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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TIME-OF-TRAVEL STUDIES SUSQUEHANNA RIVER BINGHAMTON, NEW YORK TO CLARKS FERRY, PENNSYLVANIA

Open-File Report 76 — 247

Prepared in cooperation with the
Susquehanna River Basin Coordinating Committee

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SUSQUEHANNA RIVER

BINGHAMTON, NEW YORK TO CLARKS FERRY, PENNSYLVANIA

By C. D. Kauffman, Jr., J. T. Armbruster, and Andrew Voytik

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Harrisburg, Pennsylvania

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FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the English units published herein to the International System of Units (SI).

Multiply English units	By	To obtain SI units
	Length	
miles (mi)	1.609	kilometres (km)
	Area	
square miles (mi^2)	2.590	square kilometres (km^2)
	Weight	
pounds (lb)	453.6	grams (g)
	Flow	
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)

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ABSTRACT

Results of time-of-travel studies are presented in both tabular and graphical form for several flow conditions in the Susquehanna River from Binghamton, N.Y., to Clarks Ferry, Pa. This reach is approximately 240 miles (386 kilometres) long, measured along the center of the channel, and has a drainage area of about 19,700 square miles (51,000 square kilometres) at its downstream end.

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

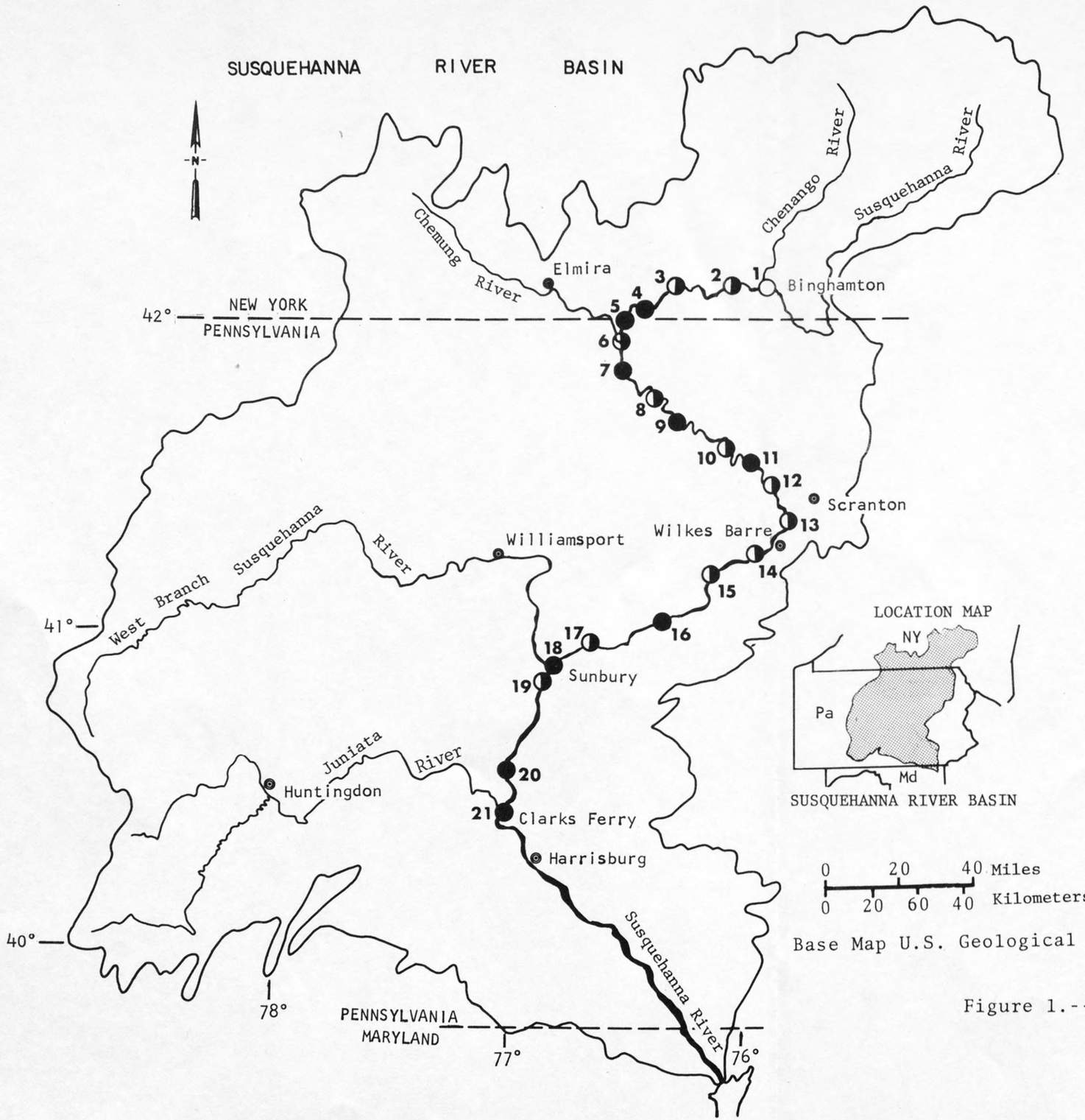
Time-of-travel data have been related to stream discharge and to distance along the river channel. These relations permit the estimation of travel time for a water-soluble contaminant moving between any two points within the study reach at any desired discharge in the lower-to-medium flow range.

The range of discharge for these studies was from 1,560 ft^3/s (44.2 m3/s) to 4,330 ft^3/s (123 m^3/s) at the Wilkes-Barre, Pa. gaging station. The recorded travel times for the typical subreach, Shickshinny, Pa. to Danville, Pa., ranged from 72.5 hours to 36.7 hours.

INTRODUCTION

This report presents the results of several individual dye-tracer time-of-travel studies made in 1965-67 on a 240-mi (386 km) reach of the Susquehanna River extending from Binghamton, N.Y., to Clarks Ferry, Pa., (mouth of Juniata River). The New York District of the U.S. Geological Survey in both independent and concurrent studies, obtained time-of-travel data for the 43.4 mi (69.8 km) reach extending from Binghamton, N.Y., to Athens, Pa., 2.9 mi (4.67 km) upstream from the mouth of the Chemung River. The Pennsylvania District gathered data for the 196-mi (315 km) reach from Athens, Pa., to Clarks Ferry, Pa (fig. 1). Results from both the Pennsylvania and New York studies have been incorporated into this report. A detailed description of the New York study was written by Dunn (1966).

Streamflows of the Susquehanna River during the study periods were equivalent to flow rates that are equaled or exceeded 64, 91, and 73 percent of the time (fig. 2). This range of flow rates represents low to medium flows, which are those of primary interest to studies on the movement of contaminants.



LOCATION MAP

SUSQUEHANNA RIVER BASIN

0 20 40 Miles

0 20 60 40 Kilometers

Base Map U.S. Geological Survey, 1963

SUSQUEHANNA RIVER

○ Injection site
● Sample site
◑ Injection & sample site

	SITE	RIVER MILE
1	Binghamton, New York	329.1
2	Vestal	320.5
3	Owego	306.1
4	Smithboro	295.9
5	NY-PA State Line	289.7
6	Athens, Pennsylvania	285.7
7	Ulster	277.4
8	Standing Stone	262.5
9	Wyalusing	249.8
10	North Mehoopany	229.4
11	Tunkhannock	217.6
12	Falls	206.8
13	Pittston	195.4
14	Plymouth	184.2
15	Shickshinny	170.6
16	Mifflinville	155.2
17	Danville	135.8
18	Northumberland	124.8
19	Hummels Wharf	119.5
20	Millersburg	96.6
21	Clarks Ferry	84.7

Figure 1.--Location of dye injection and sampling sites for the reach Binghamton, N.Y. to Clarks Ferry, Pa.

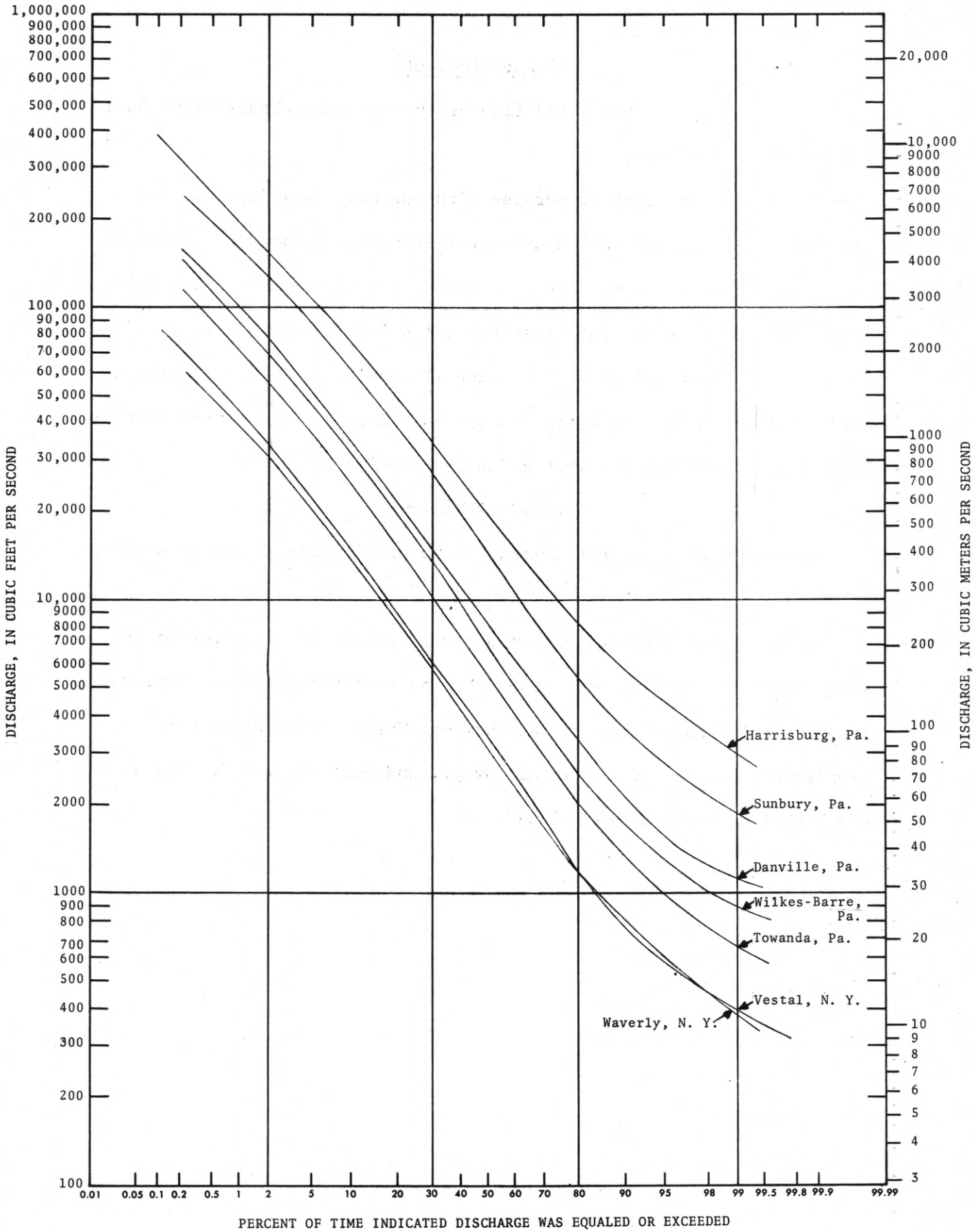


Figure 2. Duration curves of daily discharge for gaging stations on the Susquehanna River Between Vestal, N. Y. and Harrisburg, Pa.

Acknowledgments

This project was begun and financed by the Susquehanna River Basin Coordinating Committee.

Other agencies that cooperated with the U.S. Geological Survey in the study were the New York State Water Resources Commission, the U.S. Department of Agriculture, the U.S. Army Corps of Engineers, the U.S. Public Health Service, the Federal Water Pollution Control Administration (now the U.S. Environmental Protection Agency), the Pennsylvania Department of Forests and Waters (now the Pennsylvania Department of Environmental Resources), and the Pennsylvania Department of Health.

FIELD OPERATIONS

A history of the field operations for the overall study is given below.

The New York District made its first time-of-travel study on the study reach September 13-16, 1965. During that time, dye was injected into the Susquehanna River at Binghamton, Vestal, and Owego, N.Y. Samples were collected at Vestal, Owego, and Smithboro, N.Y., and at the New York-Pennsylvania State line.

For these studies, dye was injected either at one to three points per cross section or by line injection across the entire width of the river. Grab samples were taken at the main velocity thread in the cross sections at all sampling sites upstream from Ulster, Pa. Three points per cross section were sampled at sites between Ulster and Danville, Pa., and from four to five points per cross section were sampled at sites downstream from Danville.

RESULTS

Table 1 gives locations and drainage areas for the study sites and the gaging stations in the reach. Pertinent discharge and flow-duration data for gaging stations in the reach are presented in table 2. Data are listed in order of sampling and in downstream order.

Curves of time versus dye concentration were developed for each sampling site. The time-concentration curves for three points in the stream cross sections at Mifflinville and Danville, Pa., for the first and third studies, are presented in figure 3. Two features should be noted: (1) as the dye cloud travels downstream, its maximum concentration decreases, and (2) the travel time increases as discharge decreases. These curves are typical of those for each sampled cross section upstream from Northumberland, Pa. Figures 4 and 5 show time-concentration curves for tests 2 and 3 for sampling sections at Millersburg and Clarks Ferry, Pa., respectively. These curves are typical of those for cross sections below Danville.

Table 1.--Drainage area and study sites

Location of sampling site or gaging station	Approximate drainage area (square miles)
Binghamton, N.Y., Washington Street	2,290
Vestal (01513500) 1/	3,960
Vestal, State Route 26	3,960
Owego, State Route 96	4,230
Smithboro, State Route 282	4,740
Waverly (01515000) 1/	4,780
Athens, Pa., Legislative Route 08081	4,780
Ulster, Legislative Route 08079	7,330
Towanda (01531500) 1/	7,800
Standing Stone, Legislative Route 08023	8,200
Wyalusing, Legislative Route 14	8,250
North Mehoopany, State Route 87	8,670
Tunkhannock, State Route 309	8,810
Falls, State Route 92	9,440
Pittston, U.S. Route 11	9,860
Wilkes-Barre (01536500) 1/	9,960
Plymouth, Legislative Route 4	10,000
Shickshinny, State Route 239	10,200
Mifflinville, Legislative Route 19103	10,600
Danville (01540500) 1/	11,200
Danville, State Route 54	11,200
Northumberland, State Route 147	11,300
Sunbury (01554000) 1/	18,300
Hummels Wharf, Downstream End of Byers Island	18,400
Millersburg, Ferry Route	20,700
Clarks Ferry, U.S. Routes 22 and 322	20,900
Harrisburg (01570500) 1/	24,100

1/ U.S.G.S. gaging station; number of station in parenthesis

Table 2.--Gaging station data for stations located in the reach Binghamton, N.Y. to Clarks Ferry, Pa.

Gaging station location	Daily mean discharge (cubic feet per second)	Percent of time indicated discharge is equaled or exceeded
September 13, 1965		
1. Vestal, N.Y.	440	98
2. Waverly, N.Y.	472 1/	98
		Average = 98
October 11, 1965		
1. Vestal, N.Y.	2,300	64
2. Waverly, N.Y.	2,520	56
3. Towanda, Pa.	2,640	72
4. Wilkes-Barre, Pa.	4,330	65
5. Danville, Pa.	5,700	63
6. Sunbury, Pa.	10,600	62
7. Harrisburg, Pa.	13,600	64
		Average = 64
July 5, 1966		
1. Vestal, N.Y.	1,030	85
2. Waverly, N.Y.	1,340 2/	77
		Average = 81
October 24, 1966		
1. Vestal, N.Y.	915	88
2. Waverly, N.Y.	975	86
3. Towanda, Pa.	1,170	94
4. Wilkes-Barre, Pa.	1,560	91
5. Danville, Pa.	1,980	92
6. Sunbury, Pa.	3,320	91
7. Harrisburg, Pa.	4,360	94
		Average = 91
July 1, 1967		
5. Danville, Pa.	4,950	67
6. Sunbury, Pa.	7,460	72
7. Harrisburg, Pa.	10,300	74
		Average = 71

Table 2.--Gaging station data for stations located in the reach Binghamton, N.Y. to Clarks Ferry, Pa. (Continued)

Gaging station location	Daily mean discharge (cubic feet per second)	Percent of time indicated discharge is equaled or exceeded
	July 21, 1967	
1. Vestal, N.Y.	-	-
2. Waverly, N.Y.	1,380	76
3. Towanda, Pa.	2,180	77
4. Wilkes-barre, Pa.	3,520	71
5. Danville, Pa.	4,230	71
6. Sunbury, Pa.	7,860	71
7. Harrisburg, Pa.	10,600	73
		Average = 73

1/ Average for September 13-14, 1965
2/ Average for July 5-11, 1966

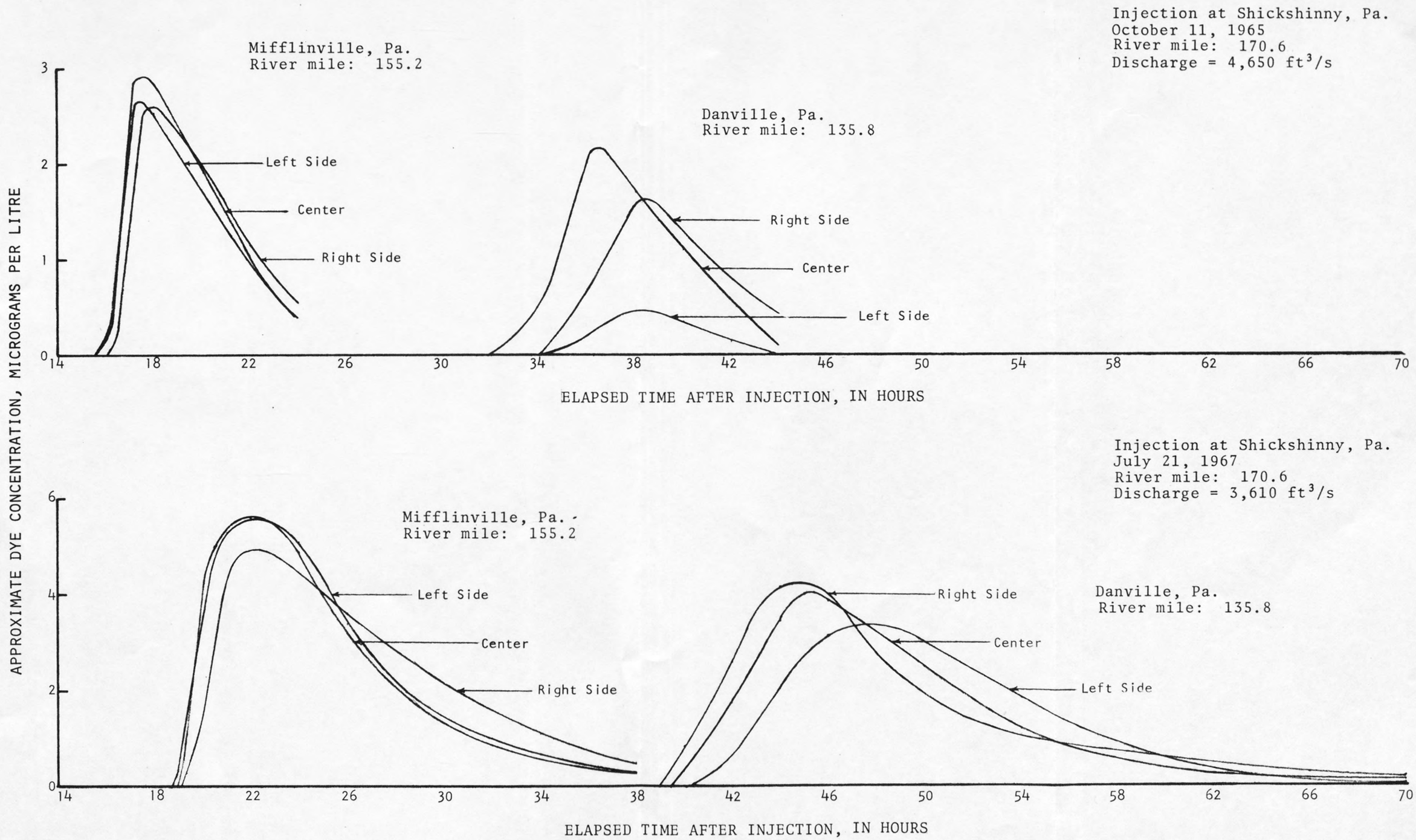
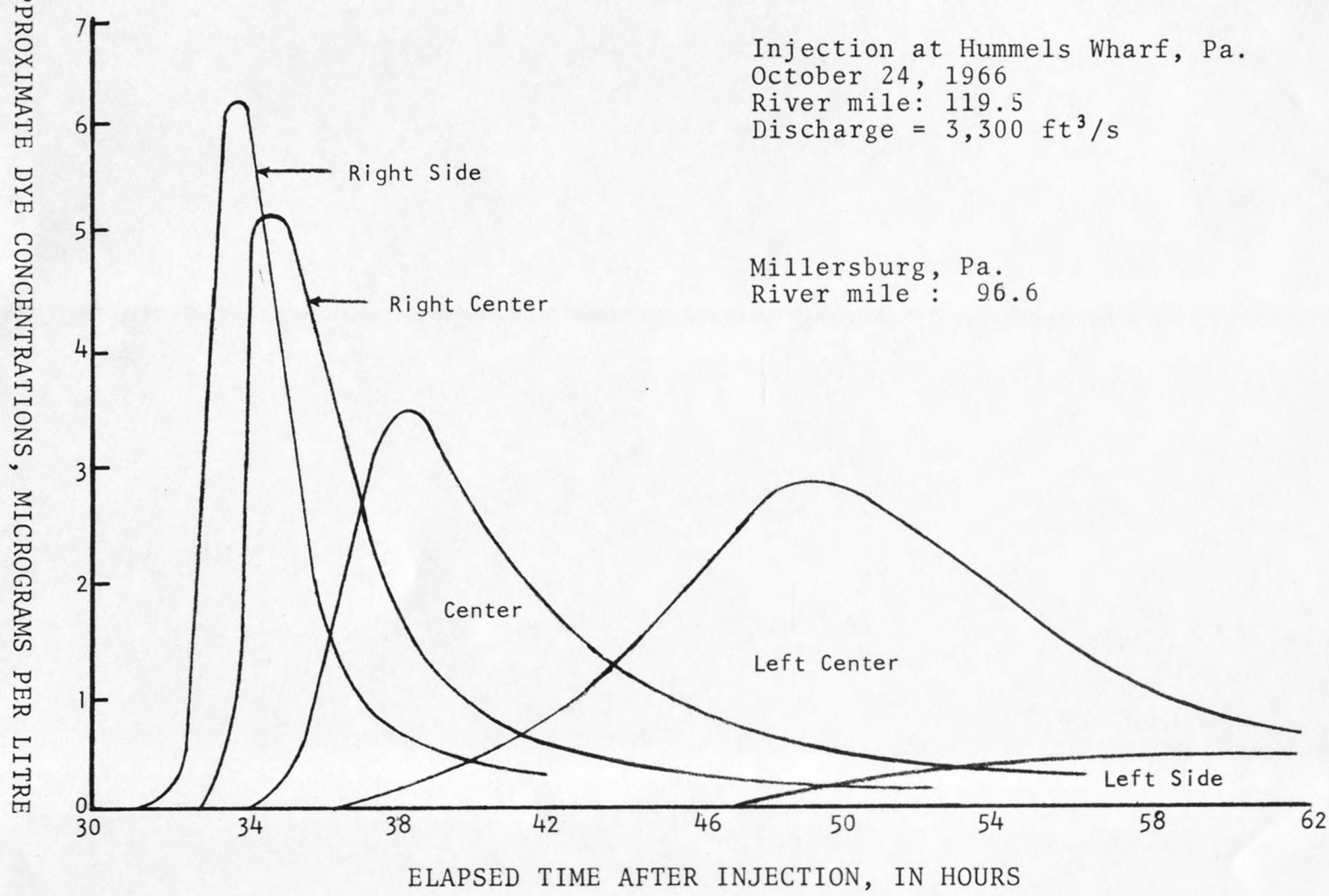


Figure 3. Variation of dye concentration with time, Mifflinville and Danville, Pa.



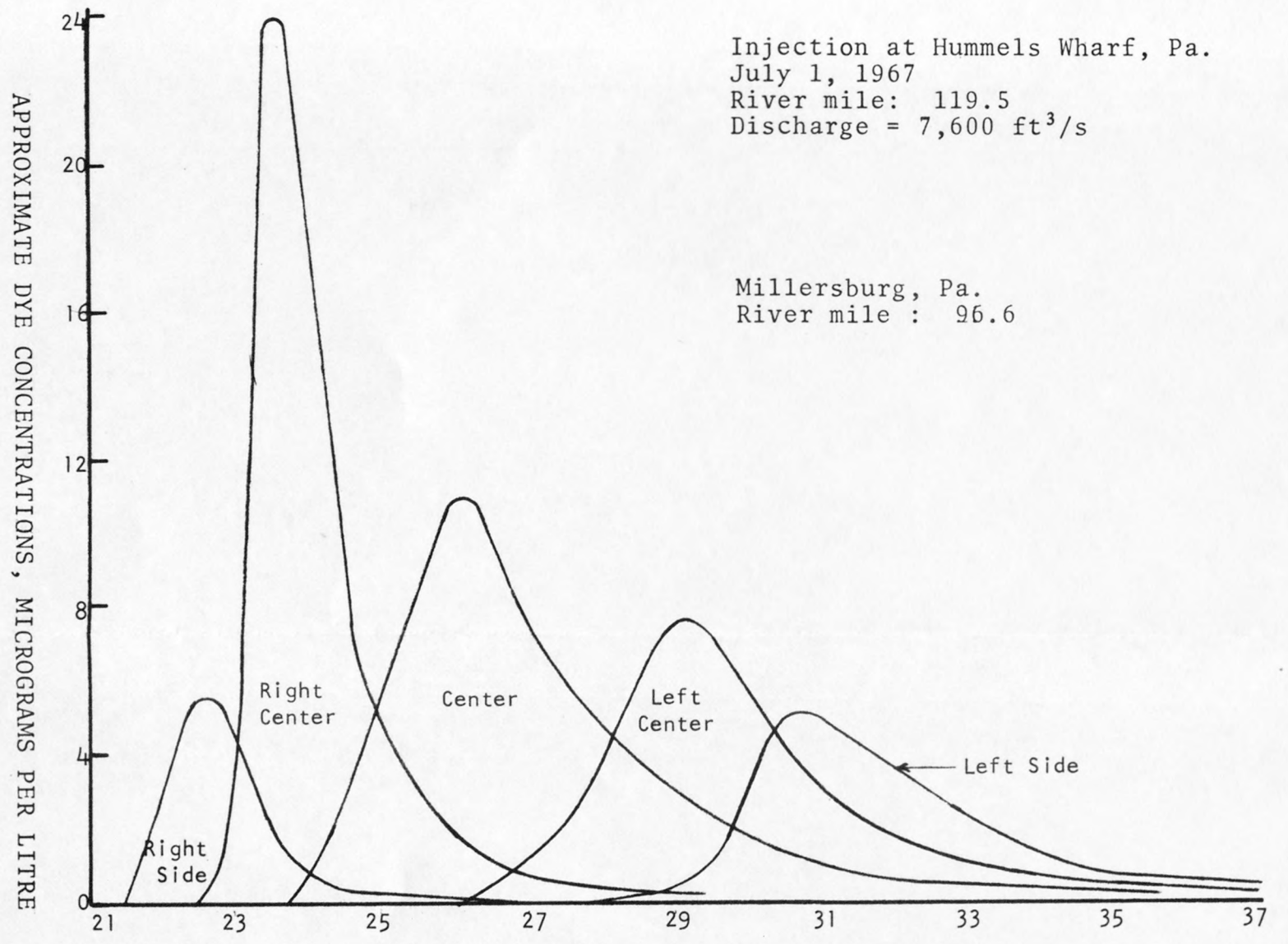


Figure 4. Variation of dye concentration with time, Millersburg, Pa.

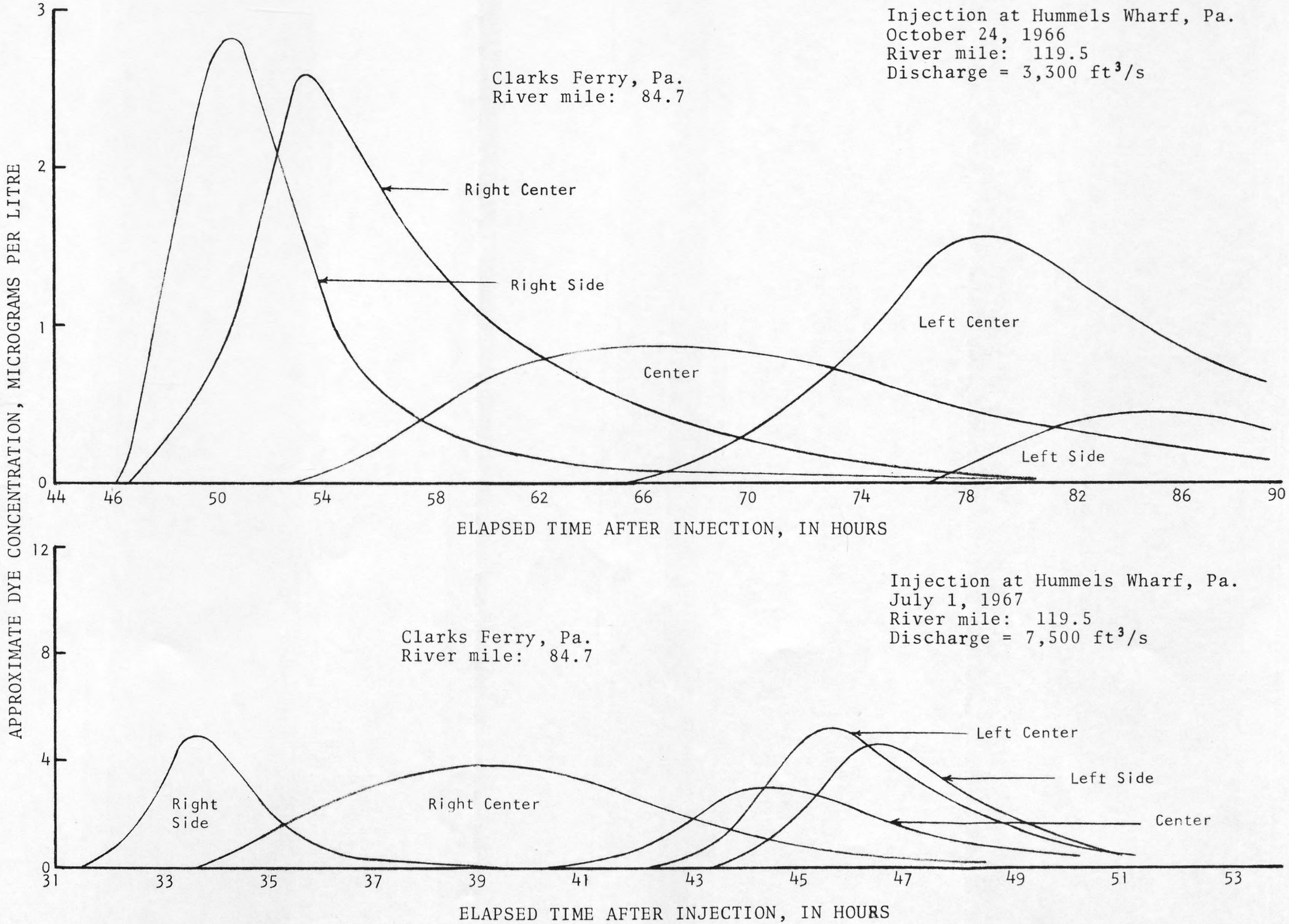


Figure 5. Variation of dye concentrations with time, Clarks Ferry, Pa.

Observed travel times differed little from point to point within each cross section upstream from Northumberland, Pa. Observed time lag between peak concentrations measured at various points within any cross section upstream from Northumberland did not exceed 3 hours. At most stations the travel time of peak concentrations at the center and quarter points were within minutes of each other.

Downstream from Northumberland, however, where the river is relatively wide (about 0.9 mi (1.45 km) at Millersburg) and relatively shallow, travel times differed considerably from point to point within each cross section, as shown by figures 4 and 5. The time spread appears to increase as discharge decreases.

In figure 3 the left sampling point at Danville shows considerably lower concentration than the other two sampling points within the cross section. This may be because of dilution caused by inflow from three small tributaries that enter on that side less than 5 mi (8 km) upstream.

Figures 6-8 show curves of relation for travel time of peak concentration versus discharge for each of the subreaches under study. In figure 6, discharge is referenced to the Vestal and Waverly, N.Y., gaging stations. In figures 7 and 8, discharge is referenced to the respective injection sites.

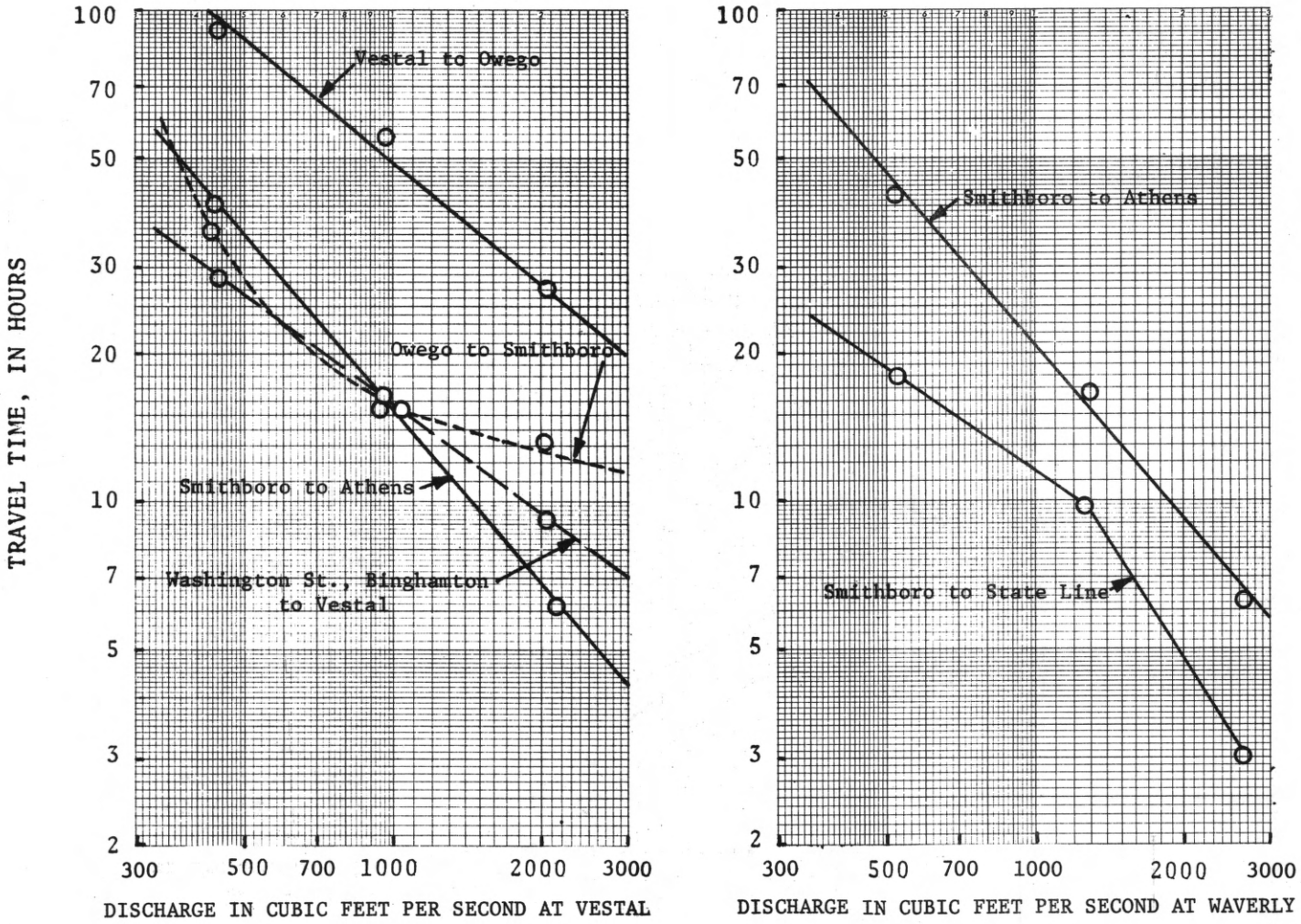


Figure 6.--Relation of time-of-travel to discharge, Susquehanna River (Reproduced from Dunn, 1966).

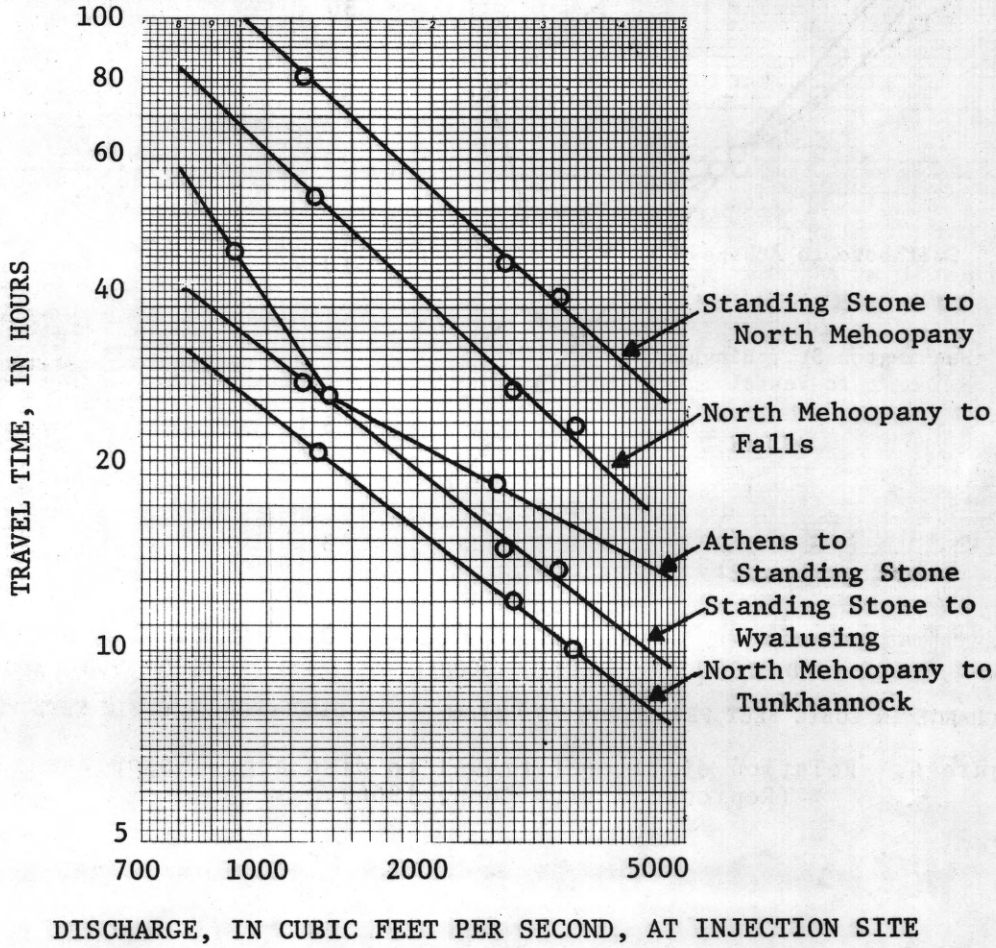


Figure 7.--Relation of time-of-travel to discharge, Susquehanna River.

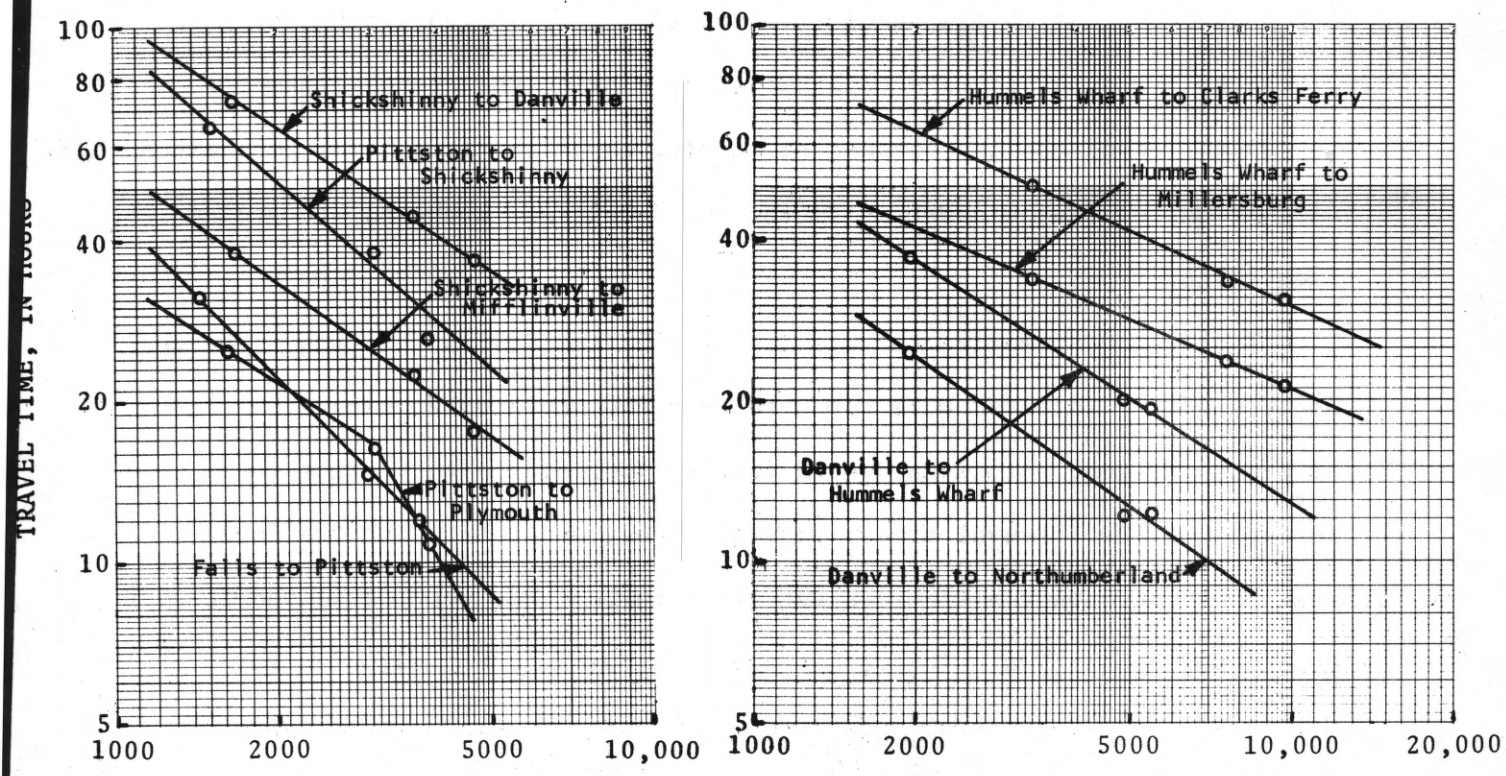


Figure 8.--Relation of time-of-travel to discharge, Susquehanna River.

Figures 9 and 10 are cumulative travel times plotted against stream distances. The curves were constructed by summing the travel times for the specified discharges between successive sampling sites below Binghamton, N.Y. Similar curves can be constructed for any discharge in the low-to medium-flow range.

Tables 3-6 summarize the results of all the studies for each subreach. Amounts of dye injected were computed from the measured volumes of 30 and 40 percent solutions dumped in the river at the respective injection sites. Travel times, passage times, and peak concentrations were obtained from the time-concentration curves that were developed for each sampling section. The peak concentrations were not adjusted for dye losses. Passage time is defined as the time required for a dye cloud to pass through a particular cross section. A high concentration of dye at the leading edge of the dye cloud renders this edge of the cloud easy to define. The trailing edge of the dye cloud, however, is usually difficult to define because the dye concentration decreases very gradually as the cloud passes. Therefore, passage time is the estimated time interval between appearances of the well-defined leading edge and poorly-defined trailing edge of the dye cloud.

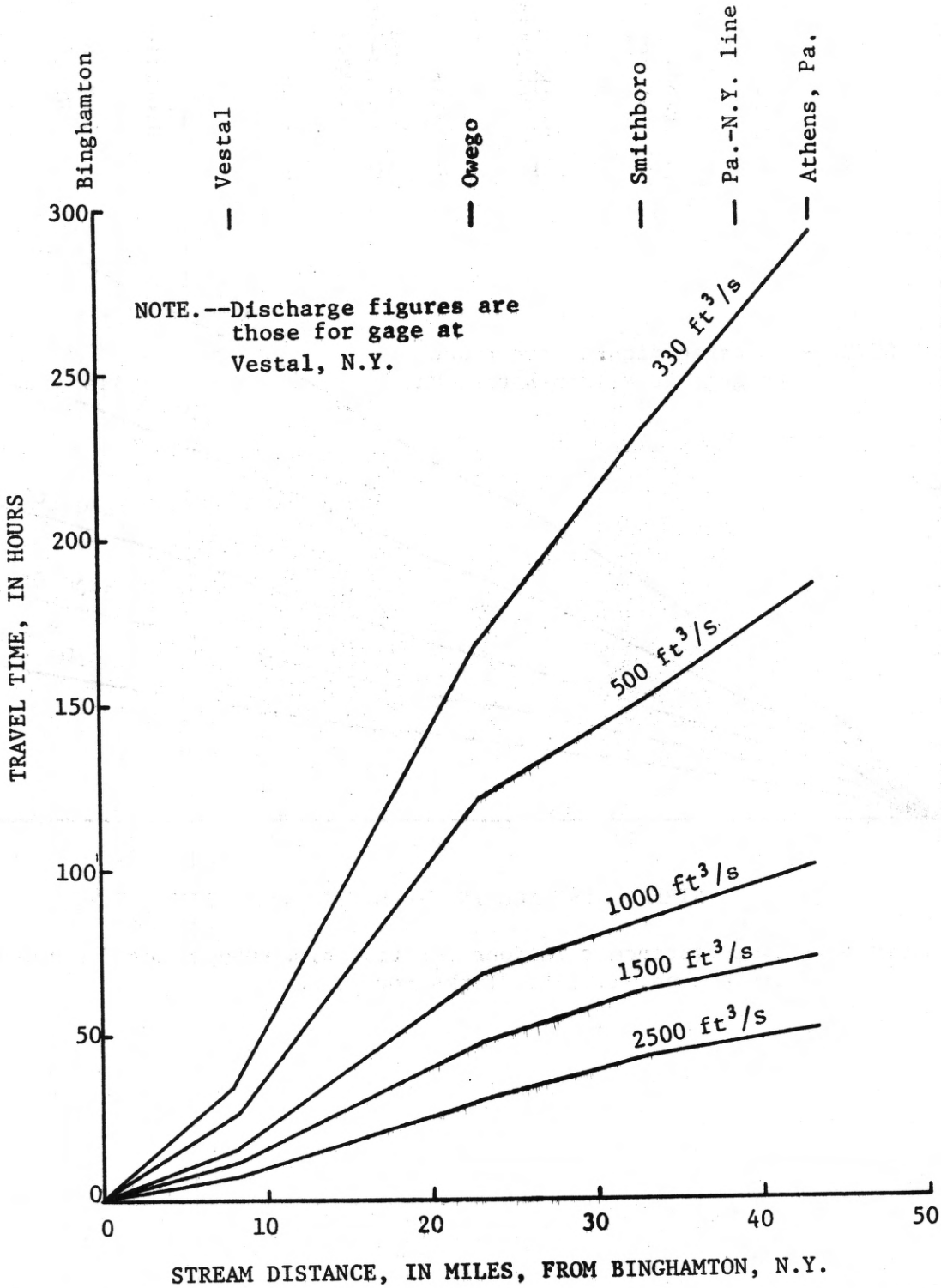


Figure 9.--Time-distance relations for five discharge rates for the reach Binghamton, N.Y. to Athens, Pa. (Reproduced from Dunn, 1966).

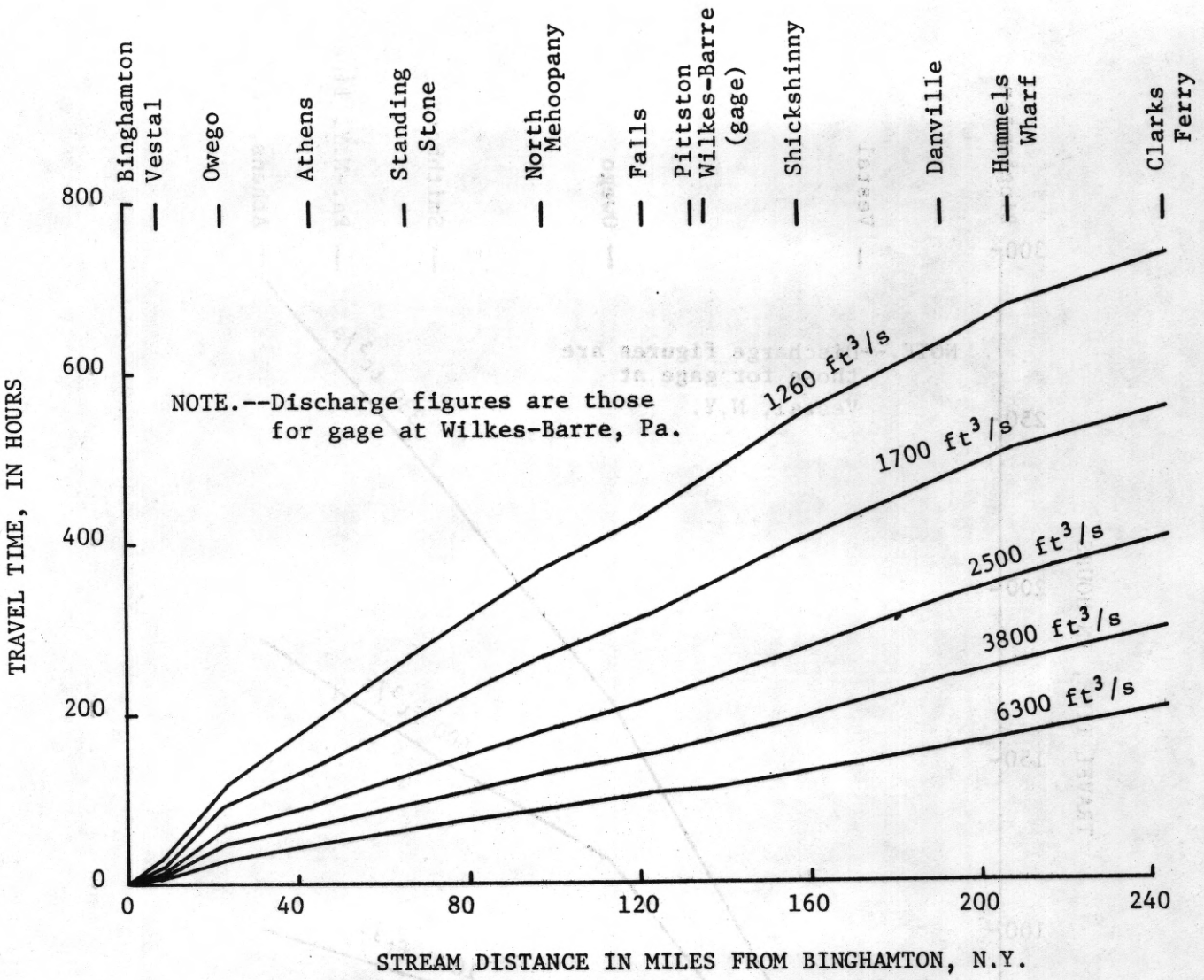


Figure 10.--Time-distance relations for five discharge rates for the reach Binghamton, N.Y. to Clarks Ferry, Pa.

Table 3.--Summary of results Sept. 13-16, 1965; July 5-8, 11-14, 1966

Injection site	Sample site	Date of injection	Distance below injection site (miles)	Discharge at inj. site (ft^3/s)	Amount of raw dye injected (lbs)	First appearance travel time (hours)	Peak travel time (hours)	Approx. passage time (hours)	Approx. peak concentration (mg/l)
Binghamton		9-13-65							
	Vestal		8.6	275	16.4	-	29.3	-	30
Vestal		9-13-65		472					
	Owego		14.4		28.6	83.0	95.2	-	11
Owego		9-14-65		450	16.4				
	N.Y.-Pa. State Line		16.4				54.5	-	11
	Athens		20.4			-		-	
Binghamton		7-11-66		575	4.3				
	Vestal		8.6			14.5	17.0	25	5.7
Vestal		7-11-66		1,010	16.4				
	Owego		14.4			45.5	57.0	50	6.2
Owego		7- 7-66		1,200	7.8				
	Smithboro		10.2			13.0	16.0	16	10.1
Smithboro		7- 5-66		1,150	6.9				
	N.Y.-Pa. State Line		6.2			8.2	9.8	13	18.5
	Athens		10.2			13.5	16.5	20	9.4

Table 4.--Summary of results - October 11-15, 1965

Injection site	Sample site	Distance below injection site (miles)	Discharge at injection site (ft^3/s)	Amount of raw dye injected (lbs)	First appearance travel time (hours)	Peak travel time (hours)	Approx. passage time (hours)	Approx. peak concentration (mg/l)
Binghamton			1,320	19.2				
	Vestal	8.6			8.5	9.5	5	42
Vestal			2,300	44.8				
	Owego	14.4			25.0	28.0	12	35
	Smithboro	24.6			35.0	41.8	20	
Owego		16.4	2,370	41.6				
	N.Y.-Pa.State Line					16.8	-	-
	Athens	20.4			18.0	20.0	10	-
Athens		8.3	2,520	33.6				
	Ulster				-	-	12	7.4
	Standing Stone	23.2				18.3[1/]	16	2.3
Standing Stone			3,180	43.8				
	Wyalusing	12.7			12.7	13.7	13	over 12
	North Mehoopany	33.1			33.0	36.4	22	5.4
North Mehoopany		11.8	3,360	33.6				
	Tunkhannock				-	10.0	-	over 4.8
	Falls	22.6			21.2	22.6	16	4.8
Falls			3,670	12.9				
	Pittston	11.4			11.0	12.0	11	4.8
Pittston			3,830	15.0				
	Plymouth	11.2			9.6[2/]	10.8[2/]	13	2.3
Plymouth			4,320	16.0				
	Shickshinny	13.6			13.6	16.1	15	1.8
Shickshinny			4,650	28.4				
	Mifflinville	15.4			16.0	17.5	10	2.9
	Danville	34.8			33.5	36.7	17	2.2
Danville			5,540	18.0				
	Northumberland	11.0			11.3[3/]	12.2[3/]	4	over 20
	Hummels Wharf	16.3			17.3[3/]	19.1[3/]	14	over 8
Hummels Wharf			9,750	85.9				
	Millersburg	22.9			20.0	21.2	9	over 40
	Clarks Ferry	34.8			29.5	30.8	17	over 14

1/ Recomputed on basis of data for Chemung River at Athens, Pa., to Susquehanna River at Standing Stone.
2/ Recomputed on basis of data for sampling 0.6 mile upstream from Hanover Street in Plymouth.
3/ Recomputed on basis of data for injection at point 1.6 miles downstream from sampling bridge at Danville.

Table 5.--Summary of results - October 24-28, 1966

Injection site	Sample site	Distance below injection site (miles)	Discharge at injection site (ft^3/s)	Amount of raw dye injected (lbs)	First appearance travel time (hours)	Peak travel time (hours)	Approx. passage time (hours)	Approx. peak concentration (mg/l)
Athens			975	30				
	Ulster	8.3			- less than 13		12	over 15
	Standing Stone	23.2			34.3	43.0	35	7.0
Standing Stone			1,260	30				
	Wyalusing	12.7			23.8	26.8	16	12.0
	North Mehoopany	33.1			69.7	81.5	35	3.2
North Mehoopany			1,330	16				
	Tunkhannock	11.8			19.0	20.8	25	7.3
	Falls	22.6			43.2	52.3	32	2.2
Falls			1,450	12				
	Pittston	11.4			24.5	31.0	30	2.4
Pittston			1,530	31				
	Plymouth	11.2			20.4 2/	24.4 2/	27	5.8
	Shickshinny	24.8			52.5 2/	64.8 2/	45	2.7
Shickshinny			1,680	32				
	Mifflinville	15.4			30.5	37.8	30	3.3
	Danville	34.8			62.5	72.5	40	2.0
Danville			1,960	12				
	Northumberland	11.0			23.0 3/	24.2 3/	12	8.0
	Hummels Wharf	16.3			34.6 3/	36.9 3/	20	3.3
Hummels Wharf			3,300	32				
	Millersburg	22.9			32.0	33.9	40	6.2
	Clarks Ferry	34.8			46.5	50.1	55	2.8

1/ Estimated on basis of partially defined time-concentration curve.
2/ Recomputed on basis of data for injection at point 0.2 mile downstream from Pittston sampling bridge.
3/ Recomputed on basis of data for injection at point 1.6 miles downstream from Danville sampling bridge.

Table 6.--Summary of results - July 1-3, 21-24, 1967

Injection site	Sample site	Distance below injection site (miles) (mi	Discharge at injection site (ft^3/s)	Amount of raw dye injected (lbs)	First appearance travel time (hours)	Peak travel time (hours)	Approx. passage time (hours)	Approx. peak concentration (mg/l)
Athens			1,380	32.0				
7/21/67	Ulster	8.3			7.2	7.9	11	42.0
	Standing Stone	23.2			22.5	25.3	19	3.9
Standing Stone			2,600	40.0				
7/21/67	Wyalusing	12.7			13.2	14.5	18	15.0
	North Mehoopany	33.1			36.6	41.3	30	3.3
North Mehoopany			2,700	32.0				
7/21/67	Tunkhannock	11.8			11.5[1/]	12.0[1/]	11	14.0
	Falls	22.6			23.2[1/]	25.8[1/]	19	3.8
Falls			2,960	16.0				
7/21/67	Pittston	11.4			13.4	14.8	16	2.8
Pittston			3,070	49.9				
7/21/67	Plymouth	11.2			12.2[2/]	16.4[2/]	20	8.4
	Shickshinny	24.8			31.3[2/]	37.8[2/]	40	3.5
Shickshinny			3,610	64.0				
7/21/67	Mifflinville	15.4			18.6	22.2	22	5.6
	Danville	34.8			39.5	44.2	33	4.2
Danville			4,060	3.9				
7/21/67	Northumberland	11.0			13.2[3/]	13.8[3/]	6	17.0
	Hummels Wharf	16.3			-	-	-	-
Danville			4,900	16.0				
7/ 1/67	Northumberland	11.0			11.9[3/]	12.3[3/]	7	19.0
	Hummels Wharf	16.3			19.0[3/]	20.0[3/]	9	7.8
Hummels Wharf			7,600	80.0				
7/ 1/67	Millersburg	22.9			21.5	23.6	17	24.0
	Clarks Ferry	34.8			31.5	33.5	26	5.3

1/ Recomputed on basis of data for injection at point 1.3 miles downstream from North Mehoopany sampling bridge.
2/ Recomputed on basis of data for injection at point 0.2 mile downstream from Pittston sampling bridge.
3/ Recomputed on basis of data for injection at point 1.6 miles downstream from Danville sampling bridge.

At Clarks Ferry, in 1967, the first appearance of dye was detected near the right side of the river 31.5 hours after injection. (See fig. 5.) The peak concentration detected at that point in the cross section occurred 33.5 hours after injection. However, the highest concentration in the entire cross section was sampled at the left-center point, 45.6 hours after injection. The time differential can probably be attributed to the channel geometry, the numerous islands in the left part of the channel, and the line method of injection at Hummels Wharf. Peak travel times were also found to differ considerably for different points in the cross sections at Millersburg, Hummels Wharf, and Northumberland, Pa. This was also true for the 1965 and 1966 studies. The passage time listed in table 6 for Clarks Ferry is the time from first appearance detected on the right side to the time the dye was last detected at the left side of the sampling section. In order to keep results uniform, minimum peak travel time (33.5 hours), instead of the 45.6 hours indicated by figure 5, was used in figure 8 for the reach from Hummels Wharf to Clarks Ferry.

CONCLUSIONS

Real-time discharge values for gaging stations within the study reach are available through the U.S. Department of Commerce, River Forecast Center, Harrisburg, Pa. By obtaining the gaging station discharge values from the River Forecast Center and using the drainage area comparison from table 1, one can compute the discharges for the study sites in the reach. Then, by use of figures 6-8, one can estimate the travel time of peak concentration of a water-borne contaminant that might have been spilled into the river at a point within the reach.

Similar curves of travel time versus discharge can be constructed for the leading and trailing edges of the dye cloud by using the data in tables 3-6. These curves can be defined by plotting the discharges for each injection site against the respective travel time to the downstream sampling sites.

Data in this report are applicable when discharge is fairly uniform and should not be used during either a period of rapidly changing discharge or when the discharge exceeds those in figures 6-8. Data presented are for instantaneous dye injections. If a contaminant were introduced into the river gradually, its passage time would be significantly greater than that for an instantaneous injection.

The range of discharge for these studies was from 1,560 ft^3/s (44.2 m^3/s) to 4,330 ft^3/s (123 m^3/s) at the Wilkes-Barre, Pa. gaging station. The recorded travel times for the subreach, Shickshinny, Pa., to Danville, Pa., ranged from 72.5 hours to 36.7 hours.

If a slug of water soluble contaminant was accidentally spilled into the river at Shickshinny, Pa., when the discharge was 1,560 ft^3/s (44.2 m^3/s) at Wilkes-Barre, Pa., the contaminant would be expected to appear at Danville about 62 hours after the spill. Its maximum concentration would appear about 72 hours after the spill, and essentially all of the contaminant would pass within 40 hours after its arrival at Danville.

SELECTED REFERENCES

Bowie, J. E., and Petri, L. R., 1969, Travel of solutes in the lower Missouri River: U.S. Geol. Survey Hydrol. Inv. Atlas HA-332.

Buchanan, T. J., 1964, Time-of-travel of soluble contaminants in streams: Am. Soc. Civil Engineers Proc., v. 90, no. SA3, paper 3932, 12 p.

Dunn, B., 1965, Time-of-travel studies Hoosic River North Adams, Mass., to Hoosic Falls, N.Y.: U.S. Geol. Survey open-file rept., 17 p.

_____1966, Time-of-travel studies Susquehanna River, Binghamton, N.Y., to Athens, Pa.: U.S. Geol. Survey open-file rept., no. TT-4, 29 p

Godfrey, R.B., and Frederick, B. J., 1963, Dispersion in natural streams: U.S. Geol. Survey open-file rept., 75 p.

Steacy, R. E., 1961, Time-of-travel of water in the Ohio River, Pittsburgh to Cincinnati: U.S. Geol. Survey Circ. 439, 14 p.

Steward, M. R., 1967, Time-of-travel of solutes in Mississippi River from Baton Rouge to New Orleans, Louisiana: U.S. Geol. Survey Hydrol. Inv. Atlas HA-260.

Taylor, K. R., 1970, Travel time and concentration attenuation of a soluble dye in the Monocacy River, Maryland: Maryland Geol. Survey Inf. Circ. 9, 23 p.

Taylor, K. R., and Solley, W. B., 1971, Travel time and concentration attenuation of a soluble dye in Antietam and Conococheague Creeks, Maryland: Maryland Geol. Survey Inf. Circ. 12, 25 p.

Wilson, J. F., Jr., 1968, Fluorometric procedures for dye tracing: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A12, 31 p.

Wilson, J. F., Jr., and Forrest, W. E., 1964, Potomac River time-of-travel measurements:. Paper presented at the "Symposium on Diffusion in Oceans and Fresh Water," the Lamont Geological Observatory of Columbia University, 25 p.