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TIME OF TRAVEL OF SOLUTES IN SELECTED REACHES OF THE SANDUSKY RIVER BASIN, OHIO 1972 AND 1973

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By Arthur O. Westfall

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Prepared in cooperation with

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TIME OF TRAVEL OF SOLUTES IN SELECTED REACHES OF THE SANDUSKY RIVER BASIN, OHIO 1972 AND 1973

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ABSTRACT

A time of travel study of a 106-mile (171-kilometre) reach of the Sandusky River and a 39-mile (63-kilometre) reach of Tymochtee Creek was made to determine the time required for water released from Killdeer Reservoir on Tymochtee Creek to reach selected downstream points. In general, two dye sample runs were made through each subreach to define the time-discharge relation for approximating travel times at selected discharges within the measured range, and time-discharge graphs are presented for 38 subreaches. Graphs of dye dispersion and variation in relation to time are given for three selected sampling sites. For estimating travel time and velocities between points in the study reach, tables for selected flow durations are given. Duration curves of daily discharge for four index stations are presented to indicate the low-flow characteristics and for use in shaping downward extensions of the time-discharge curves.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the Ohio Department of Natural Resources, made a time-of-travel study of a part of the Sandusky River basin extending from the outlet of Killdeer Reservoir on Tymochtee Creek to State Street in Fremont (figs. 1 and 2). The study, made during April 1972 to September 1973, covered 145 river miles (233 km).

The purpose of the study was to determine the time required for water released from Killdeer Reservoir at mile 39.4 (km 63.4) on Tymochtee Creek to reach selected downstream points and to move pollutants past water intakes at Tiffin and Ballville. The methods and equipment used were those described by Wilson (1968) and Kilpatrick, Martens, and Wilson (1970). The results of the study are given in tables 1 and 2.

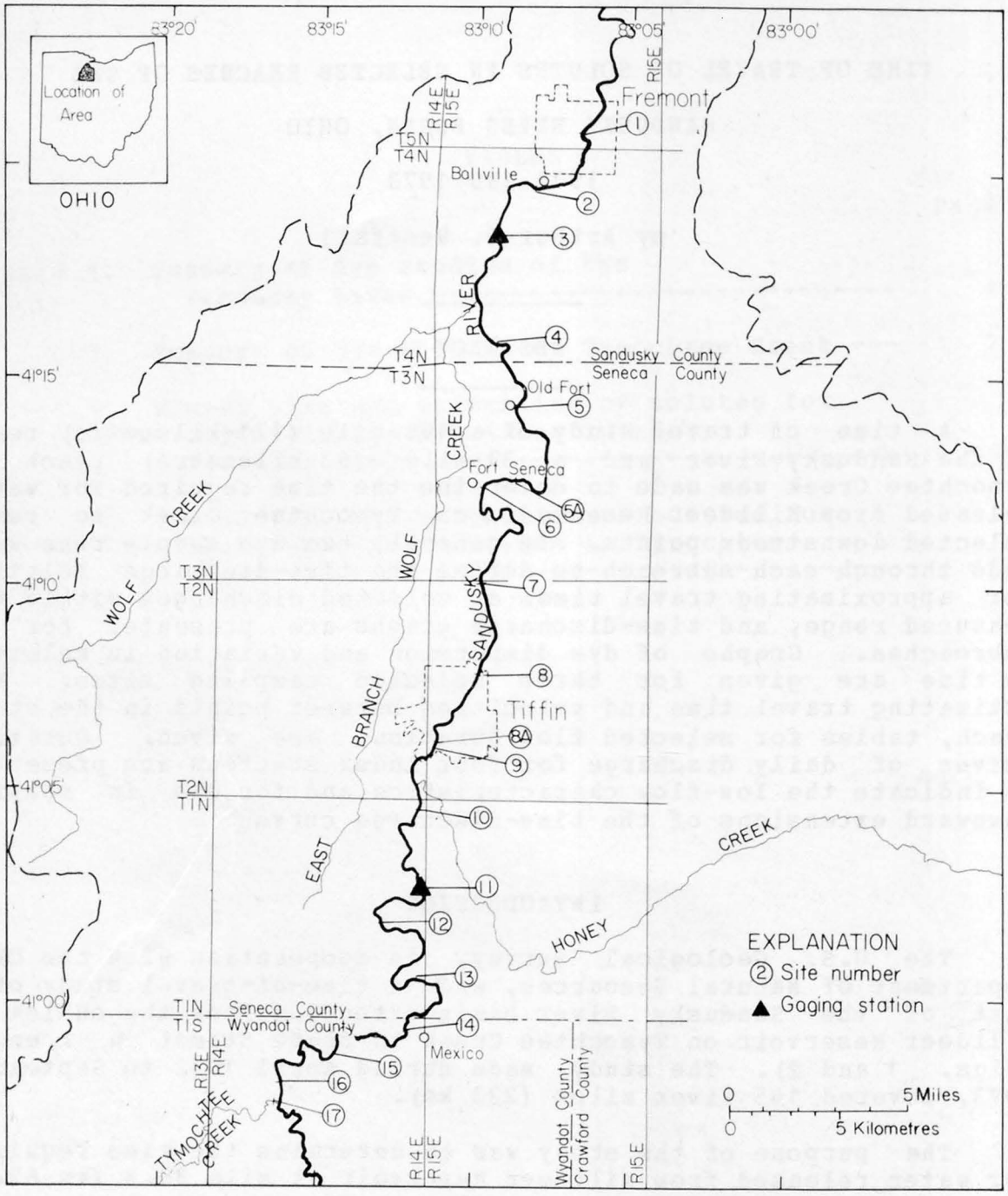

FIGURE 1.-- MAP OF SANDUSKY RIVER SHOWING DYE SAMPLING SITES

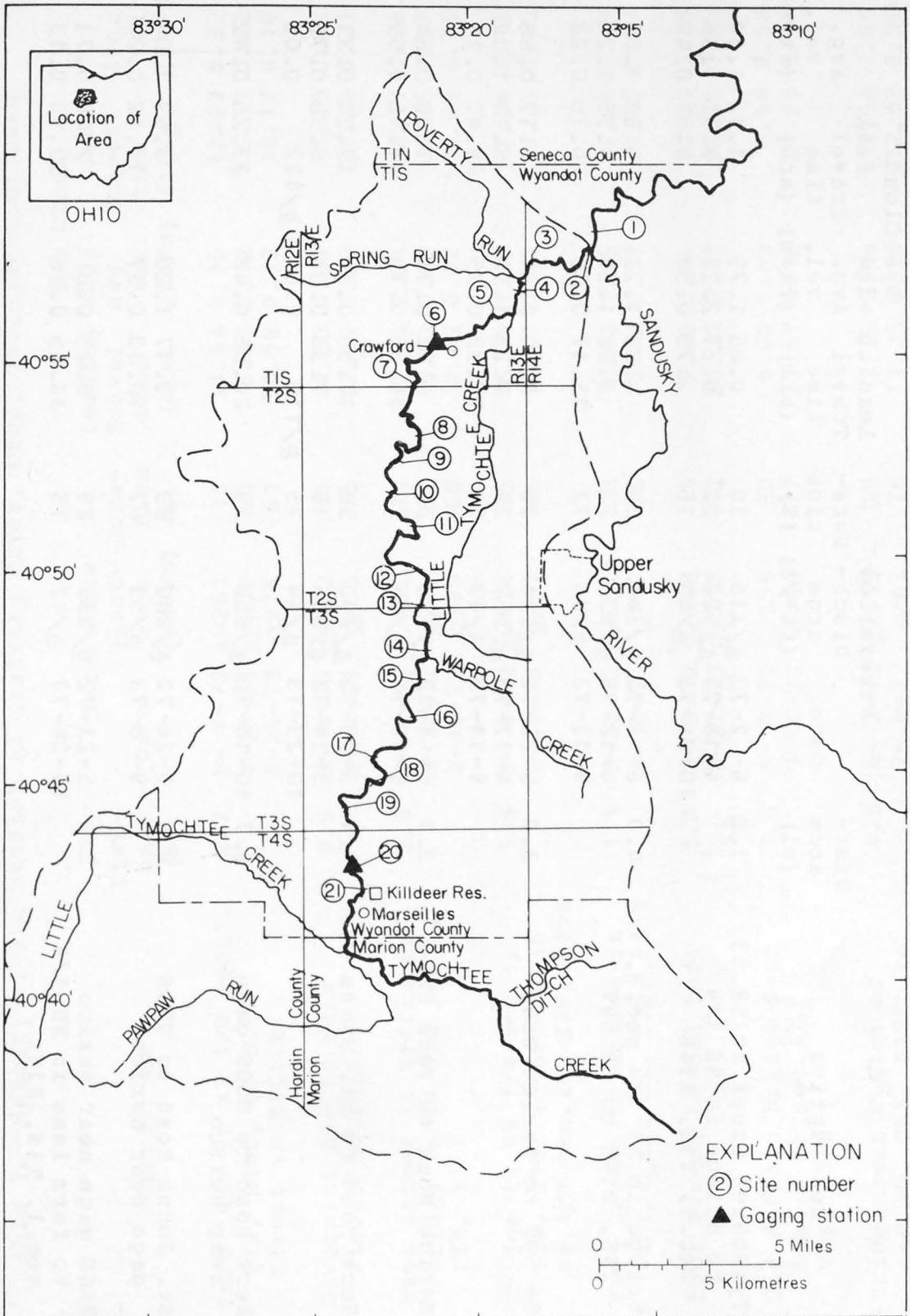

FIGURE 2.--MAP OF TYMOCHTEE CREEK SHOWING DYE SAMPLING SITES

Table 1.--Summary of dye studies on Sandusky River, Ohio, 1972-73

*Reach	Description	Distance (mi)	Streamflow Date	Streamflow Discharge (ft^3/s)	Streamflow Duration (%)	Dye Cloud leading edge Travel time (hrs)	Dye Cloud leading edge Avg. vel. (ft/s)	Dye Cloud Peak Travel time (hrs)	Dye Cloud Peak Avg. vel. (ft/s)
17-16	Tymochtee Creek at SR 53 to bridge in SE 1/4 sec.8, T1S, R14E	1.0	6- 2-72	a/318	30	0.85	1.79	1.17	1.30
			4-18-73	a/522	22	0.67	2.28	0.92	1.66
			10-26-73	a/43	75	2.75	0.54	3.67	0.42
16-15	Bridge in SE 1/4 sec.8, T1S, R14E to SR 587	4.0	6- 1-72	a/344	29	4.83	1.22	5.83	1.01
			4-18-73	a/528	22	3.83	1.54	4.75	1.24
			9-12-73	a/46	73	15.17	0.39	20.75	0.28
15-14	SR 587 to Mexico Road	3.8	5-25-72	a/231	38	6.83	0.81	8.17	0.68
			4-17-73	a/552	22	4.25	1.30	5.17	1.07
			9-11-73	a/47	73	22.33	0.25	29.42	0.19
14-13	Mexico Road to Heck Road	3.1	6- 1-72	a/338	29	6.08	0.74	7.08	0.64
			9-10-73	a/48	72	35.25	0.13	48.75	0.09
13-12	Heck Road to St. Johns Road	4.1	5-30-72	a/290	32	17.58	0.34	19.33	0.31
			5-14-73	a/816	16	7.33	0.83	8.08	0.75
			10-23-73	a/44	75	b/110	0.06	b/132	0.05
13-11	Heck Road to USGS gage near Mexico	6.7	10-16-72	a/338	29	20.58	0.48	23.25	0.42
12-11	St. Johns Road to USGS gage near Mexico	2.6	5-24-72	a/282	33	3.17	1.20	3.67	1.04
			9- 6-73	a/59	67	10.33	0.37	13.42	0.28
11-10	USGS gage near Mexico to farm lane in NE 1/4 sec.1, T1N, R14E	3.4	5-23-72	a/330	29	6.25	0.81	7.08	0.71
			10-24-73	a/42	75	31.25	0.16	39.50	0.13

See footnotes at end of table.

Table 1.--Summary of dye studies on Sandusky River, Ohio, 1972-73--Continued

*Reach	Description	Distance (mi)	Date	Streamflow Discharge (ft^3/s)	Duration (%)	Dye Cloud: Leading edge Travel time (hrs)	Dye Cloud: Leading edge Avg. vel. (ft/s)	Dye Cloud: Peak Travel time (hrs)	Dye Cloud: Peak Avg. vel. (ft/s)
10-8A	Farm lane in NE 1/4 sec.1, T1N, R14E, to Ella Street in Tiffin	2.7	5- 4-72	a/261	35	10.83	0.36	12.33	0.32
			4-16-73	a/600	20	5.42	0.72	6.33	0.62
			8-29-73	a/78	61	30.50	0.13	38.17	0.10
9-8	Diversion dam to Huss Street in Tiffin	2.9	5- 4-72	c/482	34	4.33	0.99	5.25	0.82
			9- 4-73	c/65	75	17.00	0.25	20.33	0.21
8-7	Huss Street in Tiffin to bridge in NW 1/4 sec.5, T2N, R15E	2.8	5- 4-72	c/482	34	2.00	2.04	2.17	1.88
			9-12-72	c/48	82	5.92	0.69	8.75	0.47
			8-30-73	c/88	68	4.42	0.92	5.33	0.76
7-5A	Bridge in NW 1/4 sec.5, T2N, R15E to bridge in NW 1/4 sec.21, T3N, R15E	5.8	5- 4-72	c/474	35	6.83	1.26	7.58	1.13
			8-28-73	c/97	66	16.17	0.53	19.25	0.45
6-5A	Fort Seneca to bridge in NW 1/4 sec.21, T3N, R15E	1.1	5-22-72	c/652	28	0.92	1.75	1.08	1.49
			8-30-72	c/97	66	2.83	0.57	3.42	0.47
6-5	Fort Seneca to Old Fort	5.1	5- 3-72	c/548	31	9.00	0.84	10.00	0.75
			8-27-73	c/113	62	20.25	0.37	22.75	0.33
5-4	Old Fort to bridge near center of sec.32, T4N, R15E	2.6	5- 3-72	c/558	30	6.00	0.63	6.58	0.58
			9- 6-72	c/58	77	21.67	0.18	24.25	0.16
4-3	Bridge near center of sec.32, T4N, R15E, to USGS gage near Fremont	4.5	5- 2-72	c/655	28	3.25	2.04	3.58	1.85
			9- 6-72	c/62	76	11.25	0.59	12.58	0.53

See footnotes at end of table.

Table 1.--Summary of dye studies on Sandusky River, Ohio, 1972-73--Continued

*Reach	Description	Distance (mi)	Date	Streamflow Discharge (ft^3/s)	Duration (%)	Dye Cloud Leading edge Travel time (hrs)	Dye Cloud Leading edge Avg. vel. (ft/s)	Dye Cloud Peak Travel time (hrs)	Dye Cloud Peak Avg. vel. (ft/s)
3-2	USGS gage near Fremont to diversion dam at Ballville	2.3	5- 2-72	c/645	28	6.75	0.50	7.83	0.43
			11- 7-73	c/134	59	24.17	0.14	42.75	0.08
2-1	Diversion dam at Ballville to State Street in Fremont	2.7	5- 1-72	c/655	28	2.50	1.60	3.00	1.33
			8-31-72	c/76	71	8.50	0.47	9.92	0.40
			8-23-73	c/257	47	5.08	0.79	6.17	0.65

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a/ At USGS gage near Mexico (04197000).
b/ Fragmentary data.
c/ At USGS gage near Fremont (04198000).
Note: Duration data are for base period, 1931-60.
* Numbers correspond to site numbers shown in figure 1.

Table 2.--Summary of dye studies on Tymochtee Creek, Ohio, 1972-73

*Reach	Description	Distance (mi)	Streamflow Date	Streamflow Discharge (ft^3/s)	Streamflow Duration (%)	Dye Cloud Leading edge Travel time (hrs)	Dye Cloud Leading edge Avg. vel. (ft/s)	Dye Cloud Peak Travel time (hrs)	Dye Cloud Peak Avg. vel. (ft/s)
21-20	Killdeer Reservoir outlet to USGS gage (discontinued) near Marseilles	1.2	5- 3-73	a/75	22	3.25	0.55	3.75	0.47
			5- 7-73	a/35	32	5.25	0.34	6.50	0.27
			9-18-73	a/19	40	8.25	0.22	10.00	0.18
20-19	USGS gage (discontinued) near Marseilles to SR 294	2.5	7-27-72	a/9.0	50	14.83	0.25	16.92	0.22
			5- 3-73	a/77	22	3.92	0.95	4.67	0.80
19-18	SR 294 to bridge in SE 1/4 sec.29, T3S, R13E	2.2	8- 3-72	a/6.9	53	13.25	0.24	19.58	0.17
			5- 2-73	a/94	19	3.92	0.82	4.50	0.72
			7-11-73	50	27	5.08	0.64	6.42	0.50
18-17	Bridge in SE 1/4 sec. 29, T3S, R13E, to bridge in SE 1/4 sec.20, T3S, R13E	1.5	7-27-72	a/11	48	9.58	0.24	12.00	0.19
			5- 1-73	a/136	15	1.92	1.18	2.25	1.02
			7-11-73	a/40	30	2.75	0.82	3.50	0.65
17-16	Bridge in SE 1/4 sec. 20, T3S, R13E to bridge in SW 1/4 sec.15, T3S, R13E	2.8	7-24-72	a/17	42	15.08	0.27	17.92	0.23
			5- 2-73	a/102	18	5.17	0.80	5.83	0.71
			7-11-73	a/45	29	8.00	0.51	9.50	0.43
16-15	Bridge in SW 1/4 sec. 15, T3S, R13E to bridge in SW 1/4 sec.10, T3S, R13E	1.8	7-25-72	a/16	43	6.58	0.39	8.50	0.30
			11- 7-72	a/118	17	2.67	0.97	3.25	0.80
			7-10-73	a/36	32	4.75	0.54	6.00	0.43
15-14	Bridge in SW 1/4 sec. 10, T3S, R13E to SR 53	1.5	7-19-72	a/11	48	8.50	0.26	10.25	0.21
			10-26-72	a/57	26	4.25	0.51	5.25	0.41

See footnotes at end of table.

Table 2.--Summary of dye studies on Tymochtee Creek, Ohio, 1972-73--Continued

*Reach	Description	Distance (mi)	Streamflow Date	Streamflow Discharge (ft^3/s)	Streamflow Duration (%)	Dye Cloud Leading edge Travel time (hrs)	Dye Cloud Leading edge Avg. vel. (ft/s)	Dye Cloud Peak Travel time (hrs)	Dye Cloud Peak Avg. vel. (ft/s)
14-13	SR 53 to bridge in SW 1/4 sec. 34, T2S, R13E	2.1	7-17-72	a/11	48	10.33	0.30	12.25	0.25
			10-25-72	a/57	26	4.58	0.67	6.00	0.51
13-12	Bridge in SW 1/4 sec. 34, T2S, R13E to U.S. Highway 30 N.	1.5	6-28-72	b/10	53	10.33	0.22	11.92	0.19
			10-19-72	b/50	34	4.08	0.55	5.00	0.45
			7-17-73	b/40	36	4.58	0.49	5.67	0.40
12-11	U.S. Highway 30 N to bridge in NW 1/4 sec. 27, T2S, R13E	2.9	6-27-72	b/9.1	54	25.67	0.18	28.58	0.15
			5- 8-73	b/56	33	10.33	0.42	11.75	0.37
11-10	Bridge in NW 1/4 sec. 27, T2S, R13E to bridge in SW 1/4 sec. 16, T2S, R13E	2.0	6- 8-72	b/18	46	9.08	0.33	10.75	0.28
			10-18-72	b/52	34	5.08	0.59	6.25	0.48
			4-19-73	b/160	20	2.67	1.12	3.25	0.92
10-9	Bridge in SW 1/4 sec. 16, T2S, R13E to bridge in SE 1/4 sec. 9, T2S, R13E	1.8	4- 6-72	b/42	37	4.83	0.56	5.75	0.47
			5-10-73	b/231	15	2.17	1.29	2.67	1.01
			7-19-73	b/16	48	8.25	0.33	10.42	0.26
9-8	Bridge in SE 1/4 sec. 9, T2S, R13E to bridge in NW 1/4 sec. 10, T2S, R13E	1.7	4- 6-72	b/42	36	3.42	0.73	4.17	0.60
			4-20-73	b/179	18	1.67	1.49	2.08	1.19
			7-19-73	b/18	46	5.83	0.43	7.75	0.32

See footnotes at end of table.

Table 2.--Summary of dye studies on Tymochtee Creek, Ohio, 1972-73--Continued

*Reach	Description	Distance (mi)	Streamflow Date	Streamflow Discharge (ft^3/s)	Streamflow Duration (%)	Dye Cloud Leading edge Travel time (hrs)	Dye Cloud Leading edge Avg. vel. (ft/s)	Dye Cloud Peak Travel time (hrs)	Dye Cloud Peak Avg. vel. (ft/s)
8-7	Bridge in NW 1/4 sec. 10, T2S, R13E to Riester Road	2.9	6-14-72	b/50	34	9.67	0.44	10.42	0.41
8-6	Bridge in NW 1/4 sec. 10, T2S, R13E to USGS gage at Crawford	5.4	5-15-73	b/162	20	9.58	0.82	11.33	0.70
			9-17-73	b/21	45	41.08	0.19	52.83	0.15
7-6	Riester Road to USGS gage at Crawford	2.5	6-14-72	b/62	31	10.25	0.36	12.25	0.30
			5-15-73	b/165	19	5.25	0.70	6.17	0.59
6-5	USGS gage at Crawford to Hurd Road	2.0	4- 5-72	b/40	37	3.17	0.90	3.83	0.75
			5-10-73	b/228	16	1.42	2.02	1.67	1.72
			7-18-73	b/23	44	4.67	0.61	5.75	0.50
5-4	Hurd Road to SR 103	1.6	4- 4-72	b/42	37	2.83	0.83	3.42	0.69
			5-10-73	b/209	17	1.50	1.57	1.83	1.29
			7-18-73	b/29	40	4.00	0.59	4.83	0.49
4-3	SR 103 to bridge in SW 1/4 sec. 18, T1S, R13E	1.4	4- 4-72	b/42	37	2.33	0.90	3.08	0.68
			5- 9-73	b/83	28	1.83	1.14	2.17	0.96
			7-18-73	b/32	40	3.33	0.63	4.00	0.52

See footnotes at end of table.

Table 2.--Summary of dye studies on Tymochtee Creek, Ohio, 1972-73--Continued

*Reach	Description	Distance (mi)	Date	Streamflow Discharge (ft^3/s)	Streamflow Duration (%)	Dye Cloud Leading edge Travel time (hrs)	Dye Cloud Leading edge Avg. vel. (ft/s)	Dye Cloud Peak Travel time (hrs)	Dye Cloud Peak Avg. vel. (ft/s)
3-2	Bridge in SW 1/4 sec. 18, T1S, R13E to SR 53	3.1	4- 5-72	b/42	37	5.75	0.79	6.92	0.66
			5- 9-73	b/82	28	3.83	1.19	4.50	1.01
			5-10-73	b/203	17	3.17	1.43	3.83	1.19
			7-18-73	b/31	40	7.50	0.61	9.00	0.50
2-1	SR 53 to bridge on Sandusky River in SE 1/4 sec. 8, T1S, R14E	See results of Reach 17-16 Sandusky River study.							

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a/ At USGS gage near Marseilles.
b/ At USGS gage at Crawford.
Note: Duration data are for base period, 1931-60.
* Numbers correspond to site numbers shown in figure 2.

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
feet (ft)	0.3048	metres (m)
miles (mi)	1.609	kilometres (km)
cubic feet per second (ft^3/s)	0.2832	cubic metres per second (m^3/s)

TIME OF TRAVEL

Time of travel and, to a lesser degree, dispersion characteristics were determined by injecting a fluorescent dye (rhodamine BA, 40-percent or rhodamine WT, 20-percent) as a tracer material into the river and observing its downstream movement by fluorometric analysis at selected sampling sites. The time required for the dye to move from the dosing point to the downstream sampling point is the average velocity of the water in the reach and is called the "time of travel". Assuming no difference in discharge, time of travel for reaches of equal length may vary if there are natural differences in channel characteristics, such as slope, roughness, debris, or vegetation, or differences resulting from dam, weirs, bridges, and other such features. To a lesser degree, time of travel may vary periodically or seasonally because of vegetal growth in summer or ice formation in winter.

DISPERSION CHARACTERISTICS

A dye introduced into a stream moves in the same manner as the water particles, and by monitoring the movement of the dye the movement of the water is defined. The dispersion characteristic is indicated by the time required for the dye cloud, from leading edge to trailing edge, to move past the sampling point. This is called "time of passage" of the dye cloud. Time of passage is inversely related to rate of flow. When discharge decreases, the movement of water is increasingly affected by meanders, channel roughness, pools and riffles, vegetation, and natural or artificial dams, which increase the dispersion of the dye. Conversely, when discharge increases, channel characteristics are dampened and the dye cloud tends to stay together.

For best definition of the dispersion characteristic, the entire dye cloud should be measured as it passes the sampling point. However, measurement of the entire cloud from leading edge to trailing edge requires considerable time. Because time of travel determinations at a maximum number of sites was the primary interest in this study, the time of dye passage was measured only through the peak concentration. Examples of time-concentration curves, showing time of passage of the dye clouds from leading edge to peak concentration, are given in figures 3 to 5.

TIME-DISCHARGE RELATION

Time of travel can be presented as a function of discharge. Time of travel versus discharge generally plots as a straight line on logarithmic coordinates. Figures 6 to 43 show the time-discharge relation for each subreach. Also shown are the average discharge and minimun 7-day discharge for recurrence intervals of 2 and 10 years for subreaches on the mainstem.

The minimum average discharge for 7 consecutive days with a 10-year recurrence interval is often used in low-flow studies. One of the aims of time of travel measurements is to define the time-discharge relation at that flow. However, the chance of this flow occurring during the time allotted for time of travel studies is slight. Extension of the time-discharge curves is accepted practice but should be done with extreme caution, especially when long downward extensions are made. Flow-duration curves are helpful in determing the shape of the extension.

Flow-duration curves are cumulative frequency curves and are used in studying the flow characteristics of a stream. The duration curve shows the percent of time specified discharges are equalled or exceeded during a given period. It combines in one curve the flow characteristics of a stream throughout the range of discharge, without regard to the sequence of occurence (Searcy, 1959). The slope of the curve at the lower end indicates basin characteristics: A flat slope shows sustained low base flow from surface or ground storage; and a steep slope shows little storage. Downward extensions of the time-discharge curves should be tempered by the degree of the rate of change of the lower end of the duration curve. Duration curves for the index gaging stations are shown in figures 44 to 47.

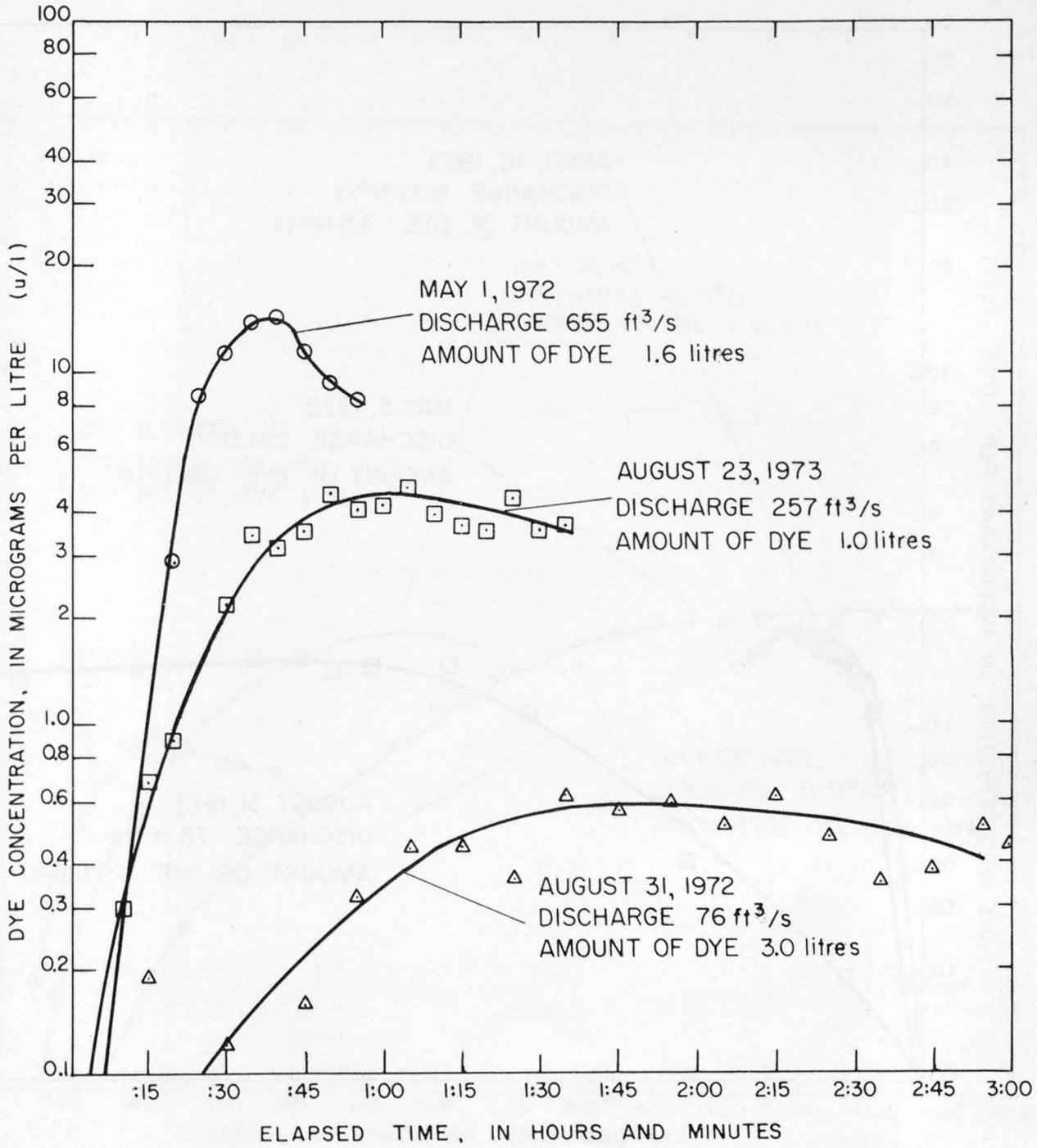

FIGURE 3.--DISPERSION AND VARIATION OF CONCENTRATION OF DYE WITH TIME AT SITE 1, STATE STREET IN FREMONT, SANDUSKY RIVER.

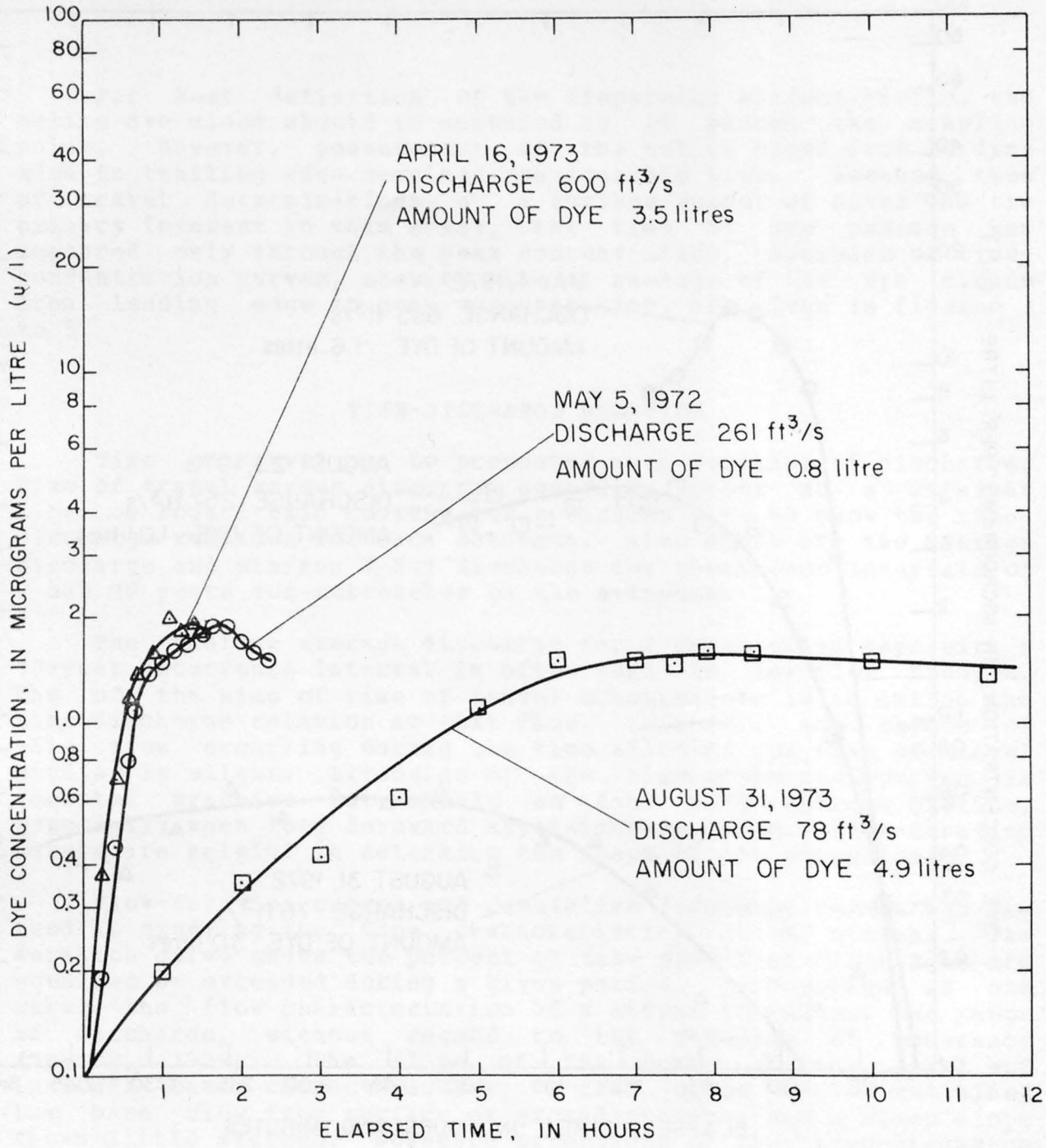

FIGURE 4.--DISPERSION AND VARIATION OF CONCENTRATION OF DYE WITH TIME AT SITE 8A, ELLA STREET IN TIFFIN, SANDUSKY RIVER.

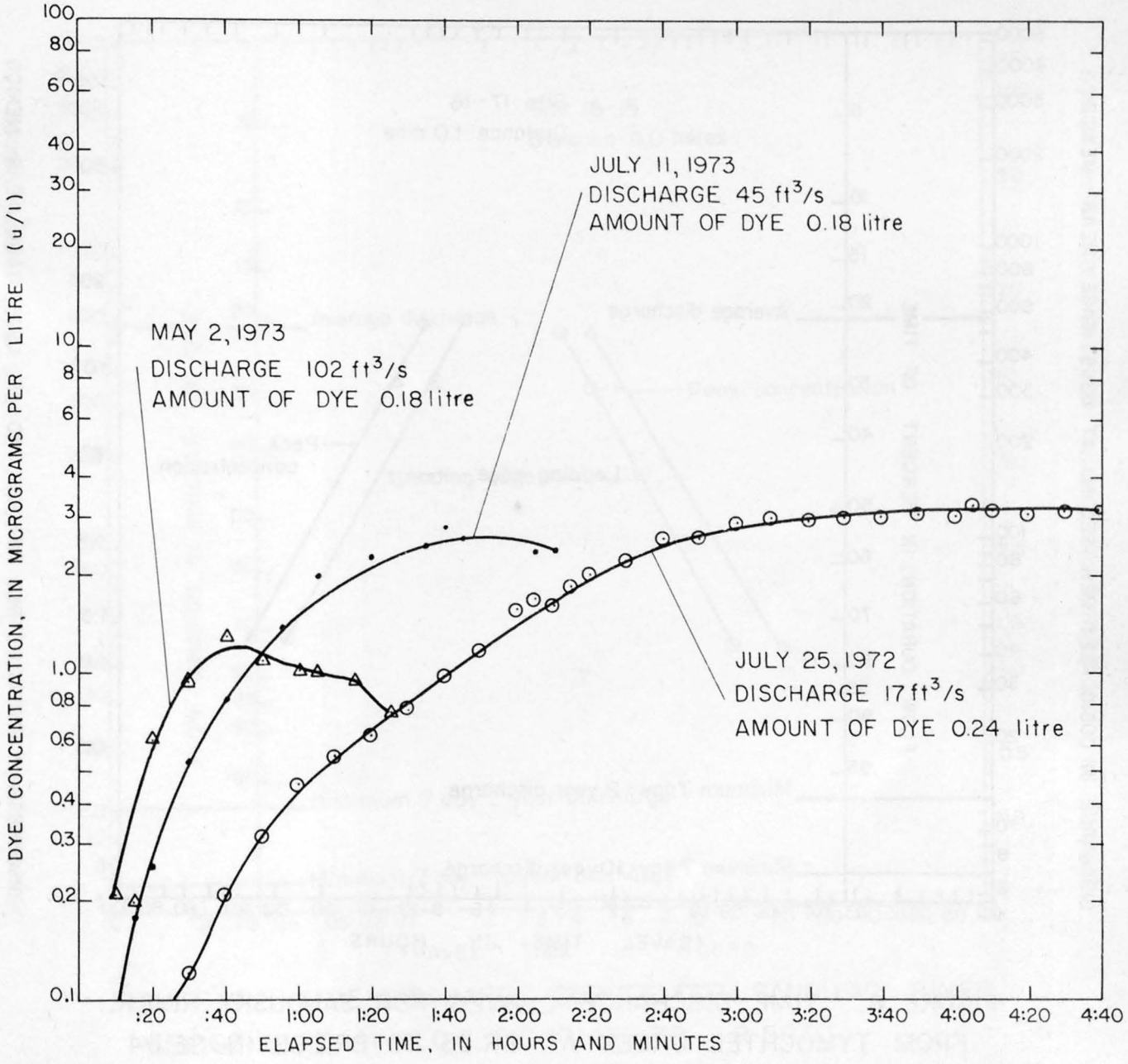

FIGURE 5.--DISPERSION AND VARIATION OF CONCENTRATION OF DYE WITH TIME AT SITE 16, TYMOCHTEE CREEK.

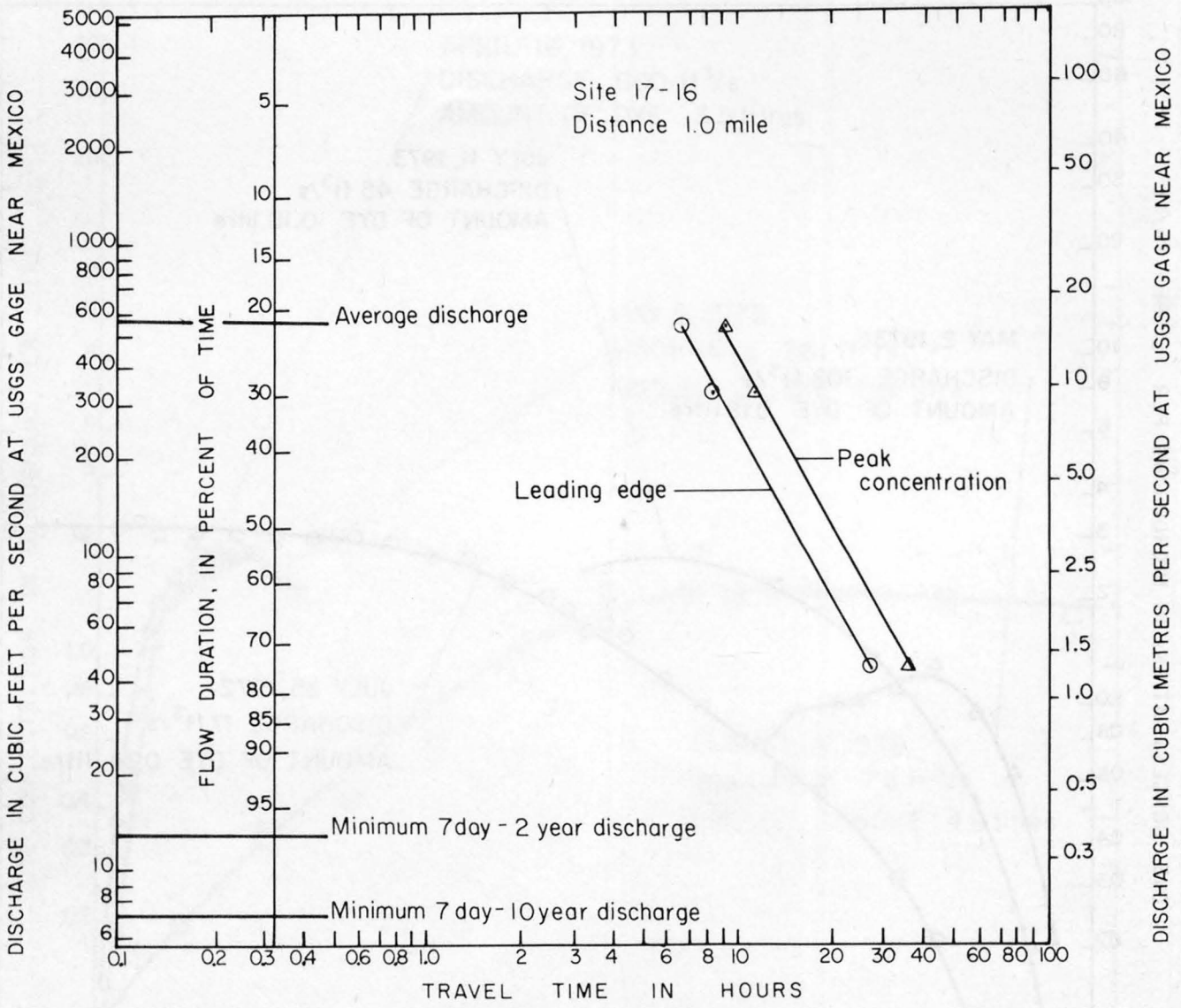

FIGURE 6.-- TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FROM TYMOCHTEE CREEK AT SR 53 TO BRIDGE IN SE 1/4 SEC. 8, T1S, R14E.

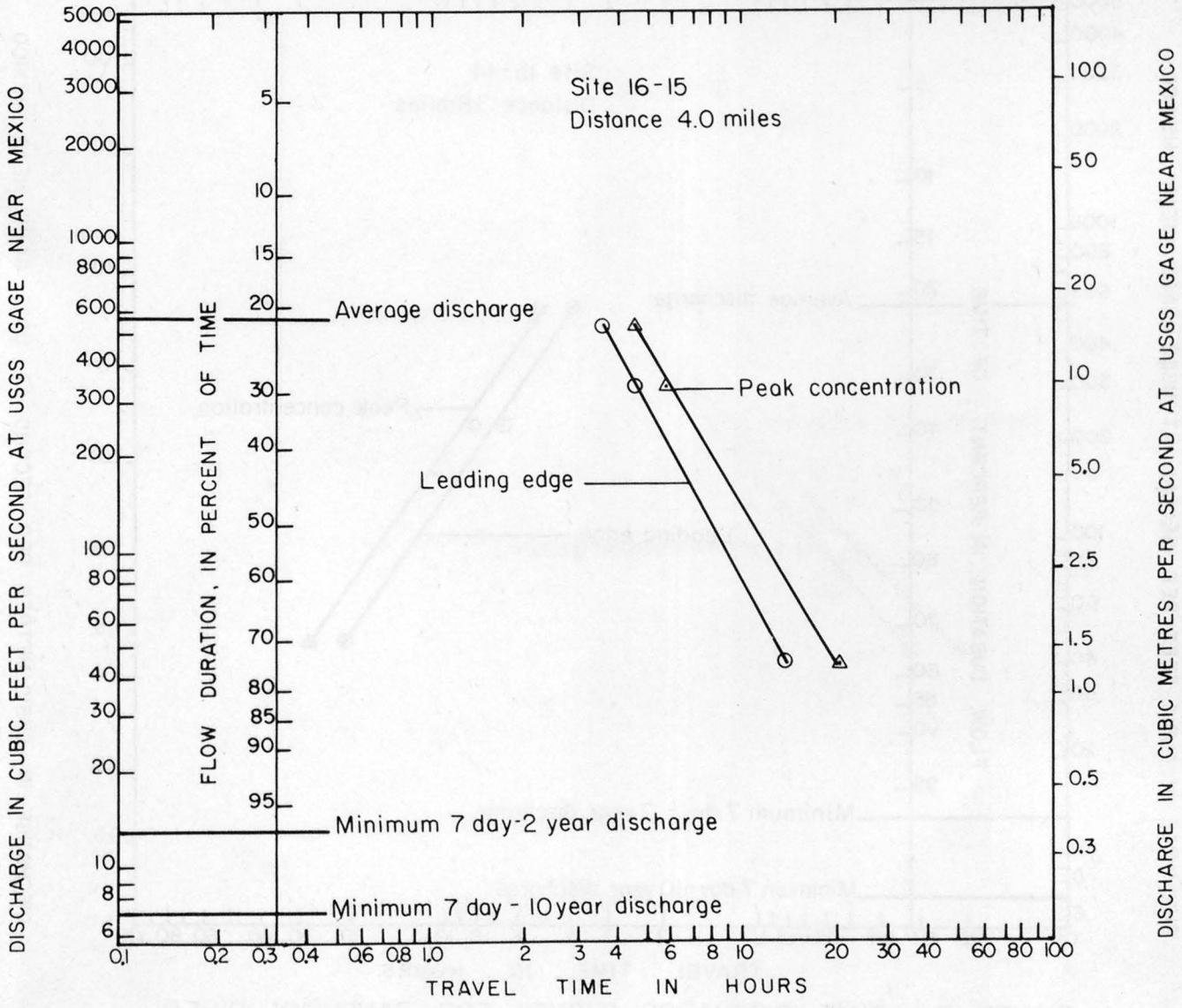

FIGURE 7.-- TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, BRIDGE IN SE 1/4 SEC. 8, T1S, R14E TO SR 587.

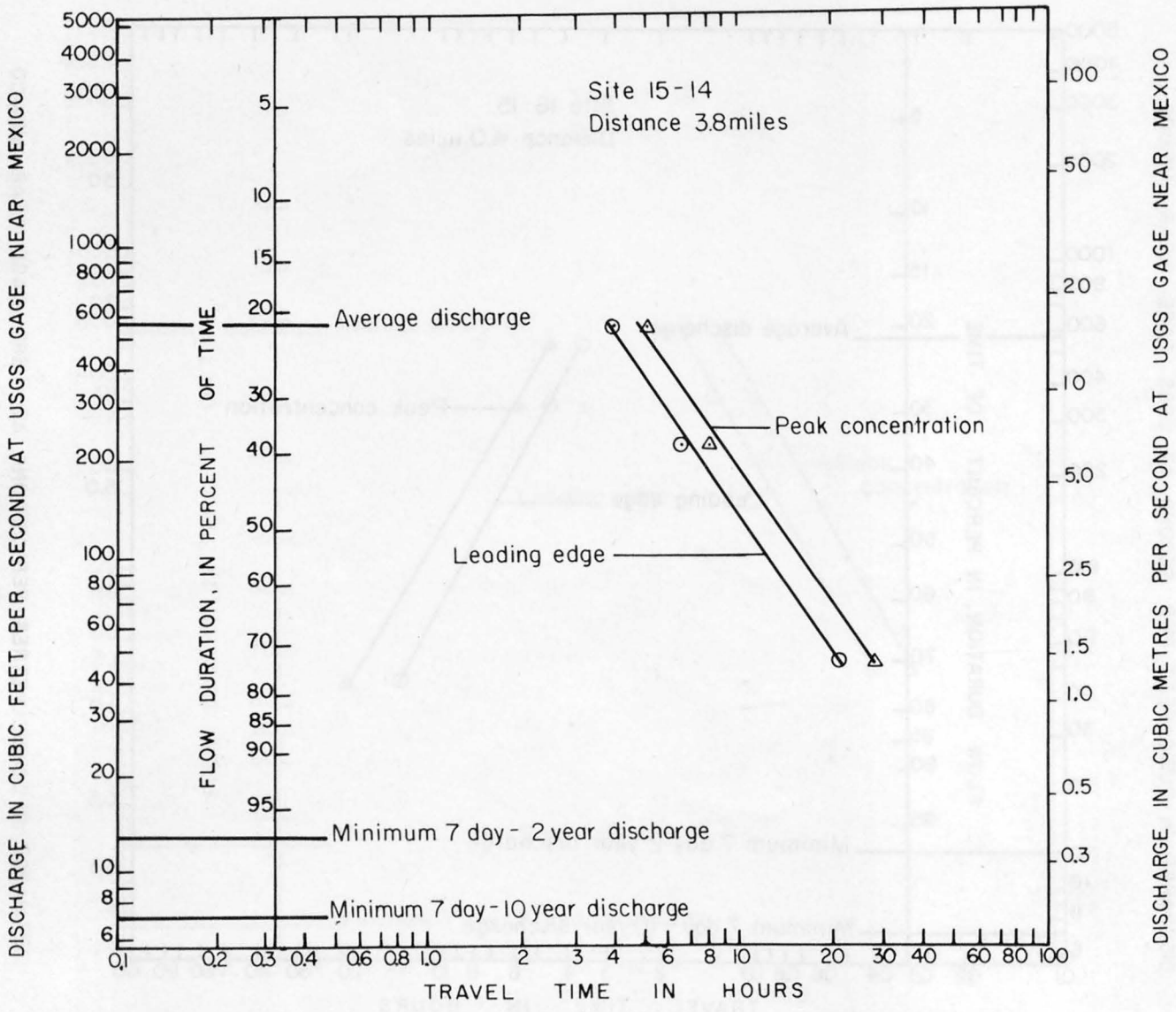

FIGURE 8.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FROM SR 587 TO MEXICO ROAD.

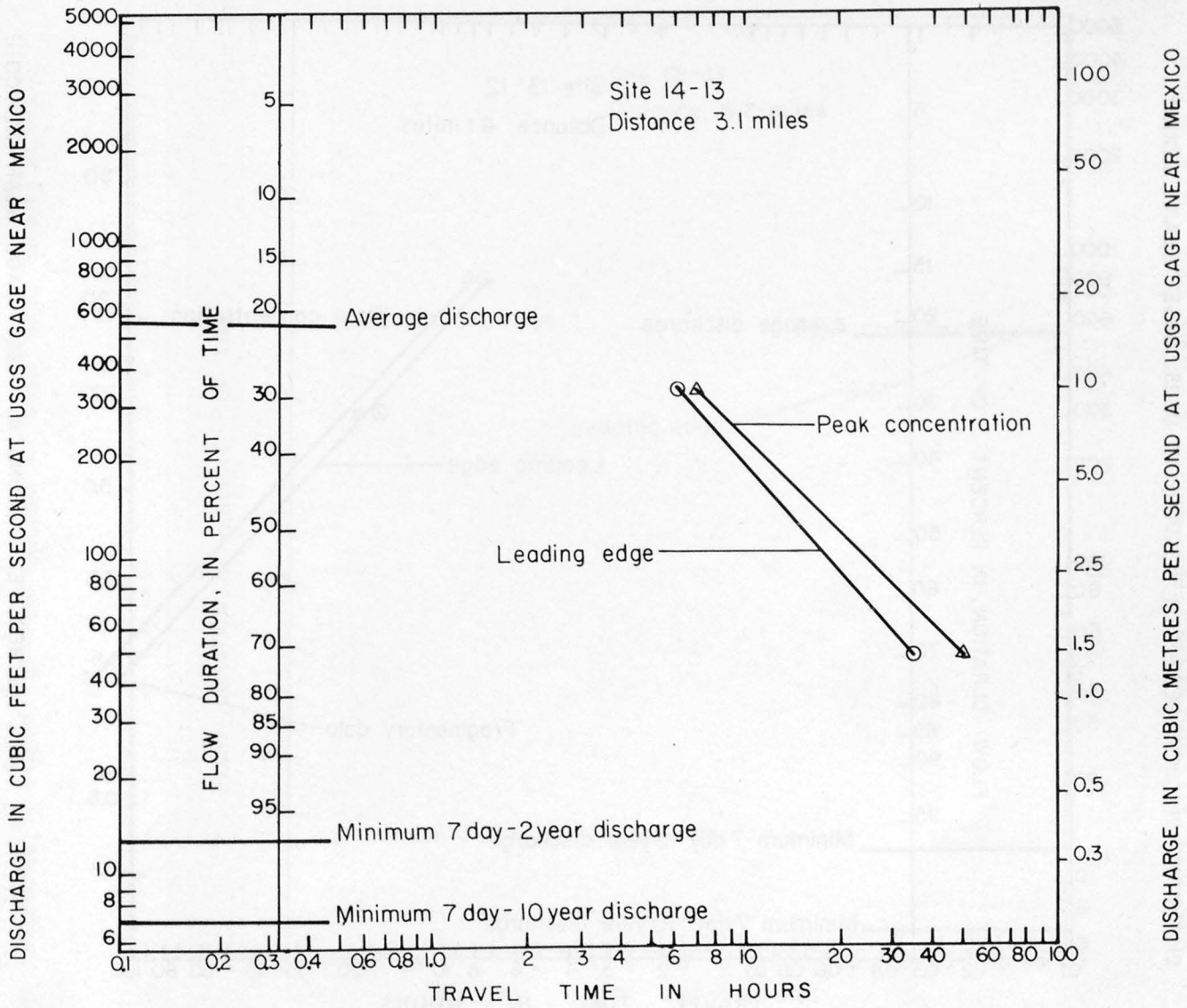

FIGURE 9.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FROM MEXICO ROAD TO HECK ROAD.

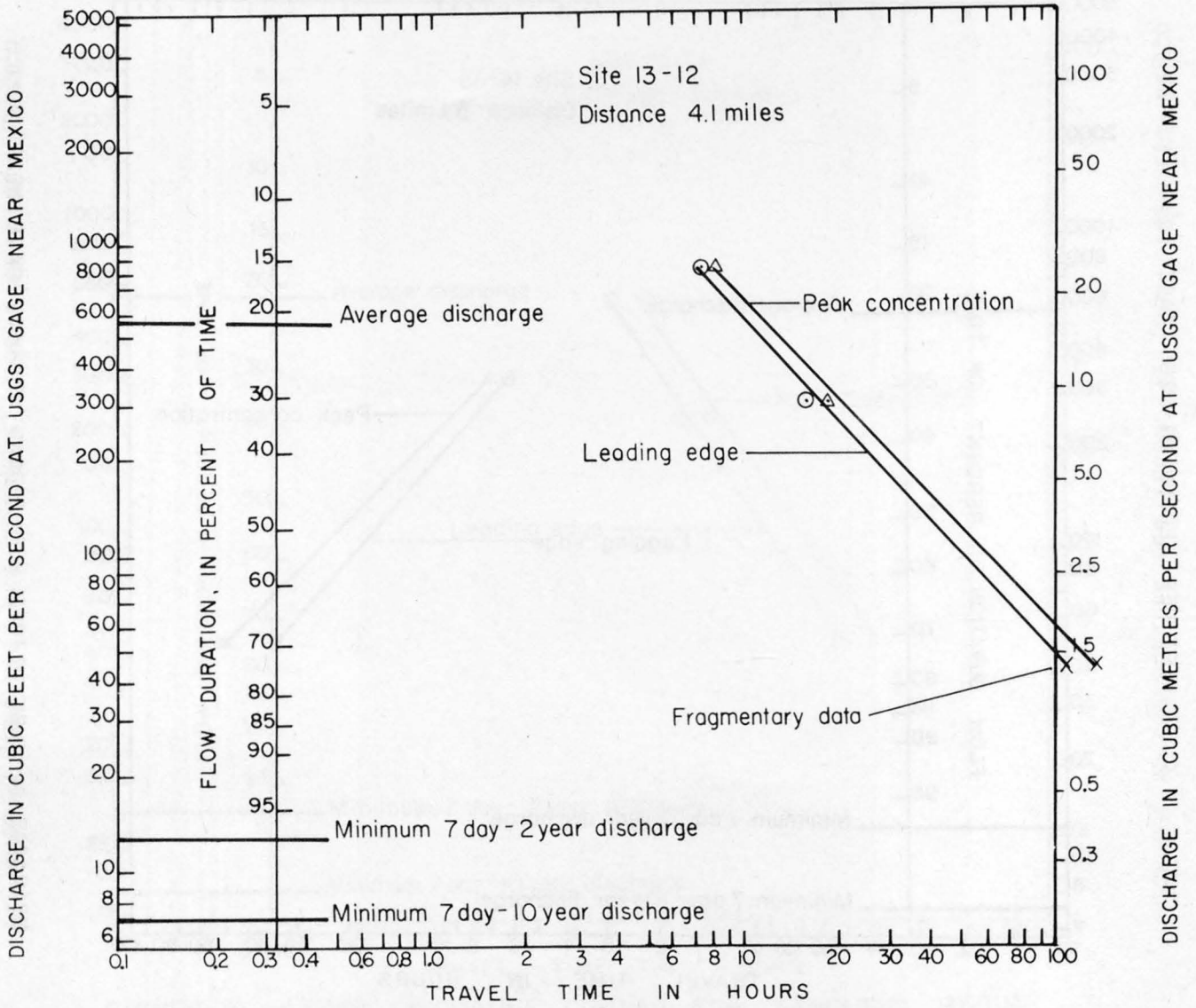

FIGURE 10.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FROM HECK ROAD TO ST. JOHNS ROAD.

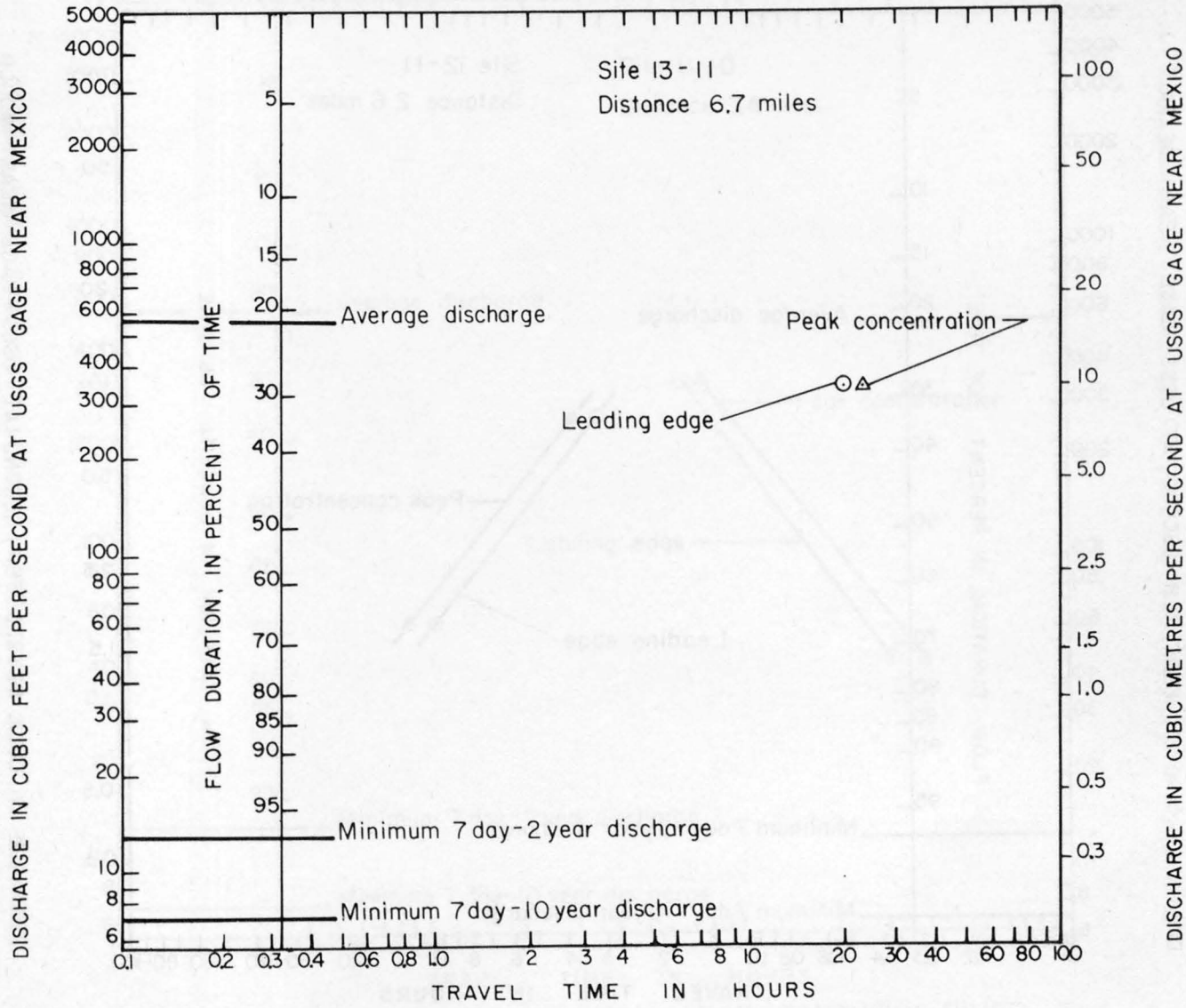

FIGURE 11.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FROM HECK ROAD TO USGS GAGE NEAR MEXICO.

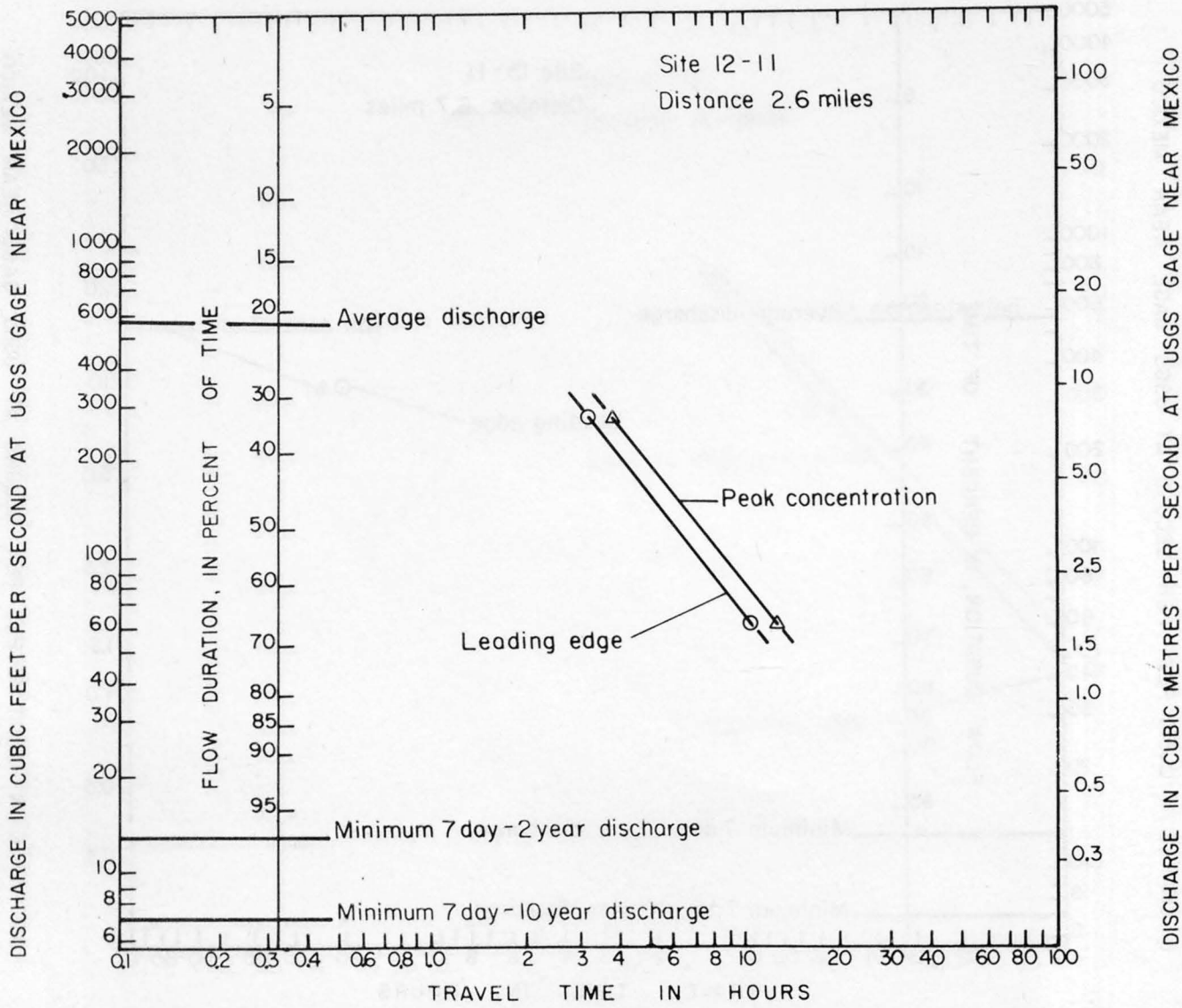

FIGURE 12.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, ST. JOHNS ROAD TO USGS GAGE NEAR MEXICO, OHIO.

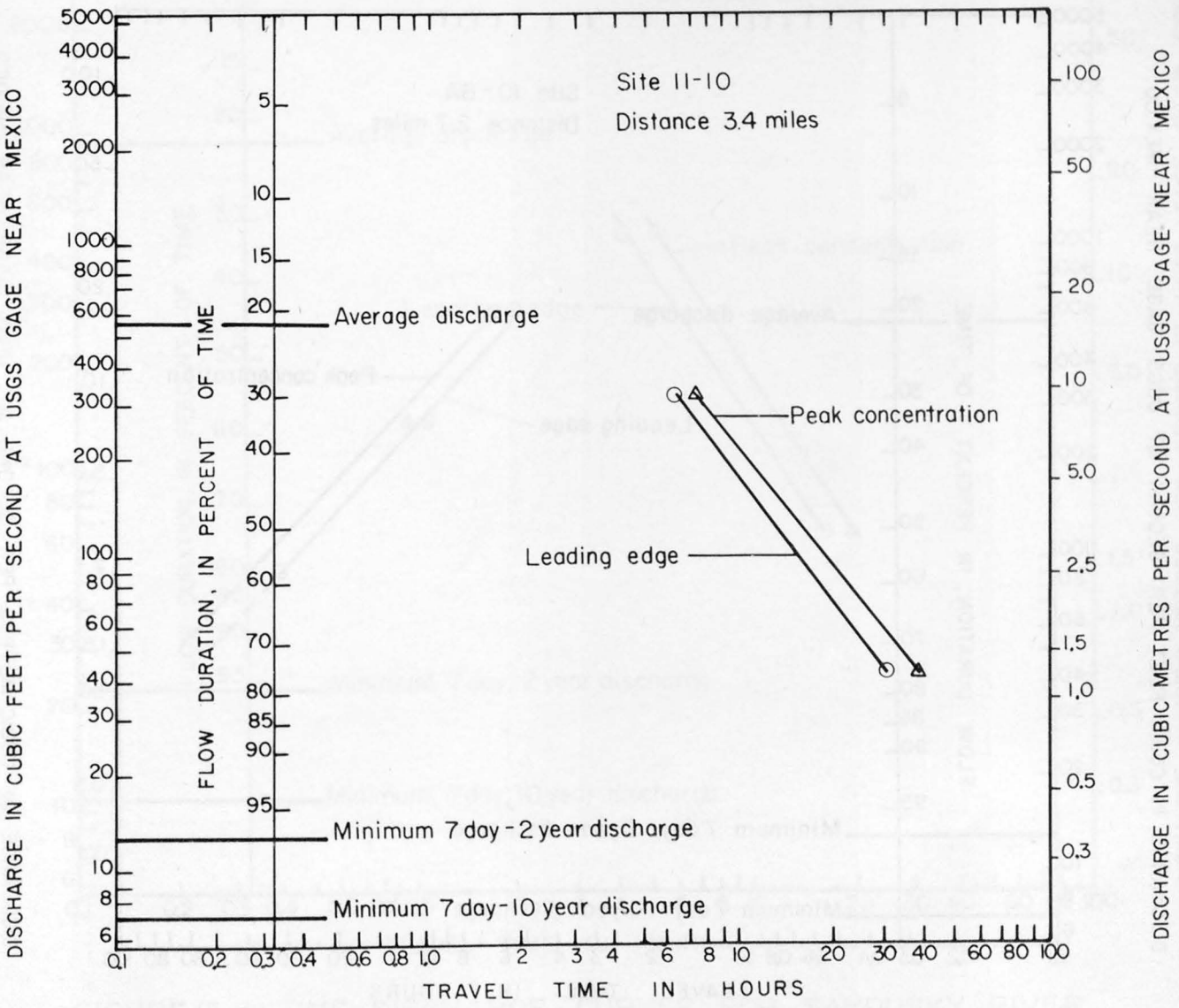

FIGURE 13.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FROM USGS GAGE NEAR MEXICO TO FARM LANE IN NE 1/4 SEC. 1, T1N, R14E.

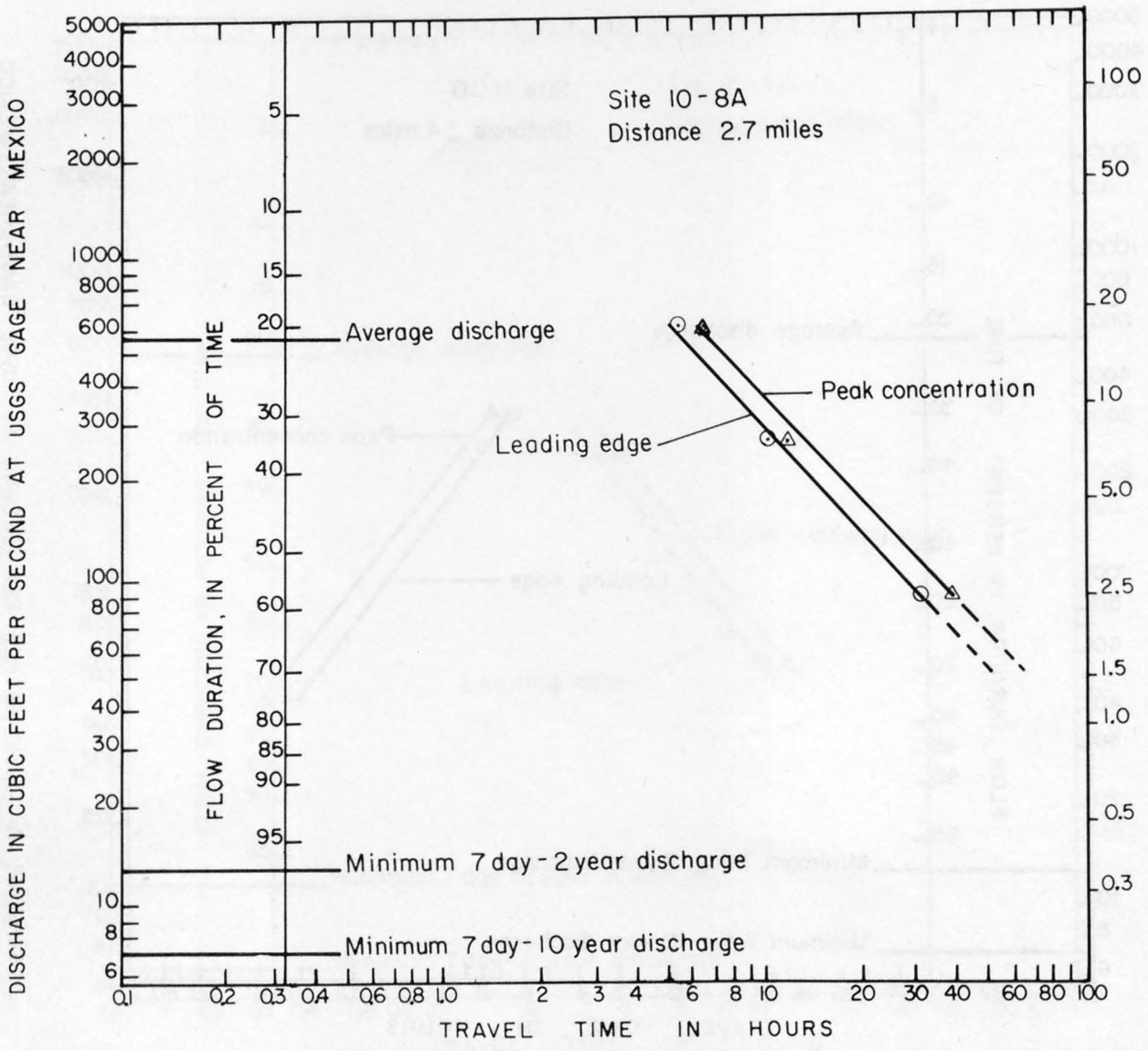

FIGURE 14.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FROM THE FARM LANE IN NE 1/4 SEC.1, T1N, R14E, TO ELLA STREET IN TIFFIN.

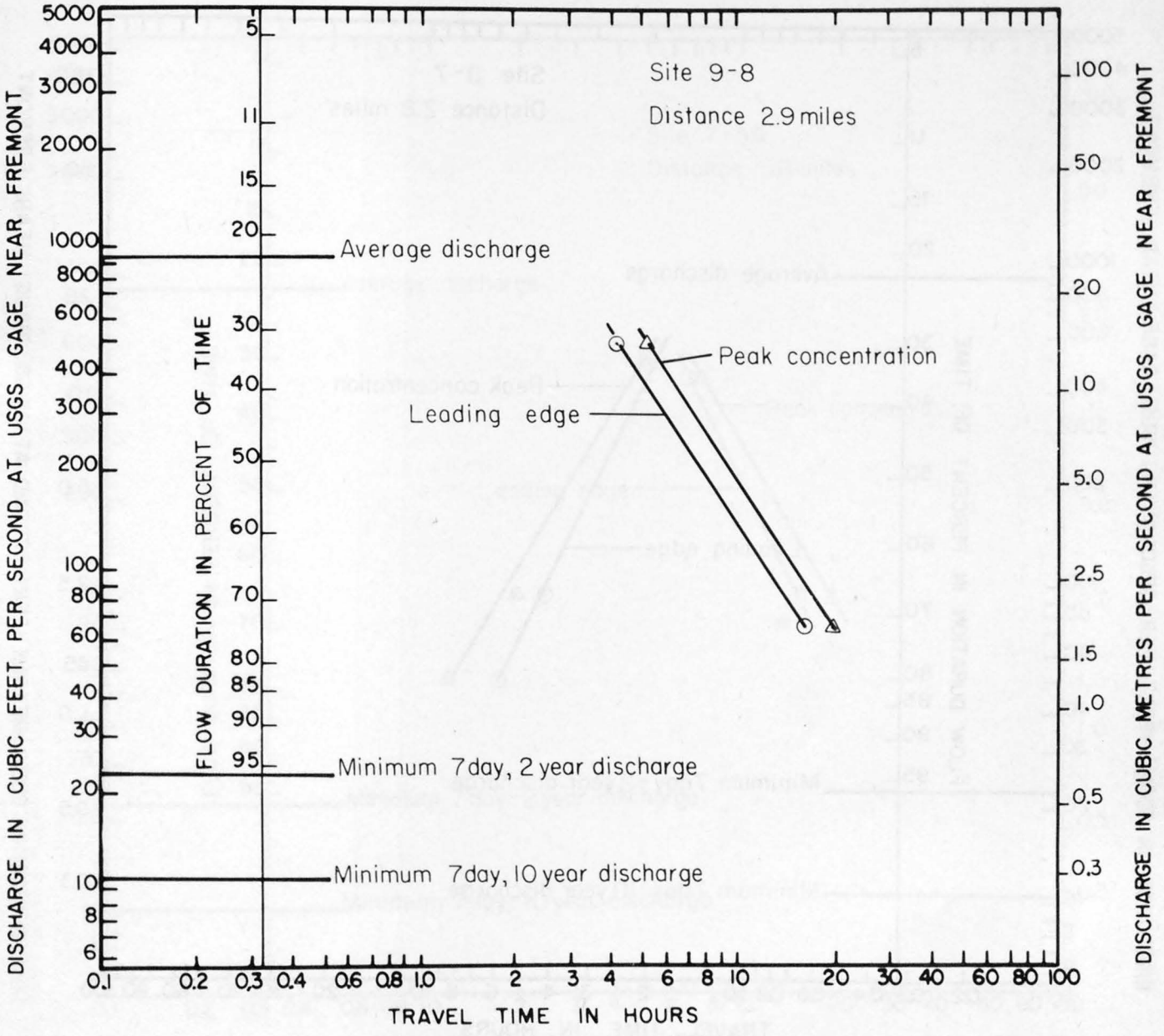

FIGURE 15.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, DIVERSION DAM TO HUSS STREET IN TIFFIN.

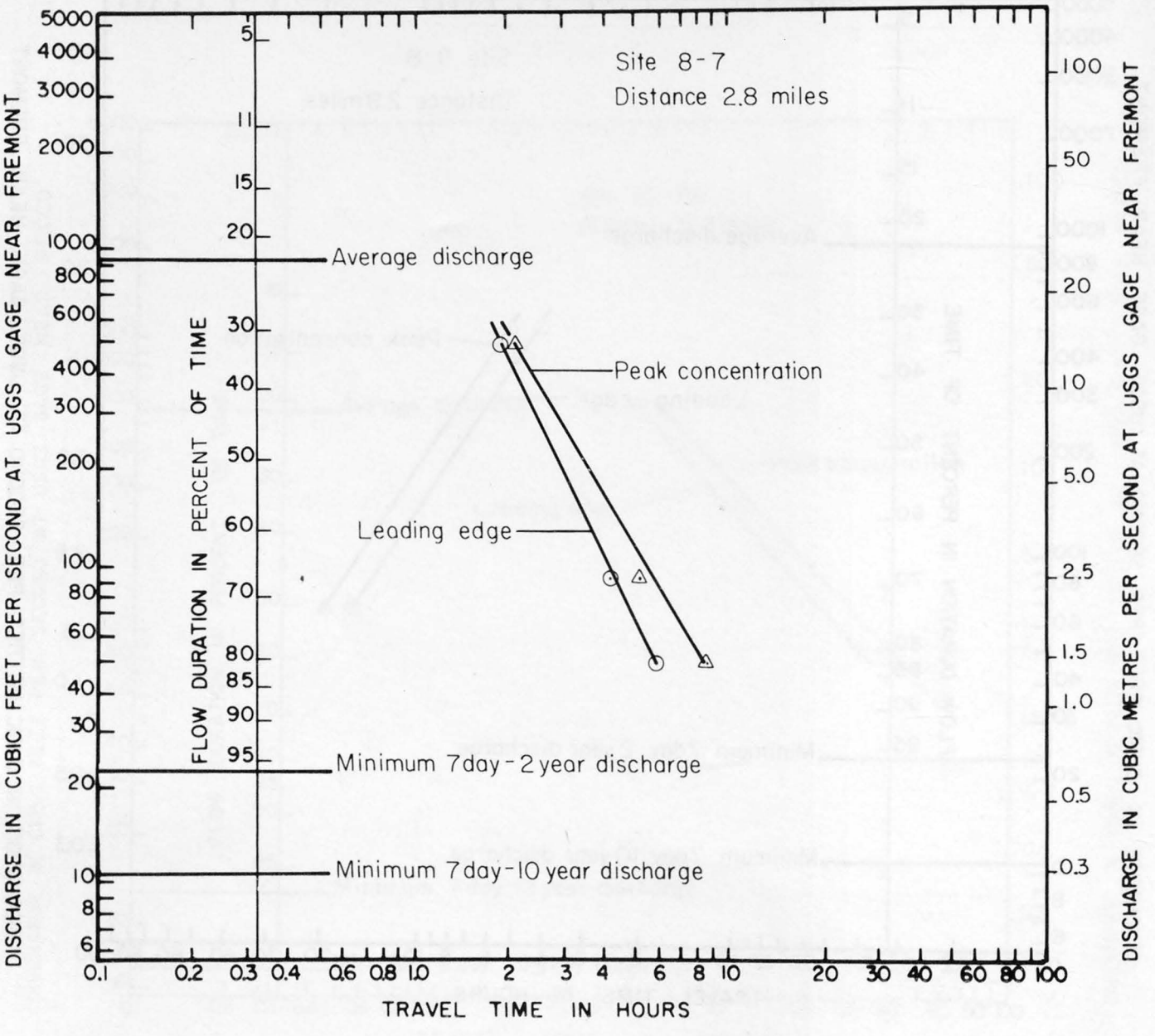

FIGURE 16.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, HUSS STREET IN TIFFIN TO BRIDGE IN NW 1/4 SEC.5, T2N, R15E.

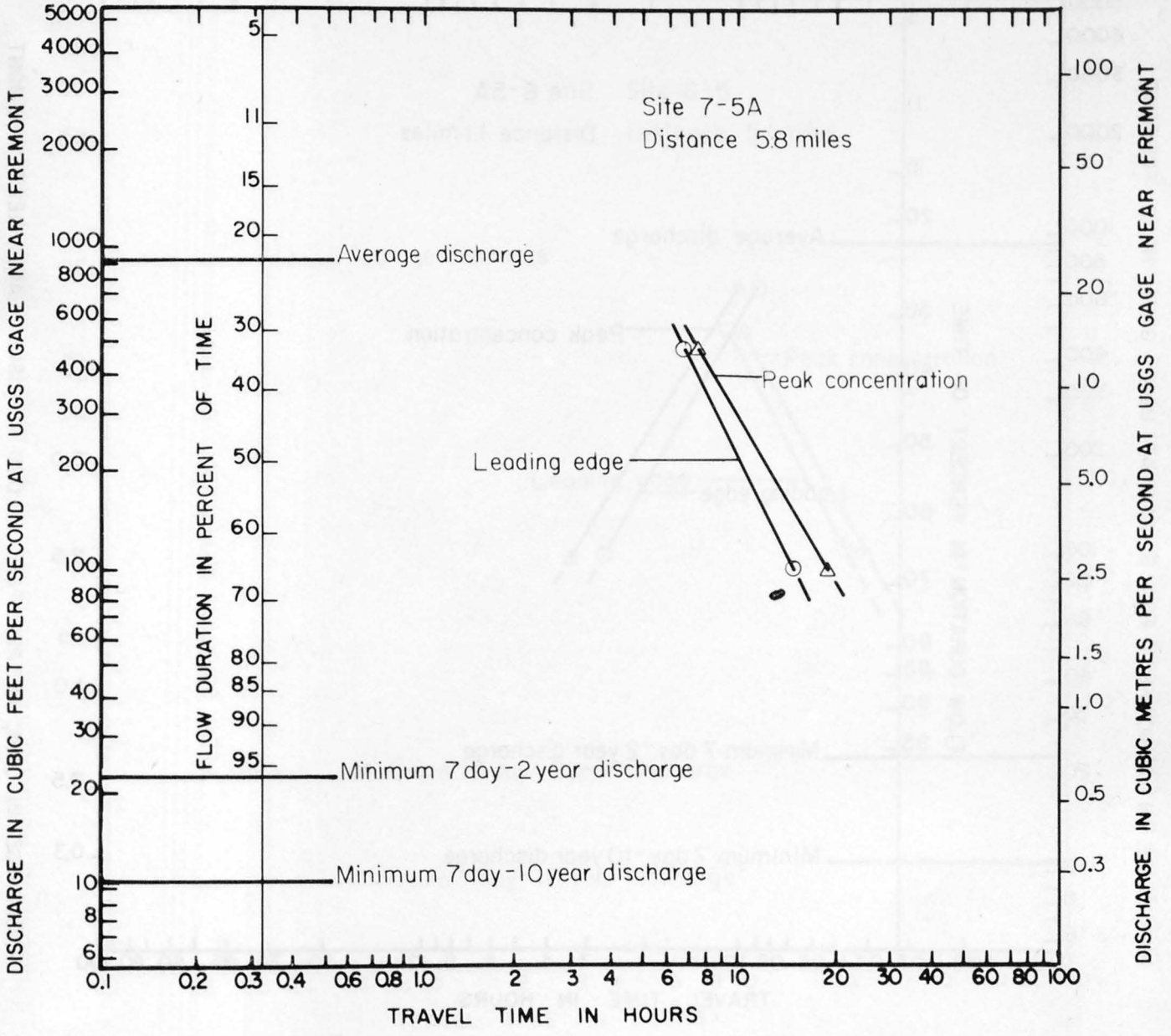

FIGURE 17 .-- TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, BRIDGE IN NW1/4 SEC. 5, T2N, R15E TO BRIDGE IN NW 1/4 SEC. 21, T3N, R15E.

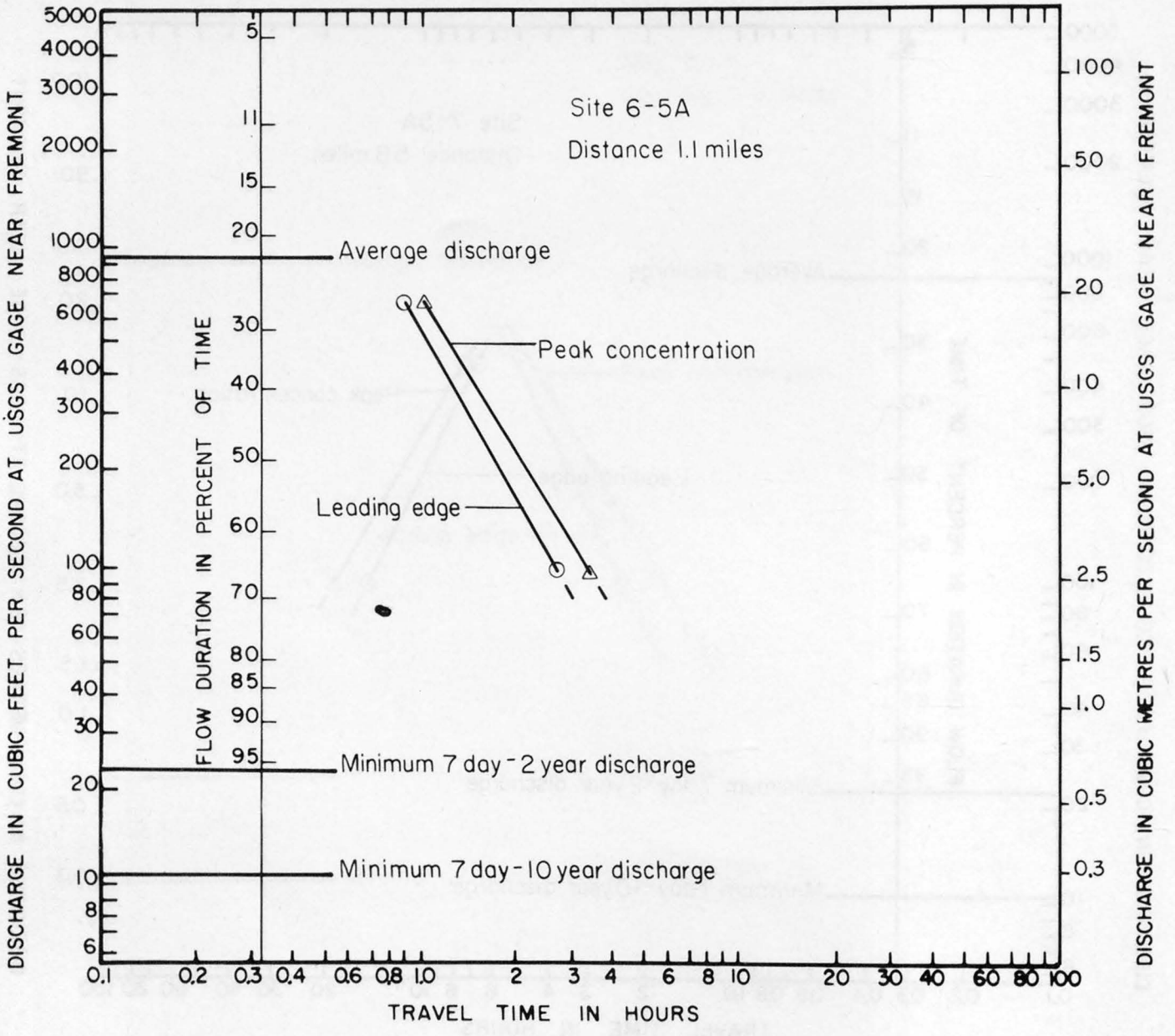

FIGURE 18.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FORT SENECA TO BRIDGE IN NW 1/4 SEC. 21, T3N, R15E.

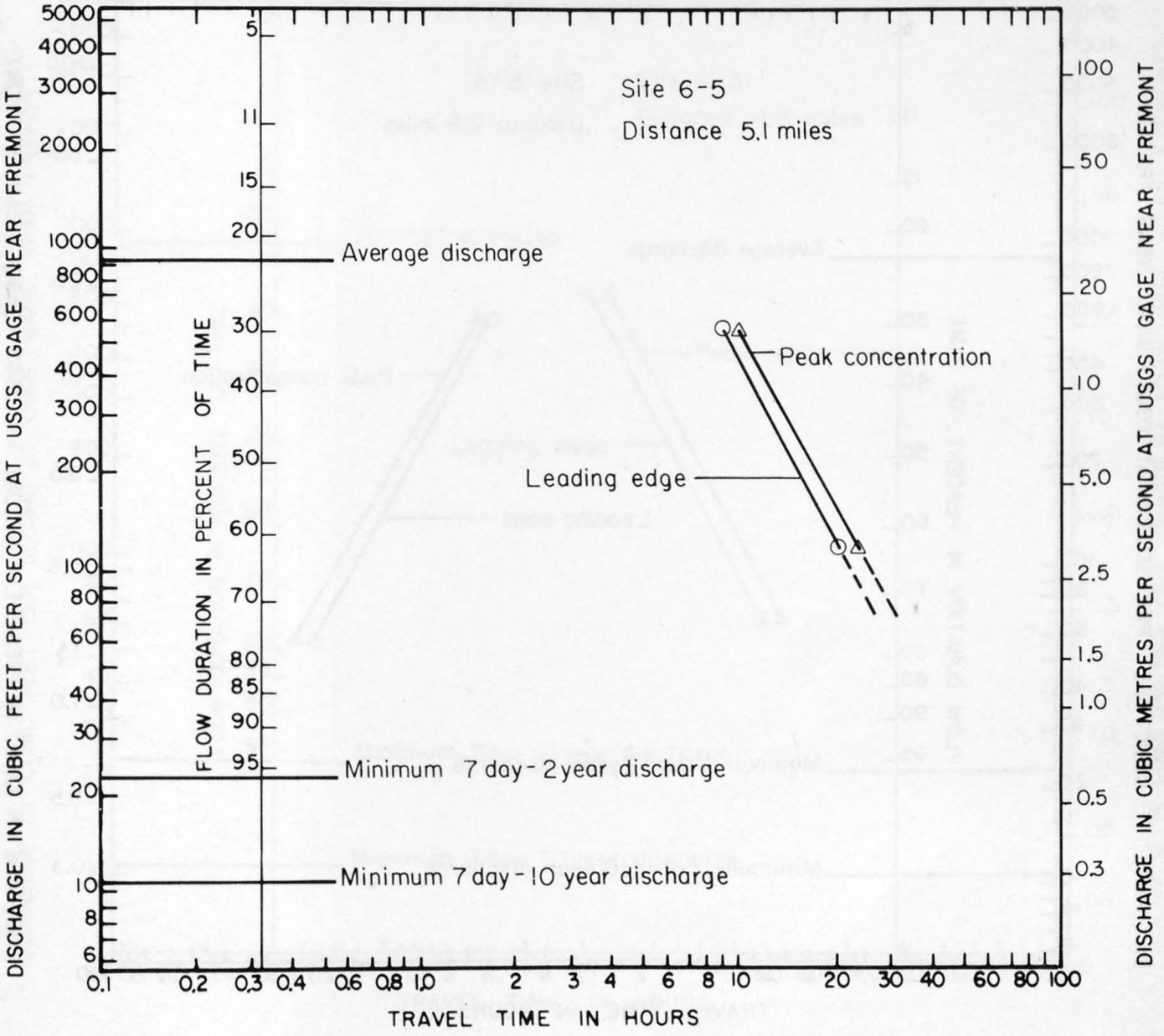

FIGURE 19.-- TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, FORT SENECA TO OLD FORT.

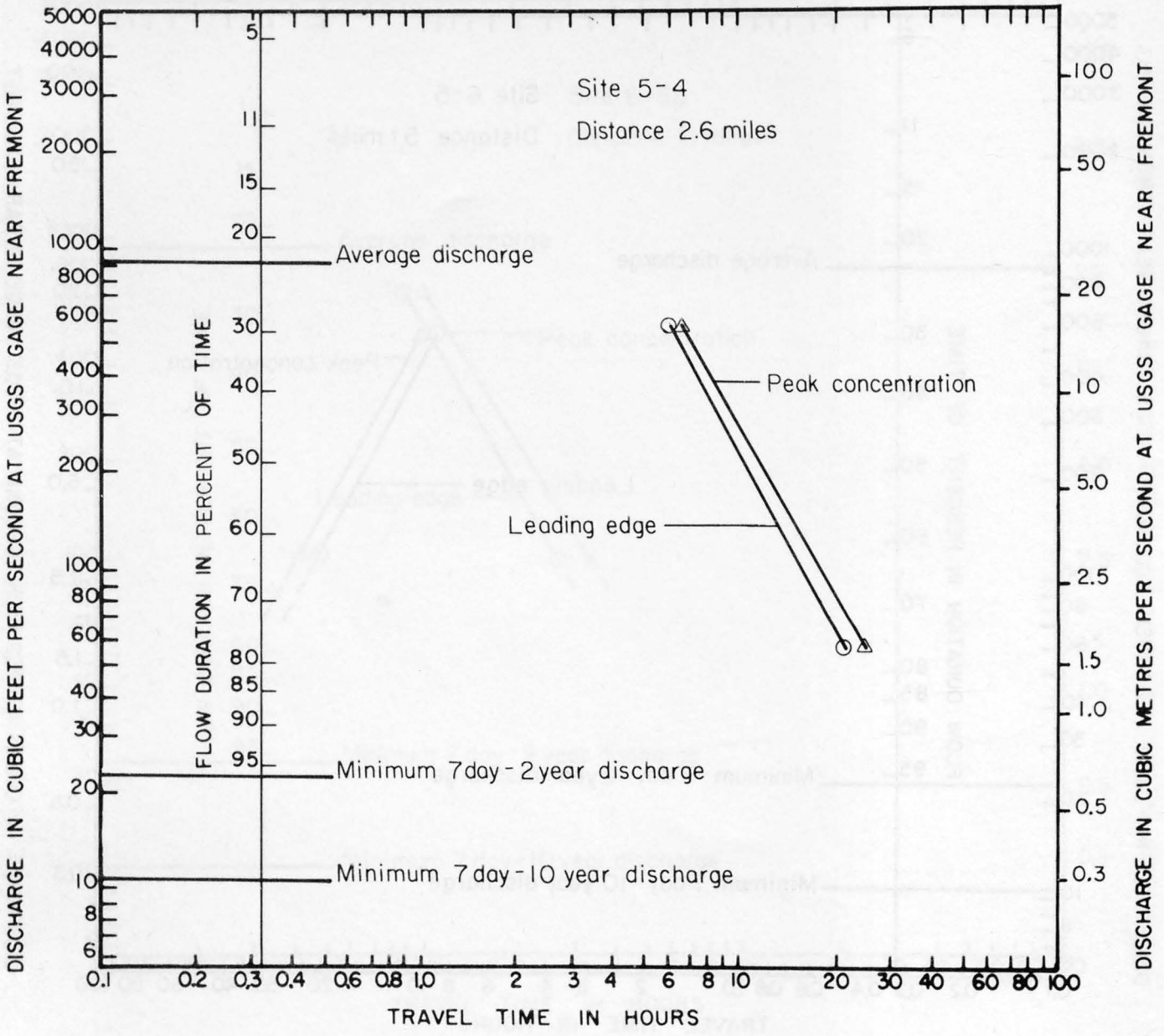

FIGURE 20.--TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, OLD FORT TO BRIDGE NEAR CENTER OF SEC. 32, T4N, R15E.

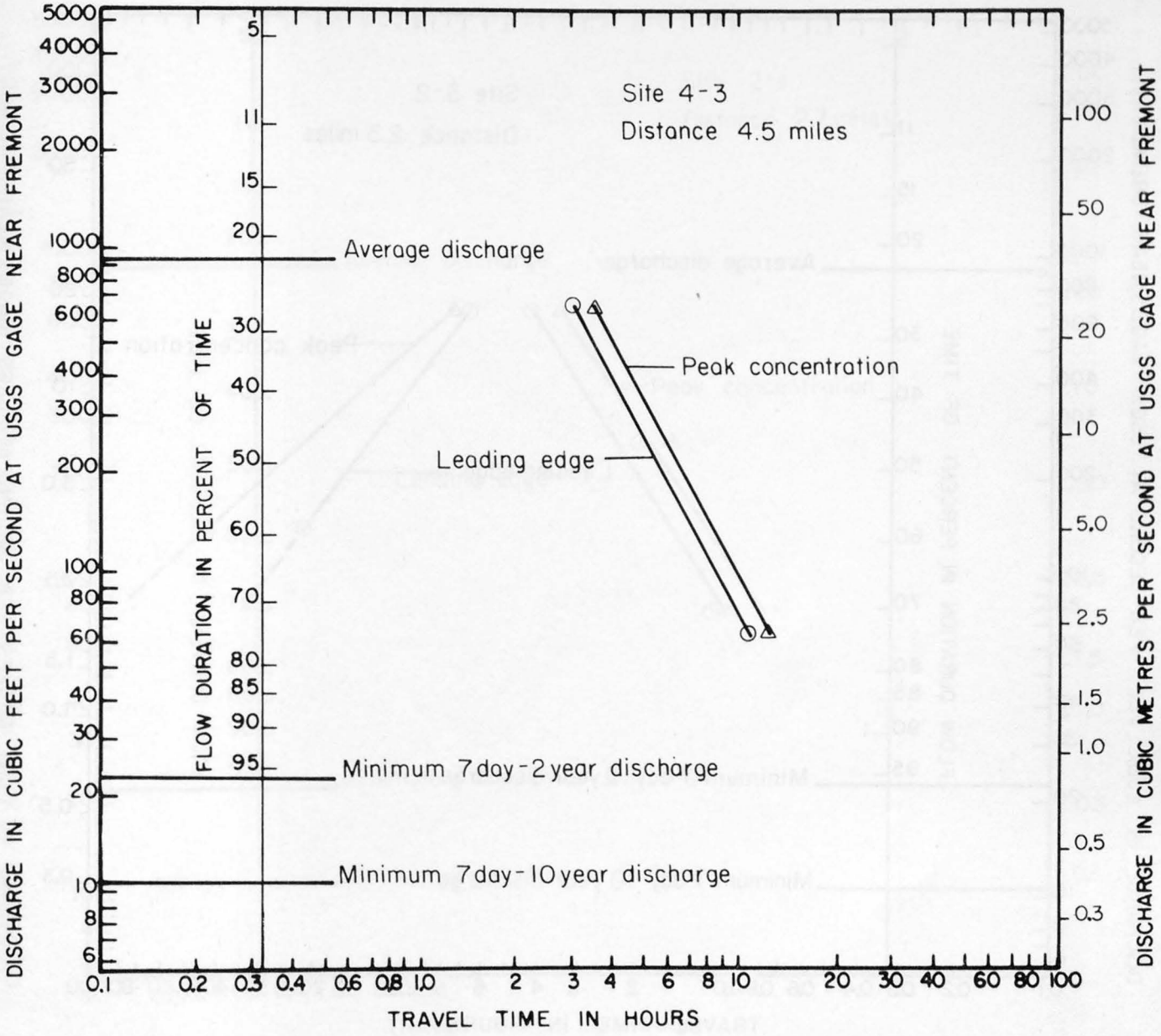

FIGURE 21.-- TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, BRIDGE NEAR CENTER OF SEC. 32, T4N, R15E, TO USGS GAGE NEAR FREMONT.

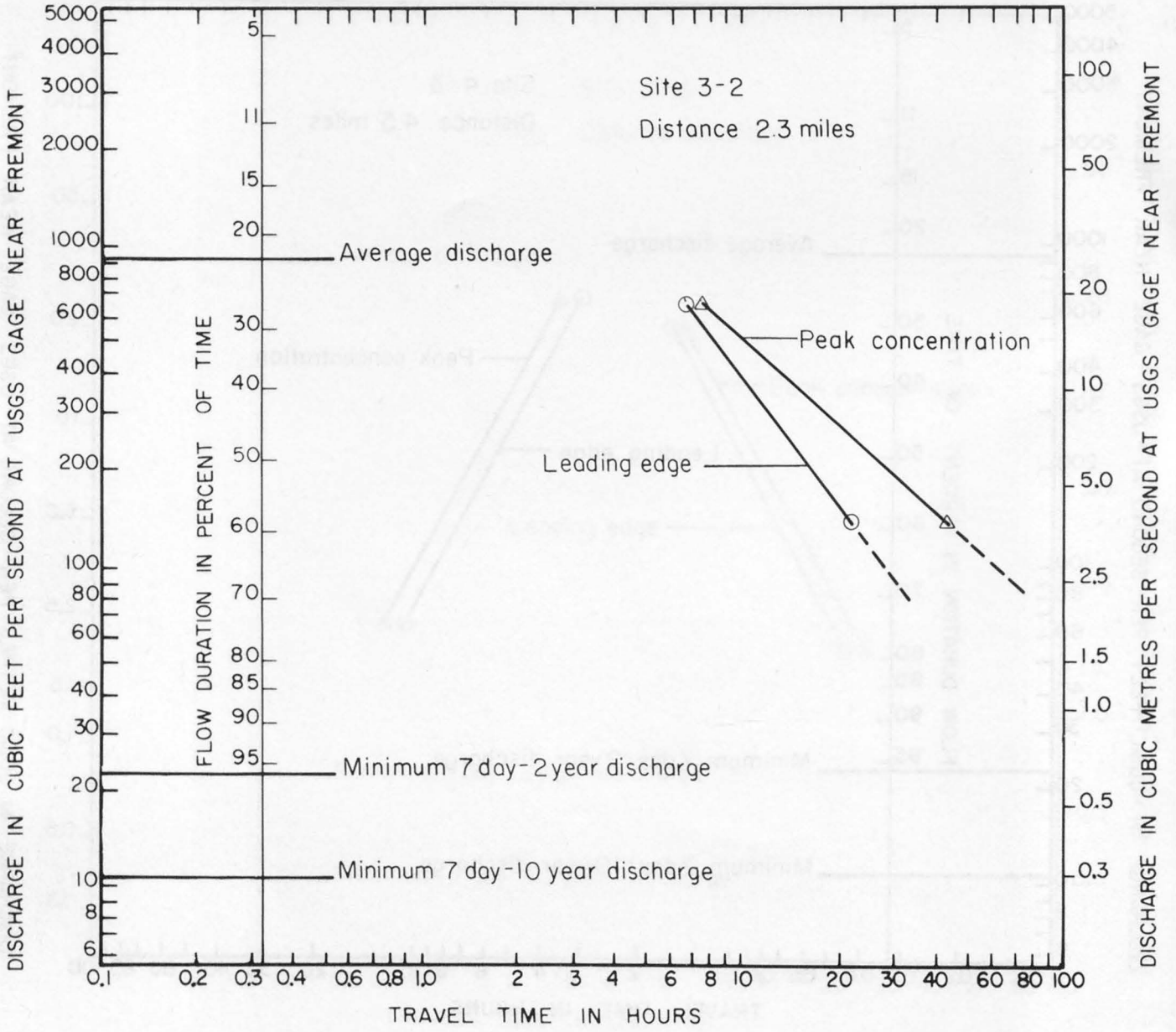

FIGURE 22.-- TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, USGS GAGE NEAR FREMONT TO DIVERSION DAM AT BALLVILLE.

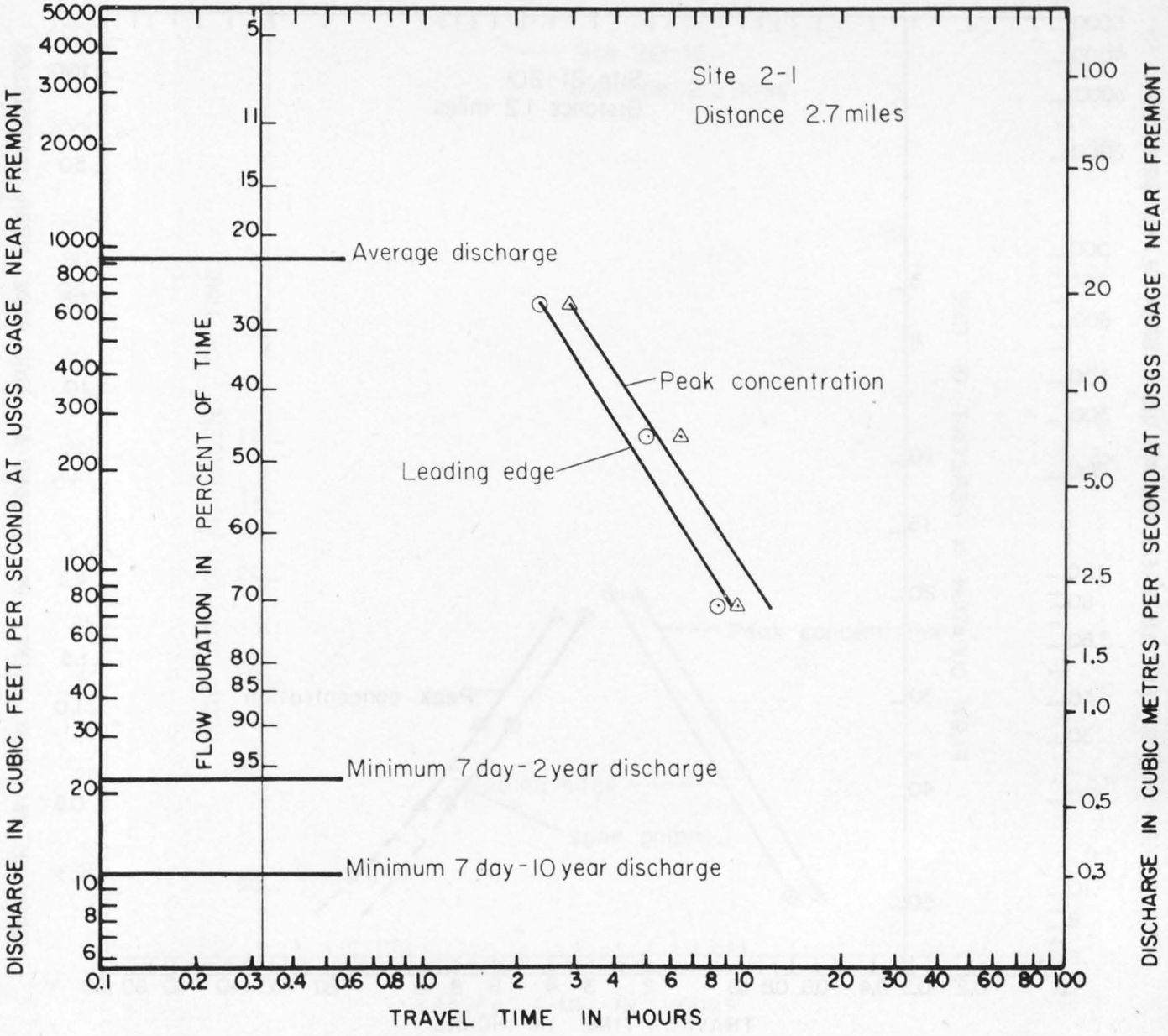

FIGURE 23.-- TIME-DISCHARGE CURVES FOR SANDUSKY RIVER, DIVERSION DAM AT BALLVILLE TO STATE STREET IN FREMONT.

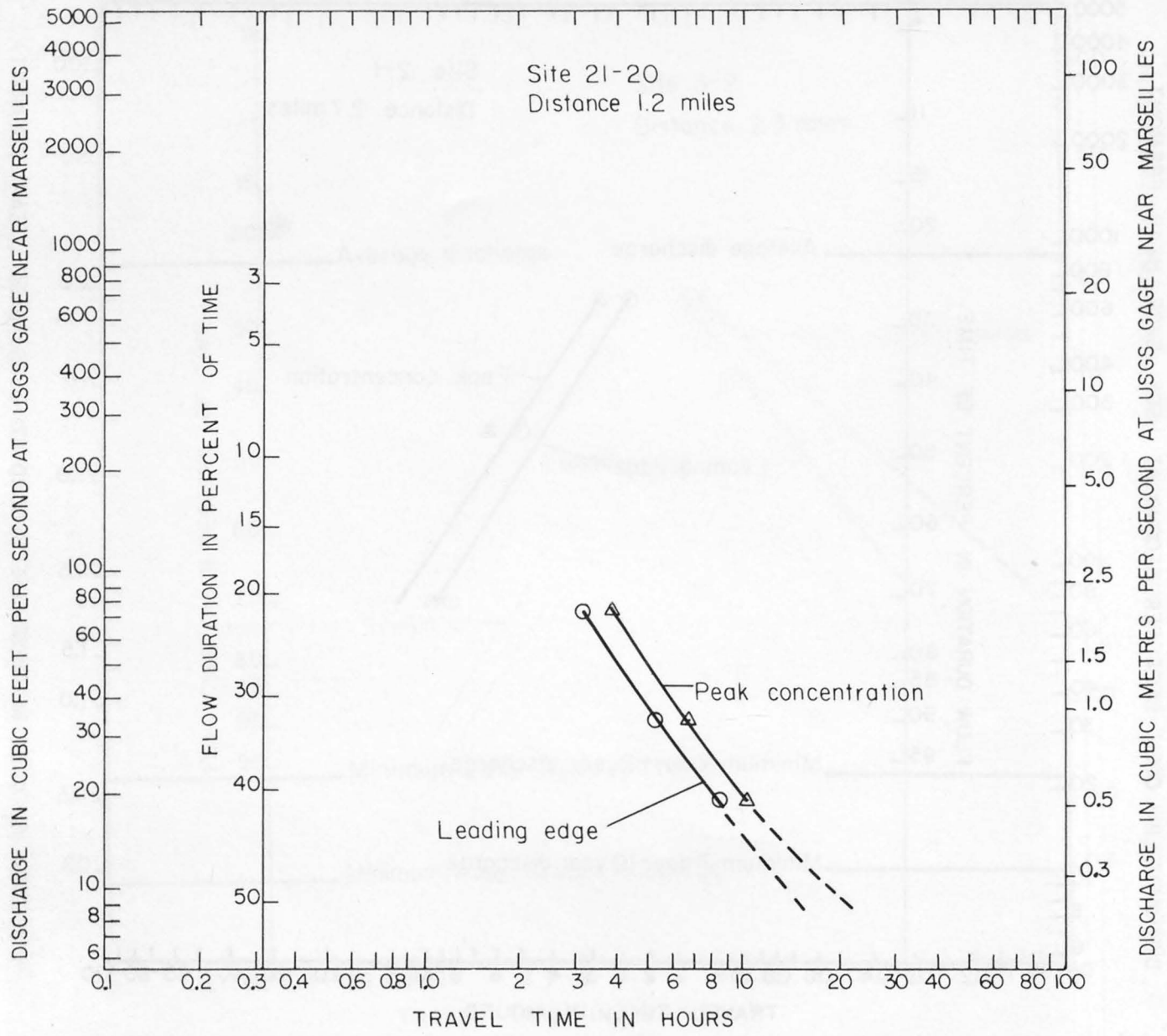

FIGURE 24.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM KILLDEER RESERVOIR OUTLET TO USGS GAGE NEAR MARSEILLES.

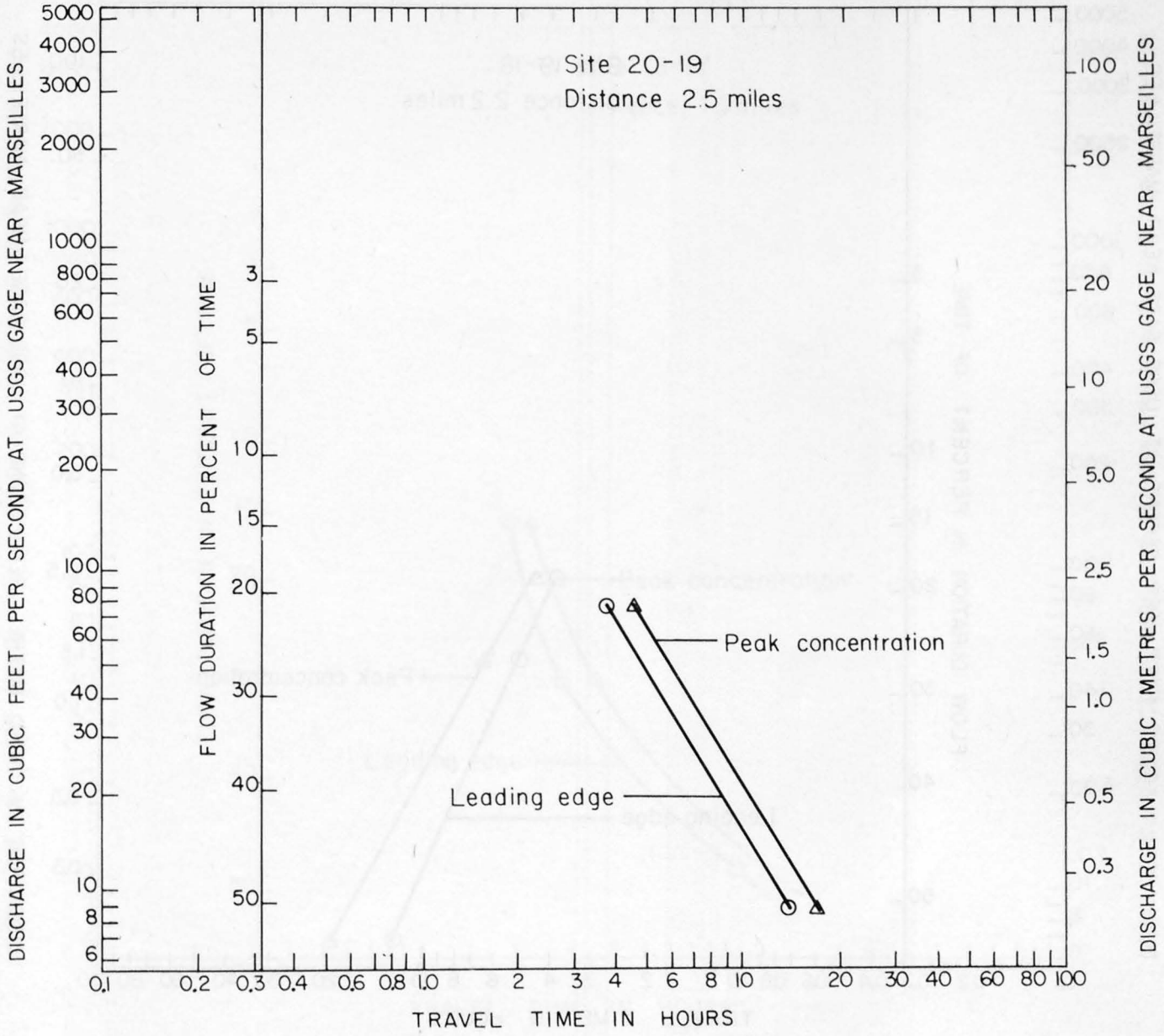

FIGURE 25.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM USGS GAGE NEAR MARSEILLES TO S.R. 294.

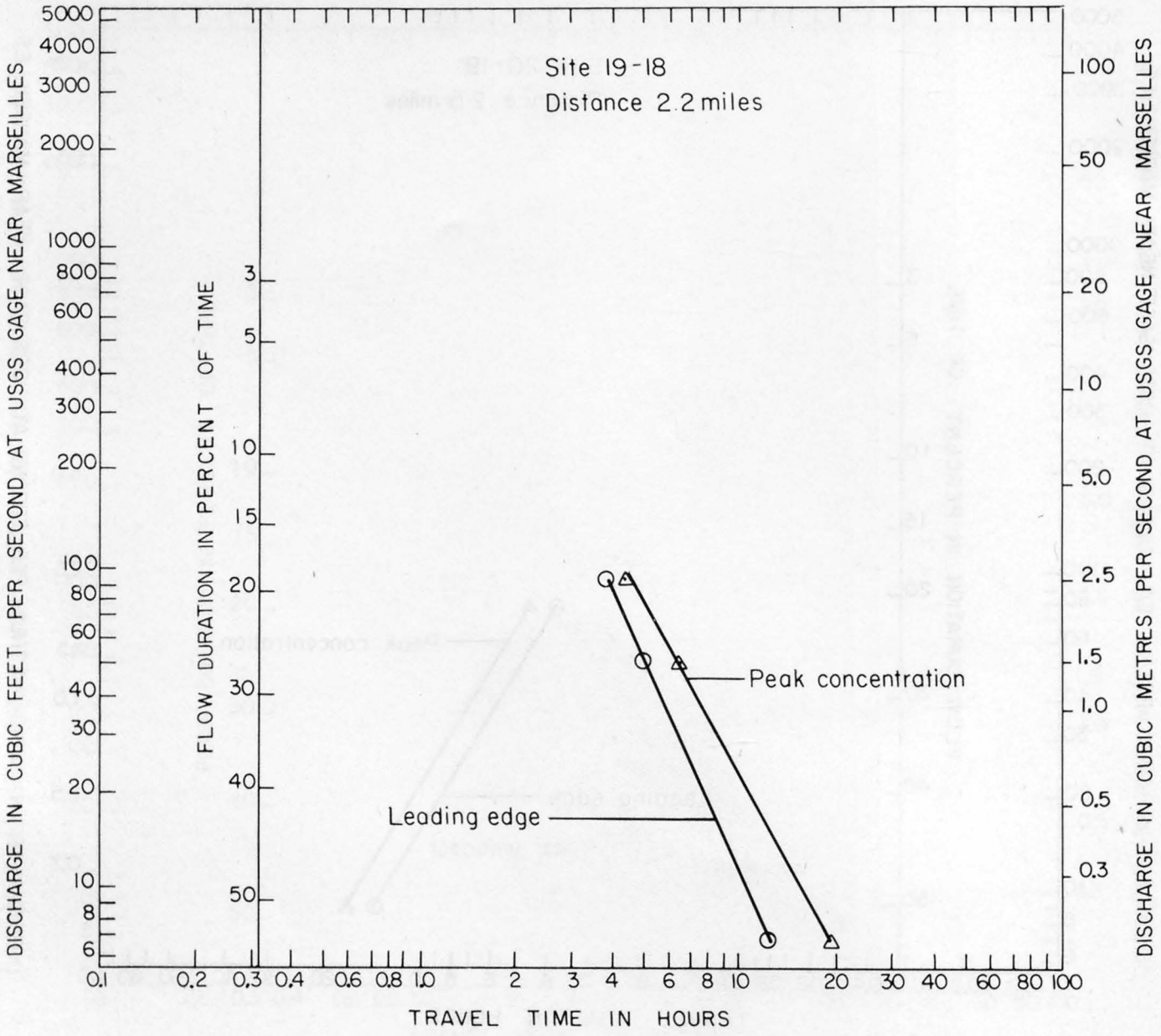

FIGURE 26.-- TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM SR 294 TO BRIDGE IN SE 1/4 SEC. 29, T3S, R13E.

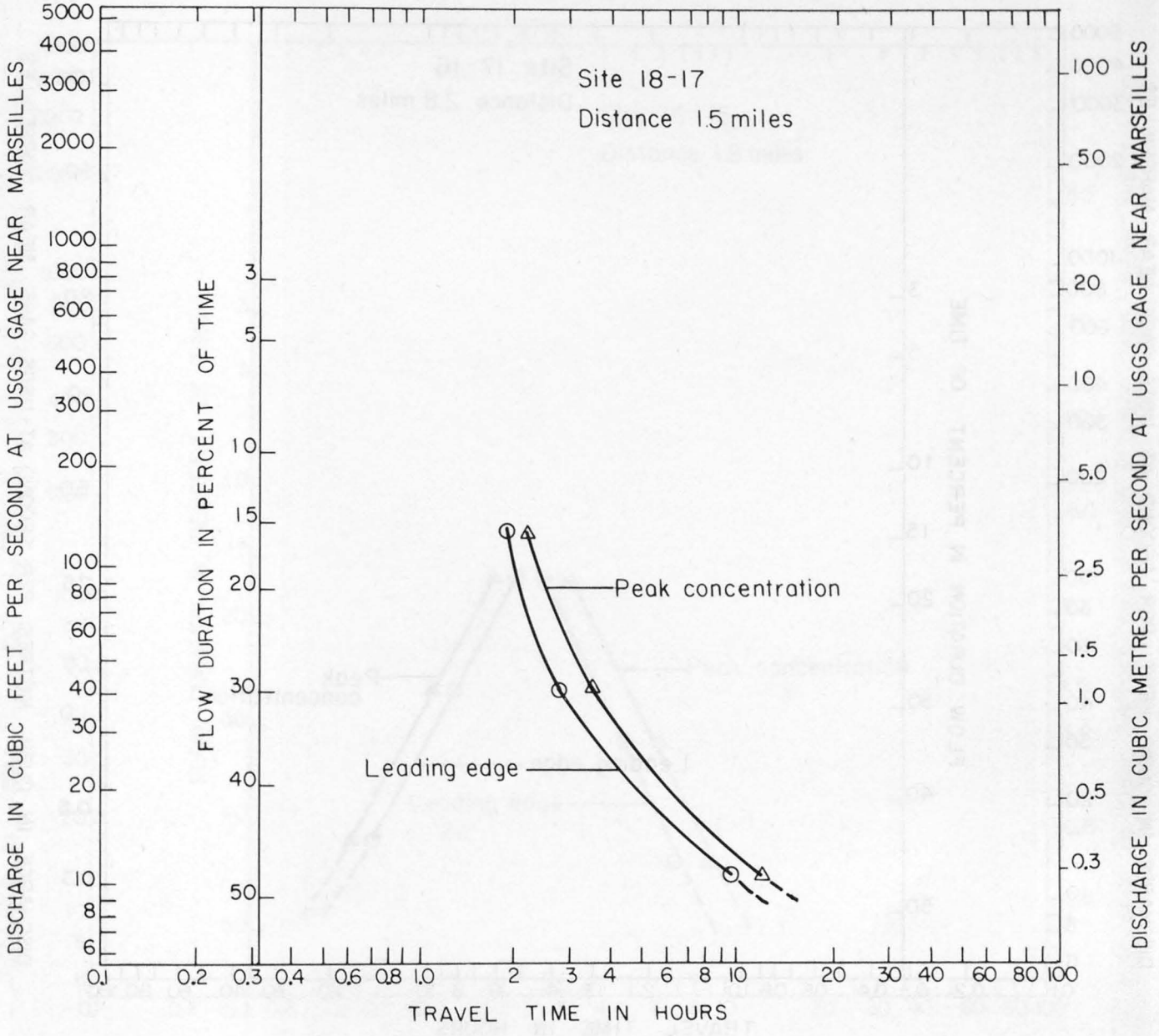

FIGURE 27.-- TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN SE 1/4 SEC. 29, T3S, R13E TO BRIDGE IN SE 1/4 SEC. 20, T3S, R13E.

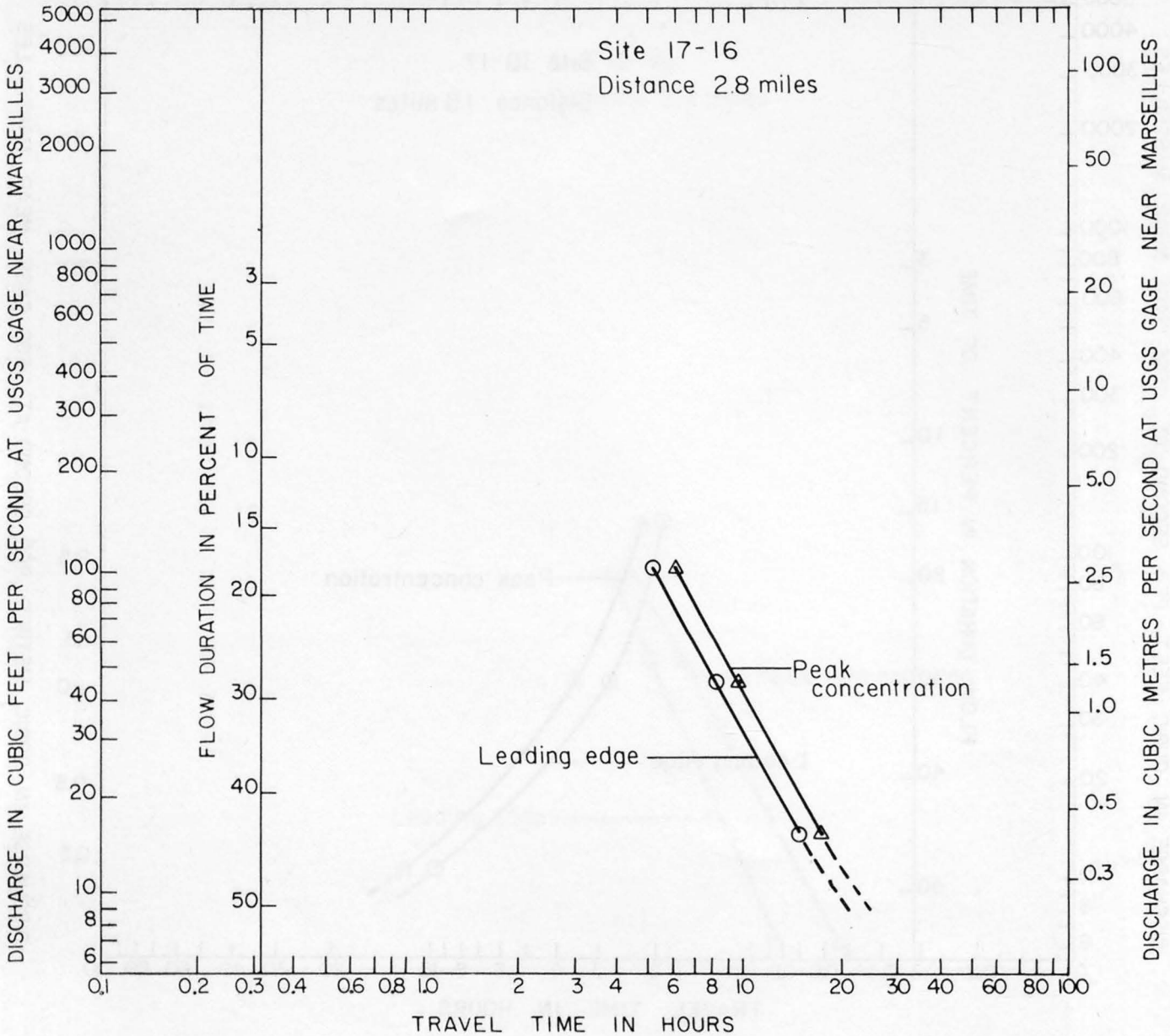

FIGURE 28.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN SE 1/4 SEC. 20, T3S, R13E TO BRIDGE IN SW 1/4 SEC. 15, T3S, R13E.

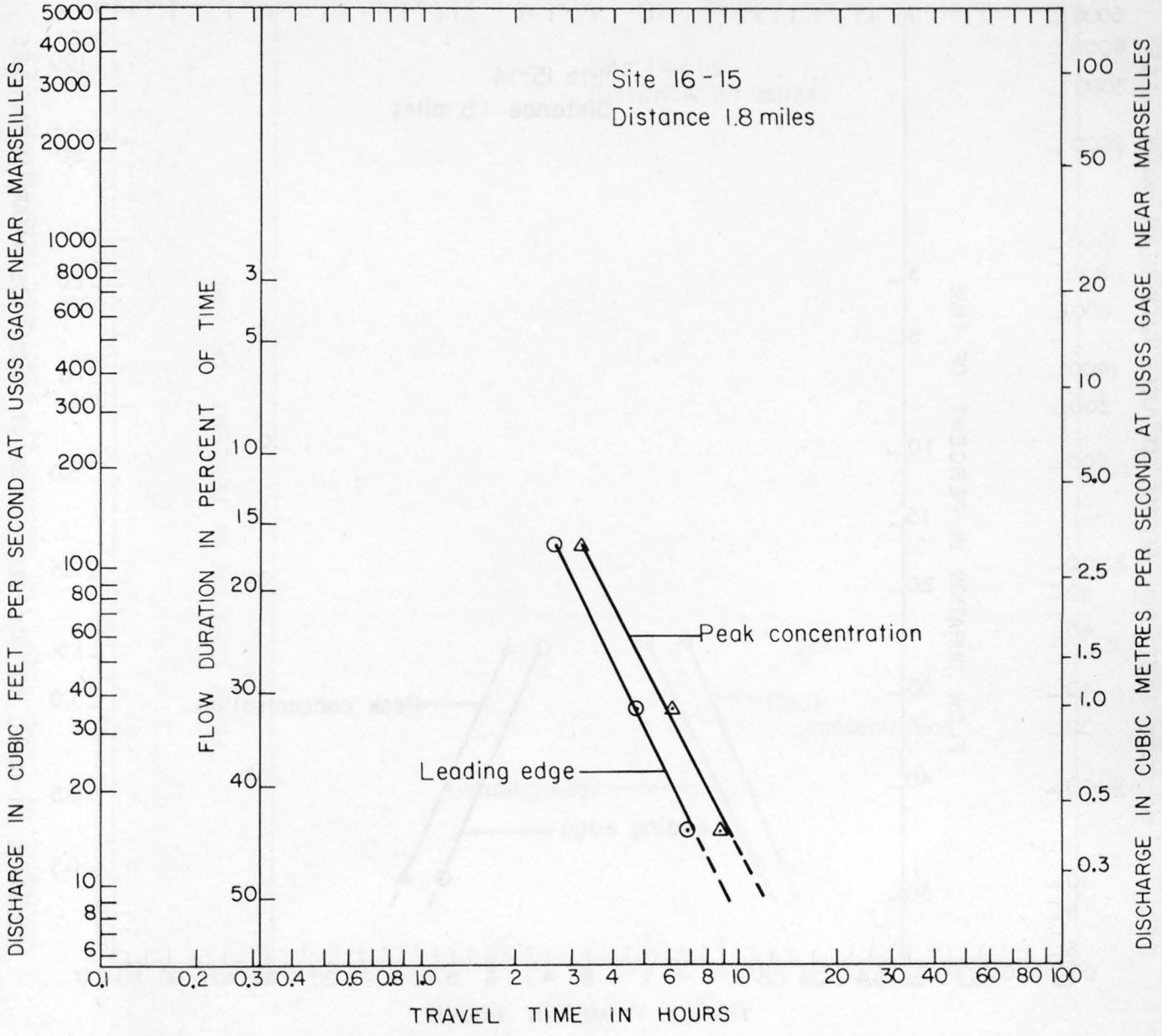

FIGURE 29.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN SW 1/4 SEC. 15, T3S, R13E TO BRIDGE IN SW 1/4 SEC. 10, T3S, R13E.

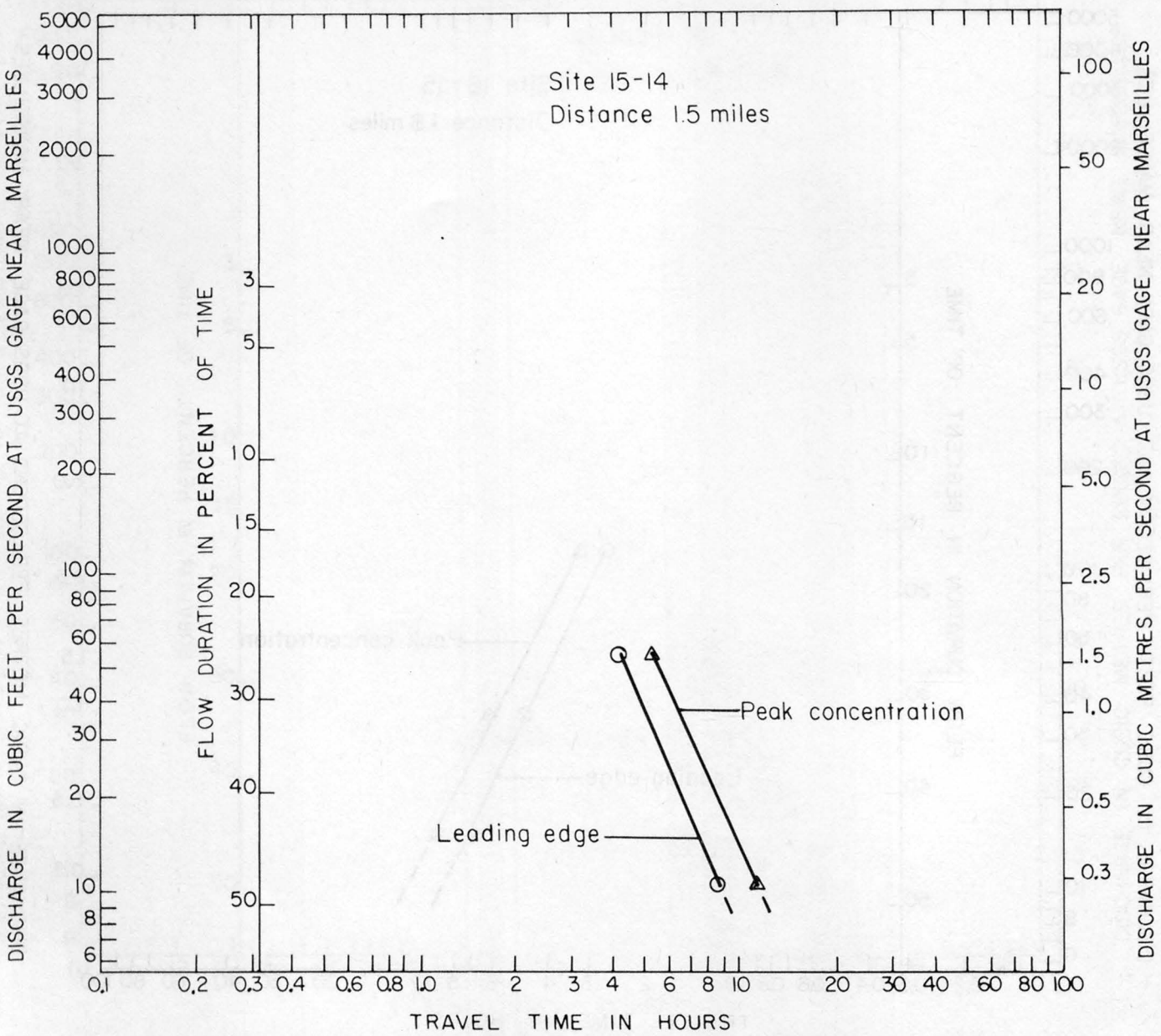

FIGURE 30.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN SW1/4 SEC 10, T3S, R13E TO S.R. 53 BRIDGE.

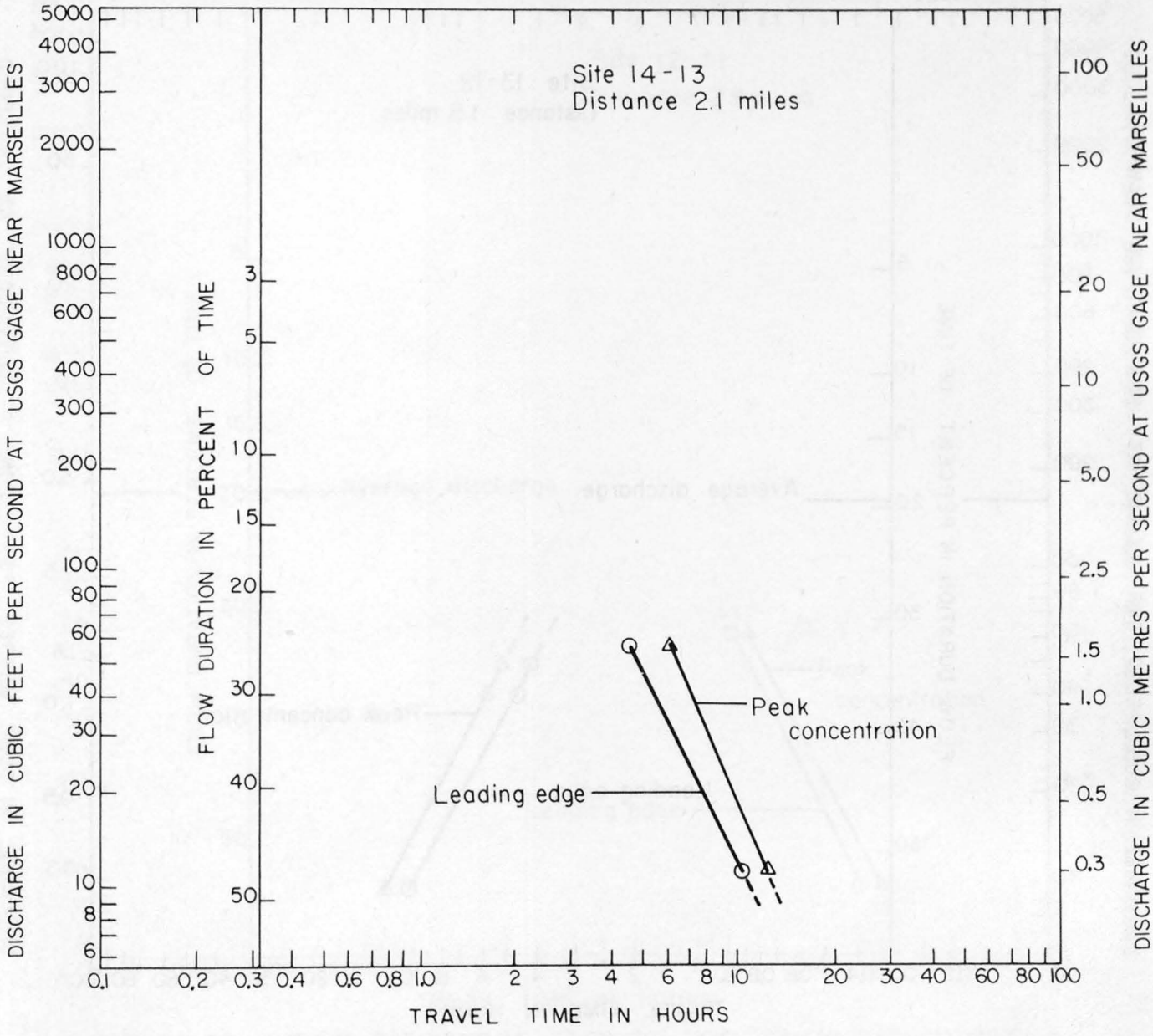

FIGURE 31.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM SR 53 TO SW 1/4 SEC. 34, T2S, R13E.

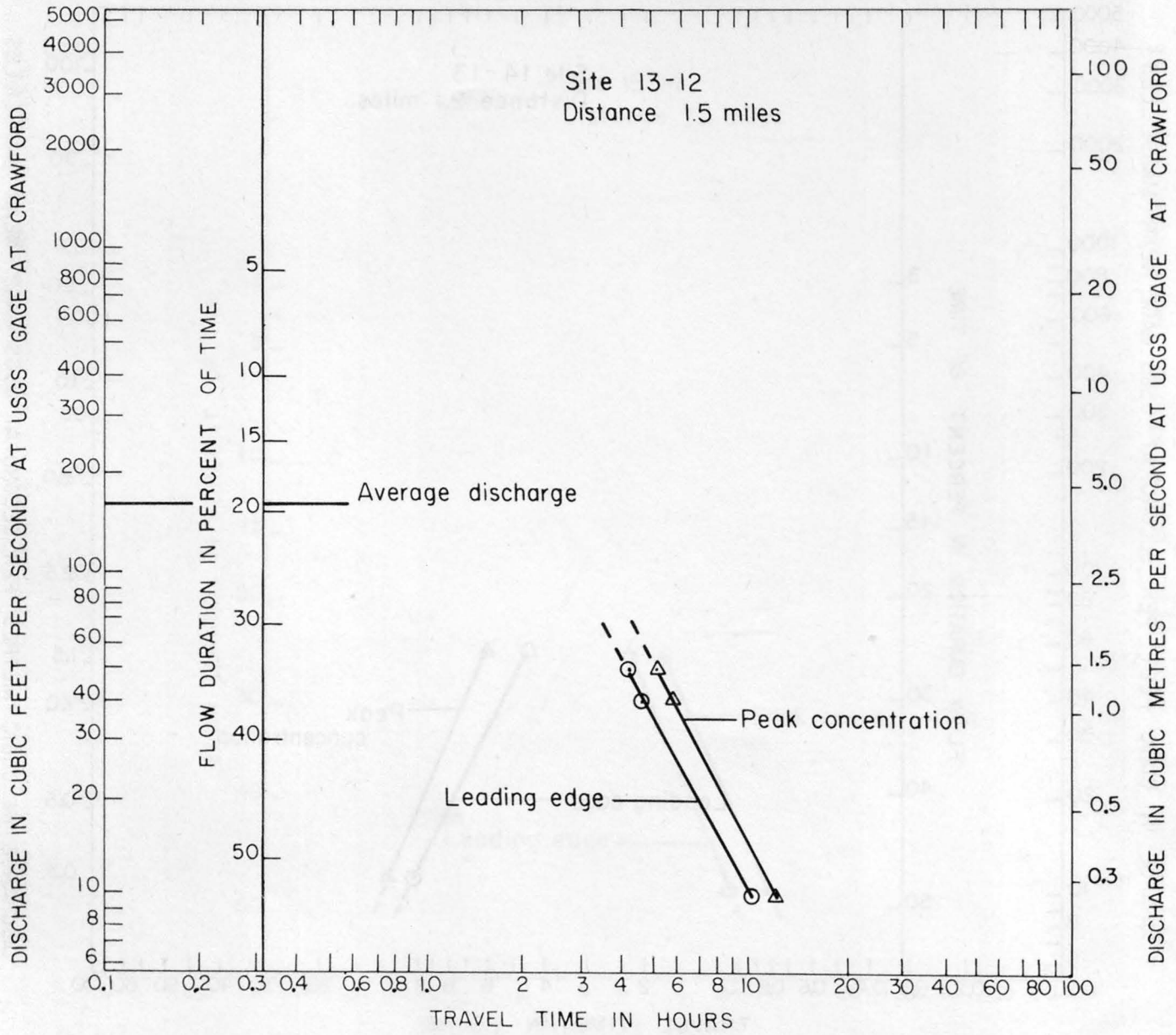

FIGURE 32.-- TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN SW 1/4 SEC. 34, T2S, R13E TO U.S. HIGHWAY 30 N.

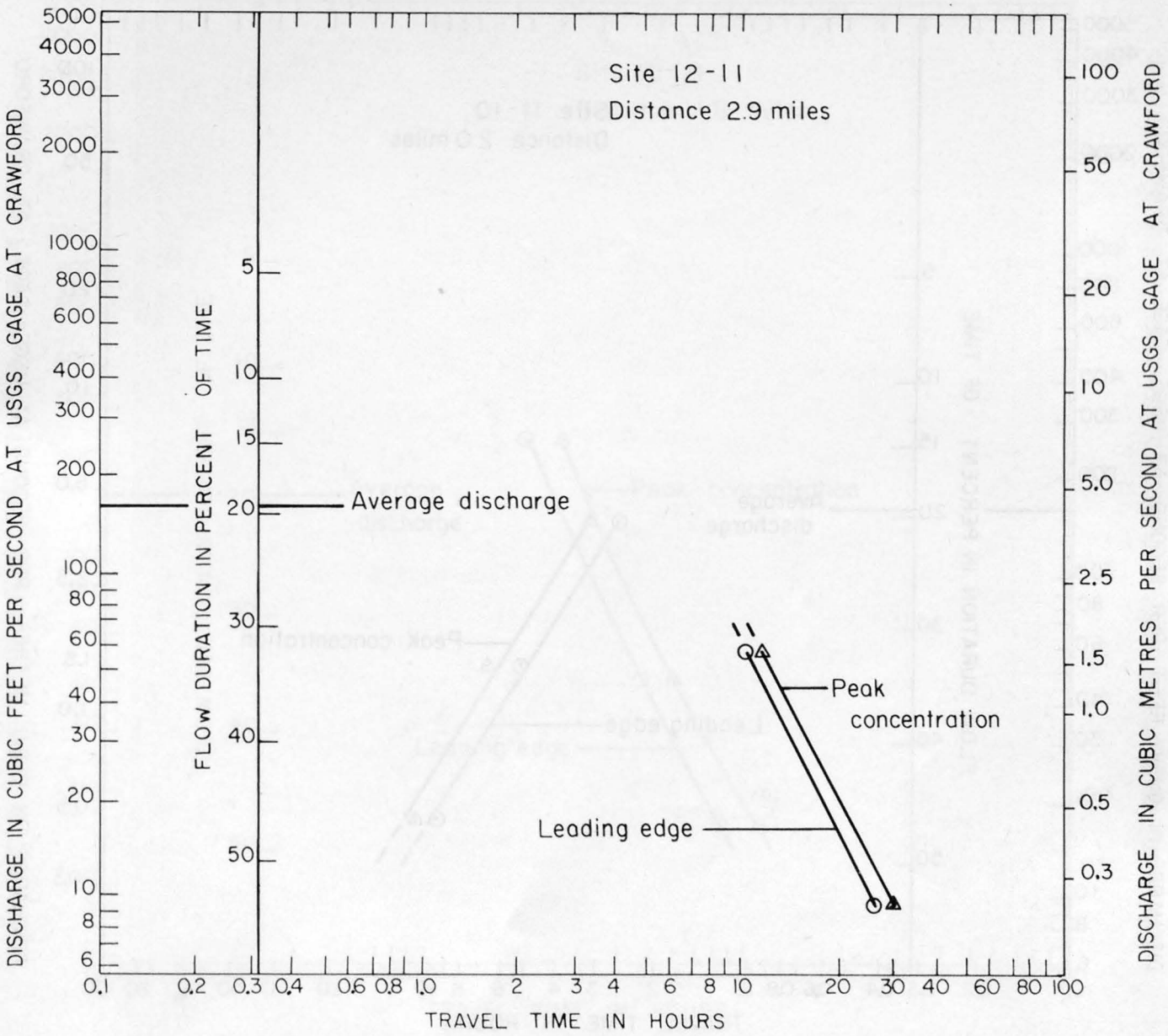

FIGURE 33.-- TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM U.S. HIGHWAY 30 N TO BRIDGE IN NW 1/4 SEC. 27, T2S, R13E.

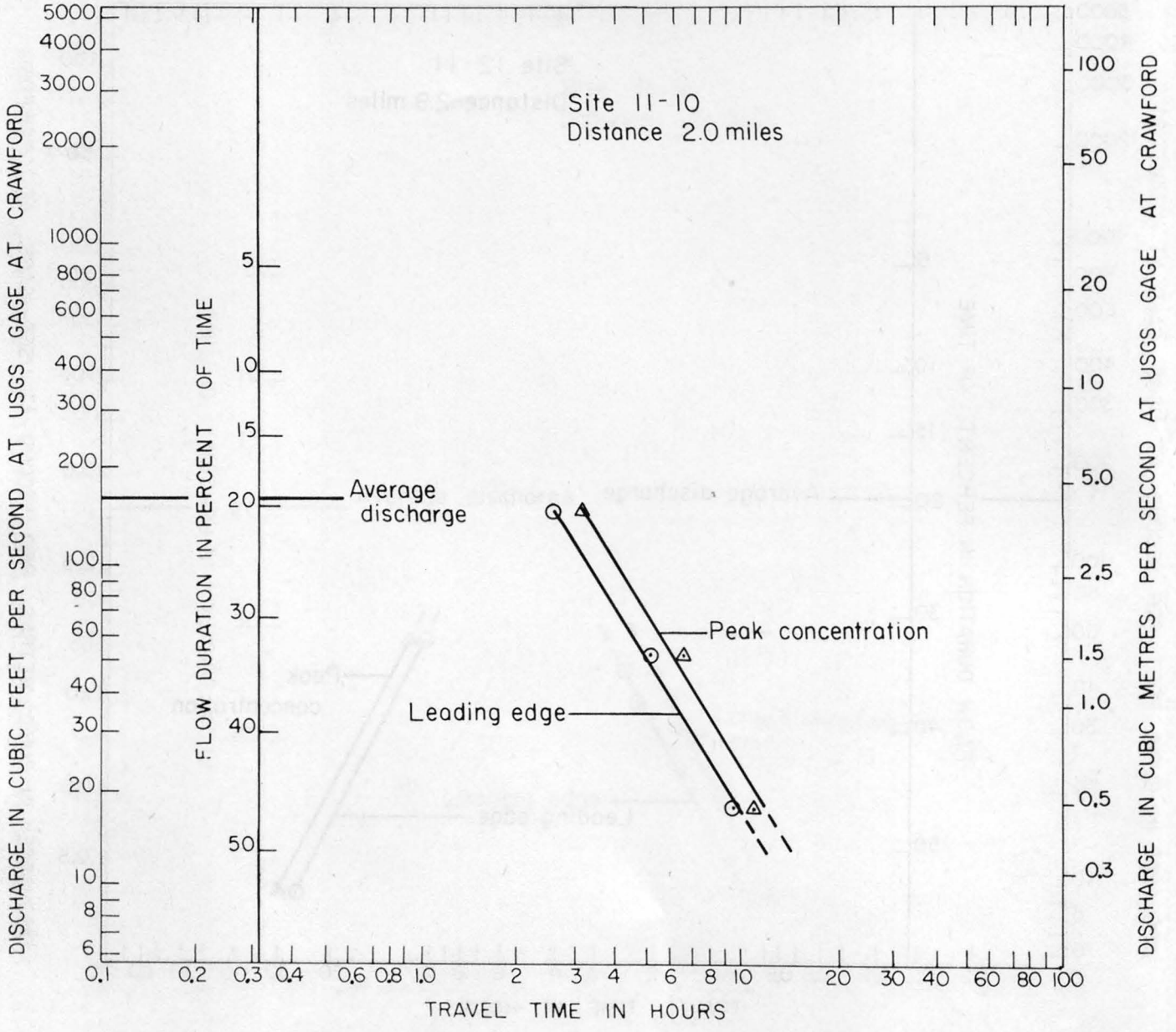

FIGURE 34.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN NW 1/4 SEC. 27, T2S, R13E TO BRIDGE IN SW 1/4 SEC. 16, T2S, R13E.

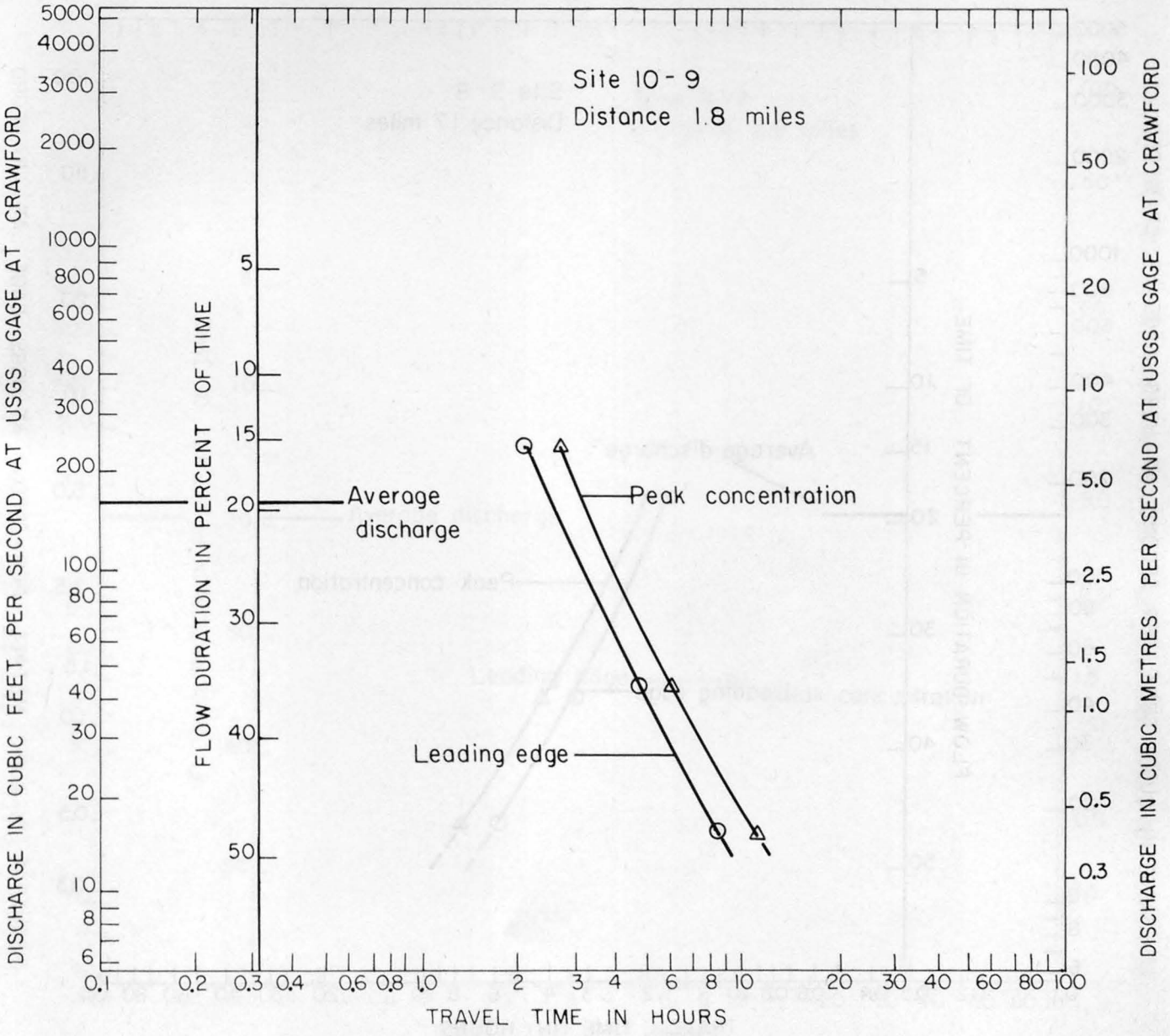

FIGURE 35.-- TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN SW 1/4 SEC. 16, T2S, R13E TO BRIDGE IN SE 1/4 SEC. 9, T2S, R13E.

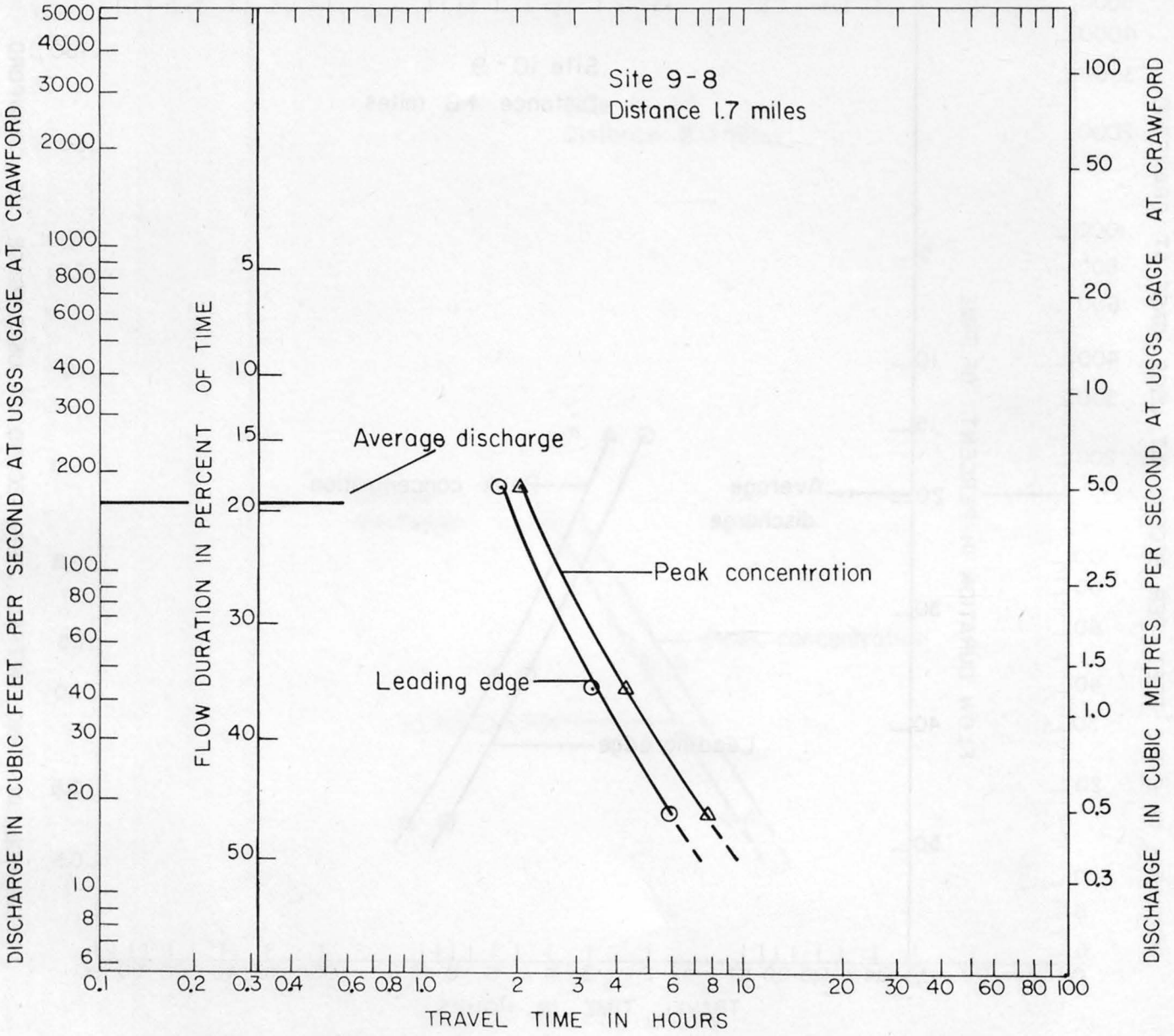

FIGURE 36.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN SE 1/4 SEC. 9, T2S, R13E TO BRIDGE IN NW 1/4 SEC. 10, T2S, R13E.

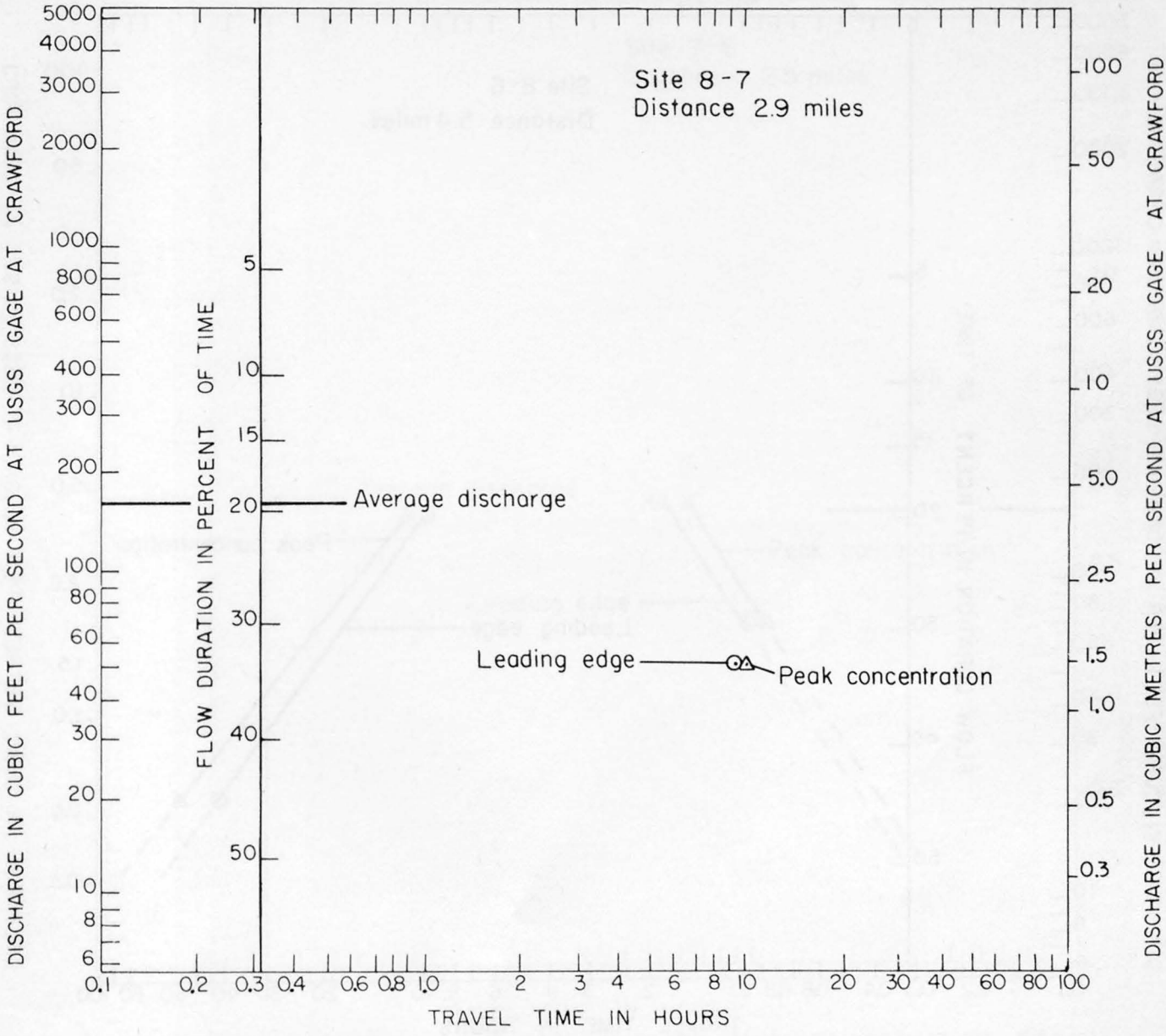

FIGURE 37.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM BRIDGE IN NW1/4 SEC. 10, T2S, R13E TO REISTER ROAD.

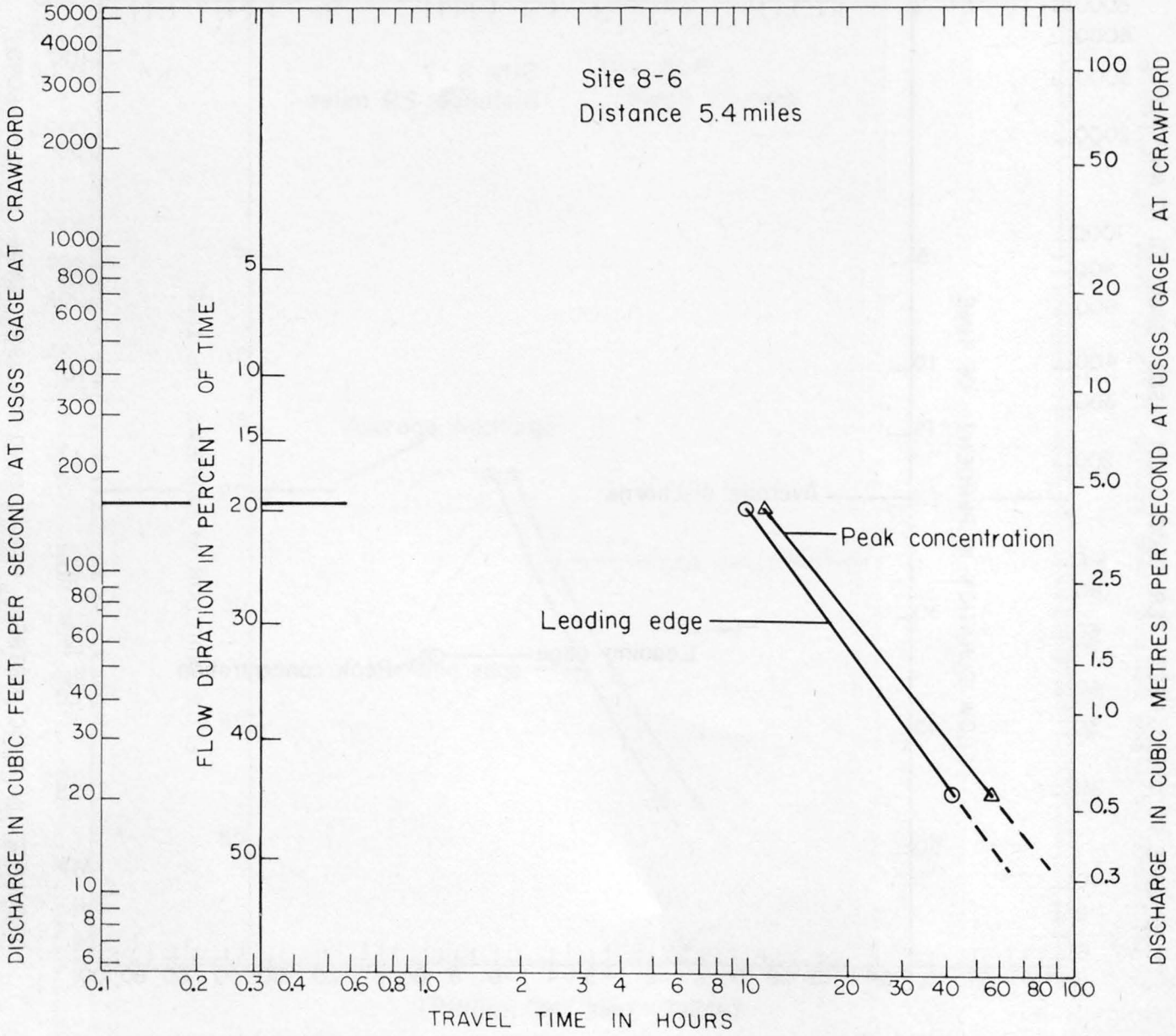

FIGURE 38.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK, FROM BRIDGE IN NW 1/4 SEC. 10, T2S, R13E TO USGS GAGE AT CRAWFORD.

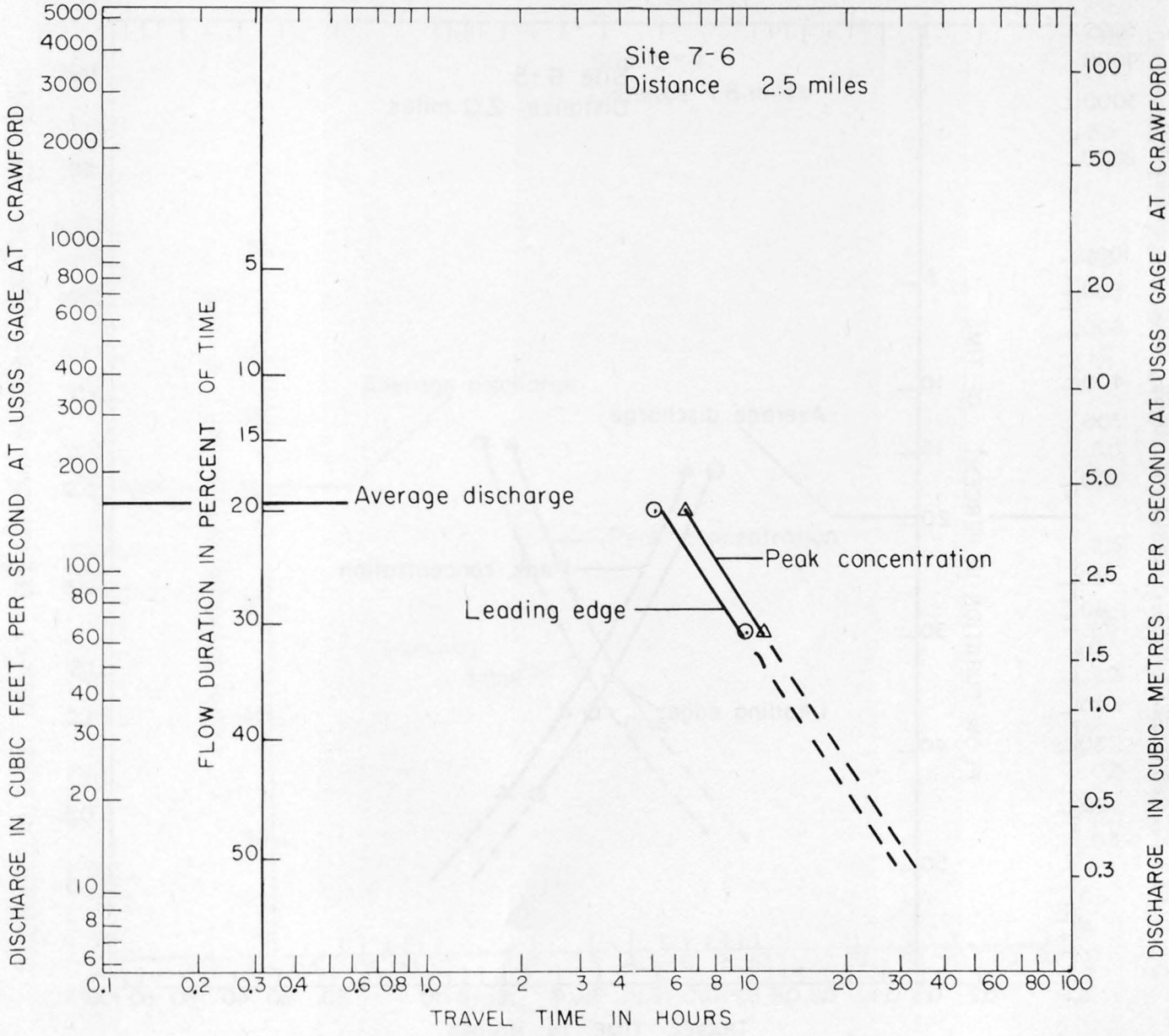

FIGURE 39.-- TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK FROM REISTER ROAD TO USGS GAGE AT CRAWFORD.

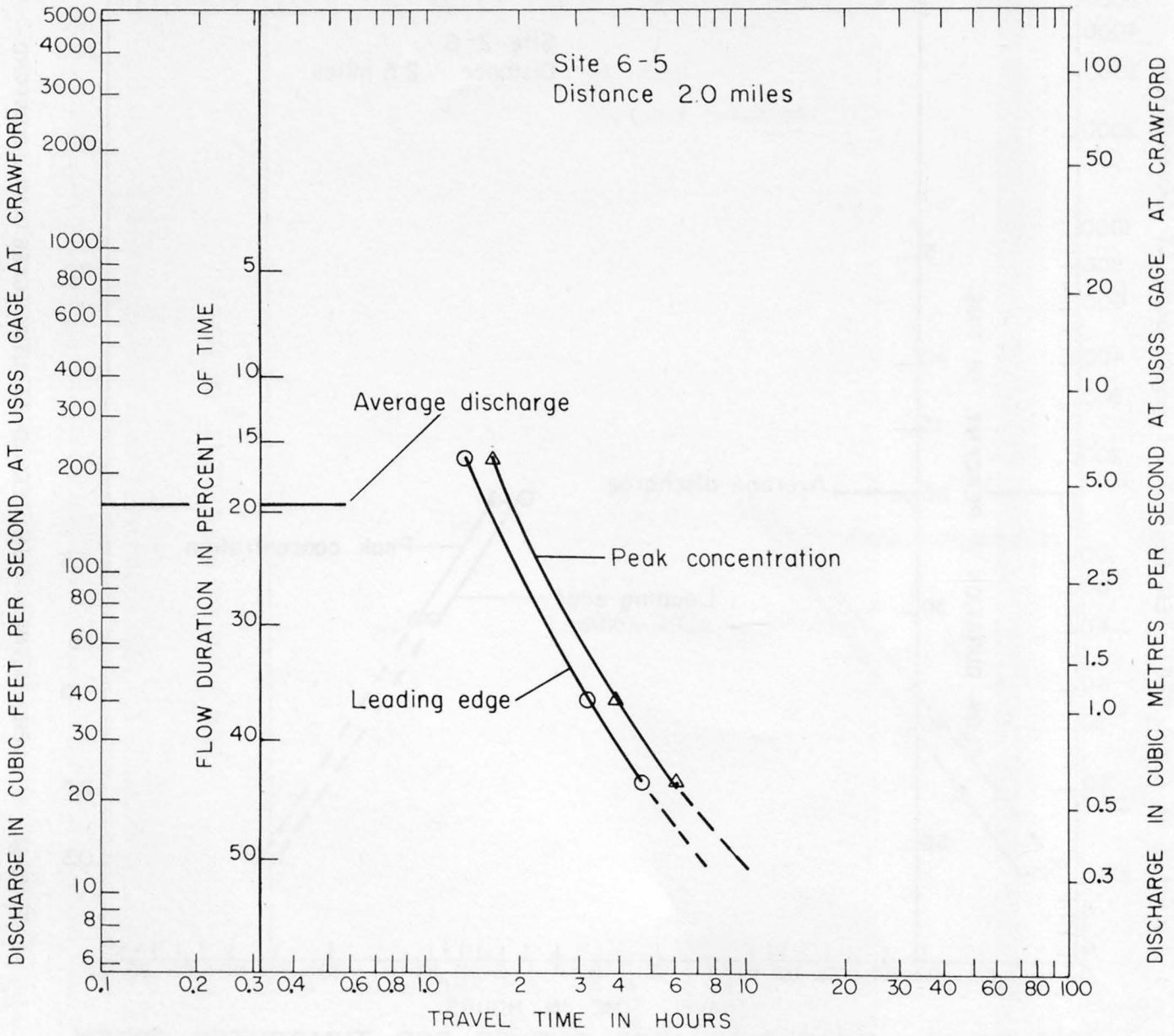

FIGURE 40.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK, FROM USGS GAGE AT CRAWFORD TO HURD ROAD.

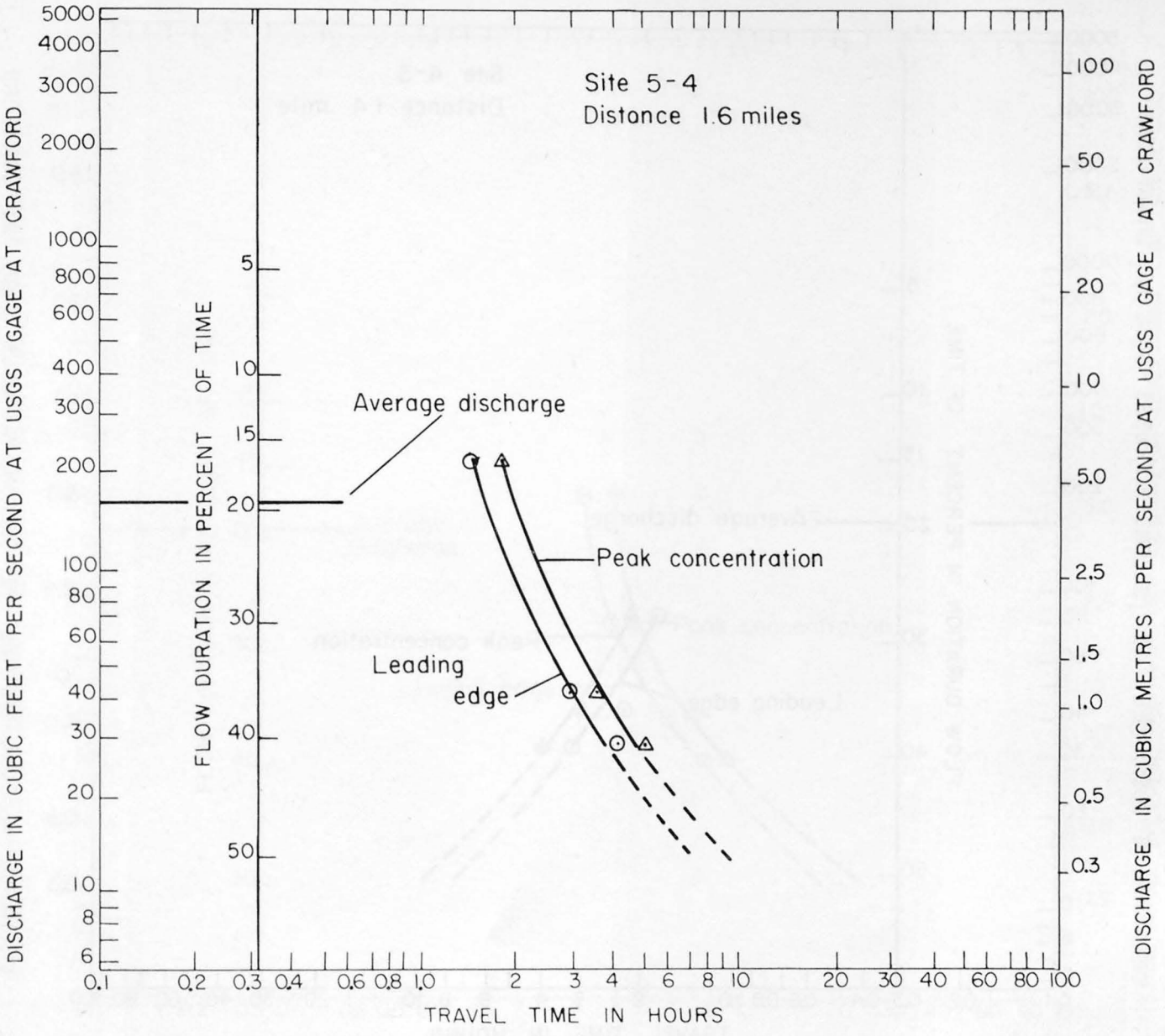

FIGURE 41.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK, FROM HURD ROAD TO SR 103.

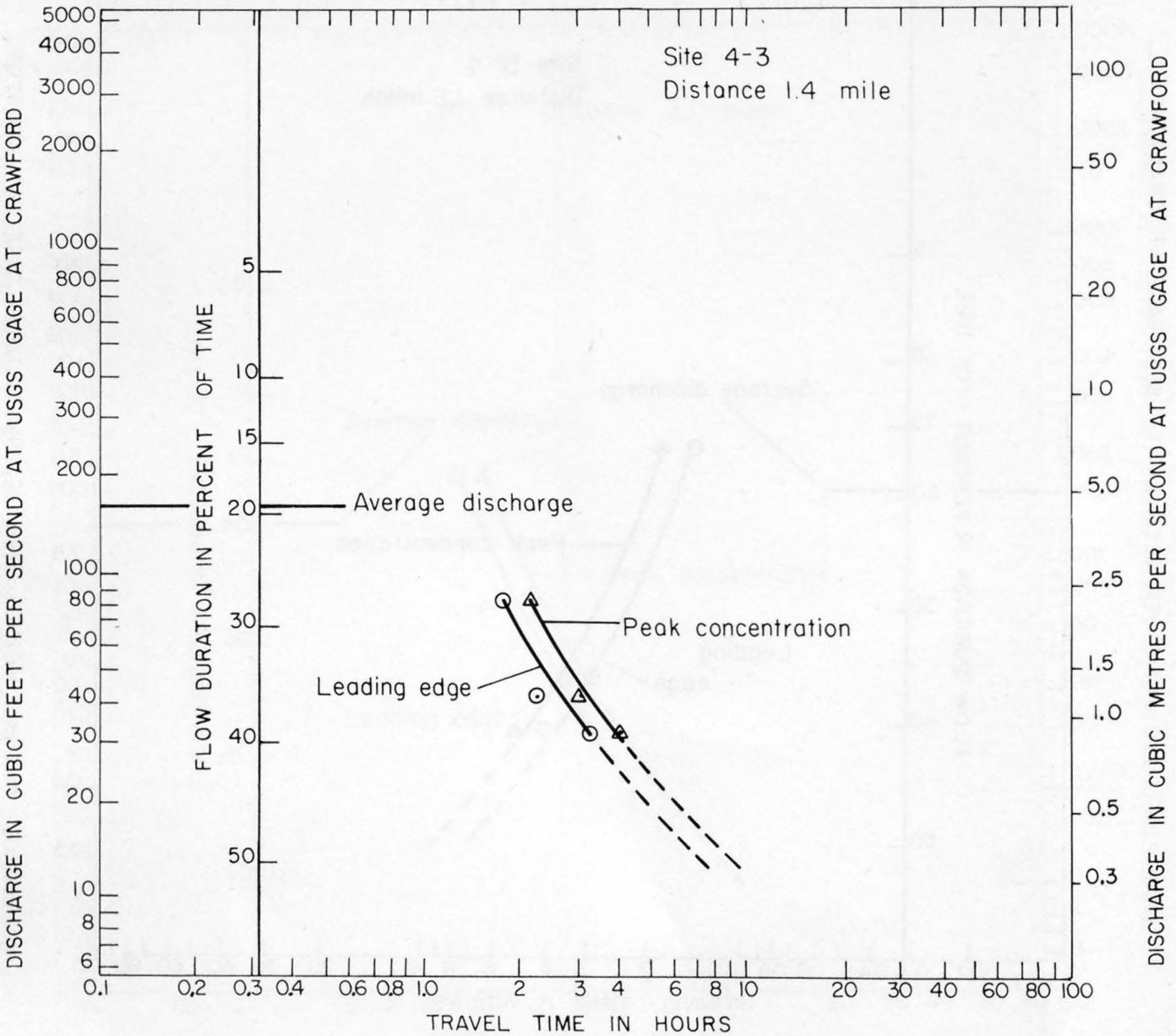

FIGURE 42.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK, FROM SR 103 TO BRIDGE IN SW1/4 SEC. 18, T1S, R13E.

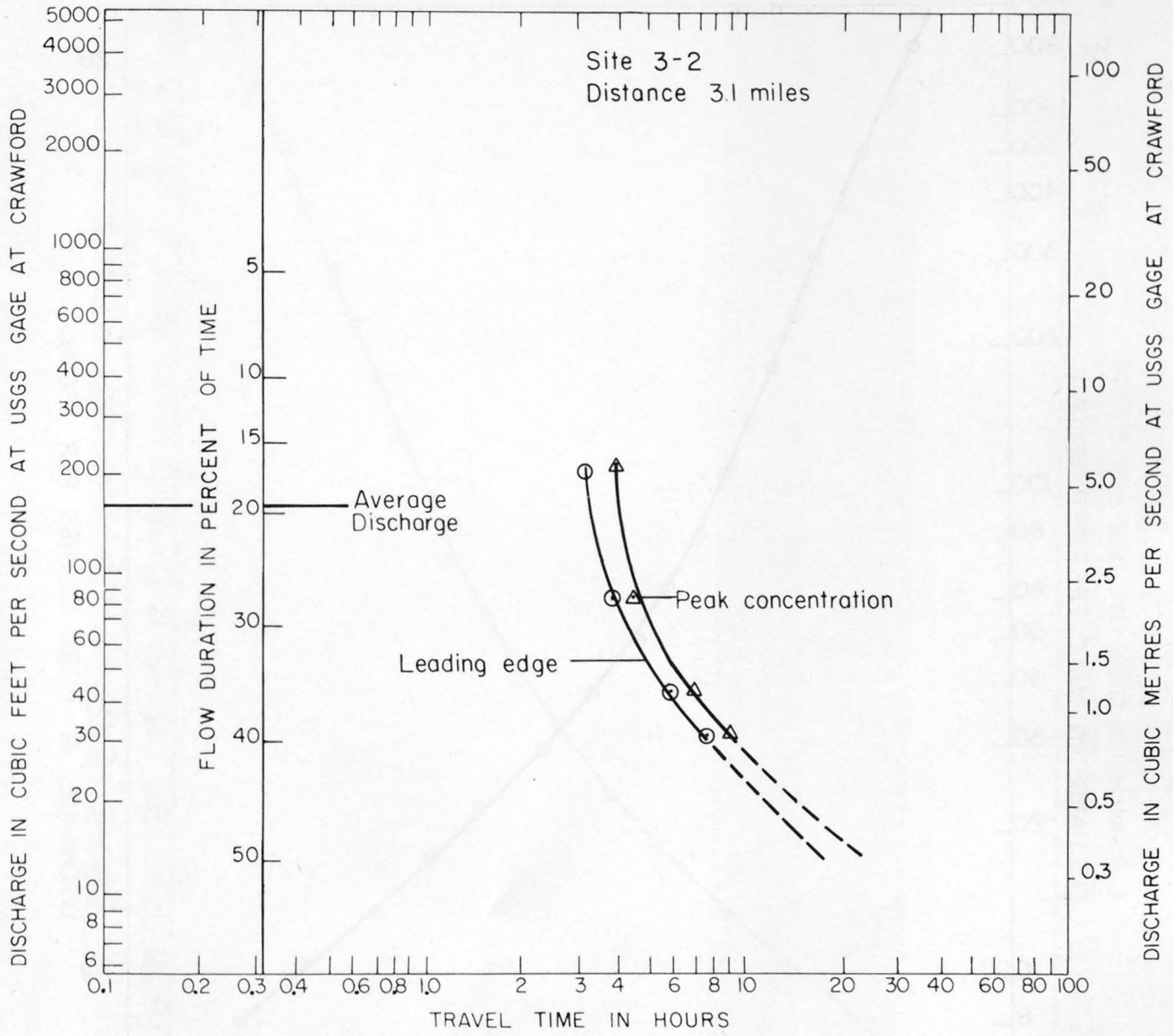

FIGURE 43.--TIME-DISCHARGE CURVES FOR TYMOCHTEE CREEK, FROM BRIDGE IN SW 1/4 SEC.18, T1S, R13E TO S.R. 53.

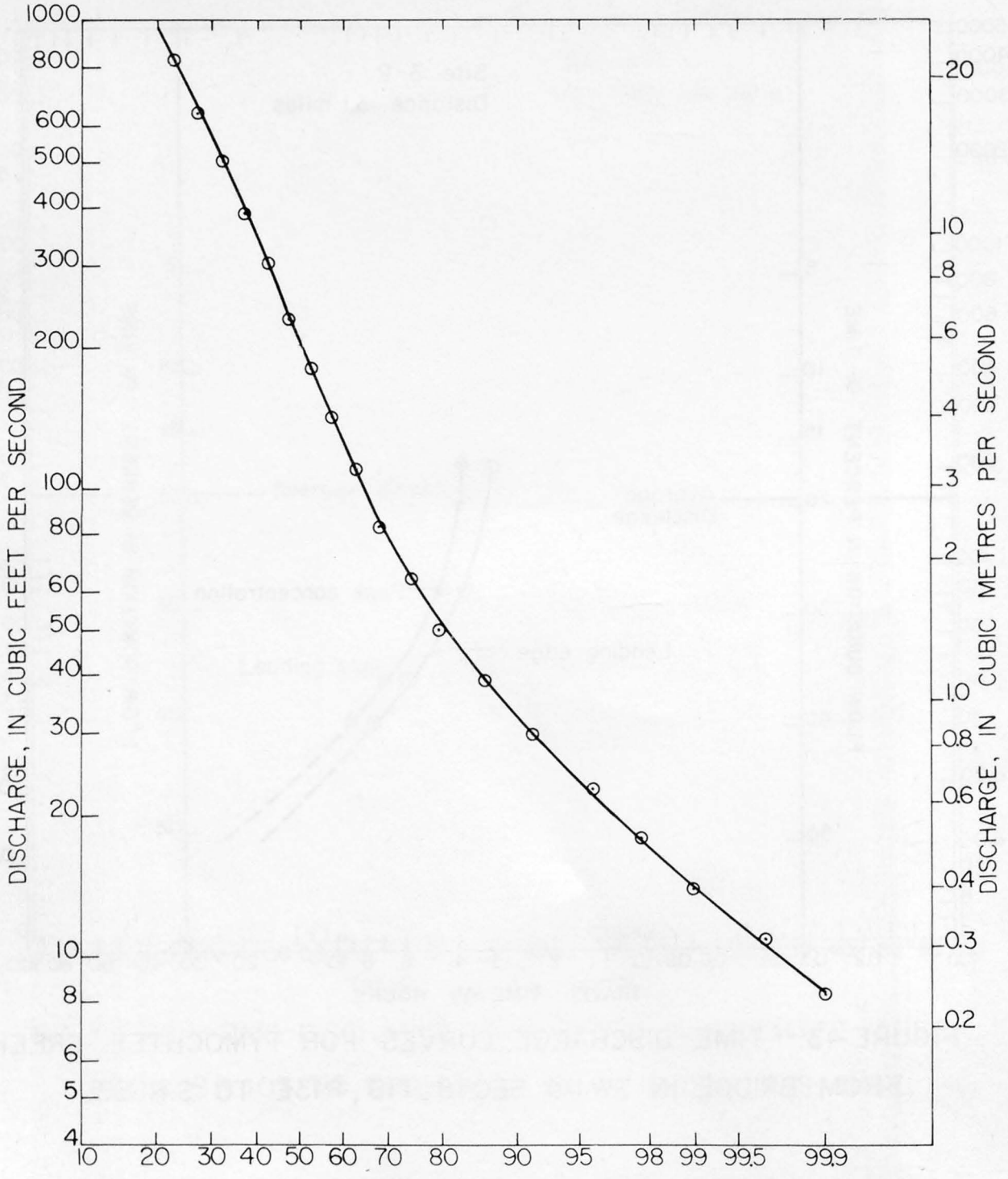

FIGURE 44.--FLOW-DURATION CURVE OF DAILY FLOW OF SANDUSKY RIVER AT FREMONT, OHIO.

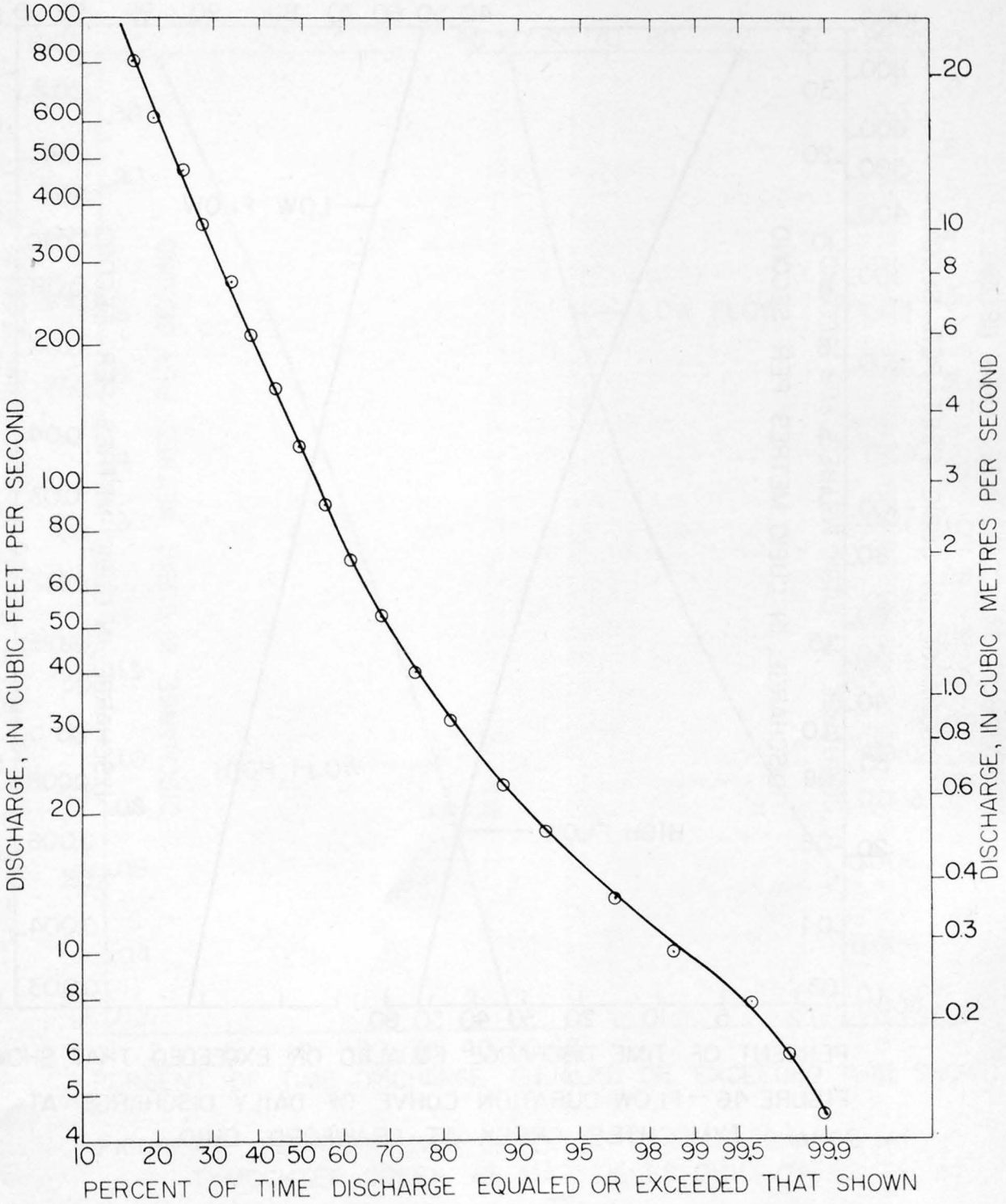

FIGURE 45.--FLOW-DURATION CURVE OF DAILY FLOW OF SANDUSKY RIVER NEAR MEXICO, OHIO.

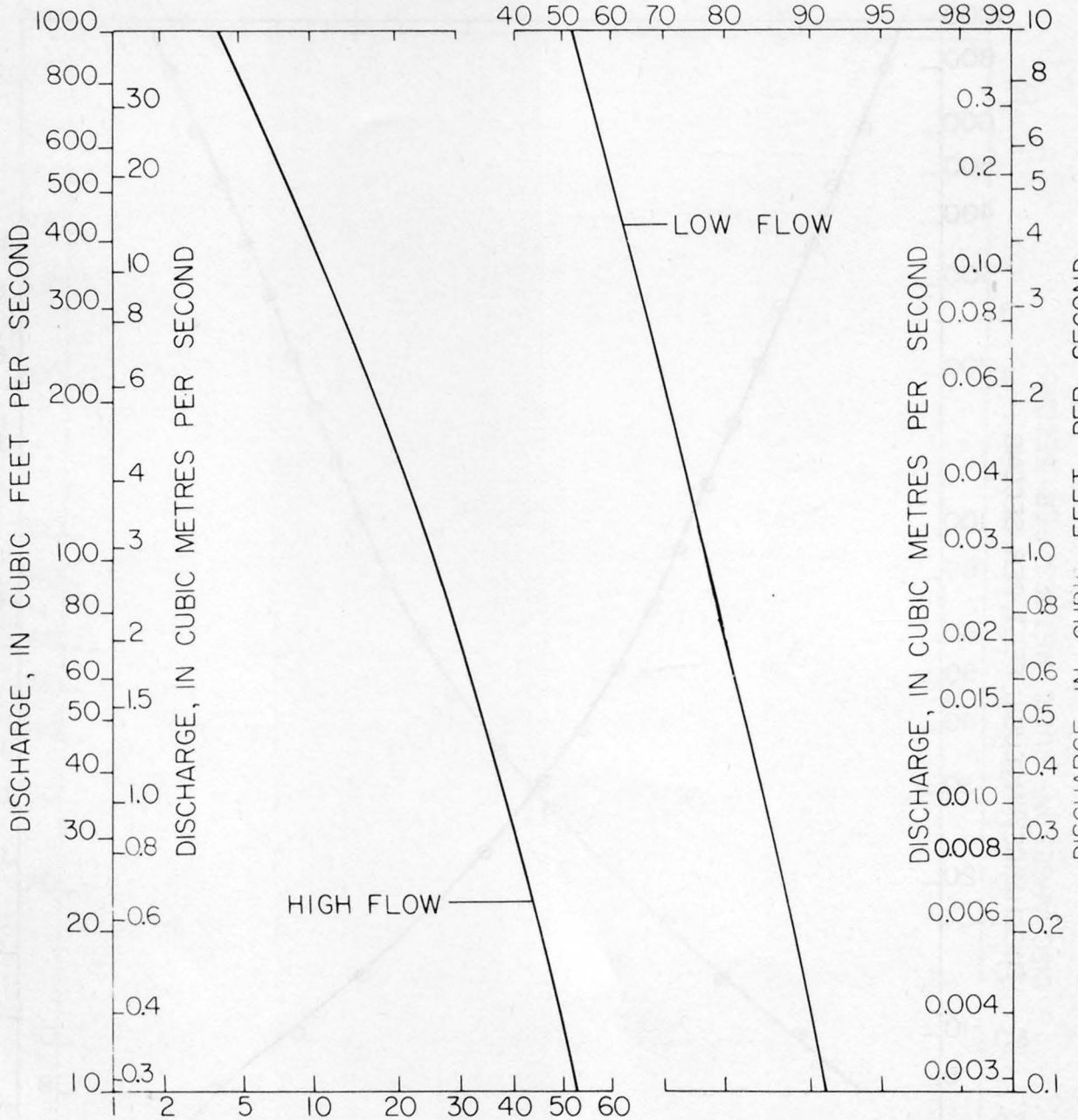

FIGURE 46.--FLOW-DURATION CURVE OF DAILY DISCHARGE AT TYMOCHTEE CREEK AT CRAWFORD, OHIO.

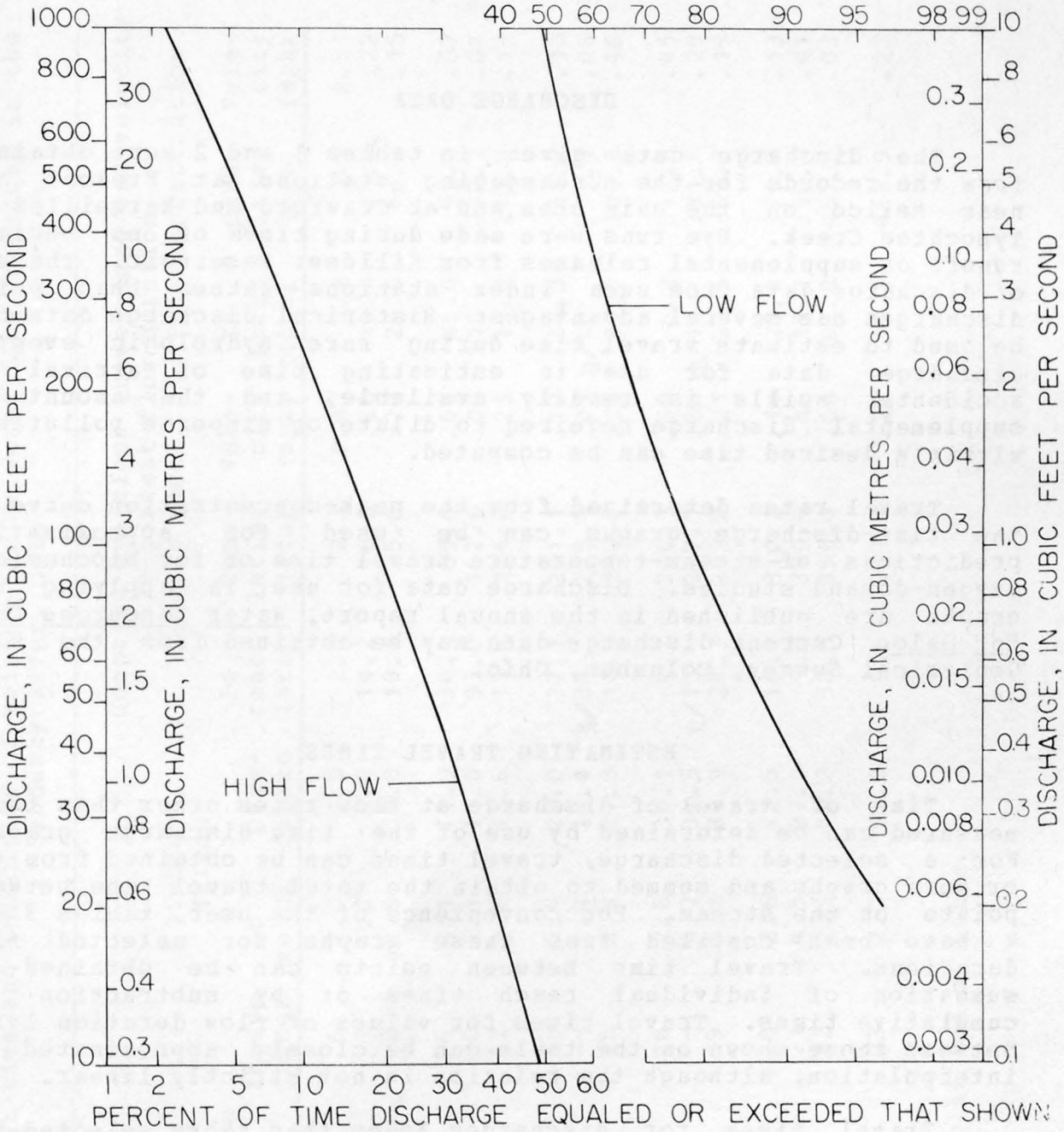

FIGURE 47.--FLOW-DURATION CURVE OF DAILY DISCHARGE AT TYMOCHTEE CREEK AT MARSEILLES, OHIO.

DISCHARGE DATA

The discharge data given in tables 1 and 2 were obtained from the records for the streamgaging stations at Fremont and near Mexico on the main stem and at Crawford and Marseilles on Tymochtee Creek. Dye runs were made during times of no surface runoff or supplemental releases from Killdeer Reservoir. The use of discharge data from such index stations rather than point discharges has several advantages: Historical discharge data can be used to estimate travel time during rare hydrologic events, discharge data for use in estimating time of arrival of accidental spills is readily available, and the amount of supplemental discharge required to dilute or disperse pollutants within a desired time can be computed.

Travel rates determined from the peak-concentration curve of the time-discharge graphs can be used for approximating predictions of stream-temperature travel time or for biochemical oxygen-demand studies. Discharge data for use in applying the graphs are published in the annual report, Water Resources Data for Ohio. Current discharge data may be obtained from the U.S. Geological Survey, Columbus, Ohio.

ESTIMATING TRAVEL TIMES

Time of travel of discharge at flow rates other than those measured can be determined by use of the time-discharge graphs. For a selected discharge, travel times can be obtained from two or more graphs and summed to obtain the total travel time between points on the stream. For convenience of the user, tables 3 and 4 have been compiled from these graphs for selected flow durations. Travel time between points can be obtained by summation of individual reach times or by subtraction of cumulative times. Travel times for values of flow duration lying between those shown on the table can be closely approximated by interpolation, although the relation is not strictly linear.

Travel times for discharges lower than those selected for the tables can be calculated by a downward extension of the time-discharge curves. It is emphasized that the shape of the extension should be guided by use of the flow-duration curves.

Table 3.--Travel time and velocities of solutes for selected flow durations in the Sandusky River, Ohio

Reach	Site number downstream end of reach	Figure number	Distance (miles) In reach	Distance (miles) Cumulative	Computed dye cloud travel time and velocity 70-percent flow duration: Leading edge In reach (hrs)	Leading edge Cumulative (hrs)	Leading edge Velocity (mph)	Peak concentration In reach (hrs)	Peak concentration Cumulative (hrs)	Peak concentration Velocity (mph)
17-16	16	6	1.0	1.0	2.3	2.3	0.43	3.2	3.2	0.31
16-15	15	7	4.0	5.0	14.2	16.5	.28	18.0	21.2	.22
15-14	14	8	3.8	8.8	19.1	35.6	.20	25.0	46.2	.15
14-13	13	9	3.1	11.9	34.0	69.6	.09	46.0	92.2	.07
13-12	12	10	4.1	16.0	93.0	162.6	.04	110	202.2	.04
12-11	11	12	2.6	18.6	11.4	174.0	.23	15.2	217.4	.17
11-10	10	13	3.4	22.0	27.1	201.1	.13	34.3	251.7	.10
10- 9	9	--	2.4	24.4	a/34	235.1	.07	a/40	291.7	.06
9- 8	8	15	2.9	27.3	14.9	250.0	.19	17.9	309.6	.16
8- 7	7	16	2.8	30.1	4.7	254.7	.60	6.2	315.8	.45
7- 6	6	--	4.7	34.8	b/13	267.7	.36	b/16	331.8	.29
6- 5	5	19	5.1	39.9	24.3	292.0	.21	27.5	359.3	.19
5- 4	4	20	2.6	42.5	18.2	310.2	.14	20.4	379.7	.13
4- 3	3	21	4.5	47.0	9.8	320.0	.46	11.1	390.8	.41
3- 2	2	22	2.3	49.3	38.0	358.0	.06	67.0	457.8	.03
2- 1	1	23	2.7	52.0	9.6	367.6	.28	12.1	469.9	.22

See footnotes at end of table.

Table 3.--Travel time and velocities of solutes for selected flow durations in the Sandusky River, Ohio--Continued

Reach	Computed dye cloud travel time and velocity											
	60-percent flow duration						50-percent flow duration					
	Leading edge			Peak concentration			Leading edge			Peak concentration		
	In reach (hrs)	Cumulative (hrs)	Velocity (mph)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)
17-16	1.9	1.9	0.53	2.6	2.6	0.38	1.5	1.5	0.67	2.0	2.0	0.50
16-15	11.5	13.4	.35	14.5	17.1	.28	8.8	10.3	.45	11.0	13.0	.36
15-14	15.0	28.4	.25	19.3	36.4	.20	11.1	21.4	.34	14.0	27.0	.27
14-13	23.5	51.9	.13	31.0	67.4	.10	15.3	36.7	.20	19.5	46.5	.16
13-12	65.0	116.9	.06	76.0	143.4	.05	42.0	78.7	.10	48.5	95.0	.08
12-11	7.4	124.3	.35	10.9	154.3	.24	5.9	84.6	.44	7.4	102.4	.35
11-10	20.0	144.3	.17	24.5	178.8	.14	13.8	98.4	.25	16.6	119.0	.20
10- 9	a/24	168.3	.10	a/30	208.8	.08	a/17	115.4	.14	a/20	139.0	.12
9- 8	10.8	179.1	.27	13.0	221.8	.22	7.7	123.1	.38	9.3	148.3	.31
8- 7	3.7	182.8	.76	4.7	226.5	.60	3.0	126.1	.93	3.6	151.9	.78
7- 6	b/10	192.8	.47	b/12	238.5	.39	b/7.6	133.7	.62	b/8.9	160.8	.53
6- 5	19.0	211.8	.27	20.6	259.1	.25	14.8	148.5	.34	16.7	177.5	.31
5- 4	13.9	225.7	.19	15.5	274.6	.17	10.5	159.0	.25	11.7	189.2	.22
4- 3	7.7	233.4	.58	8.6	283.2	.52	5.9	164.9	.76	6.4	195.6	.67
3- 2	26.0	259.4	.09	47.0	330.2	.05	17.1	182.0	.13	27.2	222.8	.08
2- 1	6.1	265.5	.44	9.0	339.2	.30	5.2	187.2	.52	6.4	229.2	.42

See footnotes at end of table.

Table 3.--Travel time and velocities of solutes for selected flow durations in the Sandusky River, Ohio--Continued

Reach	Computed dye cloud travel time and velocity											
	40-percent flow duration						30-percent flow duration					
	Leading edge			Peak concentration			Leading edge			Peak concentration		
	In reach (hrs)	Cumulative (hrs)	Velocity (mph)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)
17-16	1.1	1.1	0.91	1.5	1.5	0.67	0.9	0.9	1.11	1.2	1.1	0.83
16-15	5.6	6.7	.71	8.3	9.8	.48	5.0	5.9	.80	6.3	7.5	.63
15-14	7.1	13.8	.54	10.1	19.9	.38	5.9	11.8	.64	7.2	14.7	.53
14-13	9.7	23.5	.32	11.8	31.7	.26	6.2	18.0	.50	7.3	22.0	.42
13-12	26.2	49.7	.16	30.0	61.7	.14	16.6	34.6	.25	18.7	40.7	.22
12-11	4.0	53.7	.65	4.8	66.5	.54	2.7	37.3	.96	3.2	43.9	.81
11-10	9.3	63.0	.37	10.8	77.3	.31	6.3	43.6	.54	7.2	51.1	.47
10- 9	a/11	74.0	.22	a/13	90.3	.18	a/7.2	50.8	.33	a/8.6	59.7	.28
9- 8	5.2	79.2	.56	6.6	96.9	.44	3.9	54.7	.74	4.8	64.5	.60
8- 7	2.3	81.5	1.22	2.6	99.5	1.08	1.9	56.6	1.47	2.0	66.5	1.40
7- 6	b/5.8	87.3	.81	b/6.5	106	.72	b/4.5	61.1	1.04	b/5.0	71.5	.94
6- 5	11.6	98.9	.44	12.8	118.8	.40	9.0	70.1	.57	10.0	81.5	.51
5- 4	7.9	106.8	.33	8.6	127.4	.30	6.0	76.1	.43	6.6	88.1	.39
4- 3	4.6	111.4	.98	5.1	132.5	.88	3.5	79.6	1.29	3.9	92.0	1.15
3- 2	11.2	122.6	.21	15.7	148.2	.15	7.5	87.1	.31	9.1	101.1	.25
2- 1	3.7	126.3	.73	4.6	152.8	.59	2.7	89.8	1.00	3.3	104.4	.82

a Estimated from graph of velocity vs distance for sites 10 and 8A.
b Estimated from graph of velocity vs distance for sites 7 and 5A.

Table 4.--Travel time and velocities for selected flow durations in Tymochtee Creek, Ohio

Reach	Site number downstream end of reach	Figure number	Distance (miles) In reach	Distance (miles) Cumulative	Computed dye cloud travel time and velocity 50-percent flow duration: Leading edge In reach (hrs)	Leading edge Cumulative (hrs)	Leading edge Velocity (mph)	Peak concentration In reach (hrs)	Peak concentration Cumulative (hrs)	Peak concentration Velocity (mph)
21-20	20	24	1.2	1.2	16.5	16.5	0.07	22.2	22.2	0.05
20-19	19	25	2.5	3.7	14.0	30.5	.18	16.8	39.0	.15
19-18	18	26	2.2	5.9	11.3	41.8	.19	16.1	15.1	.14
18-17	17	27	1.5	7.4	12.0	53.8	.13	15.9	71.0	.09
17-16	16	28	2.8	10.2	23.7	77.5	.12	28.5	99.5	.10
16-15	15	29	1.8	12.0	8.8	86.3	.20	11.3	110.8	.16
15-14	14	30	1.5	13.5	9.3	95.6	.16	11.4	122.2	.13
14-13	13	31	2.1	15.6	11.4	10.7	.18	13.3	135.5	.16
13-12	12	32	1.5	17.1	8.4	115.4	.18	10.2	145.7	.15
12-11	11	33	2.9	20.0	20.8	136.2	.14	23.6	169.3	.12
11-10	10	34	2.0	22.0	10.9	147.1	.18	12.9	182.2	.16
10- 9	9	35	1.8	23.8	9.9	157.0	.18	12.2	194.4	.15
9- 8	8	36	1.7	25.5	7.6	164.6	.22	9.9	204.3	.17
8- 6	6	38	5.4	30.9	60.0	224.6	.09	78	282.3	.07
6- 5	5	40	2.0	32.9	7.6	232.2	.26	9.5	291.8	.21
5- 4	4	41	1.6	34.5	12.3	244.5	.13	17.1	308.9	.09
4- 3	3	42	1.4	35.9	7.8	252.3	.18	9.7	318.5	.14
3- 2	2	43	3.1	39.0	18.5	270.8	.17	23.5	342.1	.13

Table 4.--Travel time and velocities for selected flow durations in Tymochtee Creek, Ohio.--Continued.

Reach	Computed dye cloud travel time and velocity											
	40-percent flow duration						30-percent flow duration					
	Leading edge			Peak concentration			Leading edge			Peak concentration		
	In reach (hrs)	Cumulative (hrs)	Velocity (mps)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)	In reach (hrs)	Cumulative (hrs)	Velocity (mps)	In reach (hrs)	Cumulative (hrs)	Velocity (mph)
21-20	7.7	7.7	0.16	9.8	9.8	0.12	4.5	4.5	0.27	5.4	5.4	0.22
20-19	8.7	16.4	.29	10.4	20.2	.24	5.5	10.0	.45	6.6	12.0	.38
19-18	7.7	24.1	.29	10.2	30.4	.22	5.5	15.5	.40	6.9	18.9	.32
18-17	2.8	26.9	.54	3.5	33.9	.43	2.8	18.3	.54	3.4	22.3	.44
17-16	13.5	40.4	.21	16.0	49.9	.18	8.2	26.5	.34	9.7	32.0	.29
16-15	6.0	46.4	.30	7.6	57.5	.24	4.3	30.8	.42	5.4	37.4	.33
15-14	6.5	52.9	.23	8.0	65.5	.19	4.8	35.6	.31	5.9	43.3	.25
14-13	7.8	60.7	.27	9.5	75.0	.22	5.4	41.0	.39	6.8	50.1	.31
13-12	5.2	65.9	.29	6.4	81.4	.23	3.6	44.6	.42	4.3	54.4	.35
12-11	13.6	79.5	.21	15.6	97.0	.19	9.4	54.0	.31	10.7	65.1	.27
11-10	6.8	86.3	.29	8.2	105.2	.24	4.3	58.3	.47	5.3	70.4	.38
10-9	5.7	92.0	.32	7.0	112.2	.26	3.7	62.0	.49	4.6	75.0	.39
9-8	4.1	96.1	.41	5.3	117.5	.32	2.6	64.6	.65	3.2	78.2	.53
8-6	31.2	127.3	.17	40.0	157.5	.14	17.3	81.9	.31	21.4	99.6	.25
6-5	3.8	131.1	.53	4.7	162.2	.43	2.3	84.2	.87	2.8	102.4	.71
5-4	3.8	134.9	.42	4.7	166.9	.34	2.1	86.3	.76	2.6	105.0	.62
4-3	3.4	138.3	.41	4.2	171.1	.33	2.0	88.3	.70	2.4	107.4	.58
3-2	7.5	145.8	.41	9.2	180.3	.34	4.2	92.5	.74	5.0	112.4	.62

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