the leading edge of the pollutant arrive at Presumpscot Falls and how long would it take the pollutant to completely pass that site?

Solution.--From figure 12, the estimated time of travel of the leading edge at a discharge of 295 ft^3/s is 16.8 hours. From the same figure, traveltime to the trailing edge is 27.1 hours. Therefore, the leading edge should arrive at about 6:30 p.m. on the same day, and the trailing edge should pass 8 hours and 20 minutes later at 4:50 a.m.

Example B

The discharge of the Presumpscot River at the West Falmouth gage is 295 ft^3/s. If a spill into the Presumpscot River occurs at 11:45 a.m. just downstream from Cumberland Mill Dam, when should the centroid or center of mass of the pollutant reach the mouth of the Piscataqua River?

Solution.--From figure 1, the mouth of the Piscataqua River is 1.3 miles upstream from Presumpscot Falls. Because a discharge of 295 ft^3/s is not shown explicitly on figure 13, it is necessary to interpolate between the two discharges bracketing 295 ft^3/s; namely, 200 ft^3/s and 300 ft^3/s. At a distance of 1.3 miles upstream from Presumpscot Falls, the traveltime of the centroid of the pollutant is 15.3 hours. Thus, the centroid of the pollutant cloud will arrive at the mouth of the Piscataqua River at about 4:30 p.m. the same day.

Note that in both examples the discharge determined at the West Falmouth gage was used without adjusting for drainage area differences. Because the drainage areas of the other sites in the study reach differ from the drainage area of the West Falmouth gage, an adjustment would normally be made. However, there are several reasons for not adjusting the flows here. First, there are eight dams upstream from the study reach that control or alter the flow of the Presumpscot River except during high flow. Second, tributary inflow into the study reach is small compared to the discharge of the Presumpscot River. Finally, the maximum drainage area adjustment anywhere in the study area is less than 10 percent. Therefore, little error is introduced by neglecting the drainage area adjustment.

The procedures discussed in this report are valid only when flow conditions are steady or gradually varying.

SUMMARY

For the time-of-travel studies made between July and September 1979, a 20-percent solution of rhodamine WT, a fluorescent dye, was injected into the Presumpscot River just downstream from Cumberland Mill Dam. Water samples were collected at three sites along the river at regular time intervals, and dye concentrations were determined. The discharge at the West Falmouth gaging station was 134, 500, and 830 ft^3/s, respectively, during the three dye-tracer study runs. The dye concentrations at each sampling site were plotted against time since injection.

The arrival times of the leading edge, peak, and trailing edge were determined directly from each time versus concentration curve, and arrival time of the centroid was computed. At each sampling site, the arrival times of these four features were plotted against the corresponding discharge during the respective dye run. The arrival time of the centroid for each sampling site was plotted against distance upstream from Presumpscot Falls. Examples are given to illustrate the use of the data presented.

REFERENCES

Buchanan, T. J., 1964, Time of travel of soluble contaminants in streams: American Society of Civil Engineers Proceedings v. 90, no. SA3, paper 3932, 12 p.

Wilson, J. F., Jr., 1968, Fluorometric procedures for dye tracing: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A12, 31 p.