TIME-OF-TRAVEL AND DISPERSION STUDIES,

LEHIGH RIVER, FRANCIS E. WALTER LAKE

TO EASTON, PENNSYLVANIA

By C. D. Kauffman, Jr.

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

Multiply Inch-pound unit	By	To obtain SI units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometers (km)
square mile (mi^2)	2.590	square kilometers (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per second (ft/s)	0.3048	meter per second (m/s)
pound (lb)	0.4536	kilogram (kg)

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ABSTRACT

Results of time-of-travel and dispersion studies are presented in both tabular and graphical form for several low-to-medium flow conditions in the Lehigh River from Francis E. Walter Lake to Easton, Pennsylvania. This reach is 77.0 miles long, and has a drainage area of 1,069 square miles at its downstream end.

A solution of rhodamine WT, a fluorescent dye, was injected into the river at selected sites. Water samples were collected throughout the study reach and analyzed by fluorometer for dye concentration.

Time-of-travel data have been related to stream discharge, distance along the river channel, and dispersion. The relations permit the estimation of time of travel and maximum concentration of a water-soluble contaminant moving between any two points within the study reach at any desired discharge in the low-to-medium flow range.

The range of discharge for the time-of-travel studies was from 285 cubic feet per second to 1,320 cubic feet per second at the Walnutport gaging station. The range for dispersion studies was from 285 cubic feet per second to 738 cubic feet per second.

If 2,200 pounds of a conservative, water-soluble contaminant were accidentally spilled into the Lehigh River at Penn Haven Junction at Black Creek, 6.1 miles downstream from Rockport, when the discharge at Walnutport was 600 cubic feet per second, the leading edge, peak, and trailing edge of the contaminant would arrive 31.6 miles downstream at the Northampton water intakes 43, 52, and 66 hours later, respectively. The maximum concentration expected at the intakes would be about 1,450 micrograms per liter.

If an equal amount of contaminant were spilled at the site when the discharge was 285 cubic feet per second, the arrival of the leading edge, peak, and trailing edge would be 72, 91, and 101 hours later, respectively, and the maximum concentration expected would be 2,010 micrograms per liter.

INTRODUCTION

This report presents the results of four separate dye-tracer time-of-travel studies in 1970, 1973, 1974, and 1977 on a 77-mile reach of the Lehigh River. The reach extends from the outlet of Francis E. Walter Lake to the Third Street highway bridge in Easton, 0.3 mile upstream from the point where the Lehigh enters the Delaware River (fig. 1).

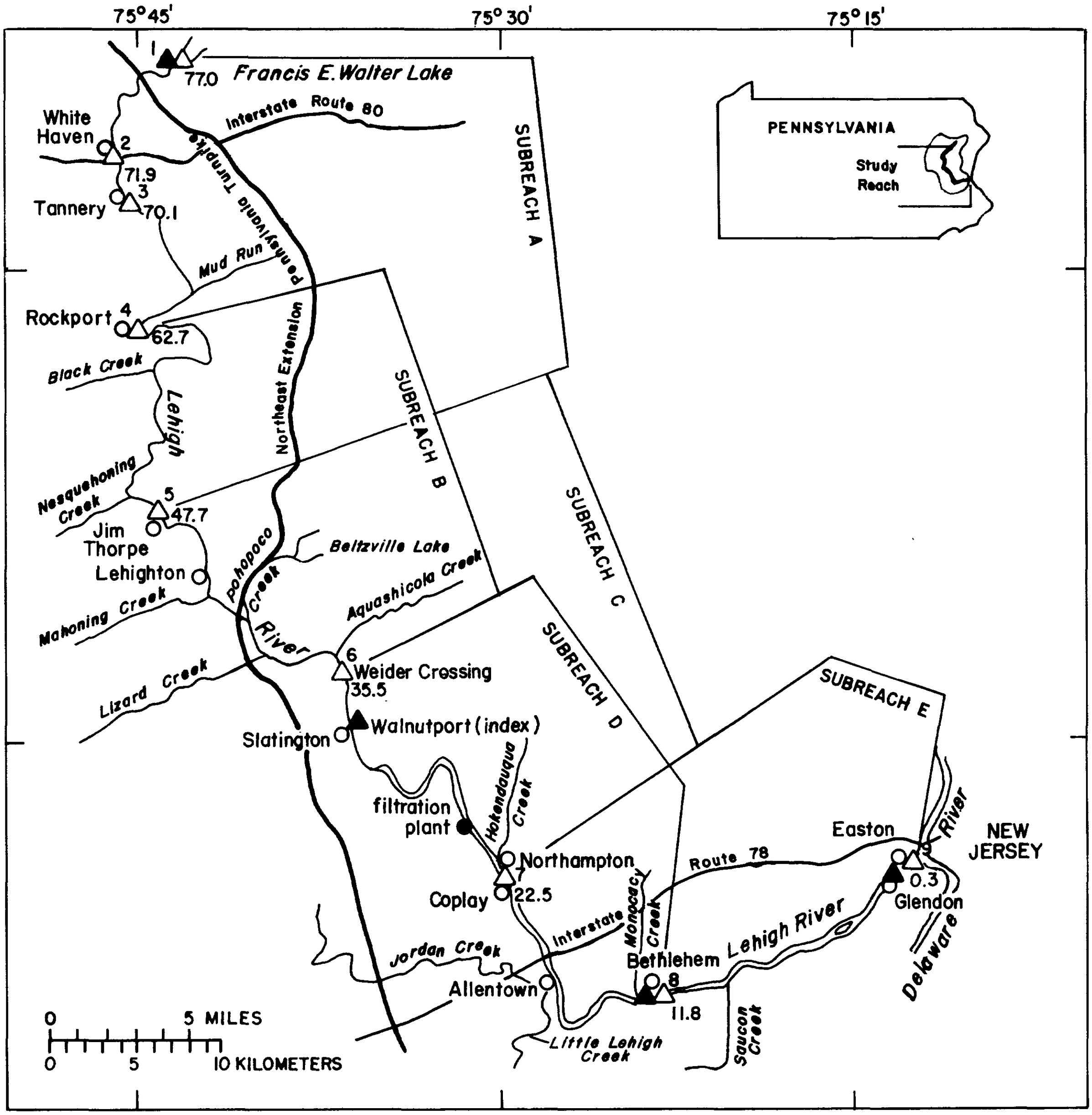
The 1970 study was designed to measure time-of-travel (also called traveltime) and passage time which is one aspect of longitudinal dispersion. The 1973, 1974, and 1977 studies included measurements of an additional aspect of longitudinal dispersion - the decrease of the maximum concentration of a solute as a function of time. The 1974 study was aborted after 1 day because of rain; however, data for that run was used.

Streamflows of the Lehigh River at Walnutport during the study periods were equivalent to flow rates equaled or exceeded 42 (1970), 67 (1974), 80 (1973), and 92 (1977) percent of the time. This range of flow rates represents low-to-medium flows, which are those of primary interest to studies on the movement of contaminants. Base-flow conditions existed during the study periods except the second day of the 1974 study. Walnutport is near the midpoint of the study area, and the gaging station at this location was, therefore, used as the index station.

A simple dye-tracer time-of-travel measurement is made by determining an index discharge, injecting a quantity of fluorescent dye (rhodamine WT in this study) into a stream and then, at a downstream point, monitoring the arrival of the leading edge, the maximum concentration, and the trailing edge of the passing dye cloud. Sampling is done either by collecting at timed intervals by hand or by continuous pumping. Testing is done by a fluorometer, an instrument that measures relative fluorescence. The traveltime of the dye cloud is related to the discharge rate of the stream.

The simple time-of-travel measurement can be upgraded by: (1) injecting the dye tracer upstream from the study reach, so that the dye cloud is completely mixed when it passes through the study reach, thereby providing traveltime data that represent the average of the stream rather than that of the main velocity thread; (2) measuring quantity of dye injected, and concentrations of the entire dye cloud, so that concentrations can be adjusted for dye losses; and (3), making a series of measurements under a variety of stable flow conditions, so predictions can be made for all common flow conditions. In general, the time-of-travel depends upon the length of the reach and the discharge.

Commonly, to reduce field time and to keep concentrations within allowable test limits, a reach is broken down into subreaches.



EXPLANATION

△ Data site, number, and river mile

▲ Gaging station

○ City, town, or village

Site number	Name	River mile
1	Below Francis E. Walter Lake	77.0
2	White Haven	71.9
3	Tannery	70.1
4	Rockport	62.7
5	Jim Thorpe	47.7
6	Weiders Crossing	35.5
7	Coplay-Northampton	22.5
8	Bethlehem	11.8
9	Easton	0.3

Figure 1.--Location of study reach, Lehigh River.

ACKNOWLEDGMENTS

These studies were coordinated by the U.S. Geological Survey in cooperation with the Delaware River Basin Commission. The U.S. Army Corps of Engineers and the Pennsylvania Department of Environmental Resources also assisted with the study.

FIELD OPERATIONS

The first field study (hereafter called run) was made October 27-29, 1970, when the discharge of the Lehigh River at Walnutport averaged 1,320 ft^3/s (cubic feet per second), a discharge equaled or exceeded 42 percent of the time. Dye was injected at the Francis E. Walter Lake outlet, and samples of that injection were collected at White Haven and Jim Thorpe. Dye was also injected at Jim Thorpe, Weiders Crossing, Coplay-Northampton (hereafter referred to as Coplay), and Bethlehem. The Jim Thorpe injection was sampled at Weiders Crossing; the Weiders Crossing injection was sampled at Coplay; the Coplay injection was sampled at Bethlehem; and the Bethlehem injection was sampled at Easton. Samples were analyzed at each sampling site by fluorometric testing to determine the arrival, relative change in concentrations, and passage of the dye cloud. No additional sample analyses were made.

The second run was made August 27-31, 1973, when the discharge at Walnutport averaged 483 ft^3/s, a discharge equaled or exceeded about 80 percent of the time. Dye was injected at Francis E. Walter Lake outlet, Rockport, Jim Thorpe, and Weiders Crossing. Each injection was sampled at two downstream cross sections, and, in addition to analyzing samples at each site the same as in 1970, samples were preserved and reanalyzed by fluorometer under laboratory conditions (Wilson, 1968, p. 20-28), so accurate concentration values could be determined. The Francis E. Walter Lake outlet injection was sampled at White Haven and Jim Thorpe; the Rockport injection was sampled at Jim Thorpe and Weiders Crossing; the Jim Thorpe injection was sampled at Weiders Crossing and Coplay; and the Weiders Crossing injection was sampled at Coplay and Bethlehem.

A third run was attempted October 15, 1974, but was abandoned the next day because of rising stream discharges. The average discharge at Walnutport on October 15 was 738 ft^3/s, a discharge equaled or exceeded 67 percent of the time. Two injections were made; Francis E. Walter Lake outlet and Coplay. Samples were collected at White Haven (Francis E. Walter injection) and Bethlehem (Coplay injection), but the relation between traveltime and stream discharge might be questionable because of slightly increasing stream discharge on October 16; the discharge at Walnutport increased from 738 ft^3/s at 12:01 a.m. to 966 ft^3/s at noon.

The fourth run was made September 5-9, 1977, when the discharge at Walnutport, averaged 285 ft^3/s, a discharge equaled or exceeded 92 percent of the time. Injection and sampling sites were the same as in 1973, with the addition of the Coplay injection, which was sampled at Bethlehem and Easton. Samples were tested the same as in 1973.

For all runs, dye was injected at either one, two, or three points in a cross section, except at Rockport, where both injections were made in a small right-bank tributary about 300 ft upstream from its mouth. All sampling was done by hand at the main velocity thread plus one or two additional points in the cross section. Concentrations were determined (except 1970 run) by averaging values for two or more points in a cross section. Sampling points were selected to represent subsections of equal discharge.

RESULTS

Table 1 gives locations and drainage areas of study sites and gaging stations in the reach. Pertinent discharge and flow-duration data for the index station at Walnutport, Pennsylvania are presented in table 2.

Time-concentration curves (except 1970 run) were developed by plotting concentration, obtained by retesting samples under controlled-temperature conditions with a calibrated fluorometer, versus traveltime after injection. A typical set of time-concentration curves is presented in figure 2. The observed concentrations were adjusted to those of conservative concentrations by the equation:

$$C_{con} = \frac{100\ C_{obs}}{PR}$$

where C_{con} is the conservative concentration (µg/L),
C_{obs} is the observed concentration (µg/L),
PR is the percent recovery.

The percent recovery was computed by the equation:

$$PR = \frac{2.25 \times 10^7\ Q_m A_c}{W_d C_s}$$

where Q_m is the maximum discharge in the reach (ft^3/s),
A_c is the area under the time-concentration curve (µg/L x hr),
W_d is the weight of the dye solution injected (lb),
C_s is the concentration of the dye solution injected (µg/L),
(20×10^7 for WT 20 percent used in this study).

Table 1.--Data collection sites

Site number and name	latitude (deg-min-sec)	longitude (deg-min-sec)	Distance from mouth (miles)	Drainage area (miles^2)
1. Below Francis E. Walter Lake (at outlet)	41-06-35	75-43-26	77.0	289
- USGS gaging station 01447800, below Francis E. Walter Lake near White Haven	41-06-17	75-43-57	76.3	290
2. White Haven	41-03-40	75-46-19	71.9	*305
3. Tannery	41-02-19	75-45-42	70.1	322
4. Rockport	40-58-00	75-45-18	62.7	*421
5. Jim Thorpe	40-52-03	75-44-10	47.7	*556
6. Weiders Crossing	40-46-58	75-36-26	35.5	*888
- USGS gaging station 01451000, at Walnut-port (Index Station)	40-45-25	75-36-12	33.7	889
7. Coplay-Northampton	40-40-33	75-29-24	22.5	*977
- USGS gaging station 01453000, at Bethlehem	40-36-55	75-22-45	11.8	1,279
8. Bethlehem	40-36-54	75-22-44	11.8	1,279
- USGS gaging station 01454700, at Glendon	40-40-09	75-14-12	2.3	1,359
9. Easton	40-41-13	75-12-32	0.3	*1,360

*Estimated

Table 2.--Discharge and duration data for index gaging station 01451000, Lehigh River at Walnutport

Date	Average discharge in cubic feet per second	Percent of time discharge is equaled or exceeded
October 27-29, 1970	1,320	42
August 27-31, 1973	483	80
October 15-16, 1974	738	67
September 5-9, 1977	285	92

Traveltime data for all four runs are given in tables 3-5. Field measurements of time and relative concentrations were used to provide traveltimes in table 3, and time-concentration curves were used to provide traveltimes and concentration values in tables 4 and 5. Discharges were obtained either by current-meter measurements, use of current stage-discharge relations, or by computations based on drainage-area comparison. Stream distances were determined by measuring scaled distances on USGS topographic maps or reference to a Delaware River Basin Commission tabulation (written communication, May 5, 1967).

Graphical representation of traveltime-distance relations for each subreach of each run is presented in figures 3-10. Cumulative traveltime-distance relations for each run are given in figures 11-13. These also were developed from field readings of the 1970 run and time-concentration curves of all other runs.

Figures 14-16 relate leading edge, peak, and trailing edge cumulative traveltimes to discharge. The curves for leading edge and peak times were drawn 4 percent above the 1970 run plotted points (except White Haven and Jim Thorpe) to compensate for faster travel (shorter traveltimes) measured from injection point to sample point, as compared to sample point to sample point measurements, which are considered to be more representative of average traveltimes. Plotted points for the 1973 run are above the curves because the discharge of the upper part of the study reach was out of balance with that of the index gage at Walnutport. (Runoff per square mile much less at Francis E. Walter Lake.) A cutback in water released from Francis E. Walter Lake was not detected at the index station at Walnutport until several hours after injections. The traveltime error was carried to downstream sections because traveltimes as plotted are cumulative.

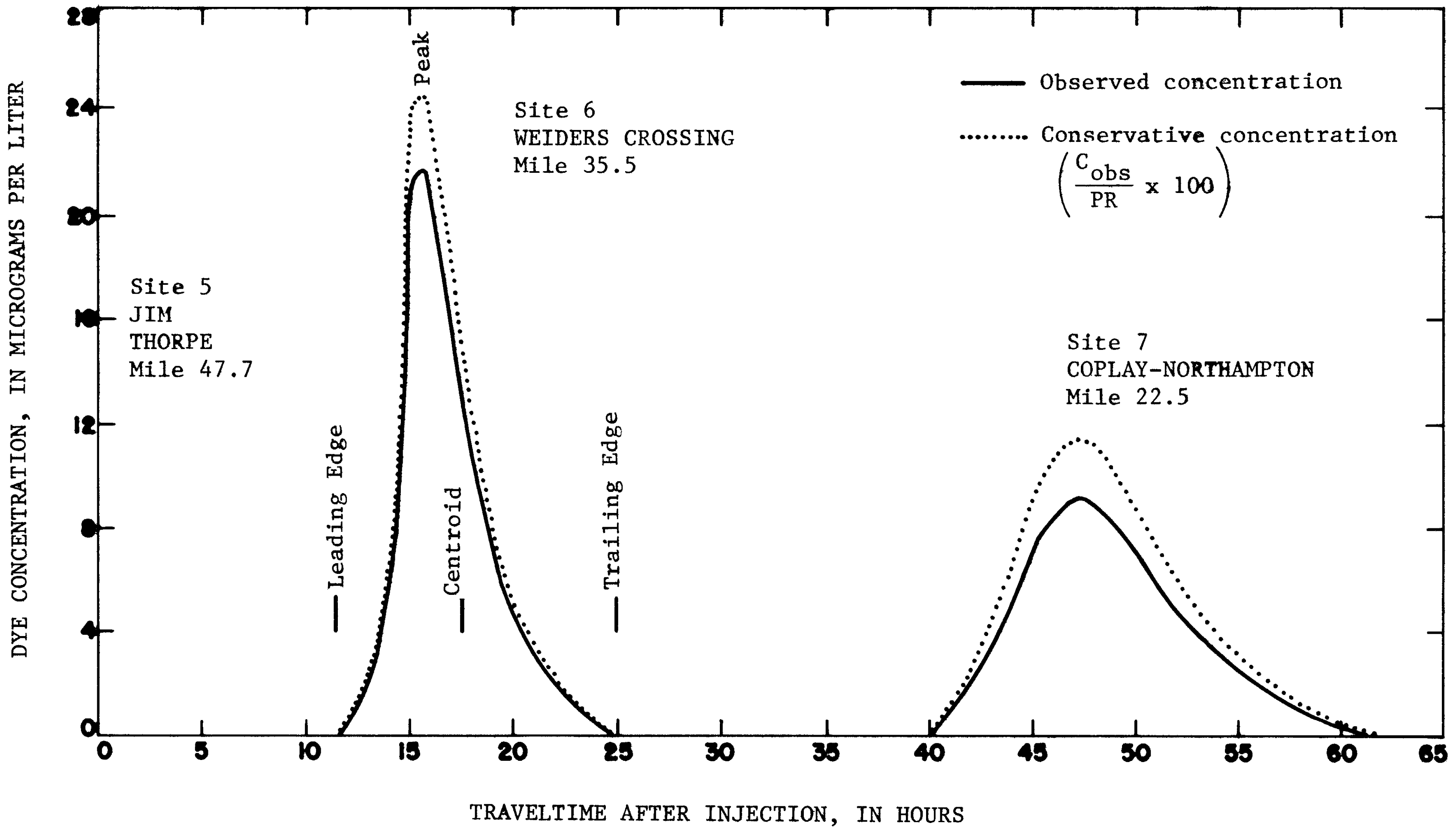


Figure 2.--Observed and conservative time-concentration curves for subreach C, Lehigh River. Injection of 61.4 pounds of Rhodamin WT, 20 percent solution, made at site 5, mile 47.7, at 2000 hours, August 27, 1973.

Table 3.--Traveltime, dispersion, and related data from the dye run of October 1970, on subreaches A through E of the Lehigh River

Site name	Site number	Distance from point of injection (mi)	Distance from mouth (mi)	Travel-time of leading edge (hr)	Cumulative travel-time of leading edge (hr)	Travel-time of peak (hr)	Cumulative travel-time of peak (hr)	Travel-time of centroid (hr)	Cumulative travel-time of centroid (hr)	Travel-time of trailing edge (hr)	Cumulative travel-time of trailing edge (hr)	Discharge at sampling site (ft^3/s)	Conservative peak concentration, Cp (µg/L)	Peak concentration produced by 1 lb of dye, C_p/W_d (1)	Unit peak concentration $C_p \cdot Q_m/W_d$ (2)	Time of passage of dye cloud (hr)
F.E. Walter	1	0	77.0	Subreach A - Injected 16.00 lb WT dye at 1445 hr, October 27, 1970. Discharge at Walnutport: 1,410 ft^3/s												
White Haven	2	5.1	71.9	4.6	4.6	5.9	5.9	--	--	11.9	11.9	308	--	--	--	7.3
Jim Thorpe	5	29.3	47.7	25.8	25.8	29.6	29.6	--	--	41.2	41.2	796	--	--	--	15.4
Jim Thorpe	5	0	47.7	Subreach B - Injected 5.00 lb WT dye at 0015 hr, October 28, 1970. Discharge at Walnutport: 1,300 ft^3/s												
Weiders Crossing	6	12.2	35.5	8.4	34.2	9.5	39.1	--	--	15.4	56.6	1320	--	--	--	7.0
Weiders Crossing	6	0	35.5	Subreach C - Injected 5.00 lb WT dye at 2305 hr, October 27, 1970. Discharge at Walnutport: 1,300 ft^3/s												
Coplay	7	13.0	22.5	12.3	46.5	13.7	52.8	--	--	21.2	77.8	1430	--	--	--	8.9
Coplay	7	0	22.5	Subreach D - Injected 6.40 lb WT dye at 0020 hr, October 28, 1970. Discharge at Walnutport: 1,300 ft^3/s												
Bethlehem	8	10.7	11.8	10.8	57.3	11.9	64.7	--	--	18.7	96.5	2200	--	--	--	7.9
Bethlehem	8	0	11.8	Subreach E - Injected 8.00 lb WT dye at 0145 hr, October 28, 1970. Discharge at Walnutport: 1,300 ft^3/s												
Easton	9	11.5	0.3	8.6	65.9	9.6	74.3	--	--	17.1	113.6	2340	--	--	--	8.5

1 $\frac{\text{Micrograms per liter}}{\text{pound}}$

2 $\frac{\text{Micrograms per liter x cubic feet per second}}{\text{pound}}$

Table 4. —Traveltime, dispersion, and related data from the dye runs of August 1973, and October 1974, for subreaches A through D of the Lehigh River

Site name	Site number	Distance from point of injection (mi)	Distance from mouth (mi)	Travel-time of leading edge (hr)	Cumulative travel-time of leading edge (hr)	Travel-time of peak (hr)	Cumulative travel-time of peak (hr)	Travel-time of centroid (hr)	Cumulative travel-time of centroid (hr)	Travel-time of trailing edge (hr)	Cumulative travel-time of trailing edge (hr)	Discharge at sampling site (ft^3/s)	Conservative peak concentration, Cp (µg/L)	Peak concentration produced by 1 lb of dye, C_p/W_d (1)	Unit peak concentration $C_p \cdot Q_m/W_d$ (2)	Time of passage of dye cloud (hr)
F.E. Walter	1	0	77.0	Subreach A - Injected 8.00 lb WT dye at 1900 hr, August 27, 1973. Discharge at Walnutport: 483 ft^3/s												
White Haven	2	5.1	71.9	13.8	13.8	17.7	17.7	19.1	19.1	30.0	30.0	58.0	124	15.5	899	16.2
Jim Thorpe	5	29.3	47.7	57.5	57.5	65.5	65.5	68.1	68.1	80.2	80.2	280	10.5	1.31	368	22.7
Rockport	4	0	62.7	Subreach B - Injected 8.00 lb WT dye at 1740 hr, August 27, 1973. Discharge at Walnutport: 483 ft^3/s												
Jim Thorpe	5	15.0	47.7	16.2	57.5	20.3	65.5	21.6	68.1	31.2	80.2	318	22.5	2.81	894	15.0
Weiders Crossing	6	27.2	35.5	32.4	73.7	37.8	83.0	39.3	85.8	50.0	99.0	483	9.51	1.19	574	17.6
Jim Thorpe	5	0	47.7	Subreach C - Injected 12.28 lb WT dye at 2000 hr, August 27, 1973. Discharge at Walnutport: 483 ft^3/s												
Weiders Crossing	6	12.2	35.5	13.0	73.7	15.8	83.0	17.0	85.8	24.8	99.0	520	24.6	2.00	1,040	11.8
Coplay	7	25.2	22.5	39.9	100.6	47.2	114.4	48.7	117.5	62.1	136.3	508	11.4	0.93	472	22.2
Weiders Crossing	6	0	35.5	Subreach D - Injected 9.58 lb WT dye at 1910 hr, August 27, 1973. Discharge at Walnutport: 483 ft^3/s												
Coplay	7	13.0	22.5	24.2	100.6	28.4	114.4	30.5	117.5	40.5	136.3	618	12.2	1.27	787	16.3
Bethlehem	8	23.7	11.8	47.3	123.7	56.4	142.4	58.5	145.5	71.3	167.1	850	4.31	0.45	382	24.0
F.E. Walter	1	0	77.0	Subreach A - Injected 6.40 lb WT dye at 1535 hr, October 15, 1974. Discharge at Walnutport: 738 ft^3/s												
White Haven	2	5.1	71.9	7.3	7.3	9.1	9.1	10.1	10.1	18.4	18.4	150	67.7	10.6	1,590	11.1
Coplay	7	0	22.5	Subreach E - Injected 10.00 lb WT dye at 1610 hr, October 15, 1974. Discharge at Walnutport: 738 ft^3/s												
Bethlehem	8	10.7	11.8	16.7	16.7	18.5	18.5	19.5	19.5	25.0	25.0	1,500	--	--	--	8.3

[1] $\frac{\text{Micrograms per liter}}{\text{pound}}$

[2] $\frac{\text{Micrograms per liter x cubic feet per second}}{\text{pound}}$

Table 5.—Traveltime, dispersion, and related data from the dye run of September 1977, on subreaches A through E of the Lehigh River

Site name	Site number	Distance from point of injection (mi)	Distance from mouth (mi)	Travel-time of leading edge (hr)	Cumulative travel-time of leading edge (hr)	Travel-time of peak (hr)	Cumulative travel-time of peak (hr)	Travel-time of centroid (hr)	Cumulative travel-time of centroid (hr)	Travel-time of trailing edge (hr)	Cumulative travel-time of trailing edge (hr)	Discharge at sampling site (ft^3/s)	Conservative peak concentration, Cp (μg/L)	Peak concentration produced by 1 lb of dye C_p/W_d (1)	Unit peak concentration $C_p \cdot Q_m/W_d$ (2)	Time of passage of dye cloud (hr)
F.E. Walter	1	0	77.0	Subreach A - Injected 5.80 lb WT dye at 1635 hr, September 6, 1977. Discharge at Walnutport: 285 ft^3/s												
White Haven	2	5.1	71.9	--	--	--	--	--	--	--	--	--	--	--	--	--
Tannery	3	6.9	70.1	22.5	22.5	24.2	24.2	26.5	26.5	36.5	36.5	73.3	96.3	16.6	1,220	14.0
Jim Thorpe	5	29.3	47.7	65.6	65.6	79.9	79.9	82.8	82.8	106.0	106.0	172	10.2	1.76	302	40.4
Rockport	4	0	62.7	Subreach B - Injected 7.80 lb WT dye at 1550 hr, September 6, 1977. Discharge at Walnutport: 285 ft^3/s												
Jim Thorpe	5	15.0	47.7	21.2	65.6	26.5	79.9	28.3	82.8	43.5	106.0	180	--	--	--	22.3
Weiders Crossing	6	27.2	35.5	43.2	87.6	52.8	106.2	55.5	110.0	72.5	135.0	280	--	--	--	29.3
Jim Thorpe	5	0	47.7	Subreach C - Injected 5.80 lb WT dye at 1655 hr, September 6, 1977. Discharge at Walnutport: 285 ft^3/s												
Weiders Crossing	6	12.2	35.5	15.6	87.6	19.2	106.2	22.0	110.0	41.0	135.0	280	--	--	--	25.4
Coplay	7	25.2	22.5	54.0	126.0	70.6	157.6	72.9	160.9	94.0	188.0	300	--	--	--	40.0
Weiders Crossing	6	0	35.5	Subreach D - Injected 5.00 lb WT dye at 1610 hr, September 5, 1977. Discharge at Walnutport: 285 ft^3/s												
Coplay	7	13.0	22.5	38.7	126.0	45.3	157.6	47.6	160.9	61.0	188.0	350	6.49	1.30	454	22.3
Bethlehem	8	23.7	11.8	68.0	155.3	83.0	195.3	85.1	198.4	109.6	236.6	573	2.25	0.45	258	41.6
Coplay	7	0	22.5	Subreach E - Injected 10.00 lb WT dye at 1720 hr, September 5, 1977. Discharge at Walnutport: 285 ft^3/s												
Bethlehem	8	10.7	11.8	28.0	155.3	34.8	195.3	37.6	198.4	54.0	236.6	573	—	--	--	26.0
Easton	9	22.2	0.3	63.2	190.5	76.5	237.0	79.5	240.3	102.0	284.6	748	--	--	--	38.8

[1] $\frac{\text{Micrograms per liter}}{\text{pound}}$

[2] $\frac{\text{Micrograms per liter x cubic feet per second}}{\text{pound}}$

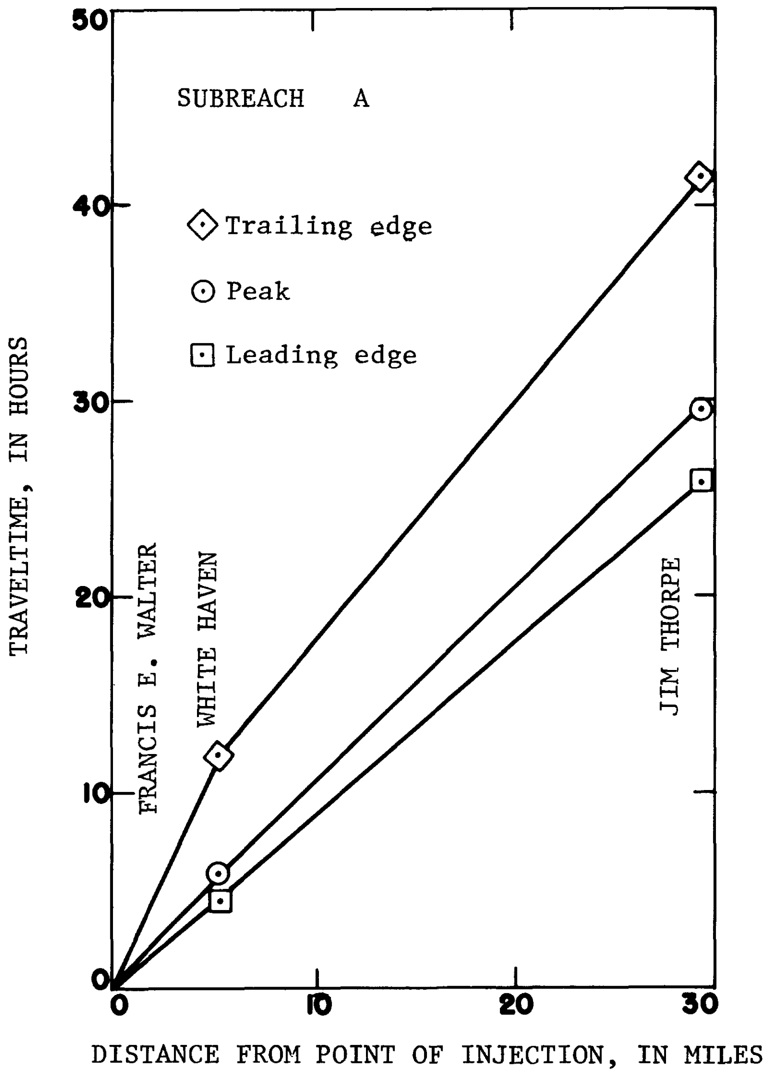


Figure 3.--Traveltime-distance relations for subreach A, Lehigh River, October 27-29, 1970. Discharge at Walnutport averaged 1,410 cubic feet per second.

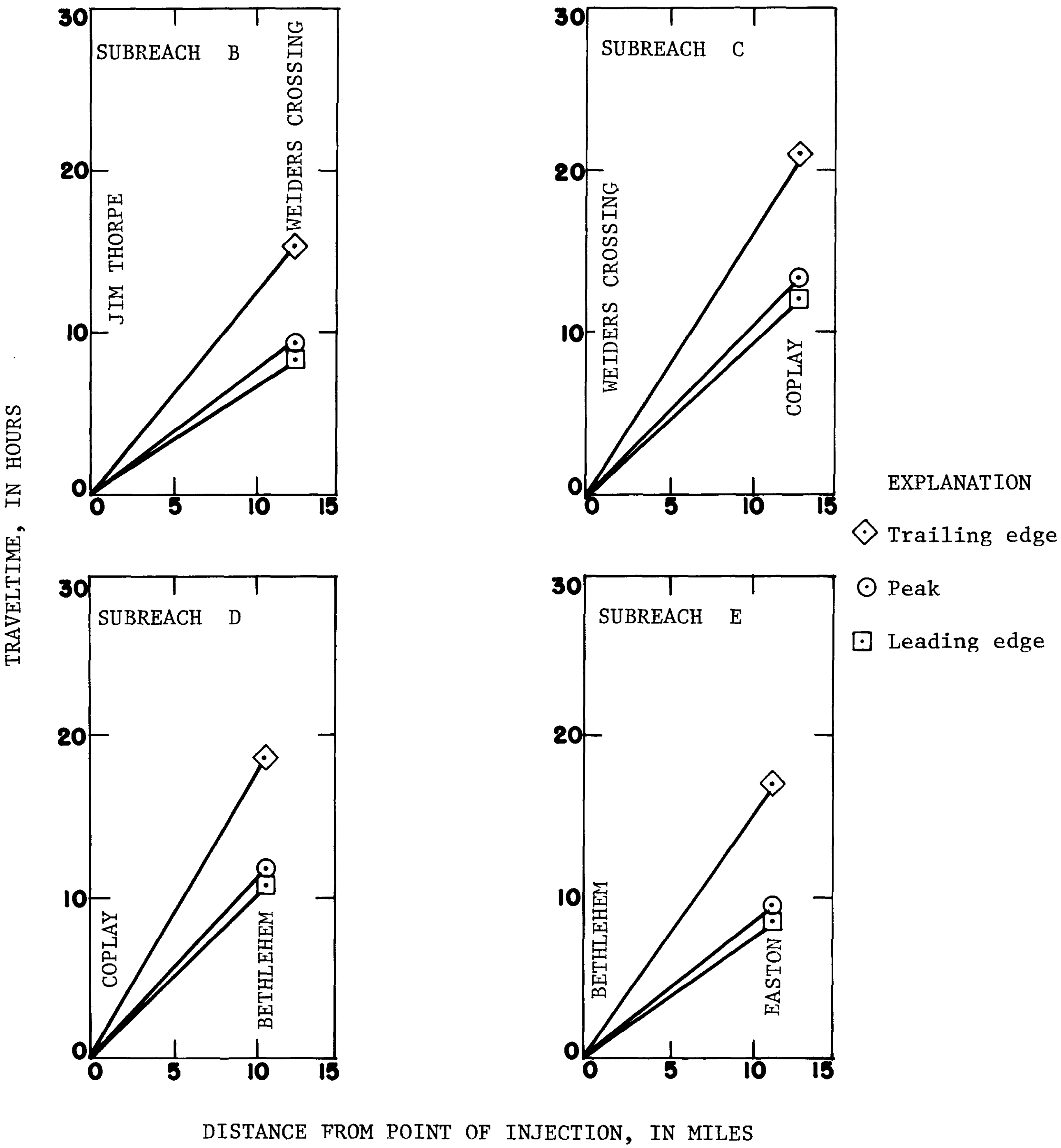


Figure 4.--Traveltime-distance relations for subreaches B, C, D, and E, Lehigh River, October 27-29, 1970. Discharge at Walnutport averaged 1,300 cubic feet per second.

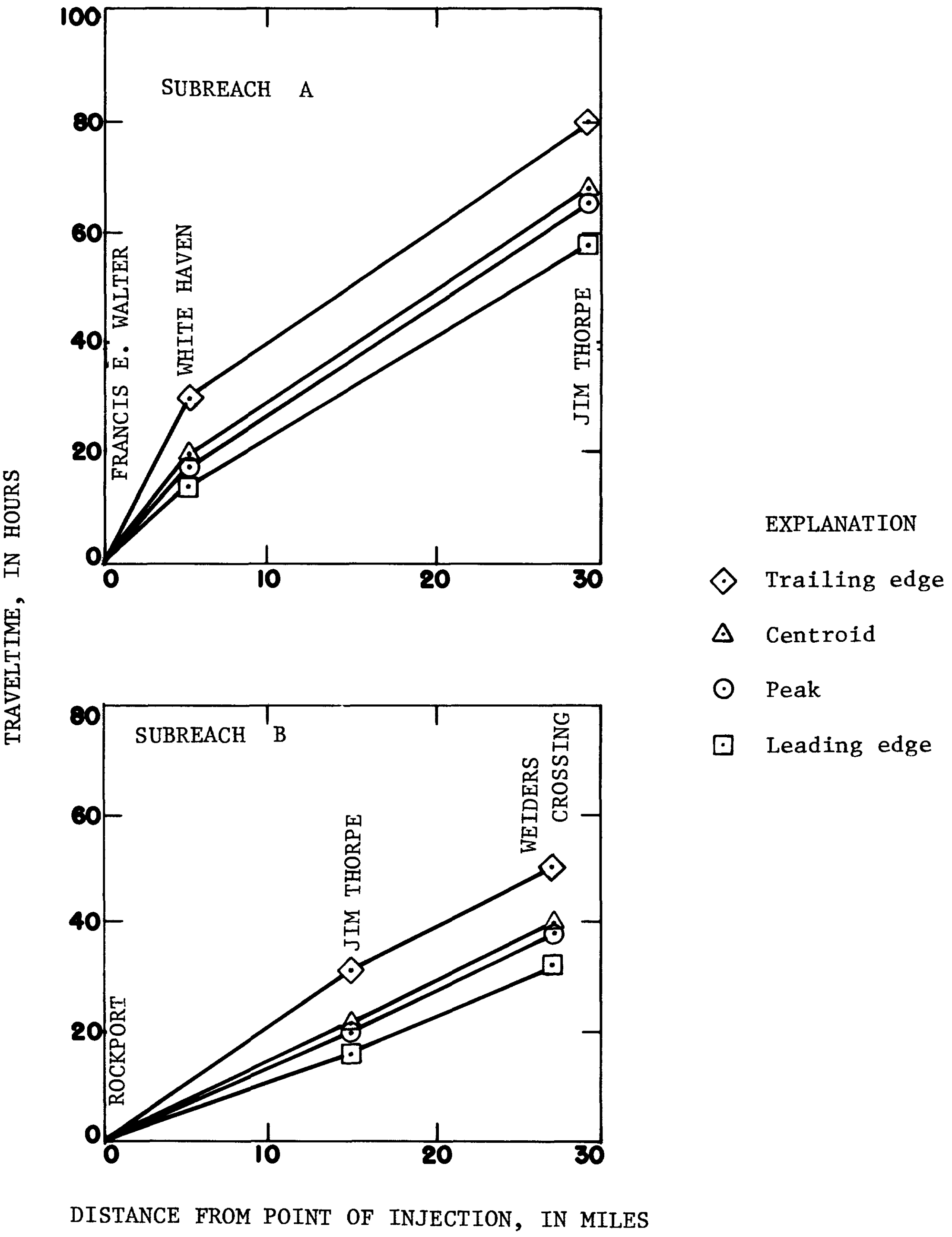


Figure 5.--Traveltime-distance relations for subreaches A and B, Lehigh River, August 27-30, 1973. Discharge at Walnutport averaged 483 cubic feet per second.

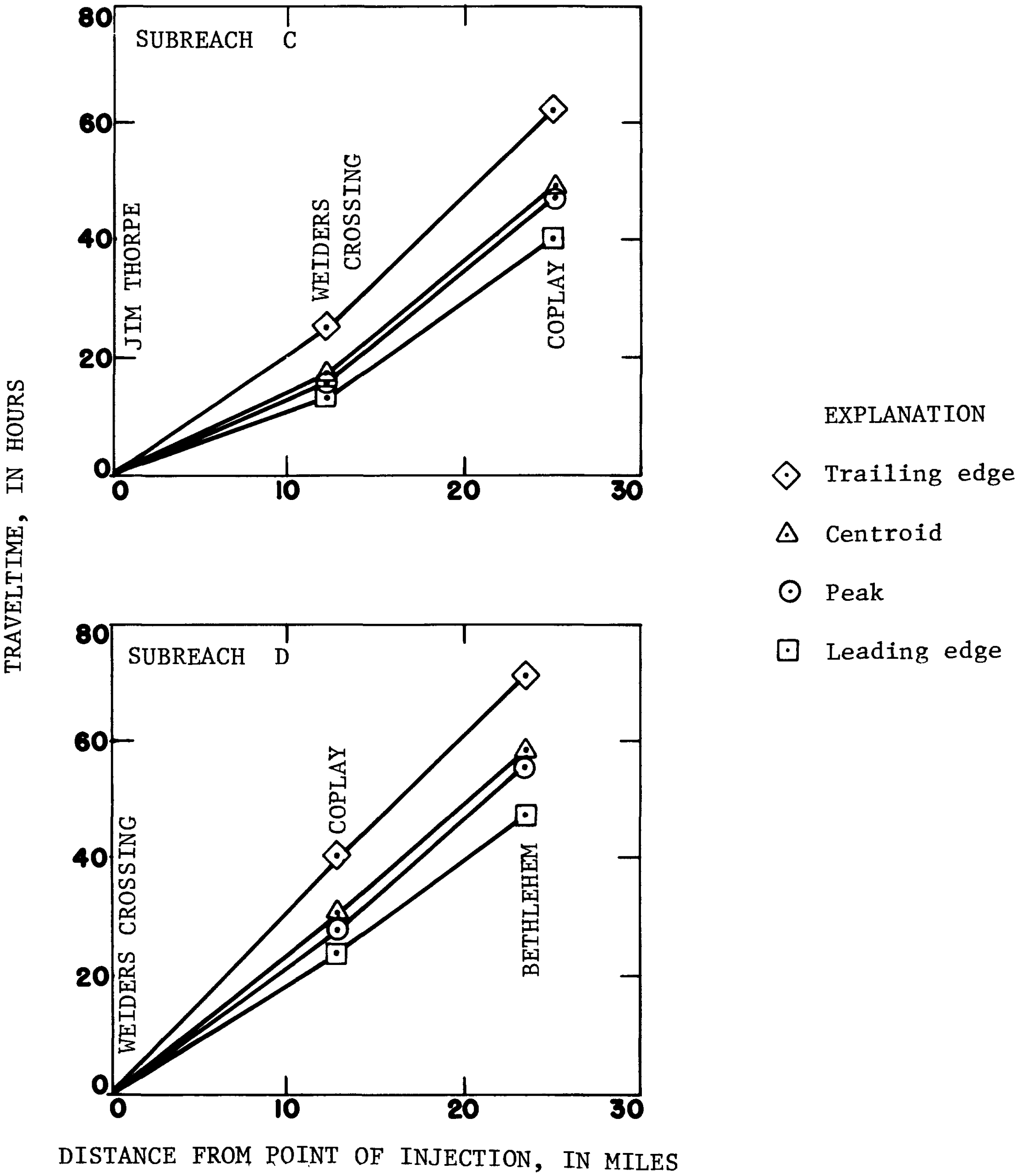


Figure 6.--Traveltime-distance relations for subreaches C and D, Lehigh River, August 27-30, 1973. Discharge at Walnutport averaged 483 cubic feet per second.

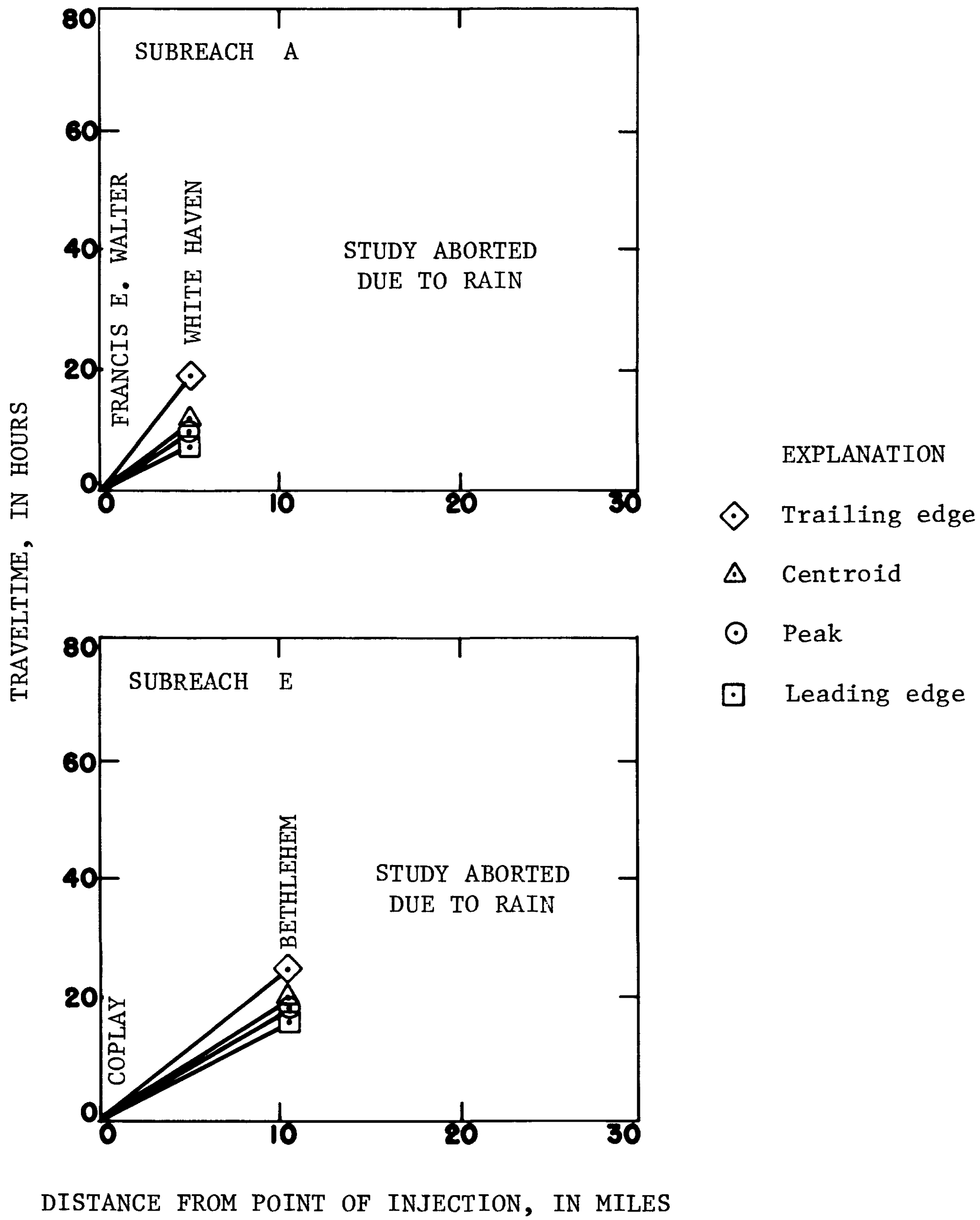


Figure 7.--Traveltime-distance relations for subreaches A and E, Lehigh River, October 15, 1974. Discharge at Walnutport averaged 738 cubic feet per second.

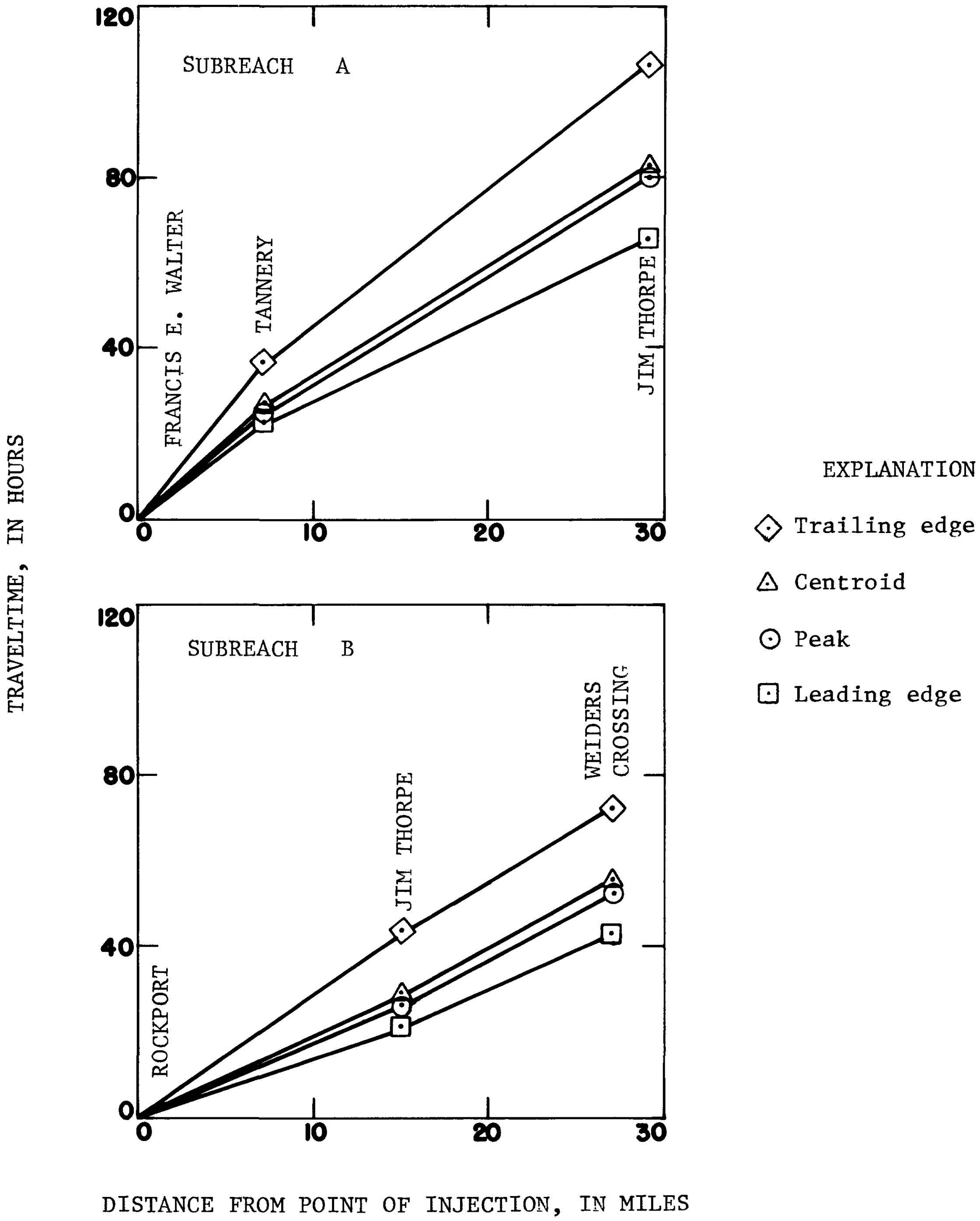


Figure 8.--Traveltime-distance relations for subreaches A and B, Lehigh River, September 6-10, 1977. Discharge at Walnutport averaged 285 cubic feet per second.

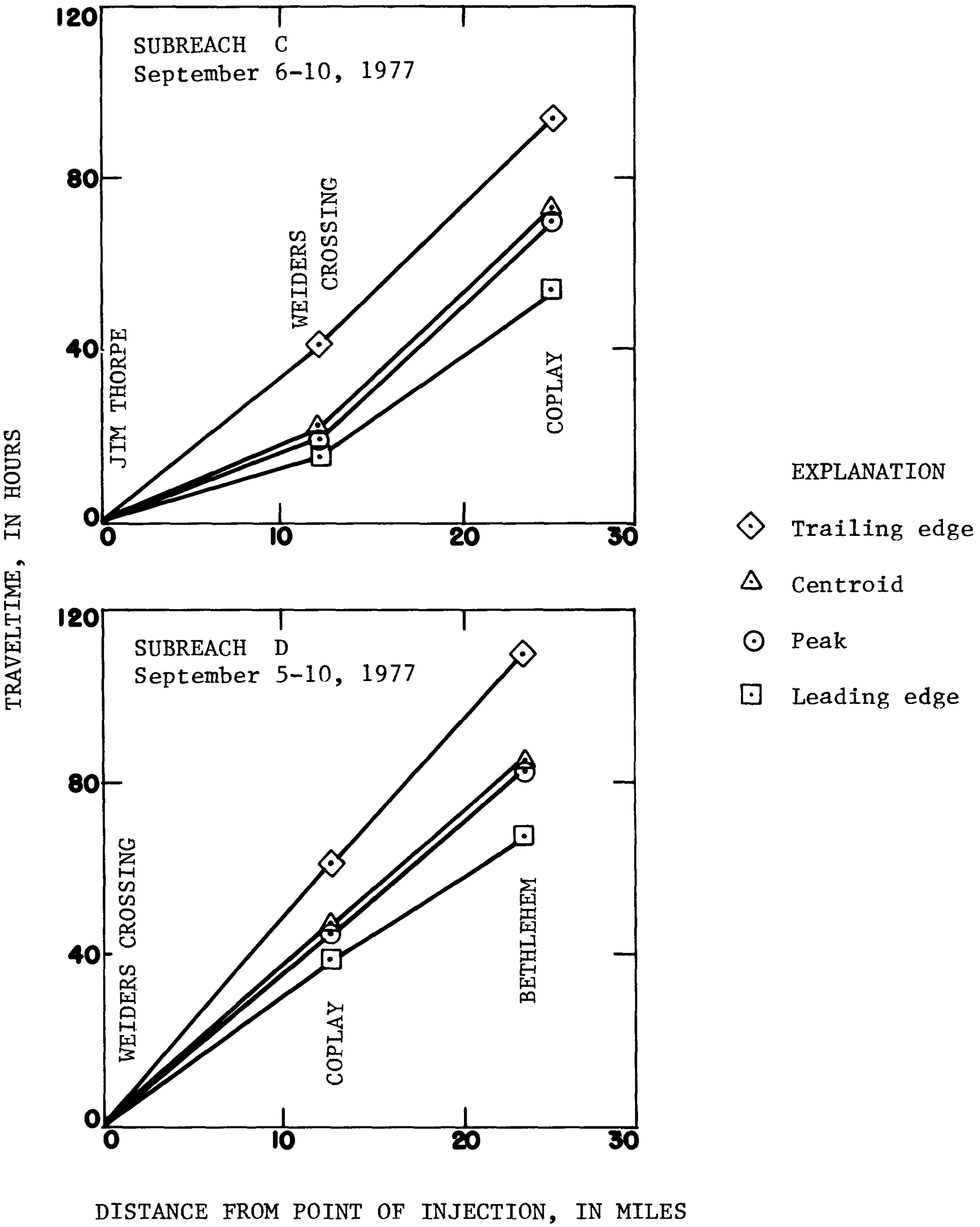


Figure 9.--Traveltime-distance relations for subreaches C and D, Lehigh River. Discharge at Walnutport averaged 285 cubic feet per second.

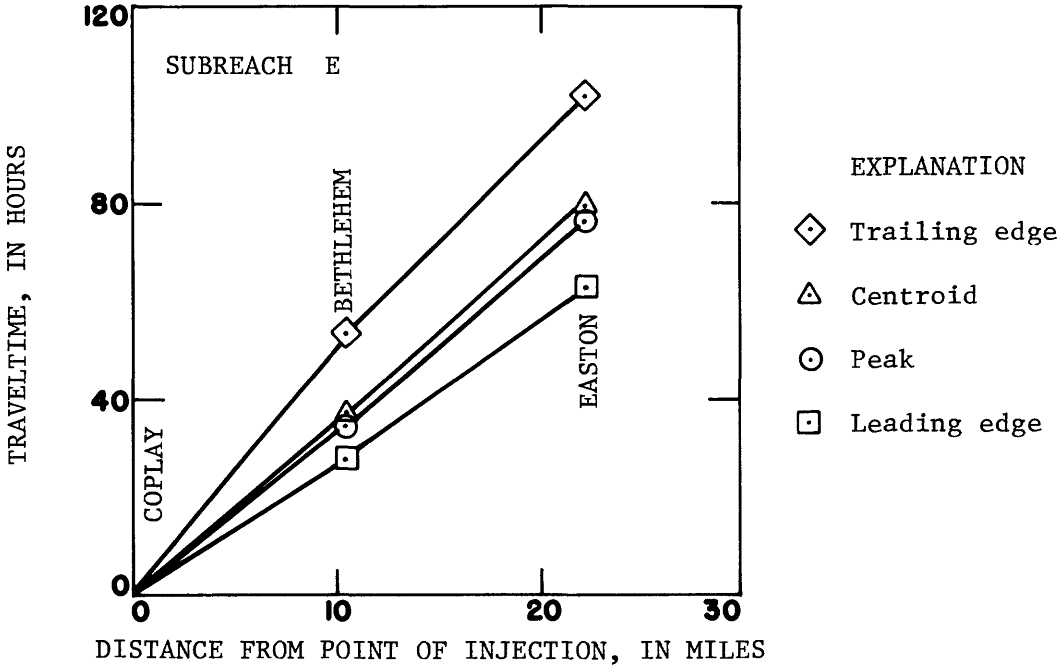


Figure 10.--Traveltime-distance relations for subreach E, Lehigh River, September 5-10, 1977. Discharge at Walnutport averaged 285 cubic feet per second.

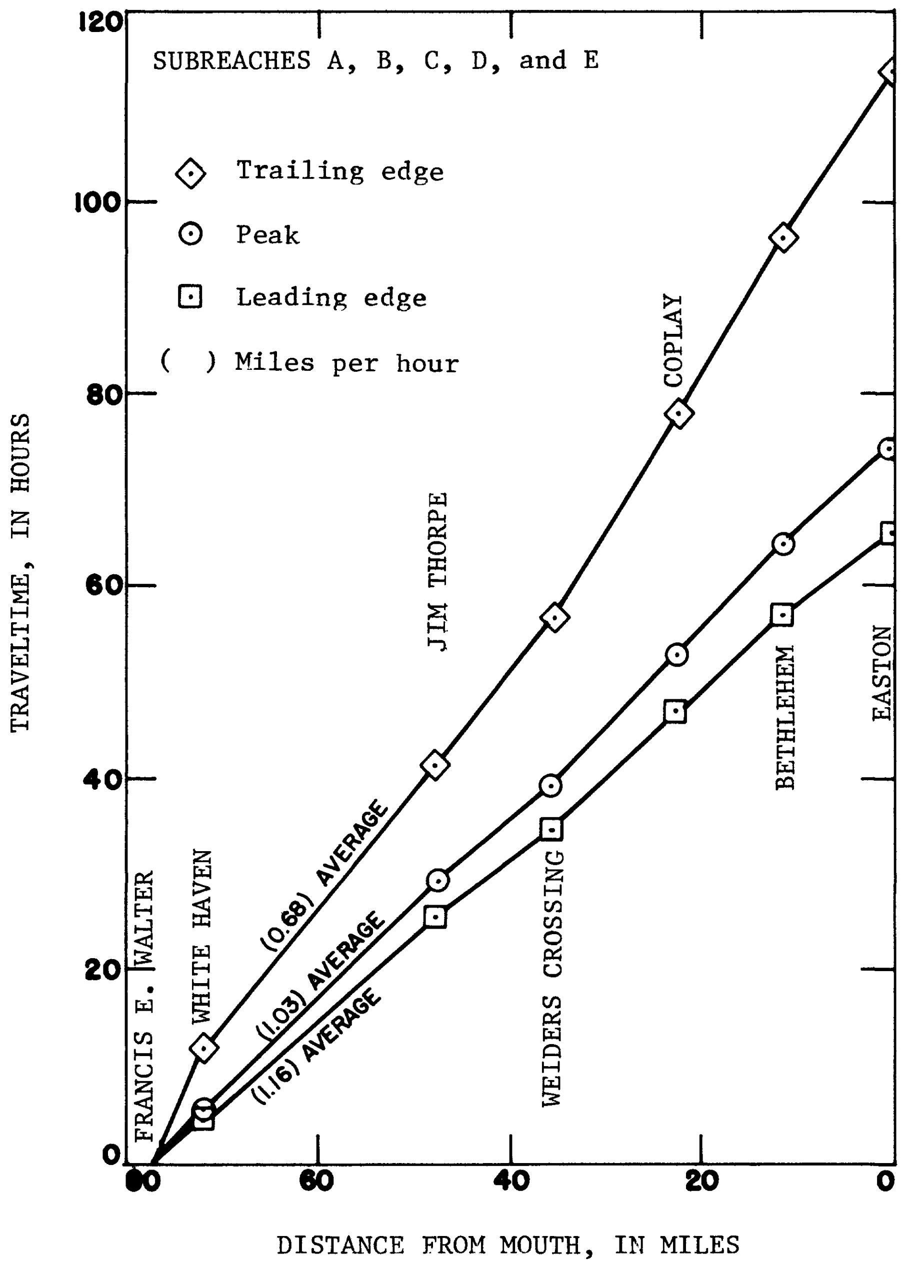


Figure 11.--Traveltime-distance relations for Lehigh River. October 27-29, 1970. Discharge at Walnutport averaged 1,320 cubic feet per second.

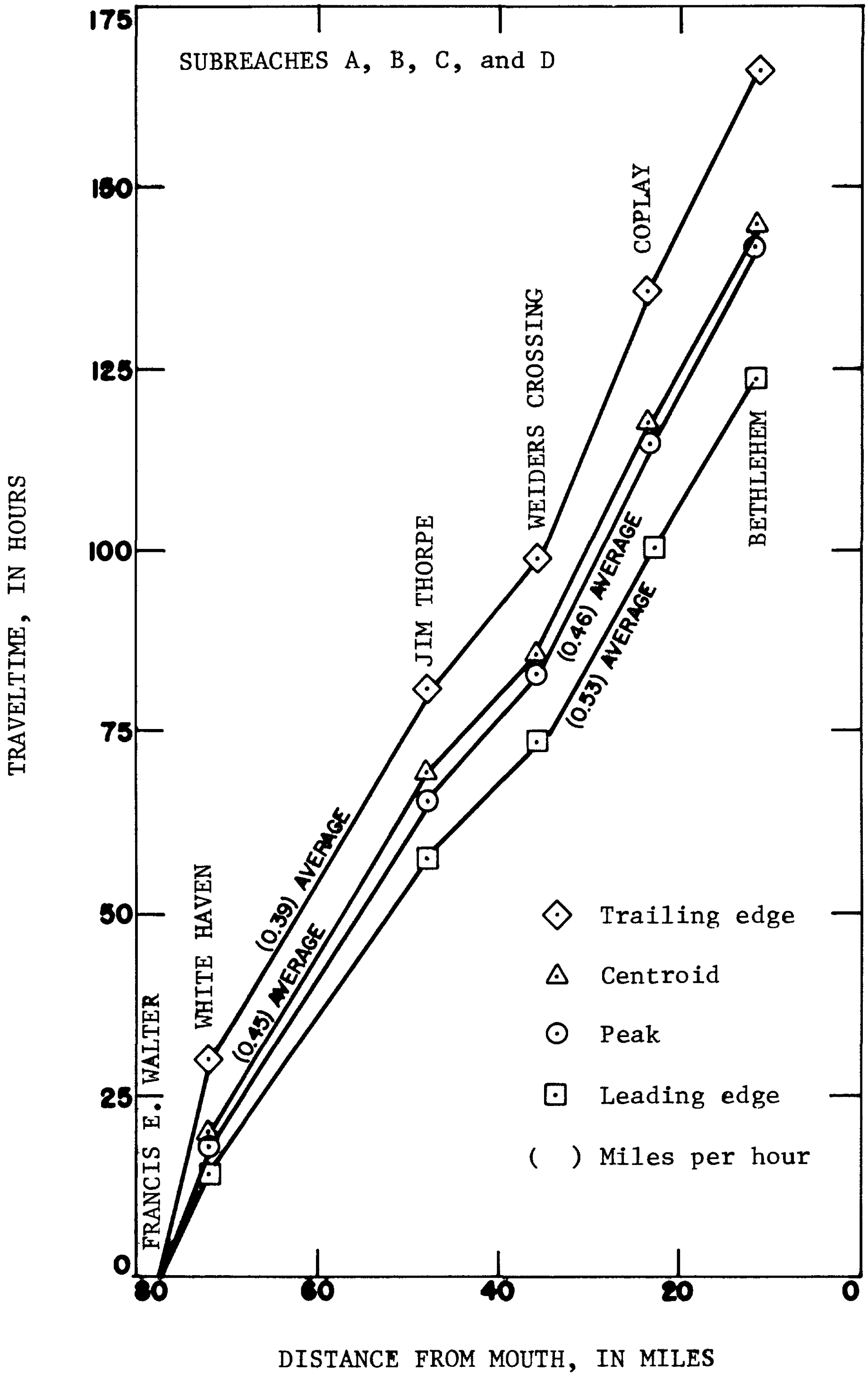


Figure 12.--Traveltime-distance relations for Lehigh River, August 27-30, 1973. Discharge at Walnutport averaged 483 cubic feet per second.

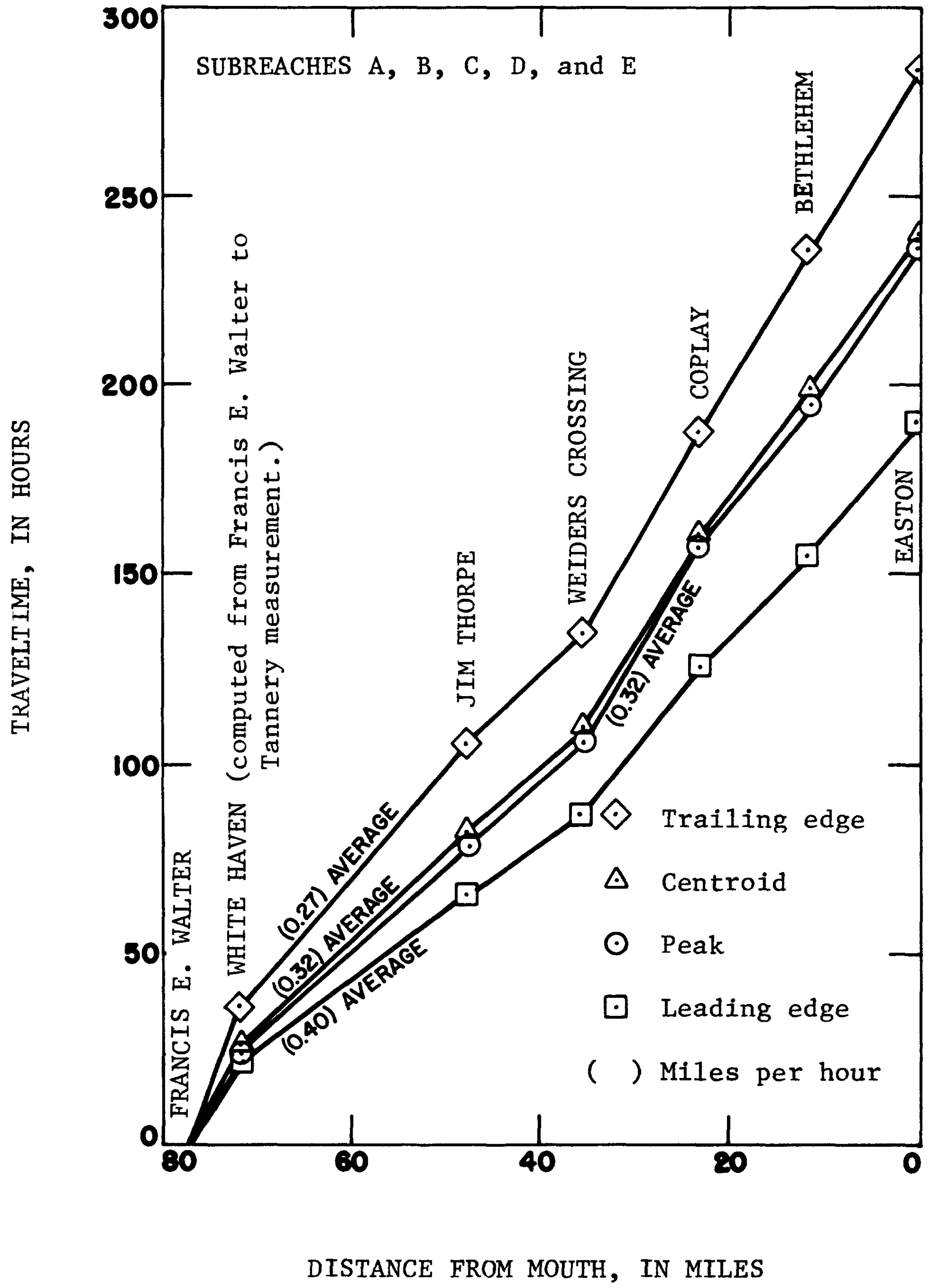


Figure 13.--Traveltime-distance relations for Lehigh River, September 5-10, 1977. Discharge at Walnutport averaged 285 cubic feet per second.

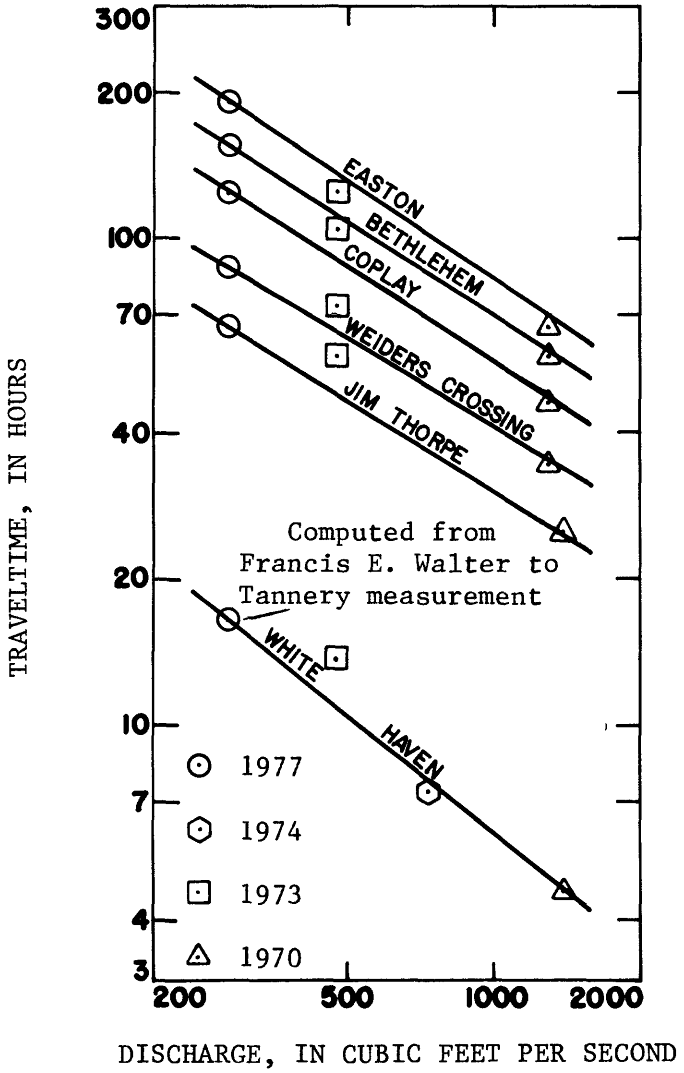


Figure 14.--Traveltime of leading edge versus discharge at Walnutport.

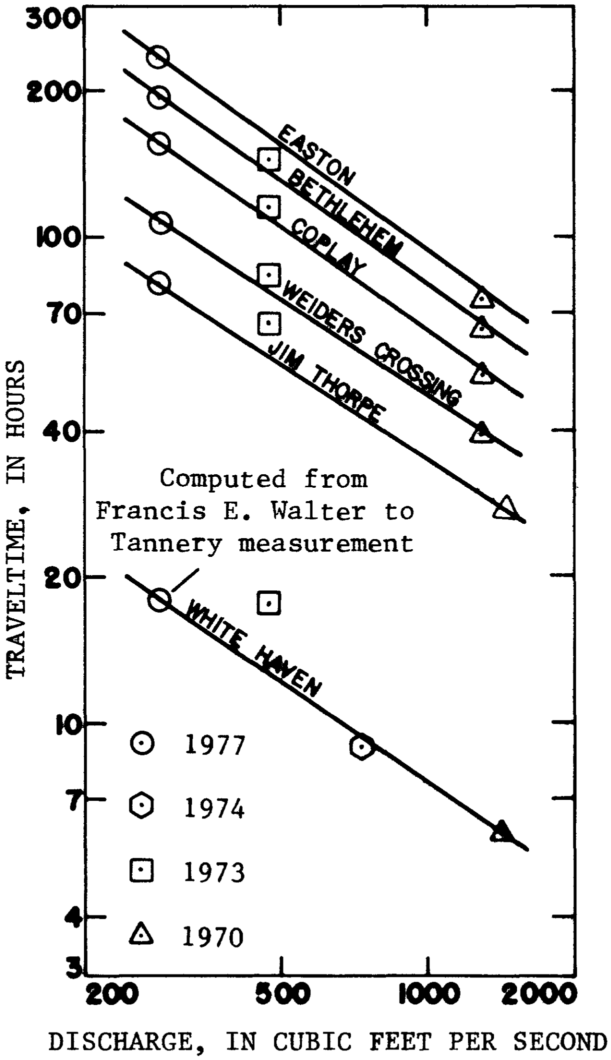


Figure 15.--Traveltime of peak concentration versus discharge at Walnutport.

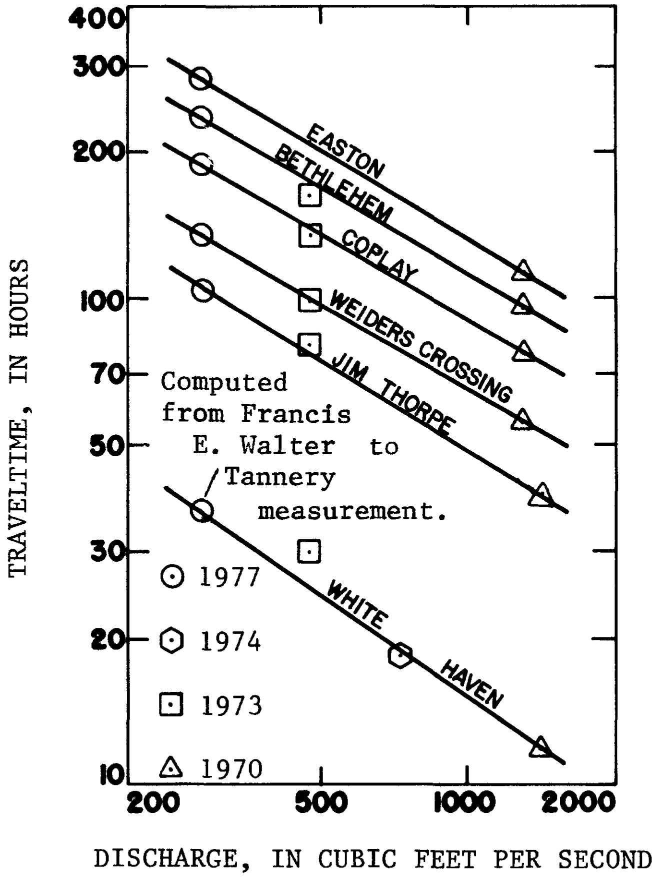


Figure 16.--Traveltime of trailing edge versus discharge at Walnutport.

Figures 17-19 relate cumulative traveltimes of leading edge, peak, and trailing edge of dye cloud to distance for a variety of discharges both observed and computed. The plot of the 1973 run is not in good alignment with other runs because of the imbalance of discharges as mentioned above. Figure 20 relates unit peak concentrations, in micrograms per liter, times cubic feet per second per pound, to traveltime of peak (table 4 and 5). The concept of unit concentration was formulated (Hubbard and others, 1982, p. 34) to expose longitudinal dispersion as related to traveltime of peak. By adjusting time-concentration curves to offset (1) the amount of dye injected, (2) the losses undergone by the dye, and (3) the discharge that serves to dilute the dye cloud in the reach, one can show a relation between unit concentration and traveltime of peak that provides insight as to how longitudinal dispersion is affected by different flow rates.

The 1977 data were given reduced weight in determining the relation in Figure 20 because computed percent recovery values exceeded 100 for some of the sample sites.

USE OF TIME-OF-TRAVEL AND DISPERSION DATA

In addition to providing accurate measurements of time-of-travel for use in water quality models, information can be used to predict arrival, peak, and trailing edge traveltimes, and peak concentration of a water-soluble substance released or spilled upstream. This is demonstrated in the sample problems below:

Problem number 1:

Suppose 2,200 lb of a water-soluble conservative contaminant were spilled into the Lehigh River at a known time at the railroad crossing at Penn Haven Junction at Black Creek 6.1 miles downstream from the Rockport study site. When would the contaminant arrive at the intakes of the Northampton Borough filtration plant, 2.5 miles upstream from the Coplay study site? When would the peak concentration and the trailing edge arrive and what would be the peak concentration?

Solution:

Call the National Oceanic and Atmospheric Administration (NOAA) River Forecast Center (RFC) in Harrisburg and request the current discharge for the index gage at Walnutport. NOAA/RFC is listed under United States Government, Department of Commerce, the office is open 24 hours a day. Assume discharge given is 600 ft^3/s.

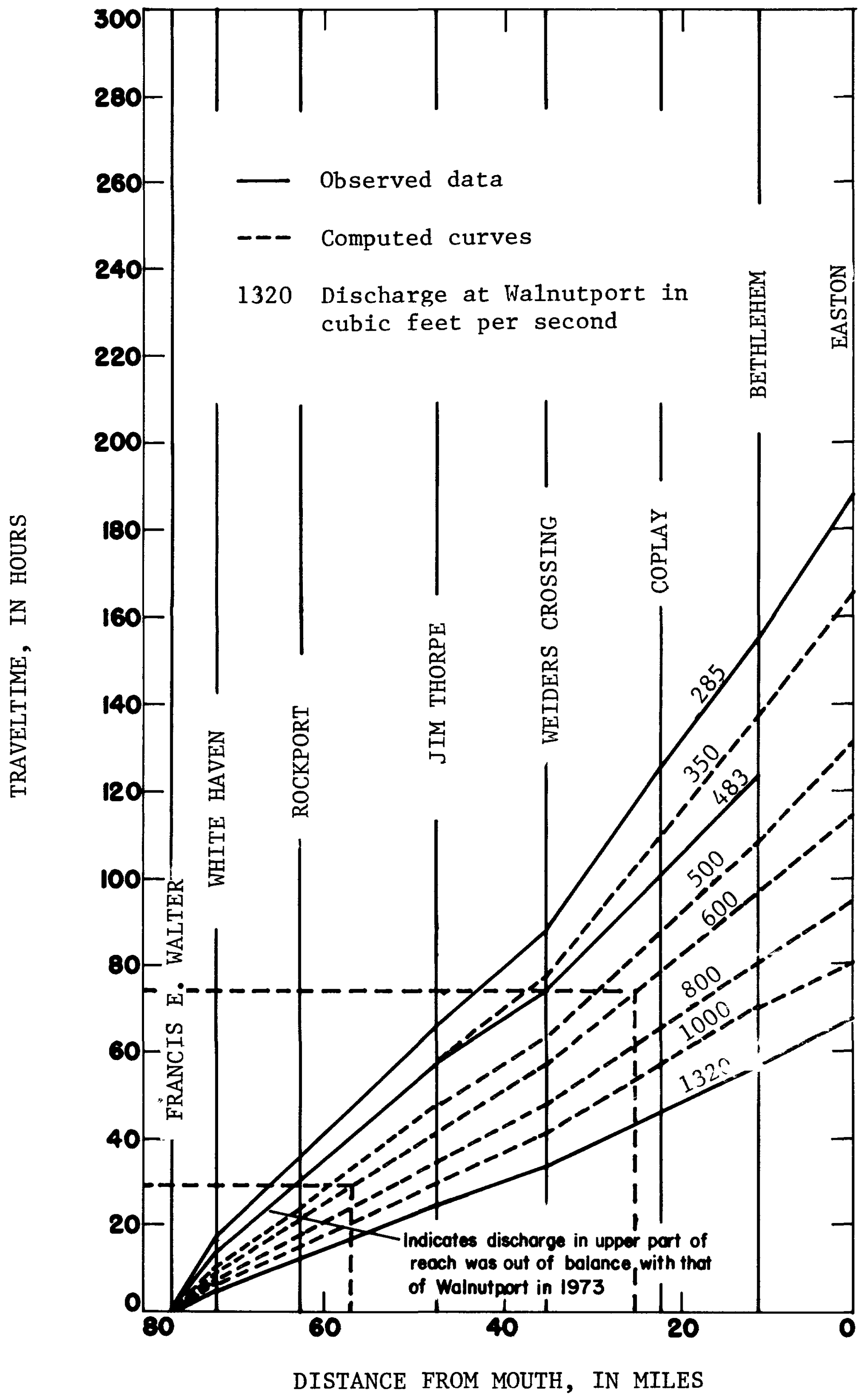


Figure 17.--Traveltime-distance relations of leading edge, Lehigh River.

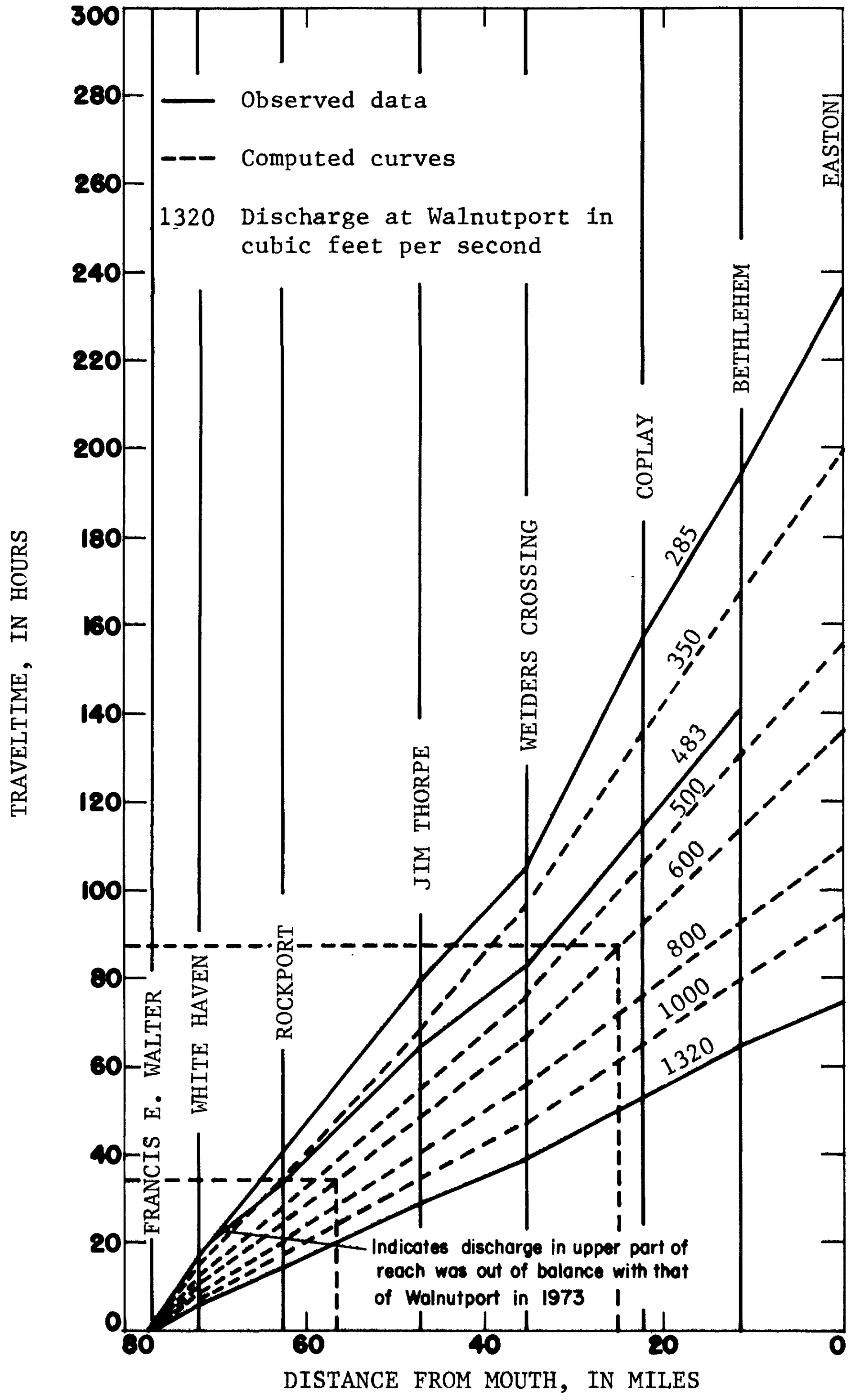


Figure 18.--Traveltime-distance relations of peak, Lehigh River.

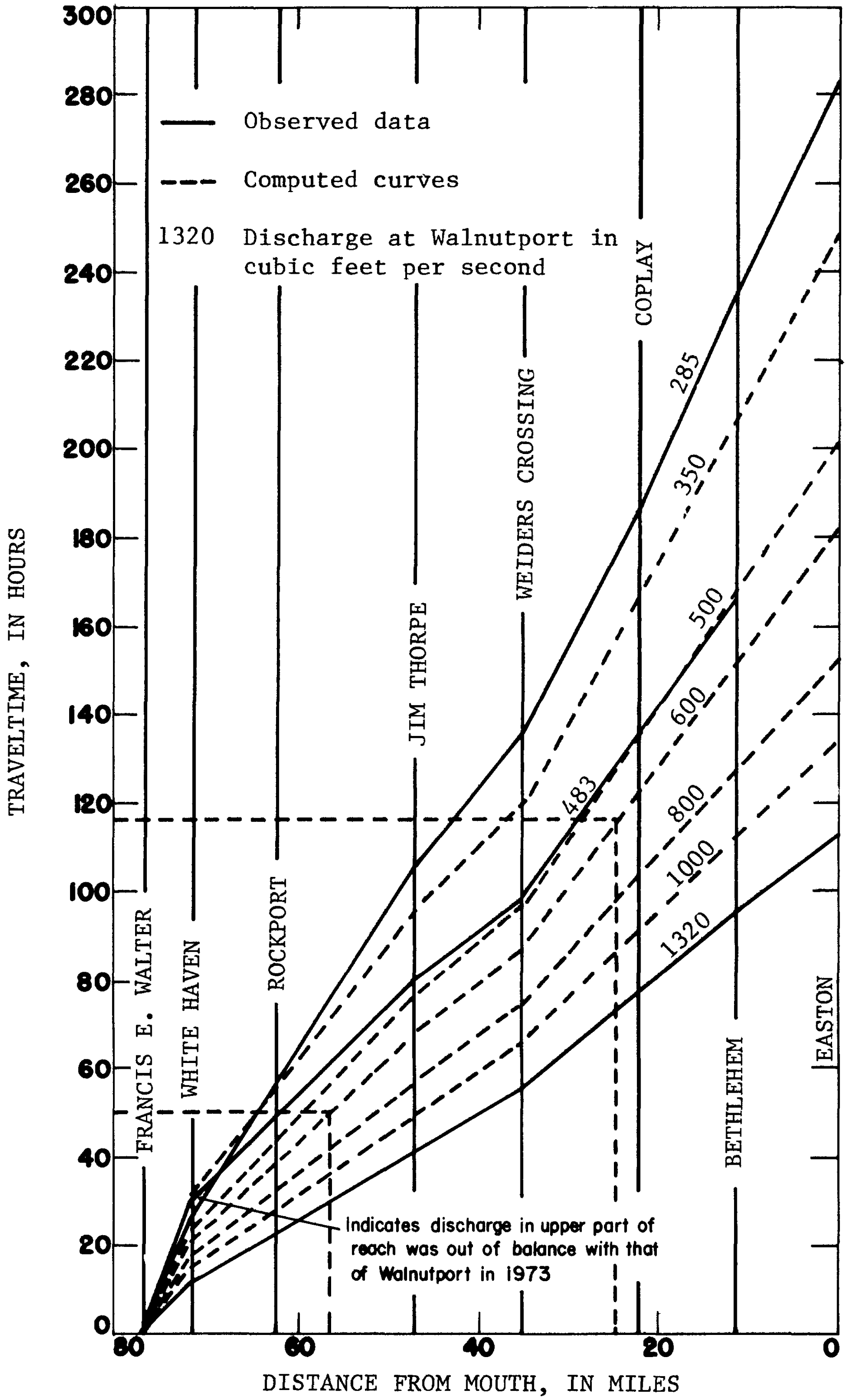


Figure 19.--Traveltime-distance relations of trailing edge, Lehigh River.

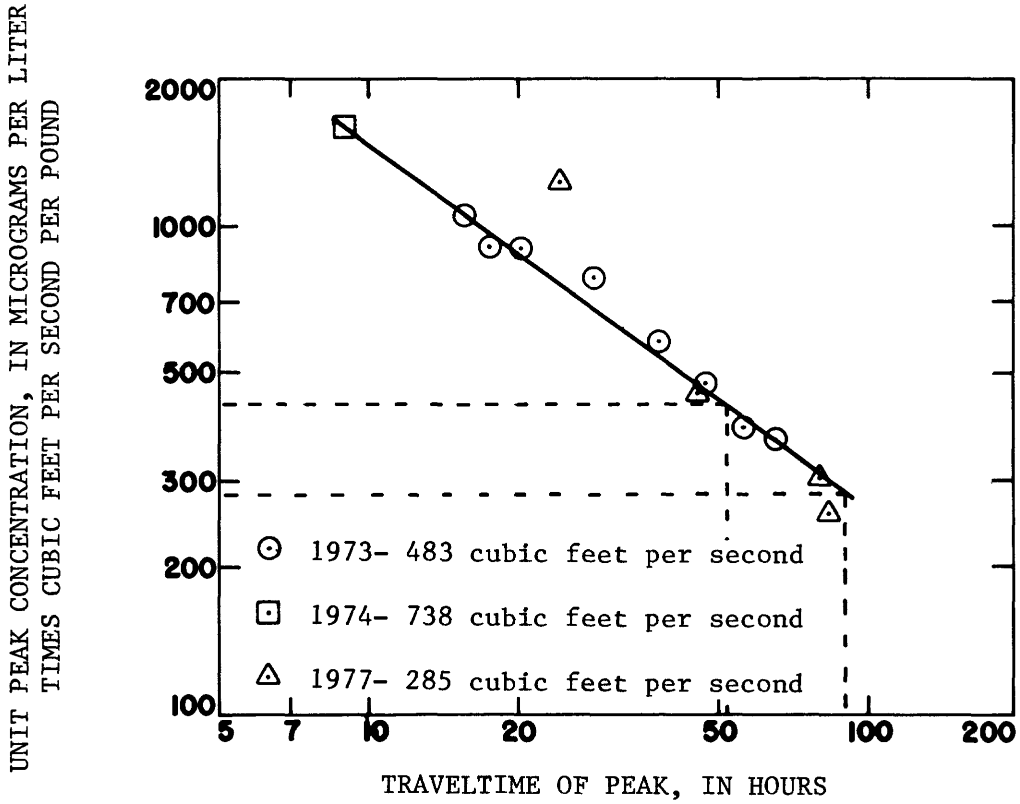


Figure 20.--Attenuation of unit peak concentration with traveltime.

Refer to figure 17 and obtain arrival time of 43 hrs after spill (74 hrs-31 hrs). Refer to figures 18 and 19 and obtain arrival time of peak to be 52 hrs and trailing edge 66 hrs.

Refer to figure 20 and obtain value of $\frac{428\ \mu/L \times ft^3/s}{lb}$ for peak traveltime of 52 hrs.

Refer to table 1 and determine drainage area at index station to be 889 mi^2 and estimate drainage area at Northampton Borough filtration plant intakes to be 964 mi^2. Multiply index station discharge by drainage-area ratio to get maximum discharge in reach in question:

$$600\ ft^3/s \times \frac{964\ mi^2}{889\ mi^2} = 651\ ft^3/s$$

Multiply $\frac{428\ \mu g/L \times ft^3/s}{lb}$ by 2,200 lb (amount of spill) and divide by 651 ft^3/s (discharge at intakes) and obtain value 1,450 µg/L (1,450 parts per billion).

The above computations represent an estimate of expected maximum concentration of a conservative contaminant, and, as all contaminants have some rate of decay, absorption, or adsorption, the actual peak concentration measured at the filtration plant intake site would probably be somewhat less than that computed by the above method.

Problem number 2:

Assume the same situation as in the preceding problem except that now the discharge is 285 ft^3/s.

New arrival times:

Leading Edge	72 hours
Peak	91 hours
Trailing Edge	101 hours

New unit peak concentration: $\frac{283\ \mu g/L \times ft^3/s}{lb}$

New maximum discharge: $$\frac{285\ ft^3/s \times 964\ mi^2}{889\ mi^2} = 309\ ft^3/s$$

New peak concentration: $$\frac{283\ \mu g/L \times ft^3/s}{lb} \times \frac{2,200\ lb}{309\ ft^3/s} = 2,010\ \mu g/L$$

(2,010 ppb)

By doubling the solute spilled, the calculated expected maximum concentration would also double. But doubling discharge, as was essentially done in the examples, does not divide maximum concentration by two because traveltime decreases as discharge increases (solute reaches a given point sooner), and time for dispersion is less.

SUMMARY

By knowing the time and place of a spill of a water-soluble substance within the study reach, the arrival time of the leading edge, peak concentration, and trailing edge of the substance can be accurately predicited at any downstream section (within the study reach) by obtaining the discharge of the Lehigh River at Walnutport from the River Forecast Center and then applying it to traveltime-distance relations developed herein. Further, by knowing the quantity spilled, adjusting the Walnutport discharge, and using the unit peak concentration-traveltime of peak relation, the maximum concentration expected at any downstream point can be predicted. The predictions are limited to those discharges indicated on the appropriate figures.

The tabulated data served as the data base for relations developed herein and can be used in other applications such as water-quality models and regionalization models. Data also provide for developing traveltime of peak-passage time relations.

SELECTED REFERENCES

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

Martens, L. A., and others, 1974, Time-of-travel of solutes in Mississippi River from Baton Rouge to Pointe A. LaHache, Lousiana, Louisana Department of Public Works, Technical Report No. 9, 1 p.

Taylor, K. R., 1970, Traveltime and concentration attenuation of a soluble dye in the Monocacy River, Maryland, Maryland Geological Survey, Information Circular 9, 23 p.

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