

Traveltime and Dispersion Data, Including Associated Discharge and Water-Surface Elevation Data, for the Upper Ohio River, Pennsylvania, Ohio, and West Virginia; October through November 1991

U.S. Geological Survey
Open-File Report 97-562

Prepared in cooperation with the
OHIO RIVER VALLEY WATER SANITATION COMMISSION



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By JEFFREY B. WILEY

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Traveltime and Dispersion Data, Including Associated Discharge and Water-Surface Elevation Data, for the Upper Ohio River, Pennsylvania, Ohio, and West Virginia, October through November 1991

By Jeffrey B. Wiley

Abstract

This report presents results of a study by the U.S. Geological Survey, in cooperation with the Ohio River Valley Water Sanitation Commission, to evaluate the traveltimes and dispersion of a dye injection on the upper Ohio River. Traveltimes and dispersion data, including discharge and water-surface elevation data, were collected to quantify the movement of a dye cloud in the mainstem of the upper Ohio River. The upper Ohio River originates at the confluence of the Allegheny and Monongahela Rivers, flows westward to the border of Pennsylvania, Ohio, and West Virginia, and then flows south-westward along the Ohio and West Virginia border. Knowledge of traveltimes and dispersion of a soluble dye can assist river managers in mitigating the effects of an accidental spill. The potential for a spill is present because chemicals and wastes are transported by rail, pipeline, highway and barge on and near the river and tributary streams.

Daily mean discharge at 10 gaging stations and water-surface elevations for all regulated pools were collected from October 20 to November 24, 1991. Ohio River discharges were about 4,000 to 6,000 ft³/s at the Pennsylvania, Ohio, and West Virginia border during the dye study. Water-surface elevations in regulated pools indicated channel storage was fairly constant while the dye cloud was traveling through the pools.

The traveltimes of peak concentration between Dashields Locks-and-Dam and Pike Island Locks-and-Dam is 609 hours. Time of passage of the dye cloud at Dashields Locks-and-Dam and Pike Island Locks-and-Dam is 80 and 129 hours, respectively.

INTRODUCTION

The Ohio River originates at the confluence of the Allegheny and Monongahela Rivers in western Pennsylvania at Pittsburgh, flows westward toward the Pennsylvania boundary with Ohio and West Virginia, and then flows south-westward along the Ohio and West Virginia boundaries (fig. 1).

The upper Ohio River provides water for municipalities and industries, and the river is used for transportation and recreation. Municipal and industrial intakes are scattered within and bordering the study area. The river is used for transporting manufacturing materials and natural resources. Recreational boating and fishing are common along the entire river.

Water quality of the upper Ohio River could be adversely affected by an accidental spill of a hazardous chemical or toxic waste. An accidental spill is possible due to transportation of chemicals and toxic waste by pipeline, rail, highway, and barge on and near the river and tributary streams. Knowledge of the movement of a spill can assist river managers in mitigation of environmental and human effects; water intakes could be closed or additional treatment could be applied, recreational uses of the river could be restricted, and regulation of streamflows could change the characteristics of the spill cloud.

On October 23, 1991, a private engineering firm injected about 240 L (590 lb) of Rhodamine 20-percent dye into the Ohio River at a constant rate of 940 mL/min from 6:00 a.m. to 10:15 a.m. to study the plume of an outfall from a sewage-treatment plant at river mile 3.2. Downstream from the plume study, a resulting dye cloud provided an opportunity to monitor traveltime and dispersion of the mainstem of the upper Ohio River. The U.S. Geological Survey (USGS), in cooperation with the Ohio River Valley Water Sanitation Commission, undertook a data-collection program to quantify the movement of the dye cloud.

Purpose and Scope

This report presents traveltime and dispersion data for the Ohio River from October 25 through November 23, 1991, in the study area from Dashields Locks-and-Dam to Pike Island Locks-and-Dam. Daily mean discharges are presented for 10 USGS streamflow-gaging stations and water-surface elevations are presented for all regulated pools, bordering and within the study area, during October 20 through November 24, 1991.

Description of Study Area

The upstream limit of the study area is Dashields Locks-and-Dam (fig. 1) at river mile (RM) 13.3, 50 ft downstream from the USGS streamflow-gaging station, "03086000—Ohio River at Sewickley, PA," 7.1 mi downstream from Emsworth Locks-and-Dams (RM 6.2), and 13.3 mi downstream from the confluence of the Allegheny and Monongahela Rivers; the drainage area at the upstream limit is about 19,500 mi² (Lescinsky and others, 1993, p. 101; U.S. Army Corps of Engineers, 1993, charts 195-197).

The Ohio River flows westward from Dashields Locks-and-Dam (RM 13.3) through Montgomery Locks-and-Dam (RM 31.7) to the State boundary with Ohio and West Virginia (RM 40.0), and includes the tributaries of Beaver River (RM 25.5), Raccoon Creek (RM 29.6), and Little Beaver Creek (RM 39.5) (U.S. Army Corps of Engineers, 1993, charts 190-195). The drainage area at the State boundary with Ohio and West Virginia is 23,487 mi² (Pennsylvania Department of Environmental Resources, 1989, p. 169). USGS streamflow-gaging stations 03107500—Beaver River

at Beaver Falls, PA; 03108000—Raccoon Creek at Moffatts Mill, PA; and 03109500—Little Beaver Creek near East Liverpool, OH, with drainage areas of 3,106, 178, and 496 mi², respectively, are within the drainage division of the Ohio River between Dashields Locks-and-Dam and the State boundary with Ohio and West Virginia (Lescinsky and others, 1993, p. 110-111, 113; Shindel and others, 1993, p. 48).

The Ohio River flows south from the State boundaries of Pennsylvania, Ohio, and West Virginia (RM 40.0) through New Cumberland Locks-and-Dam (RM 54.4) to Pike Island Locks-and-Dam (RM 84.2), and includes the tributaries of: Yellow Creek (RM 50.4); Cross Creek, WV (RM 71.6); Cross Creek, OH (RM 71.7); Buffalo Creek (RM 74.7); and Short Creek, OH (RM 81.4) (U.S. Army Corps of Engineers, 1993, charts 180-190). USGS streamflow-gaging stations 03110000—Yellow Creek near Hammondsville, OH, and 03111500—Short Creek near Dillonvale, OH, with drainage areas of 147 and 123 mi², respectively, are within the drainage division of the Ohio River between the State boundaries of Pennsylvania, Ohio, and West Virginia and Pike Island Locks-and-Dam (Shindel and others, 1993, p. 49-50).

The downstream limit of the study is Pike Island Locks-and-Dam (RM 84.2), 3.3 mi upstream from the USGS streamflow-gaging station 03111534—Ohio River at Martins Ferry, OH, (RM 87.5, and about 24,700 mi² drainage area), and 42.2 mi upstream from Hannibal Locks-and-Dam (RM 126.4) (U.S. Army Corps of Engineers, 1993, charts 172-180; Ward and others, 1993, p. 130).

Acknowledgments

The author wishes to thank the U.S. Army Corps of Engineers for allowing access to river-structure properties, and providing water-surface elevations at the locks-and-dams. Thanks also to the East Liverpool Water-Treatment Plant for allowing access to properties and to the employees; Glenn Woodward, Mike Masters, Joe Miller, Jim Holmsted, and Dave Illig, for assistance in taking water samples. Mary Ann Silagy and Eric Piniero with Ohio EPA also assisted by providing samples at the East Liverpool Water-Treatment Plant. The author thanks the Allegheny County Sanitary Authority and The Chester Engineers for providing a sample of the dye injected.

Traveltime

Time-concentration curves were developed to identify traveltime and dispersion of the dye at five primary sampling sites where water samples were collected throughout the time of passage of the dye cloud (fig. 2). Traveltime of leading edge, peak concentration, and trailing edge at any primary sampling site can be determined from this graph. Reading from the *x*-axis of figure 2, the leading edge of the dye cloud arrived at Montgomery Locks-and-Dam at 191 hours after injection and at Pike Island Locks-and-Dam at 611 hours after injection (traveltimes of peak concentration and trailing edge can be determined similarly). Traveltime data at the five primary sampling sites shown in figure 2 are summarized in table 2. The

time required for the dye cloud to move through the New Cumberland pool can be determined from table 2 as 327 hours (time since injection of the trailing edge at New Cumberland Locks-and-Dam minus time since injection of the leading edge at Montgomery Locks-and-Dam). Figure 2 or table 2 can be used to determine the traveltime of peak concentration between Dashields Locks-and-Dam and Pike Island Locks-and-Dam as 609 hours (677–68 hours).

The leading edge of the dye cloud at Dashields Locks-and-Dam was not measured because the dye cloud had arrived at this location before field personnel were able to respond. The leading edge was estimated based on the shape of the time-concentration curve as compared with time-concentration curves for other studies.

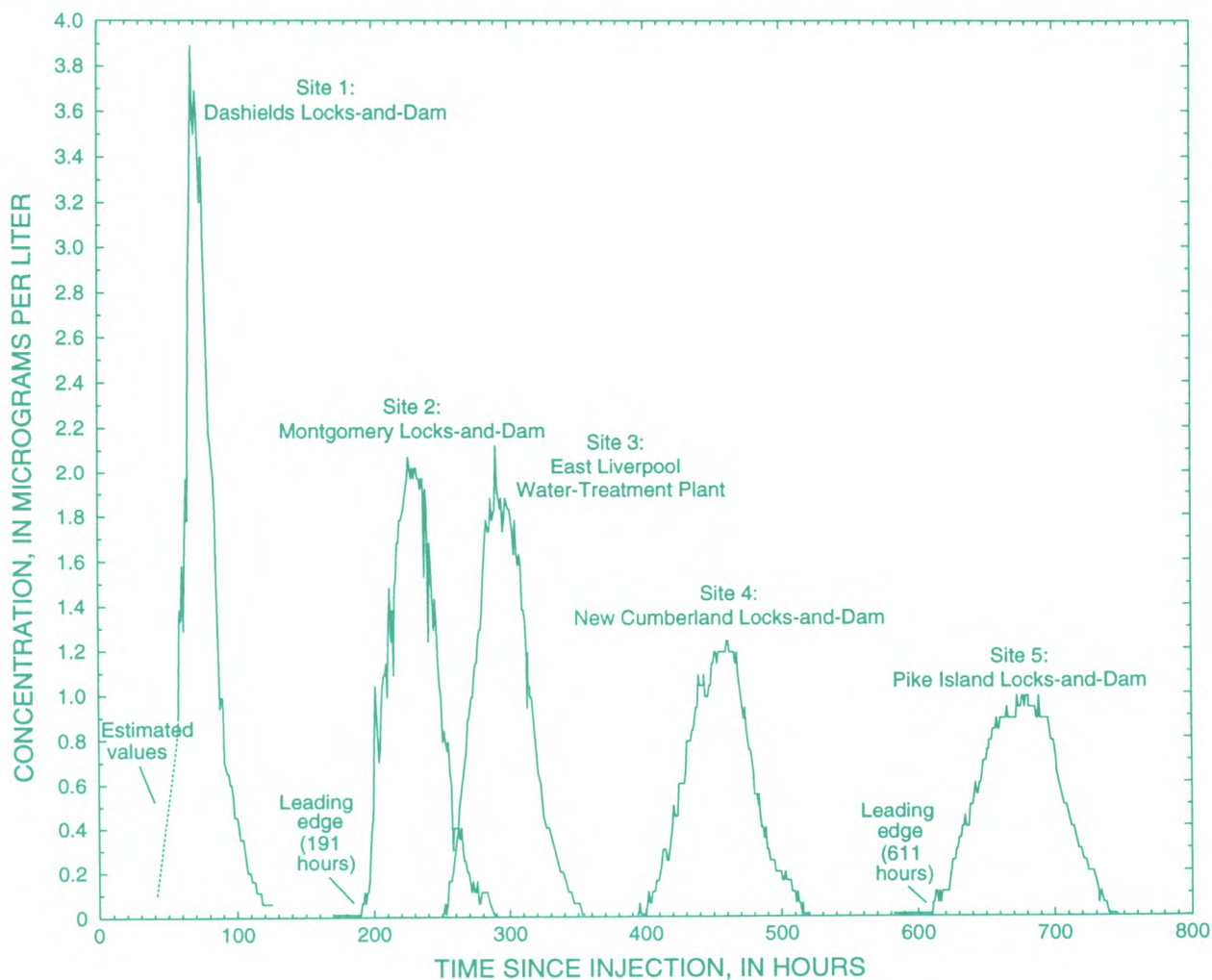


Figure 2. Time-concentration curves at the five primary sampling sites in the upper Ohio River study area.

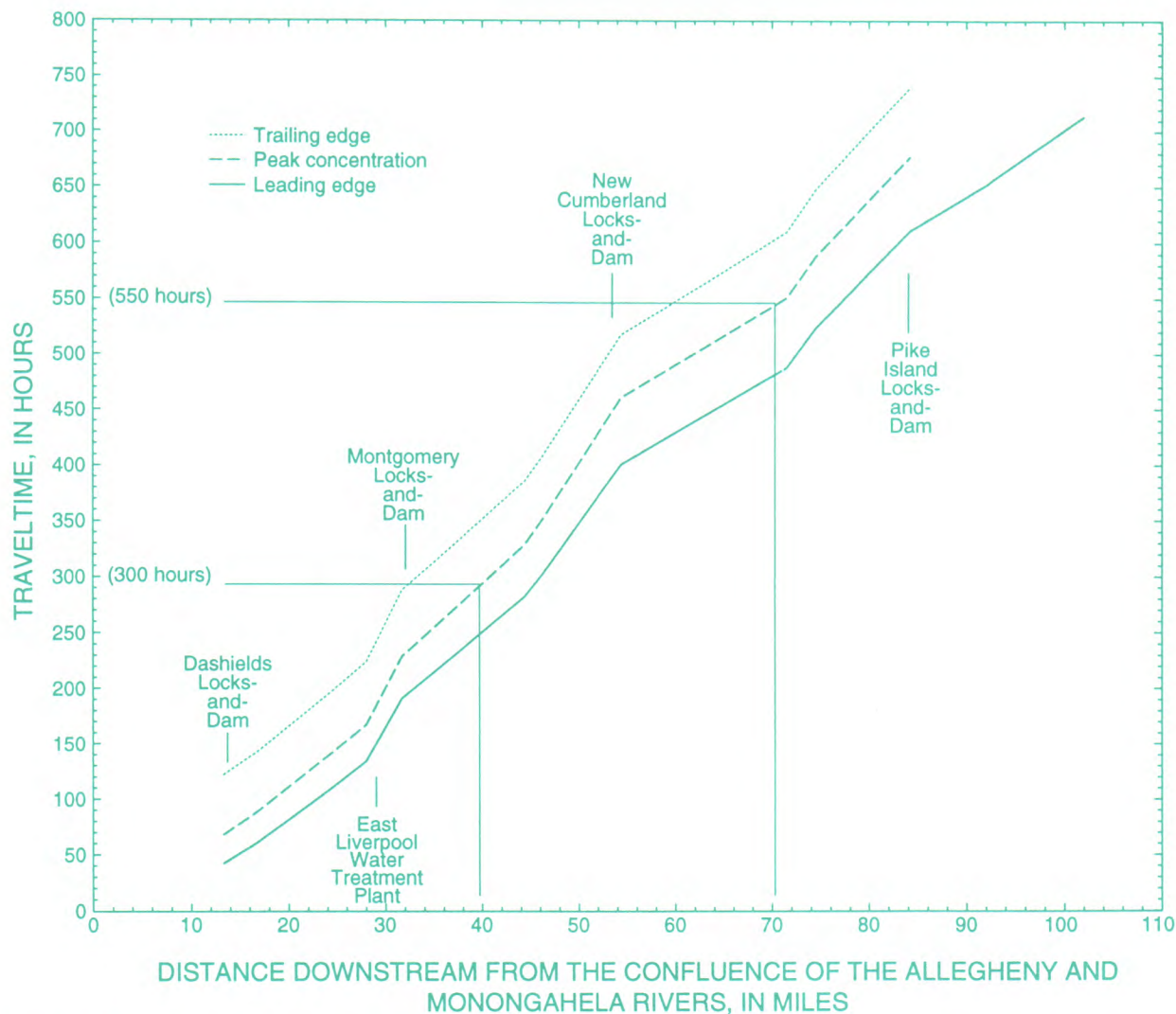


Figure 3. Traveltimes for distances downstream from the confluence of the Allegheny and Monongahela Rivers in the upper Ohio River study area.

concentration to travel from river-mile 40 (300 hours) to river-mile 70 (550 hours) is estimated from figure 3 as 250 hours, (550 – 300 hours), other traveltime data can be determined similarly.

Dispersion

Time-concentration curves (fig. 2) illustrate stream dispersion, the peak concentration decreases as time since injection increases. This is not true when comparing the peak concentration at Montgomery Locks-and-Dam with the peak concentration at the East Liverpool Water-Treatment Plant. Possible explanations for this anomaly include: the peak concentration at Montgomery Locks-and-Dam was not sampled because

the time interval between samples was too large to identify the sharpness of the spike in concentration; or, the sample collected at the East Liverpool Water-Treatment Plant was contaminated in the field or lab.

Time of passage of dye cloud (table 3) indicates dispersion, time of passage increases as time since injection increases. This relation also is illustrated in figure 3 by comparing traveltime estimates between the leading edge and trailing edge (time of passage of dye cloud) at one river-mile location with traveltime estimates at another river-mile location; note, in figure 3, as river mile increases the time of passage of dye cloud increases. Table 3 or figure 3 can be used to determine the time of passage of the dye cloud at Dashields Locks-and-Dam and Pike Island Locks-and-Dam as 80 and 129 hours, respectively.

Discharge

Ohio River discharges were about 4,000 to 6,000 ft³/s at the Pennsylvania, Ohio, and West Virginia border during the dye study as estimated from U.S. Geological Survey streamflow-gaging stations: Ohio River at Sewickley, PA (03086000); Beaver River at Beaver Falls, PA (03107500); and, Raccoon Creek at Moffatts Mill (03108000). Figures 4-6 and table 5

presents daily mean discharges from October 20, 1991, through November 24, 1991, for U.S. Geological Survey streamflow-gaging stations in the study for the stations listed above and: Little Beaver Creek near East Liverpool, OH (03109500); Yellow Creek near Hammondsville, OH (03110000); Short Creek near Dillonvale, OH (03111500); and, Ohio River at Martins Ferry, OH (03111534).

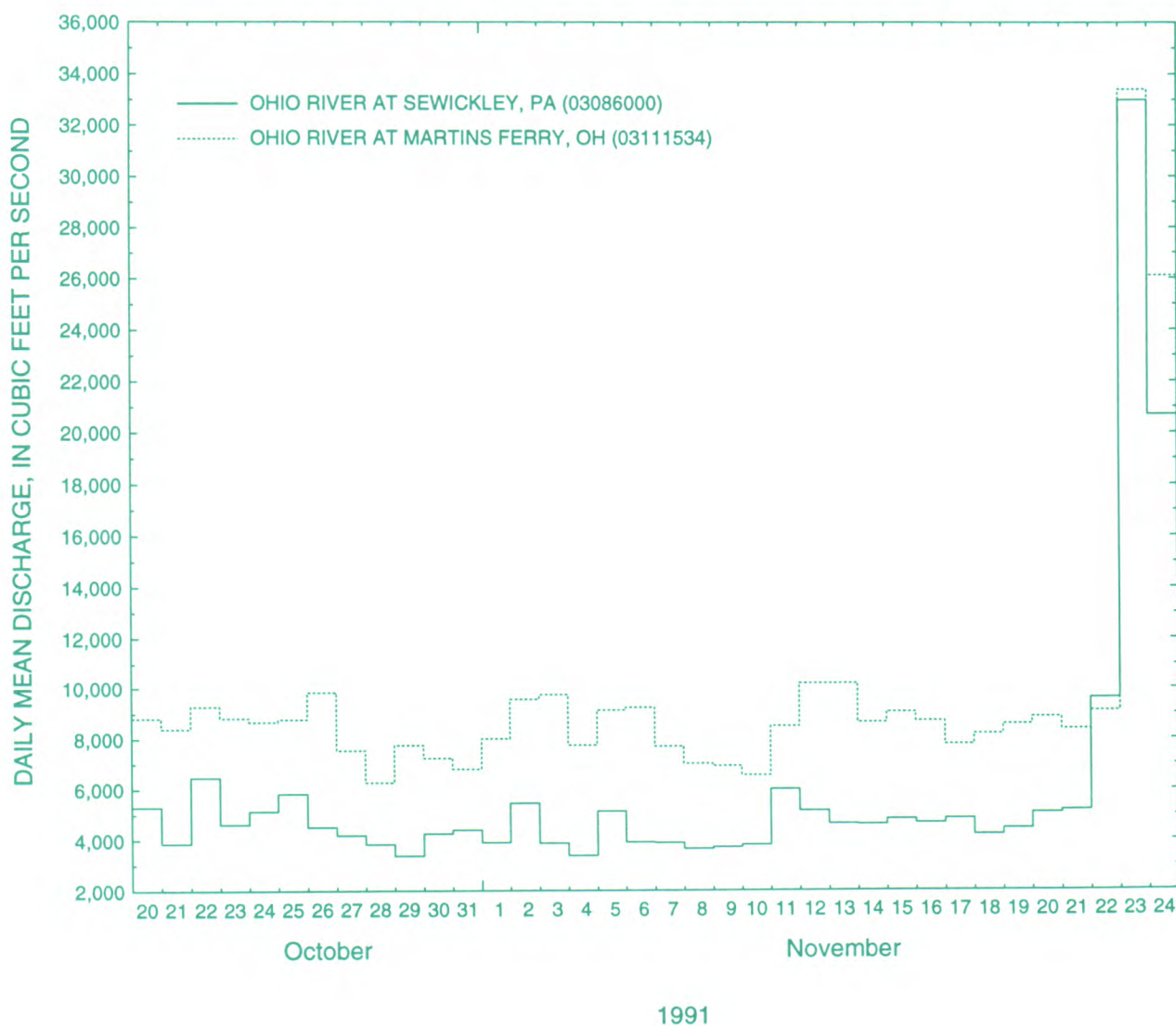


Figure 4. Daily mean discharges from October 20 through November 24 for Ohio River at Sewickley and Ohio River at Martins Ferry in the upper Ohio River study area.

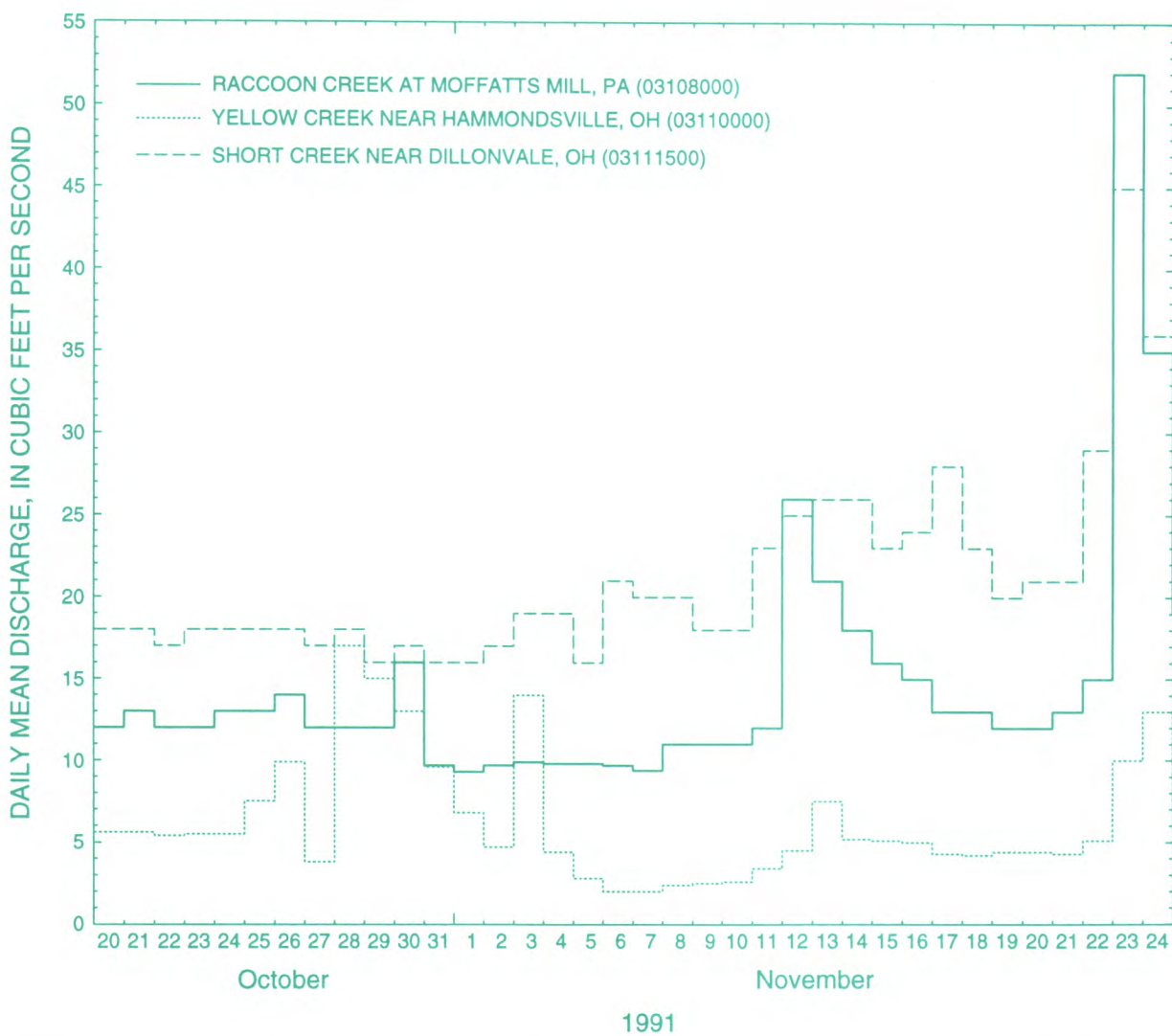


Figure 6. Daily mean discharges from October 20 through November 24 for Raccoon Creek at Moffatts Mill, Yellow Creek near Hammondsville, and Short Creek near Dillonvale in the upper Ohio River study area.

Table 5. Daily mean discharges at the indicated streamflow-gaging stations—*Continued*

Date	Discharge	Date	Discharge	Date	Discharge	Date	Discharge
03111500 Short Creek near Dillonvale, OH²—Continued		03111500 Short Creek near Dillonvale, OH²—Continued		03111534 Ohio River at Martins Ferry, OH³—Continued		03111534 Ohio River at Martins Ferry, OH³—Continued	
11-01-91	16	11-17-91	28	10-26-91	9,840	11-10-91	6,560
11-02-91	17	11-18-91	23	10-27-91	7,550	11-11-91	8,510
11-03-91	19	11-19-91	20	10-28-91	6,270	11-12-91	10,200
11-04-91	19	11-20-91	21	10-29-91	7,760	11-13-91	10,200
11-05-91	16	11-21-91	21	10-30-91	7,240	11-14-91	8,660
11-06-91	21	11-22-91	29	10-31-91	6,810	11-15-91	9,070
11-07-91	20	11-23-91	45	11-01-91	8,010	11-16-91	8,720
11-08-91	20	11-24-91	36	11-02-91	9,560	11-17-91	7,790
11-09-91	18	03111534 Ohio River at Martins Ferry, OH³		11-03-91	9,740	11-18-91	8,210
11-10-91	18	10-20-91	8,810	11-04-91	7,760	11-19-91	8,590
11-11-91	23	10-21-91	8,400	11-05-91	9,140	11-20-91	8,870
11-12-91	25	10-22-91	9,280	11-06-91	9,250	11-21-91	8,400
11-13-91	26	10-23-91	8,830	11-07-91	7,710	11-22-91	9,120
11-14-91	26	10-24-91	8,680	11-08-91	7,020	11-23-91	33,400
11-15-91	23	10-25-91	8,780	11-09-91	6,930	11-24-91	26,100
11-16-91	24						

¹Lescinsky and others, 1993, pp. 101, 110, 113.

²Shindel and others, 1993, pp. 48-50.

³Ward and others, 1993, p. 130.

Water-Surface Elevation

Water-surface elevations at Corp of Engineers Lock-and-Dams from October 20, 1991 through November 24, 1991 indicate channel storage was fairly consistent. Figures 7-11 and table 8 show water-surface elevations at the Dashields, Montgomery, New Cumberland, Pike Island, and Hannibal pools in feet above sea level. The differences between water-surface elevations at the upstream and downstream ends of the pools remained fairly constant while the dye cloud was traveling through the pools.

An increase in channel storage was indicated near the end of the study period. Water-surface elevations increased at the upstream end of the pools relative to those at the downstream end of the pools. Traveltime of the trailing edge of the dye cloud was slightly increased by the increase in channel storage in the Pike Island pool (fig. 10); this occurrence is indicated by the arrival of the trailing edge of the dye cloud at Pike Island Locks-and-Dam after the increase in water-surface elevations downstream of the New Cumberland Locks-and-Dam. Note, this slight increase in traveltime of the trailing edge of the dye cloud probably was less significant than the decrease in traveltime resulting from the increase in stream discharge (fig. 4).

The accuracy of the absolute water-surface elevations is questionable, but the relative difference between elevations used to describe changes in channel storage is accurate. In the New Cumberland pool (fig. 9), the water-surface elevations at the upstream end of the pool (downstream elevations at Montgomery Locks-and-Dam) are less than the water-surface elevations at the downstream end of the pool (upstream elevations at New Cumberland Locks-and-Dam). Water-surface elevations also are less at the upstream end than the downstream end of the Dashields pool (fig. 7). These errors in water-surface elevations probably are due to inaccurate gage readings. Gage readings at the Locks-and-Dams used for this study were those indicated on the "Monthly Gage Report—River Stage and Precipitation Data" logs provided by the U.S. Army Corps of Engineers. The U.S. Geological Survey and the U.S. Army Corps of Engineers have acknowledged possible inaccurate gage readings (James A. Kosky, U.S. Army Corps of Engineers, oral commun., 1996).

Gage datums are presented in figures 7-11 so that possible future revisions can be accounted for by applying a correction for datum differences to the water-surface elevation data presented in table 8.

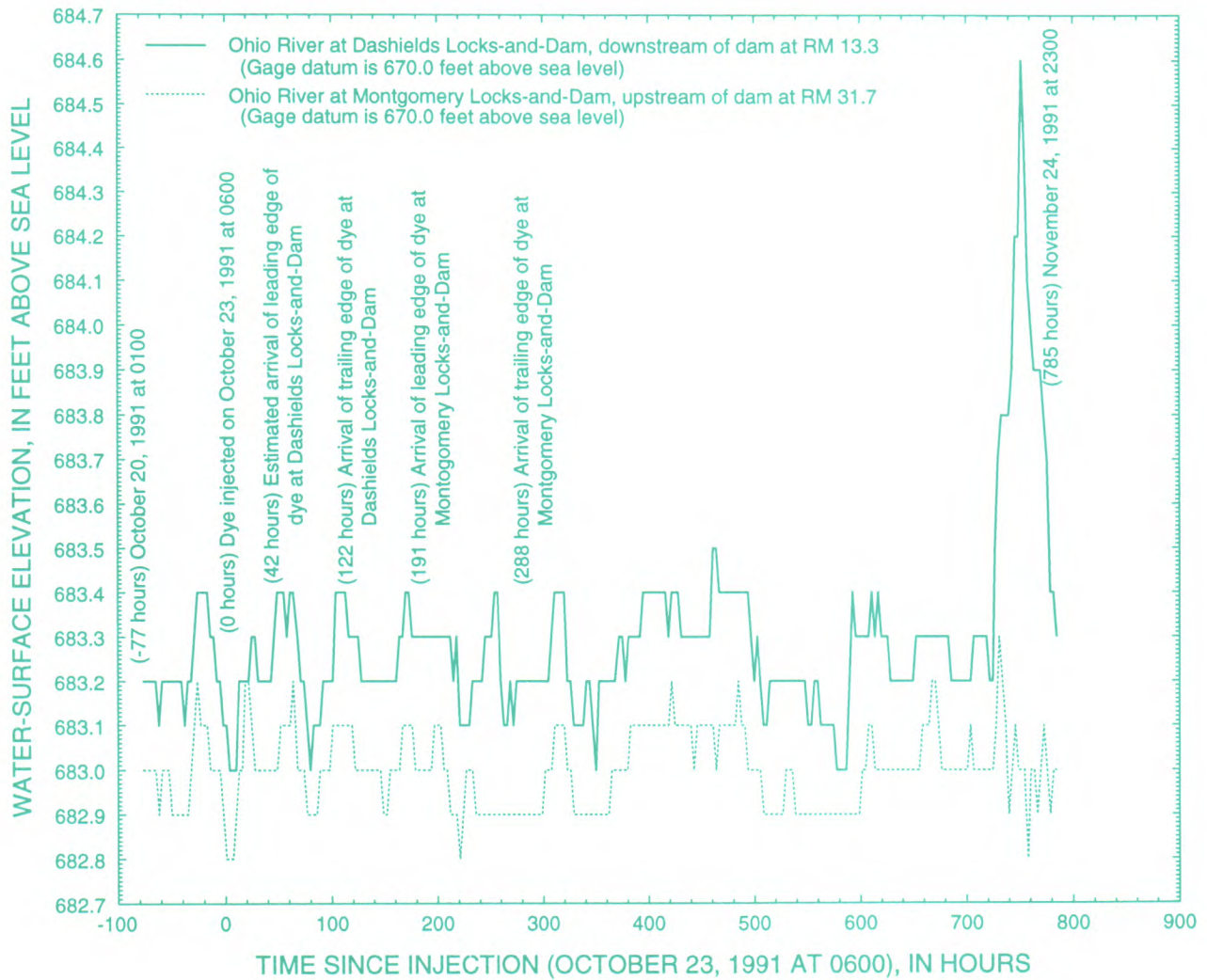


Figure 8. Water-surface elevations from October 20 through November 24 for the Montgomery Locks-and-Dam pool in the upper Ohio River study area.

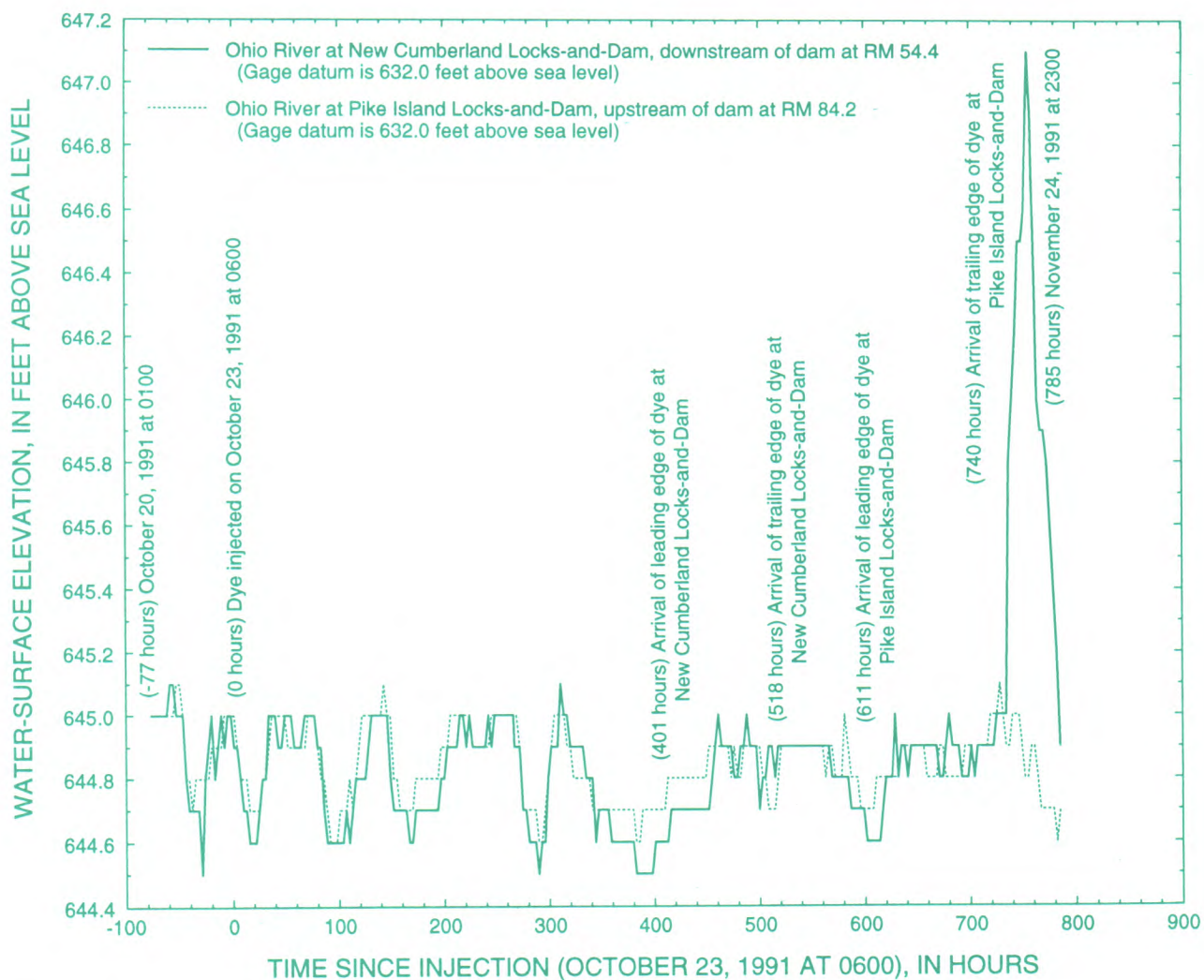


Figure 10. Water-surface elevations from October 20 through November 24 for the Pike Island Locks-and-Dam pool in the upper Ohio River study area.

Table 6. Unit times and concentrations at the five primary sampling sites in the upper Ohio River study area

[Time is Daylight Savings military time. Elapsed time is in percentage of hours since injection. Concentration is in micrograms per liter]

Date	Time	Elapsed time	Concentration	Date	Time	Elapsed time	Concentration
Dashields Locks-and-Dam, River Mile 13.3				Dashields Locks-and-Dam, River Mile 13.3—Continued			
10-25-91	1530	57.50	0.89	11-28-91	0002	114.04	0.11
	1631	58.52	1.38		0105	115.09	.11
	1733	59.55	1.33		0208	116.13	.11
	1834	60.57	1.58		0310	117.17	.11
	1936	61.60	1.29		0413	118.21	.06
	2037	62.62	1.68		0515	119.25	.06
	2139	63.65	1.97		0617	120.29	.06
	2240	64.67	1.78		0720	121.33	.06
	2342	65.70	2.86		0823	122.38	.06
	0043	66.72	3.20		0925	123.42	.06
10-26-91	0145	67.75	3.89		1028	124.46	.06
	0246	68.77	3.59		1130	125.50	.06
	0348	69.80	3.50	Montgomery Locks-and-Dam, River Mile 31.7			
	0449	70.82	3.69	10-30-91	0910	171.17	0.01
	0551	71.85	3.59		0128	187.47	.01
	0652	72.87	3.40	10-31-91	0320	189.33	.01
	0754	73.90	3.20		0416	190.27	.01
	0855	74.92	3.40		0512	191.20	.06
	0915	75.25	3.40		0608	192.13	.06
	1017	76.29	3.05		0704	193.07	.11
	1426	80.44	2.17		0800	194.00	.06
	1529	81.48	2.12		0856	194.93	.11
	1734	83.56	1.97		0952	195.87	.11
	1835	84.59	1.82		1048	196.80	.16
11-27-91	1938	85.63	1.48		1148	197.80	.30
	2152	87.87	.94		1244	198.73	.40
	2255	88.91	.99		1340	199.67	.45
	2357	89.95	.99		1436	200.60	.79
	0059	90.99	.70		1532	201.53	1.04
	0304	93.07	.65		1800	204.00	.70
	0407	94.11	.65		1856	204.93	.75
	0508	95.14	.60		1952	205.87	.94
	0611	96.18	.60		2049	206.82	1.04
	0713	97.22	.55		2145	207.75	1.09
11-27-91	0816	98.26	.45	11-01-91	2241	208.68	1.09
	0918	99.30	.45		2337	209.62	1.14
	1020	100.34	.45		0033	210.55	.99
	1123	101.38	.40		0130	211.50	1.33
	1225	102.42	.35		0226	212.43	1.48
	1230	102.50	.35		0322	213.37	1.24
	1332	103.54	.35		0418	214.30	1.38
	1435	104.58	.35		0514	215.23	1.09
	1537	105.62	.30		0611	216.18	1.48
	1640	106.67	.25		0707	217.12	1.53
11-27-91	1743	107.71	.20		0803	218.05	1.68
	1845	108.75	.20		0859	218.98	1.68
	1947	109.79	.20		0955	219.92	1.78
	2050	110.83	.16		1052	220.87	1.78
	2055	110.92	.16		1244	222.73	1.83
	2158	111.96	.16		1340	223.67	1.88
	2300	113.00	.16				

Table 6. Unit times and concentrations at the five primary sampling sites in the upper Ohio River study area—*Continued*

Date	Time	Elapsed time	Concentration	Date	Time	Elapsed time	Concentration
East Liverpool Water-Treatment Plant, River Mile 40.2—Continued				New Cumberland Locks-and-Dam, River Mile 54.4—Continued			
11-04-91	1500	297.00	1.78	11-09-91	0105	403.08	0.06
	1600	298.00	1.88		0202	404.04	.06
	1800	300.00	1.83		0300	405.00	.11
	1900	301.00	1.83		0455	406.92	.11
	2000	302.00	1.78		0553	407.88	.16
	2100	303.00	1.73		0650	408.83	.16
	2200	304.00	1.63		0747	409.79	.16
	2300	305.00	1.78		0845	410.75	.20
	2400	306.00	1.63		0900	411.00	.20
11-05-91	0100	307.00	1.58	0958	411.97	.25	
	0210	308.17	1.63	1056	412.94	.30	
	0300	309.00	1.58	1155	413.92	.30	
	0400	310.00	1.38	1253	414.89	.30	
	0500	311.00	1.38	1352	415.86	.25	
	0600	312.00	1.33	1450	416.83	.25	
	0700	313.00	1.19	1548	417.80	.30	
	0730	313.50	.94	1647	418.78	.35	
	0800	314.00	1.19	1745	419.75	.40	
	0805	314.08	1.04	1843	420.72	.50	
	0915	315.25	1.04	1850	420.83	.50	
	0930	315.50	0.99	1948	421.80	.45	
	1030	316.50	.99	2145	423.75	.45	
	1500	321.00	.65	2243	424.72	.60	
	1700	323.00	.60	2341	425.69	.60	
	1900	325.00	.45	11-10-91	0040	426.66	.60
	2100	327.00	.40		0138	427.63	.60
	2300	329.00	.40		0236	428.60	.60
11-06-91	0100	331.00	.35		0335	429.58	.65
	0300	333.00	.30		0433	430.55	.79
	0500	335.00	.25		0629	432.49	.79
	0700	337.00	.20		0728	433.46	.79
	0900	339.00	.20		0826	434.44	.84
	1100	341.00	.16		0925	435.41	.84
	1300	343.00	.11		1030	436.50	.89
	1500	345.00	.11		1128	437.47	.94
	1700	347.00	.06		1227	438.45	.94
	1900	349.00	.06		1325	439.42	1.09
2100	351.00	.06	1424		440.40	1.04	
2300	353.00	.01	1522		441.37	1.04	
11-07-91	0100	355.00	.01		1621	442.35	1.04
					1719	443.32	1.04
New Cumberland Locks-and-Dam, River Mile 54.4					1725	443.42	1.09
11-08-91	1530	393.50	0.01	1824	444.40	.99	
	1628	394.46	.01	1922	445.37	.99	
	1725	395.42	.06	2020	446.34	.99	
	1823	396.38	.01	2119	447.32	1.04	
	1920	397.33	.01	2218	448.30	1.04	
	2017	398.29	.01	2316	449.27	1.14	
	2115	399.25	.01	11-11-91	0014	450.24	1.14
	2213	400.21	.01		0113	451.22	1.19
	2310	401.17	.06		0212	452.20	1.19
	11-09-91	0007	402.12		.11	0310	453.17

Table 6. Unit times and concentrations at the five primary sampling sites in the upper Ohio River study area—*Continued*

Date	Time	Elapsed time	Concentration	Date	Time	Elapsed time	Concentration
Pike Island Locks-and-Dam, River Mile 84.2— <i>Continued</i>				Pike Island Locks-and-Dam, River Mile 84.2— <i>Continued</i>			
11-18-91	1923	637.39	0.40	11-20-91	1525	681.42	0.94
	2021	638.35	.50		1622	682.36	.94
	2119	639.31	.50		1718	683.30	.94
	2216	640.27	.50		1814	684.24	.94
	2313	641.22	.55		1911	685.18	.94
11-19-91	0011	642.18	.60		2007	686.12	.94
	0108	643.14	.55		2104	687.07	.89
	0206	644.10	.55		2201	688.01	.89
	0303	645.06	.60		2257	688.95	.99
	0401	646.02	.60		2353	689.89	.89
	0459	646.98	.65	11-21-91	0050	690.83	.89
	0556	647.94	.70		0146	691.77	.89
	0654	648.90	.70		0243	692.71	.89
	0752	649.86	.70		0339	693.65	.89
	0849	650.82	.75		0435	694.59	.89
	0947	651.78	.75		0532	695.53	.89
	1000	652.00	.79		0629	696.48	.84
	1057	652.95	.79		0725	697.42	.79
	1155	653.91	.79		0822	698.36	.79
	1252	654.86	.84		0918	699.30	.79
	1349	655.81	.84		1014	700.24	.75
	1446	656.77	.84		1111	701.18	.70
	1543	657.72	.89		1130	701.50	.65
	1640	658.67	.84		1504	705.07	.55
	1738	659.63	.84		1651	706.85	.50
	1835	660.58	.89		1838	708.64	.50
	1845	660.75	.89		2025	710.42	.45
	1941	661.69	.89		2212	712.20	.40
	2037	662.62	.89		2359	713.99	.40
11-20-91	2134	663.56	.89	11-22-91	0146	715.77	.35
	2230	664.50	.89		0334	717.56	.30
	2326	665.43	.94		0520	719.34	.30
	0022	666.37	.89		0708	721.13	.25
	0118	667.30	.89		0855	722.91	.25
	0214	668.24	.89		1041	724.69	.20
	0311	669.18	.89		1229	726.48	.20
	0407	670.11	.89		1416	728.26	.20
	0503	671.05	.89		1603	730.05	.16
	0559	671.99	.89		1750	731.83	.11
	0655	672.92	.99		1800	732.00	.06
	0752	673.86	.94		1946	733.77	.11
	0848	674.80	.94		2132	735.54	.06
	0944	675.73	.94		2318	737.30	.06
	1040	676.67	.99	11-23-91	0104	739.07	.01
	1136	677.60	.99		0250	740.84	.01
	1232	678.54	.94		0437	742.61	.01
	1329	679.48	.99		0623	744.38	.01
	1425	680.41	.99		0808	746.14	.00
	1521	681.35	.99				

Table 8. Unit water-surface elevations at the indicated locks-and-dams in the upper Ohio River study area

[Time is Eastern Standard military time. Elapsed time is in percentage of hours since injection. Elevation is in feet above sea level]

Date	Time	Elapsed time	Elevation	Date	Time	Elapsed time	Elevation
Ohio River at Emsworth Locks-and-Dams, downstream of dams at RM 6.2				Ohio River at Emsworth Locks-and-Dams, downstream of dams at RM 6.2—Continued			
10-20-91	0100	-77.00	693.5	11-15-91	0200	548.00	693.1
10-21-91	1000	-44.00	693.5	11-19-91	1400	656.00	693.1
	1300	-41.00	693.6		1700	659.00	693.5
	1600	-38.00	693.6		2300	665.00	693.5
	1900	-35.00	693.5	11-20-91	0200	668.00	693.1
10-24-91	0700	25.00	693.5	11-22-91	0800	722.00	693.1
	1000	28.00	693.3		1100	725.00	693.2
10-28-91	1400	128.00	693.3		1400	728.00	693.3
	1700	131.00	693.1		1700	731.00	693.8
	2000	134.00	693.0		2000	734.00	694.2
11-01-91	2300	233.00	693.0		2300	737.00	694.4
11-02-91	0200	236.00	693.1	11-23-91	0200	740.00	695.2
	0500	239.00	693.2		0500	743.00	695.2
	0800	242.00	693.2		0800	746.00	695.4
	1100	245.00	693.4		1100	749.00	695.8
	1400	248.00	693.4		1400	752.00	696.2
	1700	251.00	693.3		1700	755.00	695.9
	2000	254.00	693.2		2000	758.00	695.7
11-03-91	0800	266.00	693.2		2300	761.00	695.4
	1100	269.00	693.0	11-24-91	0200	764.00	695.4
	2300	281.00	693.0		0500	767.00	695.2
11-04-91	0200	284.00	693.1		0800	770.00	695.2
	1400	296.00	693.1		1100	773.00	694.6
	1700	299.00	693.0		1400	776.00	694.7
	2300	305.00	693.0		1700	779.00	694.5
11-05-91	0200	308.00	693.1		2000	782.00	694.4
	0500	311.00	693.3		2300	785.00	694.1
	0800	314.00	693.3	Ohio River at Dashields Locks-and-Dam, upstream of dam at RM 13.3			
	1100	317.00	693.2	10-20-91	0100	-77.00	693.5
	1400	320.00	693.1		0400	-74.00	693.6
11-06-91	0800	338.00	693.1		0700	-71.00	693.6
	1100	341.00	693.0		1000	-68.00	693.5
11-10-91	2000	446.00	693.0		1900	-59.00	693.5
	2300	449.00	693.1		2200	-56.00	693.6
11-11-91	0200	452.00	693.0	10-21-91	0100	-53.00	693.5
	0800	458.00	693.0		0400	-50.00	693.4
	1100	461.00	693.1		1300	-41.00	693.4
11-12-91	0200	476.00	693.1		1600	-38.00	693.3
	0500	479.00	693.0		1900	-35.00	693.3
	0800	482.00	693.0		2200	-32.00	693.4
	1100	484.00	693.1	10-22-91	0100	-29.00	693.4
11-13-91	0800	506.00	693.1		0400	-26.00	693.8
	1100	509.00	693.0		0700	-23.00	693.4
	1400	512.00	693.0		1000	-20.00	693.7
	1700	515.00	693.1		1300	-17.00	693.7
11-14-91	0200	524.00	693.1		2200	-8.00	693.6
	0500	527.00	693.0				
	2300	545.00	693.0				

Table 8. Unit water-surface elevations at the indicated locks-and-dams in the upper Ohio River study area—*Continued*

Date	Time	Elapsed time	Elevation	Date	Time	Elapsed time	Elevation
Ohio River at Dashields Locks-and-Dam, upstream of dam at RM 13.3— <i>Continued</i>				Ohio River at Dashields Locks-and-Dam, downstream of dam at RM 13.3— <i>Continued</i>			
11-21-91	0800	698.00	693.5	10-25-91	0100	43.00	683.2
	1100	701.00	693.6		0400	46.00	683.3
	2000	710.00	693.6		0700	49.00	683.4
	2300	713.00	693.5		1300	55.00	683.4
11-22-91	0800	722.00	693.5	10-26-91	1600	58.00	683.3
	1100	725.00	693.6		1900	61.00	683.4
	1400	727.00	693.8		2200	64.00	683.4
	1700	730.00	694.0		0200	68.00	683.3
11-23-91	2000	733.00	694.2	10-27-91	0500	71.00	683.2
	2300	736.00	694.5		0800	74.00	683.2
	0200	740.00	695.1		1100	77.00	683.1
	0500	743.00	695.3		1400	80.00	683.0
11-24-91	0800	746.00	695.5	10-28-91	1700	83.00	683.1
	1100	749.00	695.5		2300	89.00	683.1
	1400	752.00	695.9	10-29-91	0200	92.00	683.2
	1700	755.00	695.7		1100	101.00	683.2
11-24-91	2000	758.00	695.6		1400	104.00	683.4
	2300	761.00	695.4		2300	113.00	683.4
	0200	764.00	695.3	10-28-91	0200	116.00	683.3
	0500	767.00	695.3		1100	125.00	683.3
11-24-91	0800	770.00	695.2		1400	128.00	683.2
	1100	773.00	695.1		2300	161.00	683.2
	1400	776.00	694.8	10-29-91	0200	164.00	683.3
	1700	779.00	694.7		0500	167.00	683.3
11-24-91	2000	782.00	694.5		0800	170.00	683.4
	2300	785.00	694.2		1100	173.00	683.4
Ohio River at Dashields Locks-and-Dam, downstream of dam at RM 13.3				11-01-91	1400	176.00	683.3
10-20-91	0100	-77.00	683.2		0200	212.00	683.3
	1300	-65.00	683.2		0500	215.00	683.2
	1600	-62.00	683.1		0800	218.00	683.3
10-21-91	1900	-59.00	683.2	11-02-91	1100	221.00	683.1
	1300	-41.00	683.2		2000	230.00	683.1
	1600	-38.00	683.1		2300	233.00	683.2
	1900	-35.00	683.2	11-03-91	0800	242.00	683.2
10-22-91	2200	-32.00	683.2		1100	245.00	683.3
	0100	-29.00	683.3		1700	251.00	683.3
	0400	-26.00	683.4		2000	254.00	683.4
10-23-91	1300	-17.00	683.4		2300	257.00	683.4
	1600	-14.00	683.3	11-04-91	0200	260.00	683.2
	1900	-11.00	683.3		0500	263.00	683.1
	2300	-8.00	683.2		0800	266.00	683.1
10-24-91	0100	-5.00	683.2		1100	269.00	683.2
	0400	-2.00	683.1	11-05-91	1400	272.00	683.1
	0700	1.00	683.1		1700	275.00	683.2
	1000	4.00	683.0		2300	305.00	683.2
10-24-91	1600	10.00	683.0	11-05-91	0200	308.00	683.3
	1900	13.00	683.2		0500	311.00	683.4
	0400	22.00	683.2		1400	320.00	683.4
	0700	25.00	683.3		1700	323.00	683.2
10-24-91	1000	28.00	683.3	11-05-91	2000	326.00	683.2
	1300	31.00	683.2		2300	329.00	683.1

Table 8. Unit water-surface elevations at the indicated locks-and-dams in the upper Ohio River study area—*Continued*

Date	Time	Elapsed time	Elevation	Date	Time	Elapsed time	Elevation
Ohio River at Montgomery Locks-and-Dam, upstream of dam at RM 31.7— <i>Continued</i>				Ohio River at Montgomery Locks-and-Dam, upstream of dam at RM 31.7— <i>Continued</i>			
10-25-91	0700	49.00	683.0	11-11-91	1100	461.00	683.1
	1000	52.00	683.1		1400	464.00	683.0
	1900	61.00	683.1		1700	467.00	683.1
	2300	64.00	683.2	11-12-91	0800	482.00	683.1
10-26-91	0200	68.00	683.0		1100	485.00	683.2
	0800	74.00	683.0		1400	488.00	683.1
	1100	77.00	682.9		1700	491.00	683.1
10-27-91	2000	86.00	682.9		2000	494.00	683.0
	2300	89.00	683.0	11-13-91	0800	506.00	683.0
	0800	98.00	683.0		1100	509.00	682.9
	1100	101.00	683.1	11-14-91	0500	527.00	682.9
10-28-91	0500	119.00	683.1		0800	530.00	683.0
	0800	122.00	683.0		1400	536.00	683.0
10-29-91	0800	146.00	683.0		1700	539.00	682.9
	1100	149.00	682.9	11-17-91	0500	599.00	682.9
	1400	152.00	682.9		0800	602.00	683.0
	1700	155.00	683.0		1100	605.00	683.0
10-30-91	0200	164.00	683.0		1400	608.00	683.1
	0500	167.00	683.1	11-19-91	1700	611.00	683.1
	1400	176.00	683.1		2000	614.00	683.0
	1700	179.00	683.0		1400	656.00	683.0
10-31-91	0800	194.00	683.0		1700	659.00	683.1
	1100	197.00	683.1		2300	665.00	683.1
	1700	203.00	683.1	11-20-91	0200	668.00	683.2
	2000	206.00	683.0		0500	671.00	683.2
	2300	209.00	683.0		0800	674.00	683.1
11-01-91	0200	212.00	682.9		1100	677.00	683.0
	0800	218.00	682.9	11-21-91	1100	701.00	683.0
	1100	221.00	682.8		1400	704.00	683.1
	1400	224.00	682.9		1700	707.00	683.0
	1700	227.00	683.0	11-22-91	1100	725.00	683.0
11-02-91	2300	233.00	683.0		1400	728.00	683.1
	0200	236.00	682.9		1700	731.00	683.3
11-04-91	1700	299.00	682.9	11-23-91	2000	734.00	683.2
	2000	302.00	683.0		2300	737.00	683.1
11-05-91	0200	308.00	683.0		0200	740.00	682.9
	0500	311.00	683.1		0500	743.00	683.0
	1400	320.00	683.1		0800	746.00	683.1
	1700	323.00	683.0		1100	749.00	683.0
	2000	326.00	683.0	11-24-91	1700	755.00	683.0
11-07-91	2300	329.00	682.9		2000	758.00	682.8
	0800	362.00	682.9		2300	761.00	683.0
	1100	365.00	683.0		0200	764.00	683.0
11-08-91	0200	380.00	683.0		0500	767.00	682.9
	0500	383.00	683.1		0800	770.00	683.0
11-09-91	1700	419.00	683.1		1100	773.00	683.1
	2000	422.00	683.2		1400	776.00	683.0
	2300	425.00	683.1		1700	779.00	682.9
11-10-91	1400	440.00	683.1		2000	782.00	683.0
	1700	443.00	683.0		2300	785.00	683.0
	2000	446.00	683.1				

Table 8. Unit water-surface elevations at the indicated locks-and-dams in the upper Ohio River study area—*Continued*

Date	Time	Elapsed time	Elevation	Date	Time	Elapsed time	Elevation
Ohio River at Montgomery Locks-and-Dam, downstream of dam at RM 31.7— <i>Continued</i>				Ohio River at Montgomery Locks-and-Dam, downstream of dam at RM 31.7— <i>Continued</i>			
11-09-91	0200	404.00	665.3	11-21-91	0800	698.00	665.7
	0500	407.00	665.4		1100	701.00	665.6
	1700	419.00	665.4		1400	704.00	665.7
	2000	422.00	665.5	11-22-91	0500	719.00	665.7
	2300	425.00	665.5		0800	722.00	665.6
11-10-91	0200	428.00	665.6		1400	728.00	665.6
	1700	443.00	665.6		1700	731.00	665.7
	2000	446.00	665.5		2000	734.00	666.0
	2300	449.00	665.5		2300	737.00	666.3
11-11-91	0200	452.00	665.7	11-23-91	0200	740.00	666.2
	2000	470.00	665.7		0500	743.00	666.0
	2300	473.00	665.8		0800	746.00	666.0
11-12-91	0500	479.00	665.8		1100	749.00	666.1
	0800	482.00	665.7		1400	752.00	666.6
	1100	485.00	665.6		1700	755.00	666.8
	1400	488.00	665.5		2000	758.00	666.4
11-13-91	1100	509.00	665.5		2300	761.00	666.0
	1400	512.00	665.3	11-24-91	0200	764.00	666.0
11-14-91	0500	527.00	665.3		0500	767.00	666.1
	0800	530.00	665.4		0800	770.00	666.1
	1700	539.00	665.4		1100	773.00	666.0
	2000	540.00	665.5		1400	776.00	665.8
11-15-91	1700	563.00	665.5		1700	779.00	665.7
	2000	566.00	665.6		2000	782.00	665.5
11-16-91	0200	572.00	665.6		2300	785.00	665.3
	0500	575.00	665.7	Ohio River at New Cumberland Locks-and-Dam, upstream of dam at RM 54.4			
	0800	578.00	665.8	10-20-91	0100	-77.00	665.7
	1100	581.00	665.6		1900	-59.00	665.7
	1400	584.00	665.6		2200	-56.00	665.6
11-17-91	1700	587.00	665.5	10-21-91	0700	-47.00	665.6
	2000	590.00	665.6		1000	-44.00	665.5
	0200	596.00	665.6		1300	-41.00	665.5
	0500	599.00	665.5		1600	-38.00	665.4
	1700	611.00	665.5		2200	-32.00	665.4
11-18-91	2000	614.00	665.4	10-22-91	0100	-29.00	665.5
	2300	617.00	665.4		0400	-26.00	665.7
	0200	620.00	665.3		0700	-23.00	665.8
	0800	626.00	665.3		1900	-11.00	665.8
	1100	629.00	665.4		2200	-8.00	665.7
11-19-91	1700	635.00	665.4	10-23-91	0100	-5.00	665.8
	2000	638.00	665.3		0400	-2.00	665.7
	1100	653.00	665.3		0700	1.00	665.6
	1400	656.00	665.2		1000	4.00	665.5
	1700	659.00	665.2		1300	7.00	665.4
11-20-91	2000	662.00	665.3		2200	16.00	665.4
	0200	668.00	665.3	10-24-91	0100	19.00	665.6
	0500	671.00	665.2		0400	22.00	665.8
	0800	674.00	665.3		0700	25.00	665.9
	1400	680.00	665.3		1300	31.00	665.9
	1700	683.00	665.5		1600	34.00	665.8
	2000	686.00	665.7		1900	37.00	665.8

Table 8. Unit water-surface elevations at the indicated locks-and-dams in the upper Ohio River study area—*Continued*

Date	Time	Elapsed time	Elevation	Date	Time	Elapsed time	Elevation
Ohio River at Pike Island Locks-and-Dam, upstream of dam at RM 84.2— <i>Continued</i>				Ohio River at Pike Island Locks-and-Dam, upstream of dam at RM 84.2— <i>Continued</i>			
10-23-91	0700	1.00	645.0	11-04-91	1700	299.00	644.8
	1000	4.00	644.9		2000	302.00	644.9
	1300	7.00	644.8		2300	305.00	645.0
	1900	13.00	644.8	11-05-91	0800	314.00	645.0
	2200	16.00	644.7		1100	317.00	644.9
10-24-91	0700	25.00	644.7		1400	320.00	644.9
	1000	28.00	644.8	11-06-91	1700	323.00	644.8
	1300	31.00	644.8		0800	338.00	644.8
	1600	34.00	644.9		1100	341.00	644.7
	1900	37.00	645.0		0200	380.00	644.7
10-25-91	0700	49.00	645.0		0500	383.00	644.6
	1000	52.00	644.9	11-09-91	0800	386.00	644.6
10-26-91	0200	68.00	644.9		1100	389.00	644.7
	0500	71.00	645.0		1100	389.00	644.7
	1100	77.00	645.0	11-10-91	0800	410.00	644.7
	1400	80.00	644.9		1100	413.00	644.8
	1700	83.00	644.8	11-11-91	2300	449.00	644.8
10-27-91	2000	86.00	644.8		0200	452.00	644.9
	2300	89.00	644.7		2000	470.00	644.9
	0200	92.00	644.6	11-12-91	2300	473.00	644.8
	0800	98.00	644.6		0200	476.00	644.9
	1100	101.00	644.7		0500	479.00	644.8
	1700	107.00	644.7		0800	482.00	644.8
	2000	110.00	644.8		1100	485.00	644.9
10-28-91	2300	113.00	644.7	11-13-91	0200	500.00	644.9
	0200	116.00	644.8		0500	503.00	644.8
	0500	119.00	644.9		0800	506.00	644.8
	0800	122.00	645.0		1100	509.00	644.7
10-29-91	0200	140.00	645.0		1700	515.00	644.7
	0500	143.00	645.1	11-15-91	2000	518.00	644.8
	0800	146.00	645.0		2300	521.00	644.9
	1100	149.00	645.0		1400	560.00	644.9
	1400	152.00	644.8		1700	563.00	644.8
10-30-91	1700	155.00	644.8		2000	566.00	644.9
	2000	158.00	644.7	11-16-91	2300	569.00	644.9
	0800	170.00	644.7		0200	572.00	644.8
	1100	173.00	644.8		0800	578.00	644.8
	10-31-91	0800	194.00		1100	581.00	645.0
11-01-91	1100	197.00	644.9		1400	584.00	644.9
	1700	203.00	644.9	11-17-91	1700	587.00	644.8
	2000	206.00	645.0		2300	593.00	644.8
	1400	224.00	645.0		0200	596.00	644.7
11-02-91	1700	227.00	644.9		1400	608.00	644.7
	0800	242.00	644.9	11-18-91	1700	611.00	644.8
11-03-91	1100	245.00	645.0		1400	632.00	644.8
	1400	272.00	644.9		1700	635.00	644.9
	1700	275.00	644.7	11-19-91	1400	656.00	644.9
11-04-91	0500	287.00	644.7		1700	659.00	644.8
	0800	290.00	644.6	11-20-91	0200	668.00	644.8
	1100	293.00	644.6		0500	671.00	644.9
	1400	296.00	644.7		0800	674.00	644.9

Table 8. Unit water-surface elevations at the indicated locks-and-dams in the upper Ohio River study area—*Continued*

Date	Time	Elapsed time	Elevation	Date	Time	Elapsed time	Elevation
Ohio River at Pike Island Locks-and-Dam, downstream of dam at RM 84.2— <i>Continued</i>				Ohio River at Pike Island Locks-and-Dam, downstream of dam at RM 84.2— <i>Continued</i>			
11-05-91	1100	317.00	624.1	11-23-91	0200	740.00	625.0
11-06-91	0200	332.00	624.1		0500	743.00	625.4
	0500	335.00	624.0		0800	746.00	625.6
	0800	338.00	624.0		1100	749.00	625.9
	1100	341.00	624.1		1400	752.00	626.0
	1700	347.00	624.1		1700	755.00	626.2
11-05-91	2000	350.00	624.0		2000	758.00	626.4
11-08-91	0200	380.00	624.0		2300	761.00	626.0
	0500	383.00	623.9	11-24-91	0200	764.00	625.4
	0800	386.00	624.0		0500	767.00	625.1
	1100	389.00	624.0		0800	770.00	625.0
	1400	392.00	623.9		1100	773.00	625.1
11-09-91	1100	413.00	623.9		1400	776.00	625.0
	1400	416.00	623.8		1700	779.00	624.9
11-10-91	0200	428.00	623.8		2000	782.00	624.8
	0500	431.00	623.7		2300	785.00	624.2
	0800	434.00	623.8	Ohio River at Hannibal Locks-and-Dam, upstream of dam at RM 126.4			
11-11-91	0200	452.00	623.8	10-20-91	0100	-77.00	624.1
	0500	455.00	623.9		1300	-65.00	624.1
11-13-91	0800	506.00	623.9		1600	-62.00	624.0
	1100	509.00	624.0	10-21-91	1300	-41.00	624.0
	2000	518.00	624.0		1600	-38.00	623.9
	2300	521.00	623.9		1900	-35.00	623.8
11-14-91	1400	536.00	623.9	10-22-91	0700	-23.00	623.8
	1700	539.00	623.8		1000	-20.00	623.9
11-15-91	1100	557.00	623.8		1300	-17.00	624.0
	1400	560.00	623.9		1600	-14.00	623.9
	2000	566.00	623.9		1900	-11.00	623.9
	2300	569.00	623.8		2200	-8.00	623.8
11-16-91	0200	572.00	623.9	10-23-91	0100	-5.00	623.9
	0500	575.00	623.8		0700	1.00	623.9
	1100	581.00	623.8		1000	4.00	623.8
	1400	584.00	623.7	10-24-91	0700	25.00	623.8
	1700	587.00	623.9		1000	28.00	623.9
11-18-91	1400	632.00	623.9		1900	37.00	623.9
	1700	635.00	623.8		2200	40.00	623.8
11-19-91	0500	647.00	623.8	10-25-91	0700	49.00	623.8
	0800	650.00	623.9		1000	52.00	623.7
	1100	653.00	623.8		1300	55.00	623.7
	1400	656.00	623.9		1600	58.00	623.8
	1700	659.00	623.8		1900	61.00	623.8
11-20-91	0800	674.00	623.8		2200	64.00	624.0
	1100	677.00	623.9	10-26-91	0200	68.00	624.0
	2000	686.00	623.9		0500	71.00	624.1
	2300	689.00	623.7		0800	74.00	624.2
11-21-91	0800	698.00	623.7		1100	77.00	624.3
	1100	701.00	623.8		2000	86.00	624.3
11-22-91	0800	722.00	623.8		2300	89.00	624.0
	1100	725.00	623.9	10-27-91	0200	92.00	624.0
	1400	728.00	624.0		0500	95.00	623.9
	1700	731.00	624.1		1700	107.00	623.9
	2000	734.00	624.1		2000	110.00	624.0
	2300	737.00	624.4				

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