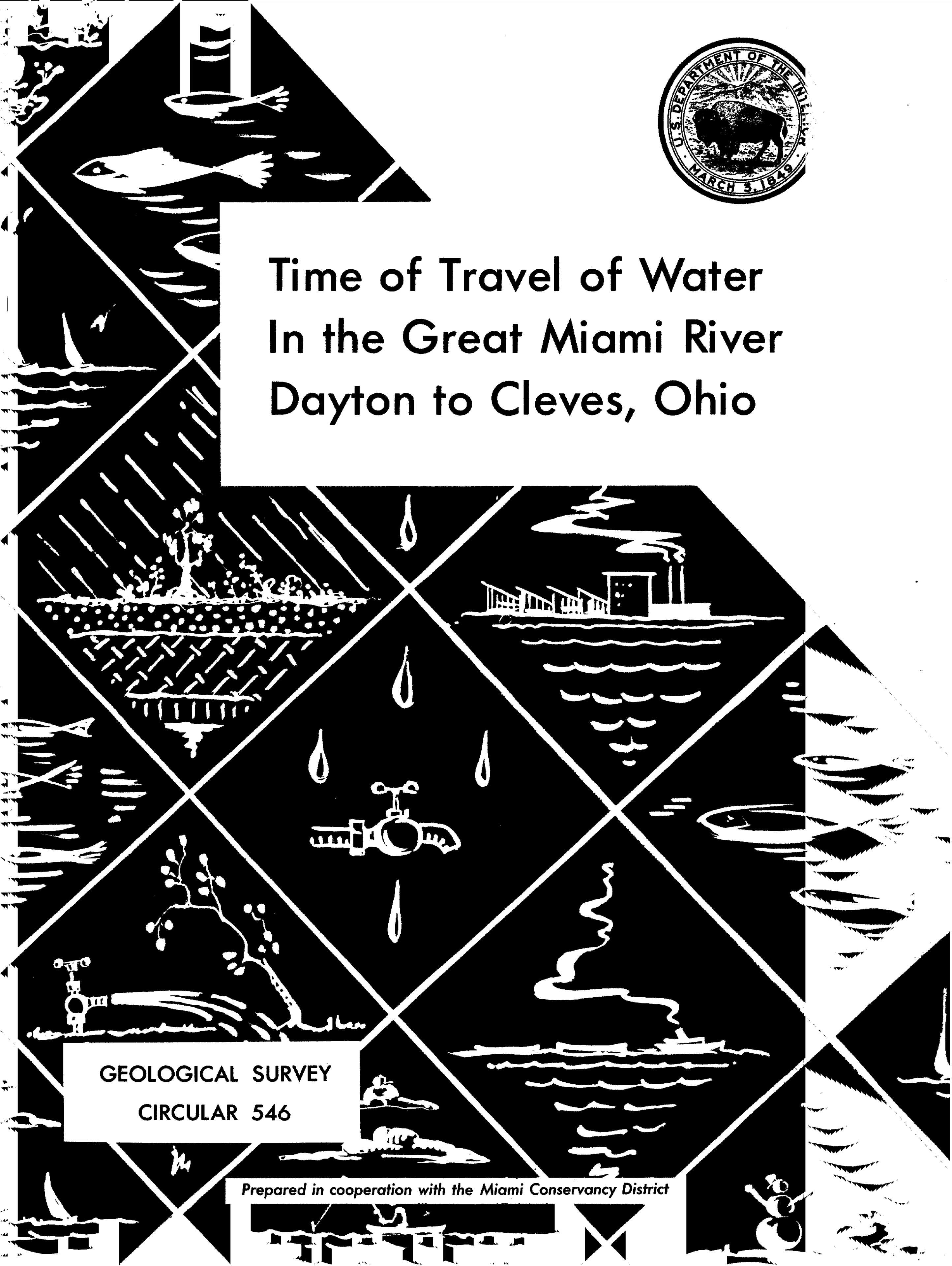
Time of Travel of Water In the Great Miami River Dayton to Cleves, Ohio



GEOLOGICAL SURVEY CIRCULAR 546

Prepared in cooperation with the Miami Conservancy District

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By Daniel P. Bauer

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CONTENTS

ILLUSTRATIONS

TABLES

Time of Travel of Water in the Great Miami River, Dayton to Cleves, Ohio

By Daniel P. Bauer

ABSTRACT

A time-of-travel study of the Great Miami River from Dayton to Cleves, Ohio, a distance of 71.3 river miles, was made in the summer of 1965 to obtain basic information about water passage. Cumulative traveltimes of 182 and 254 hours were determined for approximate discharges of 550 and 380 cfs (cubic feet per second), respectively, at Miamisburg.

Peak traveltimes averaged 91 percent of the centroid traveltimes for the entire reach from Dayton to Cleves. Traveltimes computed from the so-called average-velocity method (discharge/cross-sectional area) were somewhat shorter for a given index discharge than the traveltimes determined for the centroid of the dye cloud.

A method utilizing a straight-line log-log plot of traveltime versus index discharge to predict approximate traveltimes is stated. The resulting equation, $T=400\times10^{2}\ Q^{-.85}$, is limited to the approximate discharge range of 300–800 cfs.

PURPOSE

The Great Miami River, like many streams used extensively by man to carry away municipal and industrial wastes, receives large quantities of waste water from many sources. During summer low-flow periods the Great Miami River has high water temperatures and low dissolved-oxygen concentrations in some reaches downstream from Dayton, Ohio. During such periods information on time of travel is necessary to predict the passage of pollutants accidentally spilled into the river.

A time-of-travel study of the Great Miami River from Dayton to Cleves, Ohio, 71.3 river miles, was made in the summer of 1965 to obtain basic information about water passage. The study was made with a fourfold purpose:

1. To determine the traveltime between given sites along the stream for use in pollution studies.

2. To examine the longitudinal dispersion of the dye cloud, expressed as passage time at selected sampling sites.

3. To compare the time of travel based on the average velocity computed from discharge divided by cross-sectional area with that of the dye.

4. To examine the possibilities of predicting traveltimes at different discharges.

The techniques utilizing a soluble dye tracer were developed by the U.S. Geological Survey and were perfected by measurements on many streams prior to this study (Buchanan, 1964; Wilson and Forest, 1965).

The study was made under a cooperative program between the Miami Conservancy District, M. L. Mitchell, chief engineer, and the U.S. Geological Survey, Water Resources Division, Columbus, Ohio, J. J. Molloy, district chief, H. P. Brooks, U.S. Geological Survey, and L. C. Crawford, Miami Conservancy District, coordinated the field operations.

DETERMINATION OF TRAVELTIMES

To determine traveltime, a soluble dye, Rhodamine BA, was used as a tracer. The study reach, 71.3 river miles, was divided into 7 subreaches during the July run and 9 subreaches during the August run to minimize dye concentration and total time required for the

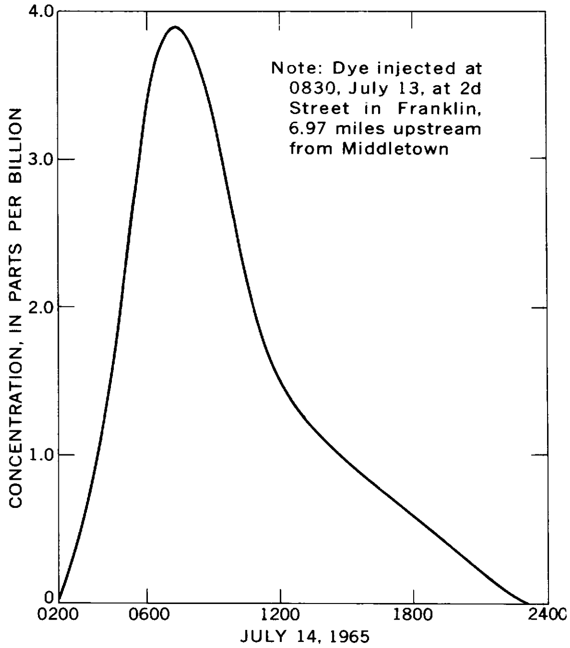

Figure 1.—Time distribution of dye concentration, Central Avenue, Middletown.

study. The dye was injected into the river as a slug at the head of each subreach. Water samples were then collected at selected sites downstream from the injection site. The samples were tested for dye concentrations with an instrument called a fluorometer. From the tests the time distribution of the tracer was determined for each sampling site and plotted as shown in figure 1. From such graphs the data presented in this report were extracted. This study required a 20-man field crew for each run.

From Dayton to Cleves (fig. 2), cumulative traveltimes of 182 and 254 hours were computed at approximate index discharges of 550 and 380 cfs (cubic feet per second). The Miamisburg gage was selected as the index station for the study reach. These traveltimes, shown in figures 3 and 4, are for the centroid of the dye-cloud mass.

The approximate peak traveltimes are listed in tables 1 and 2. Many of the concentration curves contained two or more peaks of approximately equal magnitude, particularly during the August run. The peak-time occurrence was then computed by weighting each peak time by its respective concentration magnitude. During the July run multiple peaks did not occur, but some curves had poorly defined peaks, which made determinations of peak traveltime equally difficult.

TRAVELTIME COMPARISON

A curve computed by using the average-velocity method for an index discharge of 394 cfs at Miamisburg was available previous to this study. The average velocity was computed by dividing the average discharge in a subreach by the average cross-sectional area. Traveltime was then obtained by dividing the average reach length by the average velocity. A curve using average velocity traveltime is shown in figures 3 and 4. Data for the curve were obtained from the Miami Conservancy District. It plots between the curves developed from the traveltime of the dye clouds and indicates a traveltime too short for the discharge.

In the entire reach, Dayton to Cleves, for the July and August runs, the peak traveltimes averaged 91 percent of the centroid traveltimes (figs. 5–8). Curve characteristics for the two runs appear to agree fairly closely.

ANALYSIS OF DISCHARGE

SAMPLING-SITE DISCHARGE

To compute the discharges for sampling sites shown in tables 1 and 2, a point-source method was used. By this method any contributing tributary discharge and industrial- or municipal-sewage effluent were added to the streamflow. For most sites, a true balance of discharge at the downstream end of the reach was not achieved. To refine the discharge further, a discharge-drainage-area computation was applied for each sampling site.

Because of the lack of knowledge of flow diversion at the Hamilton diversion canal, it was assumed that most of the flow would travel through the canal. During the July run a sampling station was located on the river within the canal-river complex. Results of the run indicated that only a small portion of the flow took the river route; most of the flow traveled through the canal. During the August run no samples were taken at this river site.

No canal-discharge measurements were made at Franklin. However, a canal-discharge estimate of 225 cfs was made using dye-cloud mass recovery at Franklin. This estimate was made by dividing the area under the dye-cloud concentration curve for the canal outfall by the area under the curve for Franklin; this quotient was then multiplied by the total discharge at Franklin. The computation assumed

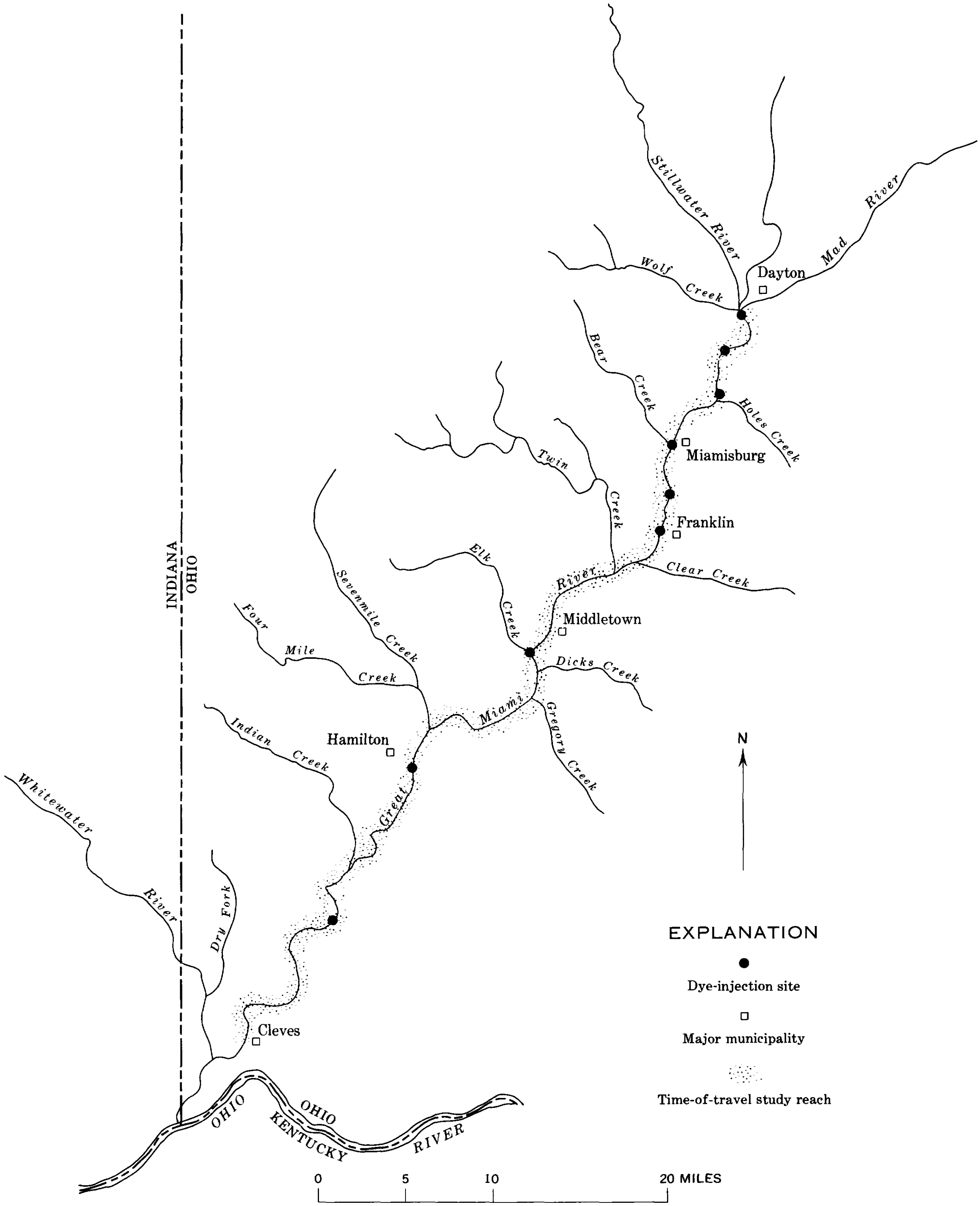

Figure 2.—Great Miami River basin.

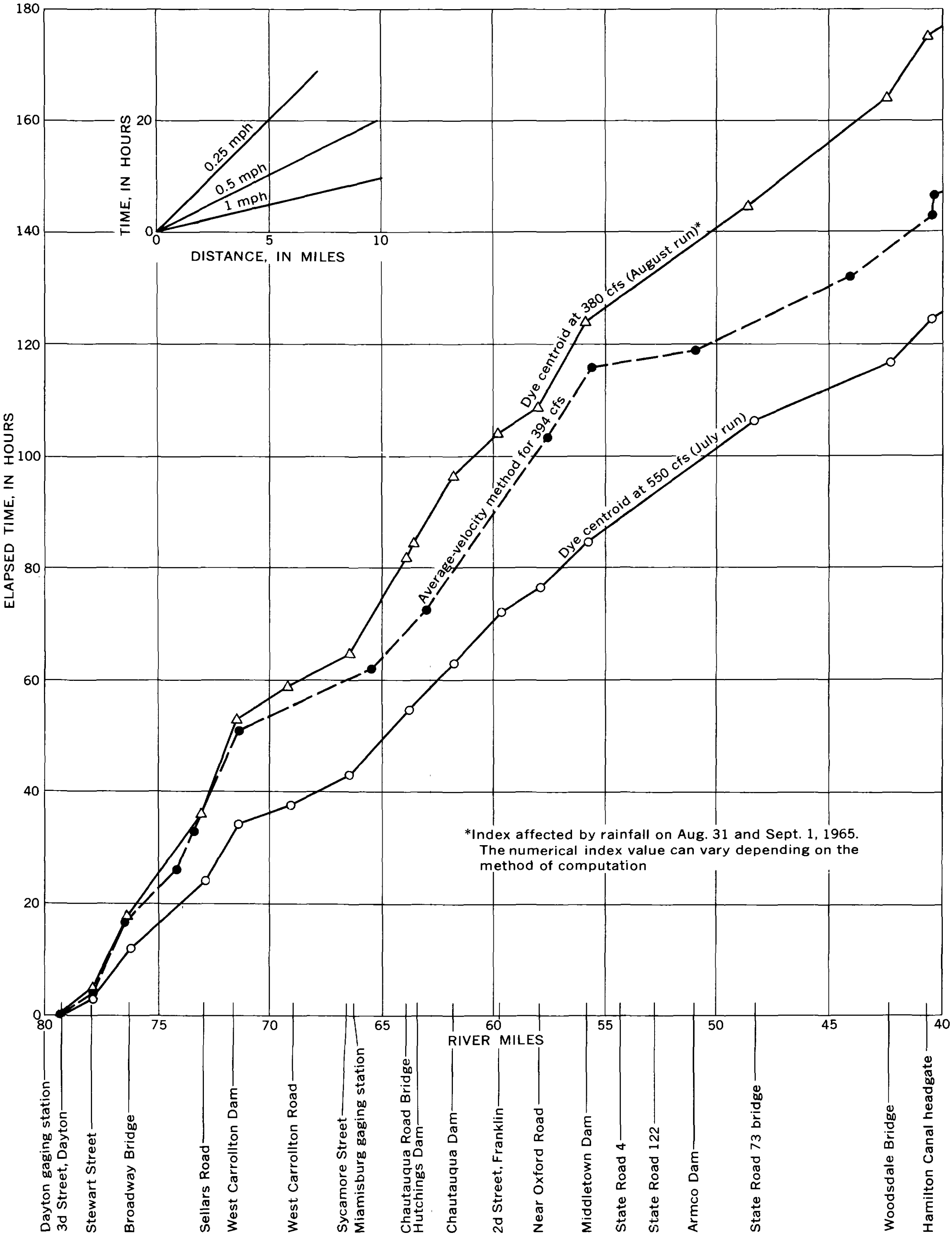

Figure 3.—Traveltime of Great Miami River, mile 80 to mile 40.

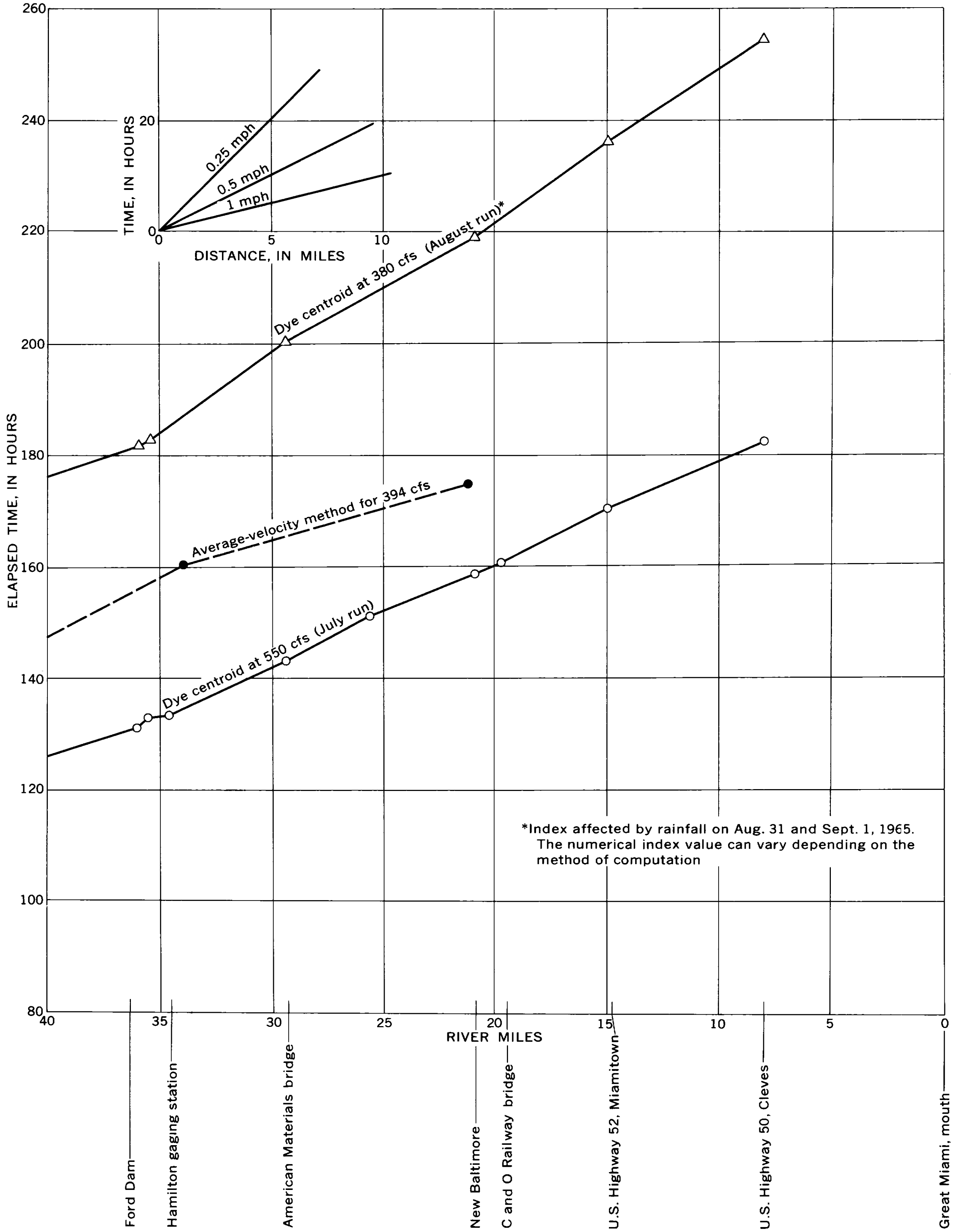

Figure 4.—Traveltime of Great Miami River, mile 40 to mile 0.

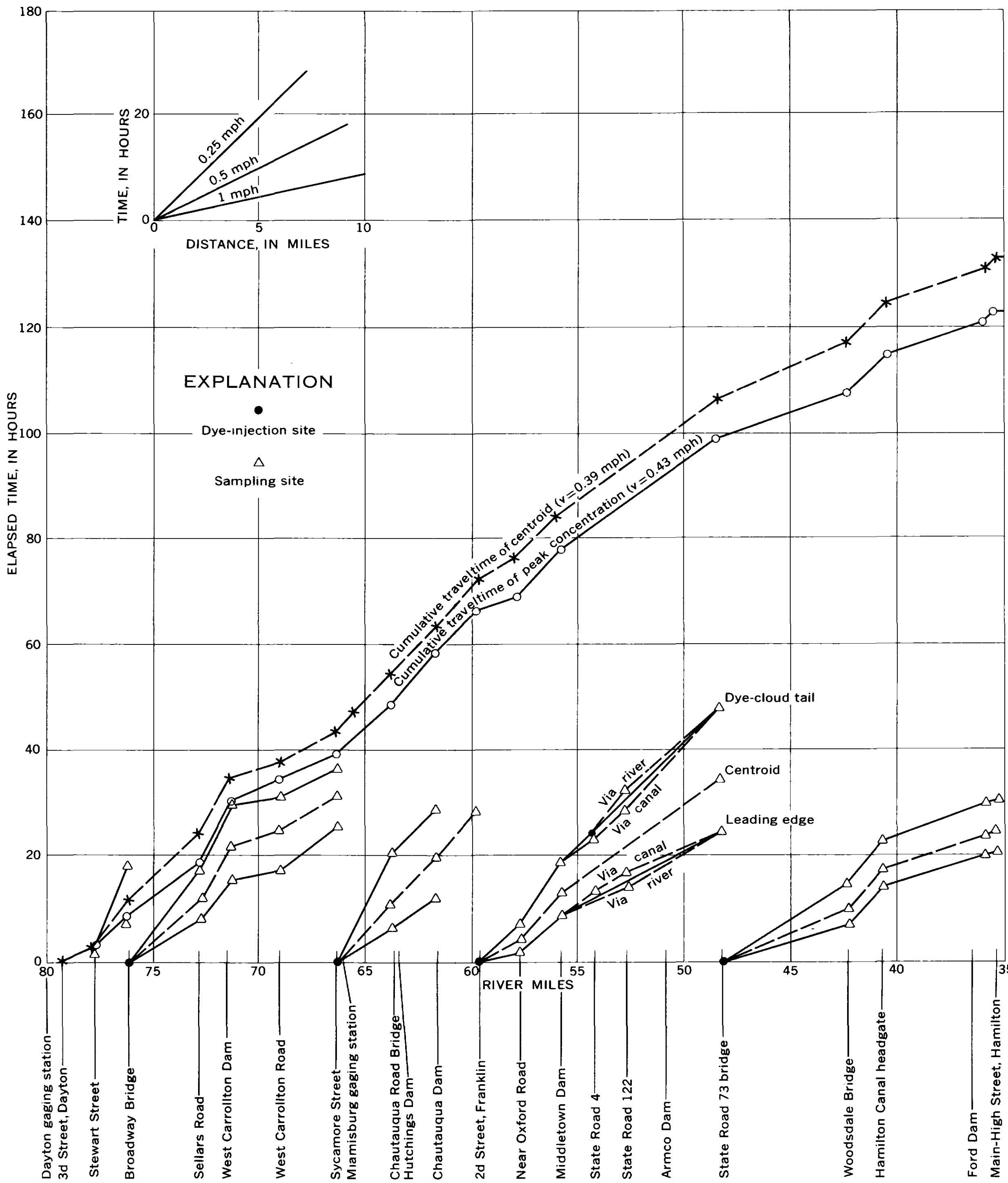

Figure 5.—Traveltime of dye cloud and longitudinal dispersion characteristics of Great Miami River at index flow of 550 cfs, mile 80 to mile 35.

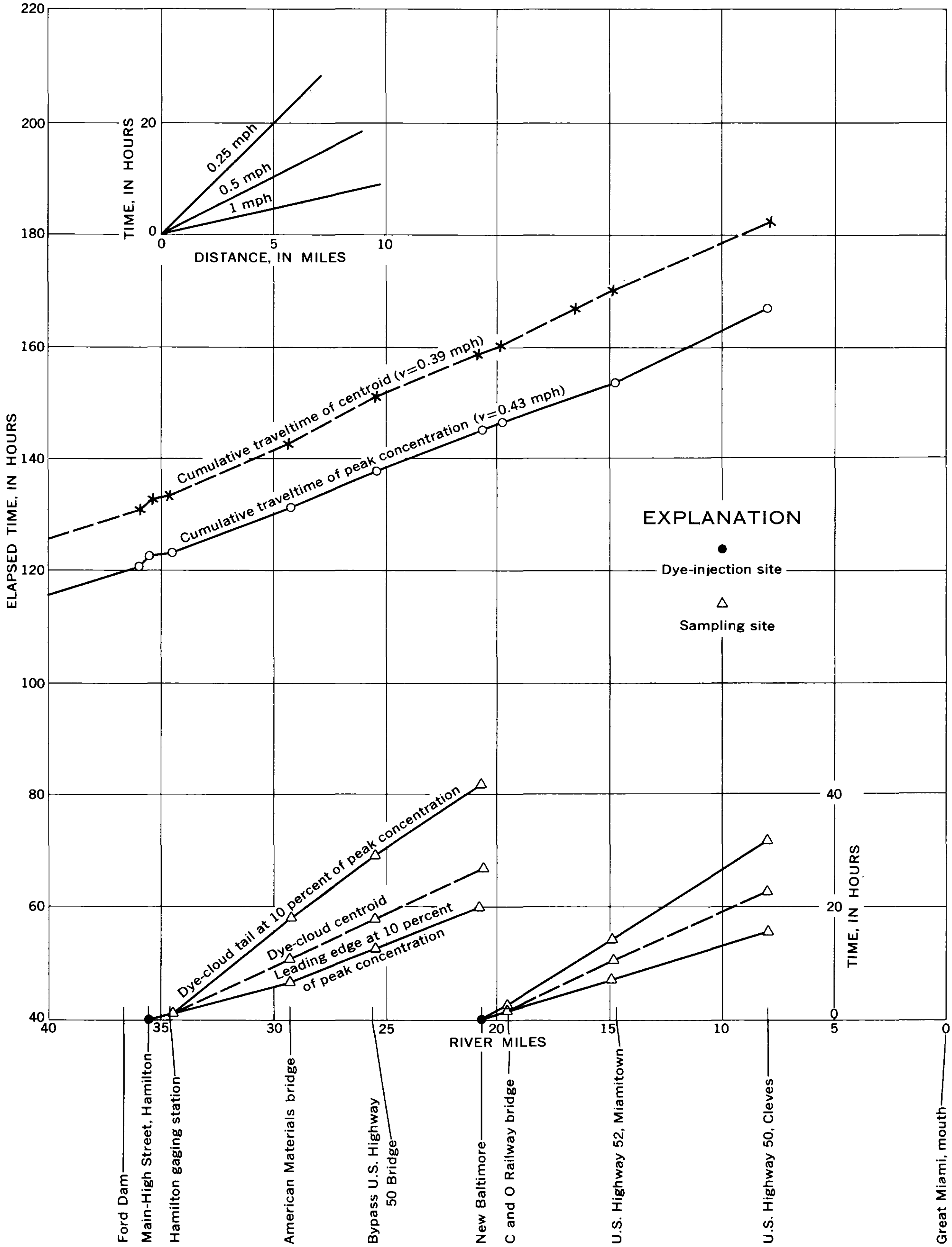

Figure 6.—Traveltime of dye cloud and longitudinal dispersion characteristics of Great Miami River at index flow of 550 cfs, mile 40 to mile 0.

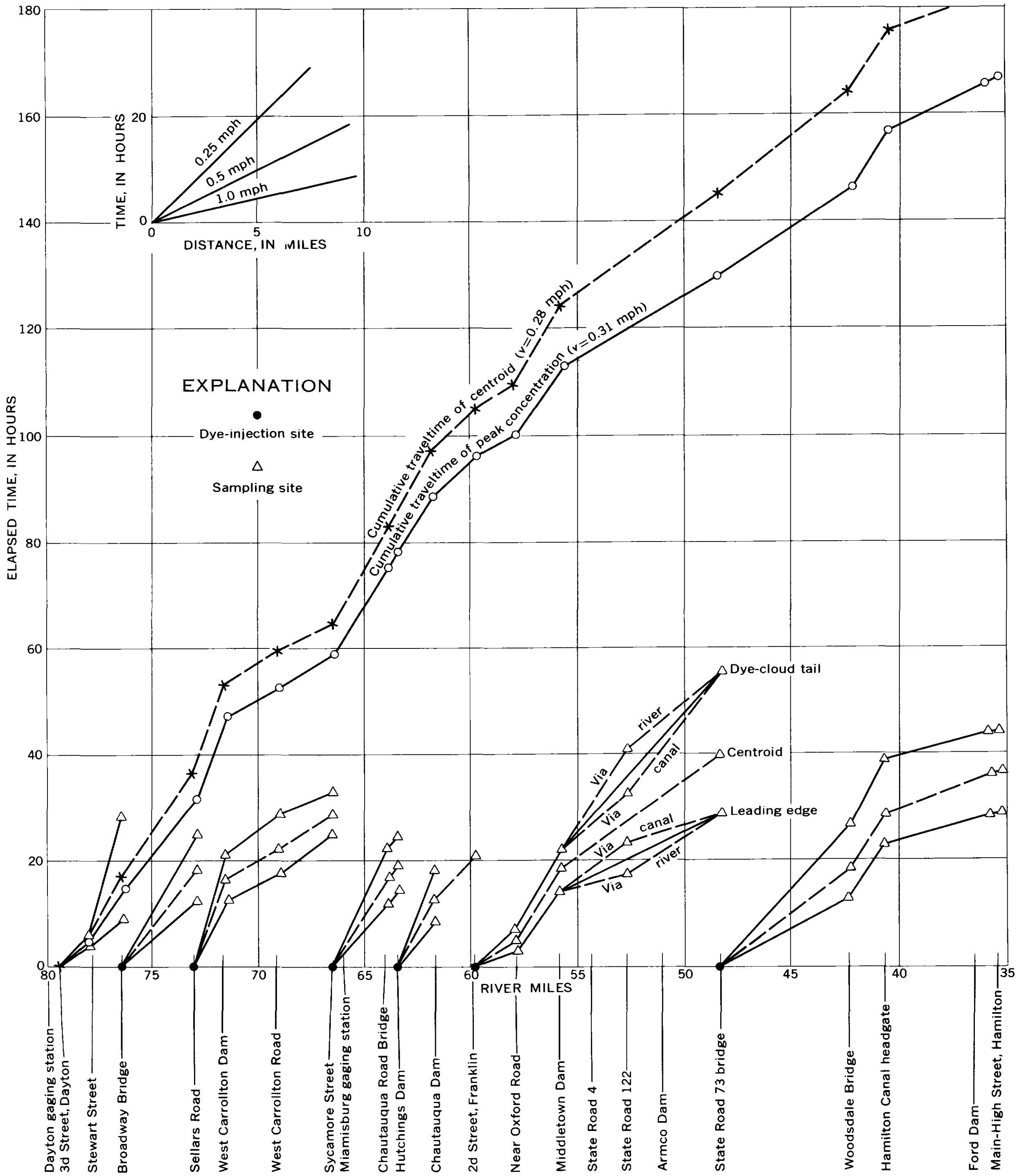

Figure 7.—Traveltime of dye cloud and longitudinal dispersion characteristics of Great Miami River at index flow of 380 cfs, mile 80 to mile 35.

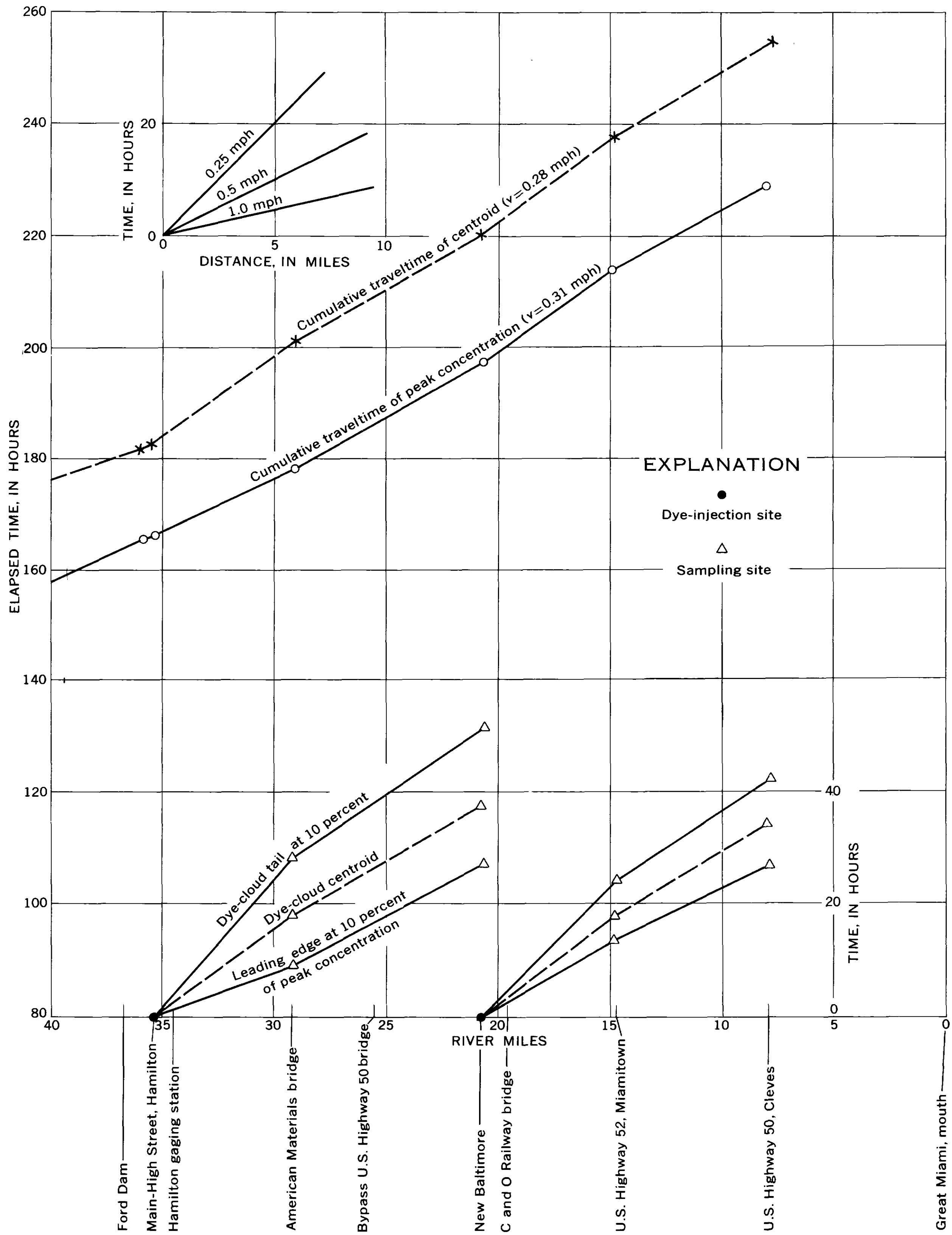

Figure 8.—Traveltime of dye cloud and longitudinal dispersion characteristics of Great Miami River at index flow of 380 cfs, mile 40 to mile 0.

Table 1.—*Traveltime for index discharge of 550 cubic feet per second at Miamisburg, July 13—15, 1965*

Location	Distance from mouth[1] (miles)	Mean discharge (cfs)	Traveltime of centroid of mass from previous site[2] (hr)	Mean velocity of centroid between present and previous sites (mph)	Time leading edge precedes centroid[3] (hr)	Persistence after centroid[3] (hr)	Traveltime of peak concentration (hr)
3d St., Dayton	79.32	340	--	--	--	--	--
Stewart St., Dayton	77.95	360	3.2	0.42	0.9	0.7	2.7
Broadway Bridge, Dayton[4]	76.36	370	8.8	.18	4.4	6.1	7.0
Sellars Rd	72.90	490	12.3	.28	3.6	5.5	9.9
West Carrollton Dam	71.48	490	10.0	.14	6.2	8.0	11.2
West Carrollton Rd	69.00	520	3.1	.79	5.7	6.0	4.4
Sycamore St., Miamisburg[4]	66.44	540	6.0	.43	5.8	5.2	4.6
Chautauqua Road Bridge	63.84	540	11.6	.22	4.5	9.6	9.0
Chautauqua Dam	61.70	520	8.4	.25	7.0	9.0	9.6
2d St., Franklin, via canal	59.71	510	7.8	.25	--	--	5.5
Chautauqua Dam	61.70	520	--	--	7.0	9.0	--
2d St., Franklin, via river	59.71	510	9.8	.20	--	--	10.8
Near Oxford Rd	57.93	540	4.2	.42	1.9	3.2	3.0
Middletown Dam	55.82	570	8.9	.24	3.9	6.2	9.0
Middletown Canal, at State Route 4	54.24	240	4.6	.34	4.1	6.4	3.2
Middletown Canal south, at State Route 122	52.74	240	3.3	.46	4.6	7.0	4.0
Middletown Dam	55.82	570	--	--	3.9	6.4	--
River-State Route 4	54.24	330	4.8	.33	4.3	7.1	4.0
River-State Route 122	52.74	330	7.4	.20	6.9	10.7	6.5
Middletown Dam	55.82	570	--	--	3.9	6.4	--
500 ft upstream, State Route 73 bridge[4]	48.47	590	21.2	.35	9.8	13.9	20.5
Woodsdale Bridge	42.36	620	10.3	.59	3.1	4.6	8.7
Hamilton Canal headgate	40.68	610	7.6	.60	3.2	4.7	7.4
Canal outfall	36.00	610	6.0	.78	3.5	6.1	5.5
Main-High St., Hamilton[4]	35.52	620	1.6	.30	3.2	5.1	2.3
1,000 ft downstream Hamilton gage	34.46	640	.7	1.47	.1	.1	.6
American Materials bridge	29.30	680	10.0	.52	4.6	7.2	7.8
U.S. Bypass 50	25.56	680	7.7	.48	6.8	11.4	6.8
New Baltimore[4]	20.84	710	8.2	.57	7.0	15.1	7.4
Chesapeake and Ohio Railway bridge	19.64	720	1.5	.81	.6	.2	1.0
U.S. 52, Miamitown	14.90	710	9.9	.48	3.9	3.3	8.1
U.S. 50, Cleves	7.98	690	12.0	.57	6.3	8.7	12.2

[1]Total mileage=71.3 miles.
[2]Total centroid traveltime=182 hr; average velocity=0.39 mph.
[3]Computed for 10 percent of peak concentration.
[4]Dye-injection points.

Table 2.—*Traveltime for index discharge of 380 cubic feet per second at Miamisburg, Aug. 31 to Sept. 2, 1965*

Location	Distance from mouth[1] (miles)	Mean discharge (cfs)	Traveltime of centroid of mass from previous site[2] (hr)	Mean velocity of centroid between present and previous sites (mph)	Time leading edge precedes centroid[3] (hr)	Persistence after centroid[3] (hr)	Traveltime of peak concentration (hr)
3d St., Dayton[4]	79.32	200	----------	----------	----------	----------	----------
Stewart St., Dayton	77.95	200	4.8	0.28	1.0	0.9	4.2
Broadway Bridge, Dayton[4]	76.36	290	13.2	.12	8.0	10.7	11.4
Sellars Rd[4]	72.90	350	18.2	.19	4.8	7.3	15.9
West Carrollton Dam	71.48	290	17.5	.08	3.2	5.0	16.3
West Carrollton Rd	69.00	300	5.7	.44	5.2	6.8	5.2
Sycamore St., Miamisburg[4]	66.44	440	5.5	.47	3.9	4.6	6.7
Chautauqua Road Bridge	63.84	350	17.7	.15	5.2	6.5	16.0
Below Hutchings Dam[4]	63.50	420	1.8	.18	4.9	5.3	2.6
Chautauqua Dam	61.70	290	12.8	.14	3.9	6.2	10.9
2d St., Franklin, via canal[4]	59.71	300	4.0	.50	----------	----------	6.0
Chautauqua Dam	61.70	290	----------	----------	3.9	6.2	----------
2d St., Franklin, via river	59.71	300	13.0	.15	----------	----------	14.0
Near Oxford Rd	57.93	300	4.7	.38	1.5	1.6	3.7
Middletown Dam	55.82	340	14.8	.14	4.5	3.4	13.4
Middletown Canal south, at State Route 122	52.74	230	7.5	.41	4.2	5.3	8.3
Middletown Dam	55.82	340	----------	----------	4.5	3.4	----------
River-State Route 122	52.74	510	17.6	.17	9.9	13.6	14.0
Middletown Dam	55.82	340	----------	----------	4.5	3.4	----------
State Route 73 bridge[4]	48.37	750	20.9	.35	10.6	16.3	16.9
Woodsdale Bridge	42.36	400	19.0	.32	6.3	8.9	15.6
Hamilton Canal headgate	40.68	500	10.6	.15	5.4	10.6	11.4
Hamilton Canal outfall	36.00	620	5.8	.80	6.3	9.2	7.0
Main-High St., Hamilton[4]	35.52	570	.6	.80	6.7	7.8	.8
American Materials bridge	29.30	420	18.5	.34	9.5	9.5	12.1
New Baltimore[4]	20.84	590	19.2	.44	10.2	14.2	19.8
U.S. 52, Miamitown	14.90	450	17.8	.33	4.3	6.0	16.5
U.S. 50, Cleves	7.98	550	16.7	.41	7.3	8.80	15.0

[1]Total mileage=71.3 miles.
[2]Total centroid traveltime=253.6 hr; average velocity=0.28 mph.
[3]Computed for 10 percent of peak concentration.
[4]Dye-injection points.

no dye loss for the 1,200-foot distance between the canal outfall and Franklin.

Adequate discharge measurements were made at Middletown to determine flow in the river and in the canal.

Table 3 gives representative discharges for selected sites along the Great Miami River and its tributaries. For most sites, tributary discharges were adjusted for discharge from the intervening drainage area between the gage site and the mouth.

A summary of industrial- and municipal-waste effluents is given in tables 4 and 5. Industrial- and municipal-waste effluents were computed on the assumption that the flow rate was constant over the entire 24-hour day. Besides the industries which utilize ground water, there are also industries which use the river water for cooling. Industries utilizing the river water for this purpose are not listed, for most of the water is returned to the stream.

Table 3.—*Discharges at selected sites on Great Miami River and tributaries*

Stream	Mean discharge (cfs)					
	7–13–65	7–14–65	7–15–65	8–31–65	9–1–65	9–2–65
Great Miami at Dayton	333	320	312	200	355	255
Wolf Creek	6	6	6	6	50 (peak)	5
Bear Creek[1]	6	6	6	2	2	2
Great Miami at Miamisburg	552	544	530	295	652	395
Great Miami at Franklin[2]	520	510	500	290	380	350
Clear Creek[2]	2	2	2	1	4	3
Twin Creek[1]	24	22	21	8.1	13	12
Great Miami at Middletown, canal	240	240	240	230	230	240
Great Miami at Middletown, river[2]	340	330	320	50	200	280
Elk Creek	2	2	2	1	4	2
Dicks Creek	4	4	4	8	18	7
Four Mile Creek	20	18	15	5	10	7
Great Miami at Hamilton	642	623	594	315	498	676
Indian Creek[1]	1	1	1	.5	2	1
Great Miami at New Baltimore	720	710	680	370	480	900
Great Miami at Cleves[3]	--------	-------	664	-------	----------	551

[1]Discharge adjusted for drainage-area change between gage site and mouth.
[2]Nonrecording gage; discharge computed from 8:00 a.m. reading each day.
[3]Measurements, July 15 at 10:00 a.m. and Sept. 2 at 9:00 a.m.

Table 4.—*Municipal sewage-plant effluent*

City	Mean discharge (cfs)					
	7–13–65	7–14–65	7–15–65	8–31–65	9–1–65	9–2–65
Dayton	75.5	76.9	74.8	69.1	75.3	66.0
Hamilton	11.3	11.4	11.6	11.6	15.1	12.8
Miamisburg	2.2	2.2	2.2	2.0	2.3	2.1
Middletown	9.7	9.7	9.7	18.3	10.7	12.7
Franklin	.1	.1	.1	.1	.1	.1
West Carrollton[1]	1.0	1.0	1.0	1.0	1.0	1.0
Miami Shores[1]	1.0	1.0	1.0	1.0	1.0	1.0
Totals	100.8	102.3	100.4	103.1	105.5	95.7

[1]Approximate effluent by graphical comparison.

Table 5.—*Waste effluent from industries using ground-water supply*

Plant	Mean discharge (cfs)					
	7–13–65	7–14–65	7–15–65	8–31–65	9–1–65	9–2–65
National Cash Register Co., Dayton	9.5	9.8	10.4	8.2	16.5	7.7
Howard Paper Div., St. Regis Paper Co., Dayton[1]	-------	-------	-------	-------	-------	-------
Frigidaire Corp., Dayton[1]	-------	-------	-------	-------	-------	-------
Frigidaire Corp., Moraine City	30.1	30.3	30.3	28.9	19.1	18.7
Parchment Co., West Carrollton	1.7	1.7	1.7	1.7	1.7	1.7
Oxford Paper Co., North Carrollton	5.6	5.6	5.6	6.2	6.2	6.2
Kimberly-Clark Corp., West Carrollton	7.8	7.8	8.5	6.5	2.5	7.7
Miamisburg Box Board Div., Interstate Folding Box Co., Miamisburg	-------	-------	-------	1.7	1.7	1.7
Cheney Pulp and Paper Co., Franklin	.4	.4	.4	.4	.4	.4
Miami Valley Coated Paper Div., Millen Industries, Franklin	.1	.1	.1	.1	.1	.1
Logan Long Co., Franklin	.3	.3	.3	.3	.3	.3
Stone Container Corp., Franklin	.8	.8	.8	.8	.8	.8
Harding Jones Paper Co., Middletown	1.3	1.3	1.3	1.3	1.4	1.4
Sorg Paper Co., Middletown	3.8	4.1	3.9	2.4	2.5	3.0
Wren Paper Div., Mead Paper Corp., Middletown	.9	.9	.9	.9	.9	.9
Crystal Tissue Co., Middletown	3.6	3.6	3.6	3.5	3.5	3.5
Armco Steel Corp., Middletown	15.5	15.5	15.5	15.5	15.5	15.5
U.S. Plywood, Champion Paper, Inc., Hamilton	-------	-------	20.6	19.8	19.3	18.4
Nicolet Industries, Inc., Hamilton	-------	-------	-------	.2	.2	.2
Totals	81.4	82.2	103.9	98.4	92.6	88.2

[1]Tied in with city sewer.

DETERMINATION OF MIAMISBURG INDEX DISCHARGE

During the July run, discharges at Miamisburg remained nearly constant during the run. Over this time span, an average index discharge of 550 cfs was computed for Miamisburg. The index discharge is defined as the average discharge at Miamisburg for the traveltime occurrence.

During the August run, a rainstorm occurred covering the entire reach under consideration with approximately $1–1\frac{1}{4}$ inches of rainfall. Generally, peak dye-cloud concentration occurred at all sampling sites before the effects of the rainfall were noted. Many of the tailing ends of the time-concentration curves were affected and caused a dilution effect in some places. In a few of the more critical situations, the concentration curves were extended by estimating the recessions. To determine the effects of the rain more thoroughly, a discharge-drainage-area relation was computed for each concentration curve, based on the time of occurrence of the centroid. Results of computations showed discharge per square mile to range from 0.078 to 0.241 cfs with an average of 0.128 cfs. Eighty-seven percent of the values ranged from 0.100 to 0.179 cfs with only one extreme of 0.241 cfs. It was therefore concluded that the rainfall had minor effect.

The computation of index discharge for the August run was determined by considering sampling-site discharge, drainage area, and mean discharge at Miamisburg. (See table 6.) To arrive at a representative value, the following procedure was used: A discharge factor was computed for each sampling site, the discharge factor being defined as the quotient of the mean Miamisburg discharge and the mean sampling-site discharge. Discharge results from the July run were used to compute the discharge factors. Mean sampling-site discharges were then computed for the August run. Next, Miamisburg index discharges for

Table 6.—*Miamisburg index discharges for mean discharges in subreaches during August run*

Location	Mean discharge (Q)[1] (cfs)	Discharge factor (F)	Product $Q \times F$ (cfs)	Average Miamisburg index discharge (cfs)
3d St., Dayton[2]	203	1.59	323	312
Stewart St., Dayton	200	1.50	300	368
Broadway Bridge, Dayton	291	1.46	437	
Broadway Bridge, Dayton[2]	202	1.46	295	318
Sellars Road	310	1.10	341	
Sellars Road[2]	291	1.10	320	318
West Carrollton Dam	288	1.10	317	320
West Carrollton Road	310	1.04	322	355
Sycamore St., Miamisburg	388	1.00	388	
Sycamore St., Miamisburg[2]	290	1.00	290	325
Chautauqua Road Bridge	360	1.00	360	389
Below Hutchings Dam	410	1.02	418	
Below Hutchings Dam[2]	293	1.02	299	302
Chautauqua Dam	294	1.04	306	310
2d St., Franklin	295	1.06	313	
2d St., Franklin[2]	295	1.06	313	304
Near Oxford Road	295	1.00	295	309
Middletown Dam	340	.95	323	484
State Route 73 Bridge	700	.92	644	
State Route 73 Bridge[2]	316	.92	291	321
Woodsdale Bridge	404	.87	351	404
Hamilton Canal headgate	514	.89	457	496
Hamilton Canal outfall	600	.89	534	524
Main-High St., Hamilton	590	.87	513	
Main-High St., Hamilton[2]	315	.87	274	307
American Materials bridge	425	.80	340	394
New Baltimore	590	.76	448	
New Baltimore[2]	370	.76	281	300
U.S. 52, Miamitown	420	.76	319	366
U.S. 50, Cleves	530	.78	413	

[1]Mean discharge at the time of dye-cloud passage or at the time of dye injection.
[2]Dye-injection locations.

each sampling site were determined from the product of the mean sampling-site discharges and the respective discharge factors. Index discharges at the upstream and downstream ends of each subreach were then averaged. Instead of using an arithmetic average of the tabulated discharge, it was felt that weighting each discharge by its incremental reach drainage area would give a truer discharge index for the entire reach, Dayton to Cleves. By this method, an index discharge for the Miamisburg gage was computed to be 380 cfs. This index is limited to applications involving the entire stream reach, and if indices are desired for other subreaches, from Dayton to Middletown, for example, a similar computation would have to be followed.

TRAVELTIME PREDICTION

To predict traveltimes, a linear log-log plot of traveltime versus Miamisburg index discharge was made. A straight line was drawn between the two points and an equation developed for the curve. The equation which was developed for the entire reach, Dayton to Cleves, is, $T = 400 \times 10^2 Q^{-.85}$, where T is traveltime in hours and Q is discharge in cfs.

The above equation is applicable for an approximate index-discharge span of 300–800 cfs; these limits were determined from a study of varying Miamisburg index discharges and the corresponding stream cross-sectional areas at random sites along the reach.

The two index discharges of 550 and 380 cfs represent flow durations of 76 and 90 percent, respectively, at Miamisburg. The index discharges therefore represent very low flow conditions, and the traveltimes are nearly the longest and the longitudinal spreads are nearly the greatest to be expected. An accidental spill at a discharge much greater than 550 cfs would travel faster and be less dispersed.

DYE-CLOUD PASSAGE TIME

Passage time of the dye cloud may be determined by inspection of the curves in figures 5–8. The time intervals from the centroids of the concentration curves are plotted and are given in tables 1 and 2. Because of the uncertainty of the actual beginning or ending of many concentration curves, values were taken at 10 percent of the peak concentration. By using 10 percent of the peak concentration instead of zero concentration, the differences for the leading edges are usually slight; for most cases, the trailing edge 10-percent point is significantly short of the point of nondetectability.

As a point of interest, the Middletown canal and river longitudinal dispersion characteristics are also shown on figure 5. Only an average centroid curve is plotted; both the canal and river values were plotted from this base.

By comparing the longitudinal dispersion characteristics of the two runs, some uncommon time-concentration patterns are noted that are similar to those reported by Godfrey and Frederick (1963). This variation can be attributed to the many controls and extensive use of the stream. Even if a rerun would be possible at discharges equal to those during this study, the resulting shape of the time-concentration curve would probably differ.

CONCLUSIONS

The time-of-travel study of the Great Miami River gave representative traveltimes for the river during low streamflow between Dayton and Cleves, a distance of 71.3 river miles. The longitudinal spread of the dye cloud showed unusual effects, especially in the upper portion of the reach where the stream is highly controlled. Comparison of observed traveltimes with those computed by using the average-velocity method indicated very poor correlation between the two methods. The average-velocity method indicated a faster traveltime for a given index discharge at Miamisburg. Within the index-discharge range, 300–800 cfs, one may make reasonable estimates of time of travel for a given index discharge. However, extrapolations of the traveltime-discharge relation beyond that range should be made with caution.

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