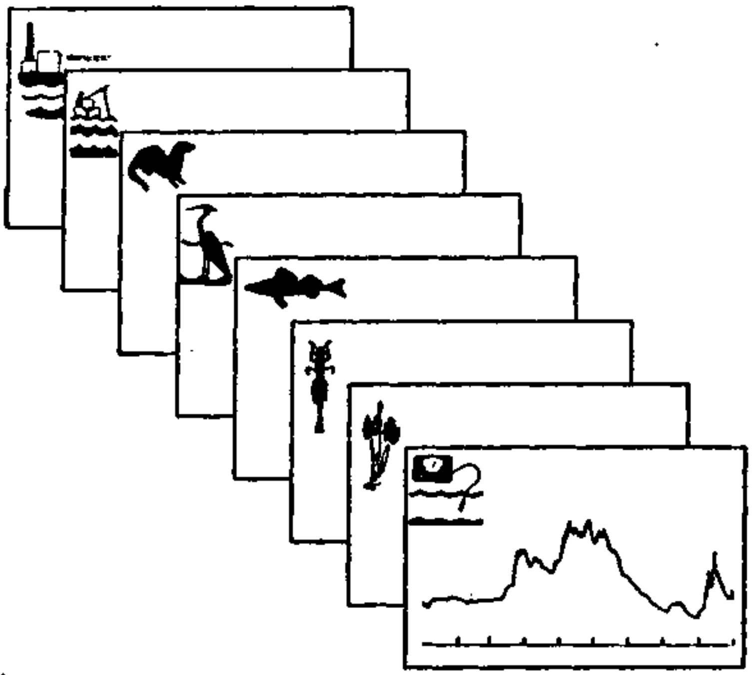
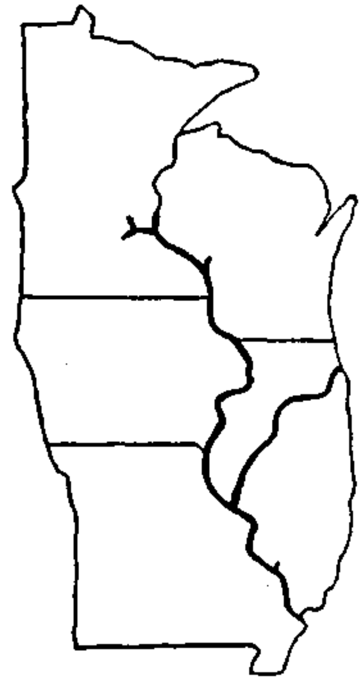
ENVIRONMENTAL MANAGEMENT PROGRAM

LONG TERM RESOURCE MONITORING PROGRAM

UPPER MISSISSIPPI RIVER SYSTEM





IMPACTS OF BARGE TRAFFIC
ON
WAVES AND SUSPENDED SEDIMENTS
OHIO RIVER AT RIVER MILE 581

OCTOBER 1989

U. S. RSH AND WILLDFE SERVICE
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675 LESTER DRIVE
ONALAKSKA, WISCONSIN 54650

LLINOIS STATE WATER SURVEY
2204 GRIFFITH DRIVE
CHAMPAIGN, ILLINOIS 61820

REPORT DOCUMENTATION PAGE	REPORT NUMBER EMTC/8905	RECIPIENT'S NUMBER
TITLE AND SUBTITLE Impacts of Barge Traffic on Waves and Suspended Sediments: Ohio River at River Mile 581		DATE October 1989
AUTHOR(S) Nani G. Bhowmik, Ta Wei Soong and William C. Bogner		
PERFORMING ORGANIZATION NAME AND ADDRESS Illinois State Water Survey 2204 Griffith Drive Champaign, Illinois 61820		
SPONSORING ORGANIZATION U. S. Fish and Wildlife Service, Environmental Management Technical Center 575 Lester Drive Onalaska, Wisconsin 54650		

Abstract This report summarizes the data collected during a field trip made in July-August 1987 to the Ohio River near RM 581. During this time, the Louisville District of the U.S. Army Corps of Engineers conducted extensive field experiments with rented barges and towboats to determine the physical impacts of barge traffic on the Ohio River. The data collected by the Illinois State Water Survey consist of suspended sediments at a single station, waves and drawdown at two stations, and some water quality data. Water quality data for pH, temperature, conductivity, and dissolved oxygen (DO) did not show significant variations except that DO was observed to have been reduced slightly over several individual events. Suspended sediment data indicated a clear increase in suspended sediment concentrations with the 5600 HP towboat running at low RPMs. The durations of these increases ranged from 25 to 30 minutes. Wave and drawdown data were collected from two sampling verticals. Most of the waves were of small amplitudes, with a few fairly high-amplitude waves. Maximum measured drawdown was 0.55 feet and the maximum wave height was 1.6 feet; however, measured average maximum wave height was 0.45 feet at wave gage no. 1 (outer) and 0.42 feet at wave gage no. 2 (inner). Average drawdown was 0.14 feet for wave gage no. 1 (outer) and 0.10 feet for wave gage no. 2 (inner).

Hydraulic and geomorphic parameters for selected pools along the Illinois and Mississippi Rivers, when compared with similar parameters from the Ohio River at the test site, indicated that on a relative scale and also for similar watershed areas, the Ohio River conveys much higher discharges than the UMRS. Lower reaches of the UMRS also flow on a bed of sand, silt, and clay extending from the main channel to channel border areas and side channels, compared to the coarse-grained particles that were observed to exist on the Ohio River. These natural differences in the general character of the Ohio River and UMRS make it difficult to generalize sediment resuspension impact information from one river to another. However, data collected on waves and drawdown from one river basin may be useful for another similar river basin.

DOCUMENT ANALYSIS

a) DESCRIPTORS

Environmental Data Analyses

b) IDENTIFIERS/OPEN ENDED TERMS

Navigation, Physical Impacts, Waves, Drawdown, Suspended Sediment, Ohio River and Barge-Tow

RELEASE UNLIMITED: NTIS 5285 PORT ROYAL ROAD SPRINGFIELD, VA 22161	UNCLASSIFIED	
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Illinois State Water Survey Division
SURFACE WATER SECTION

SWS Contract Report 470

IMPACTS OF BARGE TRAFFIC ON WAVES AND SUSPENDED SEDIMENTS: OHIO RIVER AT RIVER MILE 581

Completion Report Submitted to the
U.S. Fish and Wildlife Service
through the Illinois Department of Conservation

by

Nani G. Bhowmik, Ta Wei Soong, and
William C. Bogner

Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820

Funding for this work was partially provided
by the U.S. Fish and Wildlife Service through
the Illinois Department of Conservation.

Project Number FWS14-16-0003-88-973

Champaign, Illinois
March 1989

Illinois Department of Energy and Natural Resources

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IMPACTS OF BARGE TRAFFIC ON WAVES AND SUSPENDED SEDIMENTS: OHIO RIVER AT RIVER MILE 581

by

Nani G. Bhowmik, Ta Wei Soong, and
William C. Bogner

INTRODUCTION

The Illinois State Water Survey (ISWS) participated with the Louisville District of the U.S. Army Corps of Engineers in field experiments for the collection of data on waves and sediment resuspension due to navigation traffic in the Ohio River from July 28 through August 5, 1987. The project was funded by the U.S. Fish and Wildlife Service (USFWS) in connection with the Environmental Management Plan (EMP) of the Upper Mississippi River System (UMRS) under the Long Term Resource Monitoring Program (LTRMP), to determine the physical impacts of navigation on the Ohio River at the test site. The field experiments were conducted by the Louisville District of the U.S. Army Corps of Engineers with three rented commercial towboats that navigated a prescribed course through the experimental site at various speeds, propeller speeds, and spacings from the instruments. The ISWS researchers concentrated their efforts on only two areas: waves and suspended sediment variations. Significant data on velocity changes were collected by the Corps of Engineers (Maynord, 1988). Techniques for the collection of field data have been incorporated in a report prepared by Bogner et al. (1988) and published by the U.S. Fish and Wildlife Service. This report presents the analyses of the field data that were collected during July and August 1987.

BACKGROUND

Research conducted by Bhowmik et al. (1981a, b, c), Johnson (1976), ESE (1981), Simons et al. (1981, 1987), Schijf and Jansen (1953), Kaa (1978), and Bouwmeester et al. (1977) indicates that navigation traffic can resuspend sediment, increase turbidity, and generate waves and drawdown. These studies indicate that the magnitudes of these factors depend on various hydraulic, geomorphic, and traffic-related characteristics. Theoretical, semi-empirical, and empirical relationships are available to estimate some of these traffic-induced disturbances within a riverine environment. A detailed review of the literature and theory of navigation impacts on a river system was beyond the scope of this brief project. Therefore this report essentially covers two areas of navigation-induced impacts:

• Resuspension of sediments
• Waves and drawdown

This data analysis directly relates to many of the areas included under Major Work Tasks PA(NE)1, PA(NE)4, and PA(NE)7 of the *Operating Plan of the Long Term Resource Monitoring Program for the Upper Mississippi River System* by Rasmussen and Wlosinski (1988). This report also briefly summarizes the hydraulic and physical characteristics of the Ohio River at the test site and the applicability of this project to the UMRS.

OBJECTIVES

This project was designed to collect and analyze a set of data on waves, drawdown, suspended sediment, and some water quality parameters from the Ohio River at a site selected by the U.S. Army Corps of Engineers. Data collection was conducted in conjunction with the field experiments on the physical impacts of navigation conducted by the Louisville District of the U.S. Army Corps of Engineers.

All aspects of the experiment dealing with site selection, basic setup, and operational coordination were dictated by the overall data collection program designed by the Louisville District. The main emphasis of the Water Survey's data collection program was to compare some of the physical impacts of navigation (drawdown, waves, and sediment resuspension) on the Ohio River with similar types of impacts on the UMRS.

FIELD DATA COLLECTION

General Setup

The field data were collected from the Ohio River at River Mile (RM) 581 (below Pittsburgh). Figure 1 shows the study site, with the project area identified. This site is just above Eighteen Mile Island and 25 miles above the McAlpine Lock and Dam at Louisville. A typical cross section at the test site is shown in figure 2. The cross-sectional data were collected on April 13, 1988, when the stage on the Ohio River was about 4 feet above the stage from July 28 through August 5, 1987.

The general layout of the project area is shown in figure 3. Five guide buoys were placed to indicate the planned barge track. For all passages, the barge navigated on the east side of the buoy line. Two additional buoys were installed perpendicular to, and to the east of, the five guide buoys to locate the equipment to be set by divers. The barges ran between these two buoys, and the Corps' main data collection effort was located along this line.

The ISWS shore station was located on the left descending bank immediately downstream of the Corps' monitored cross section on this test reach (figure 3). Figure 4

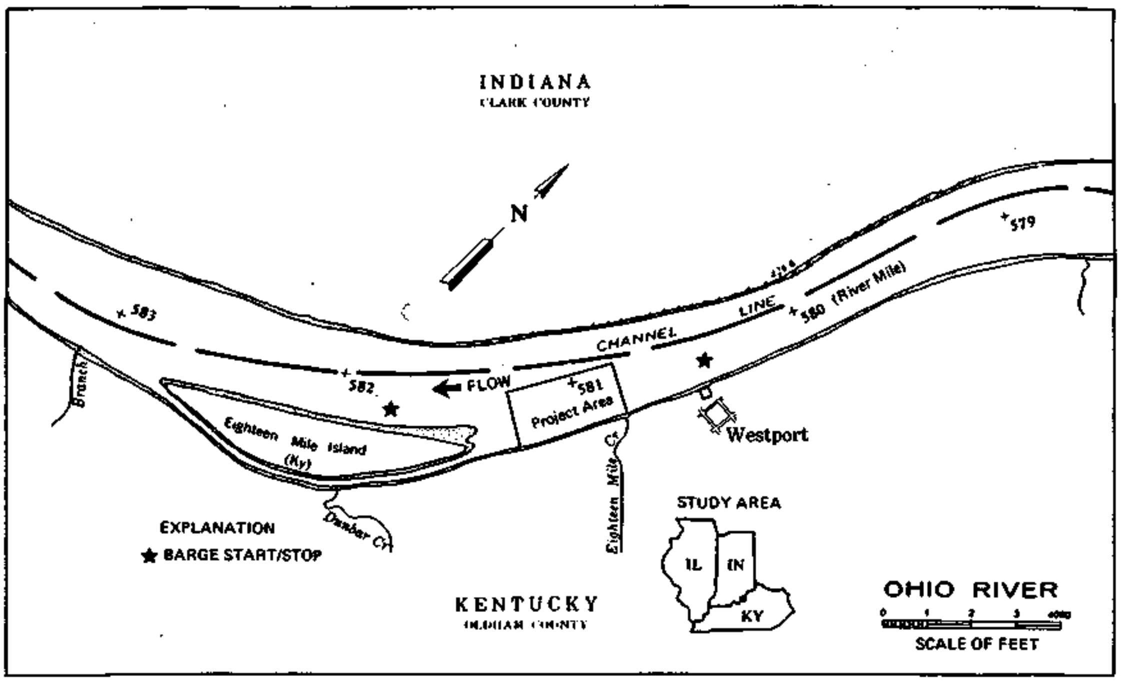


Figure 1. Location of the study area

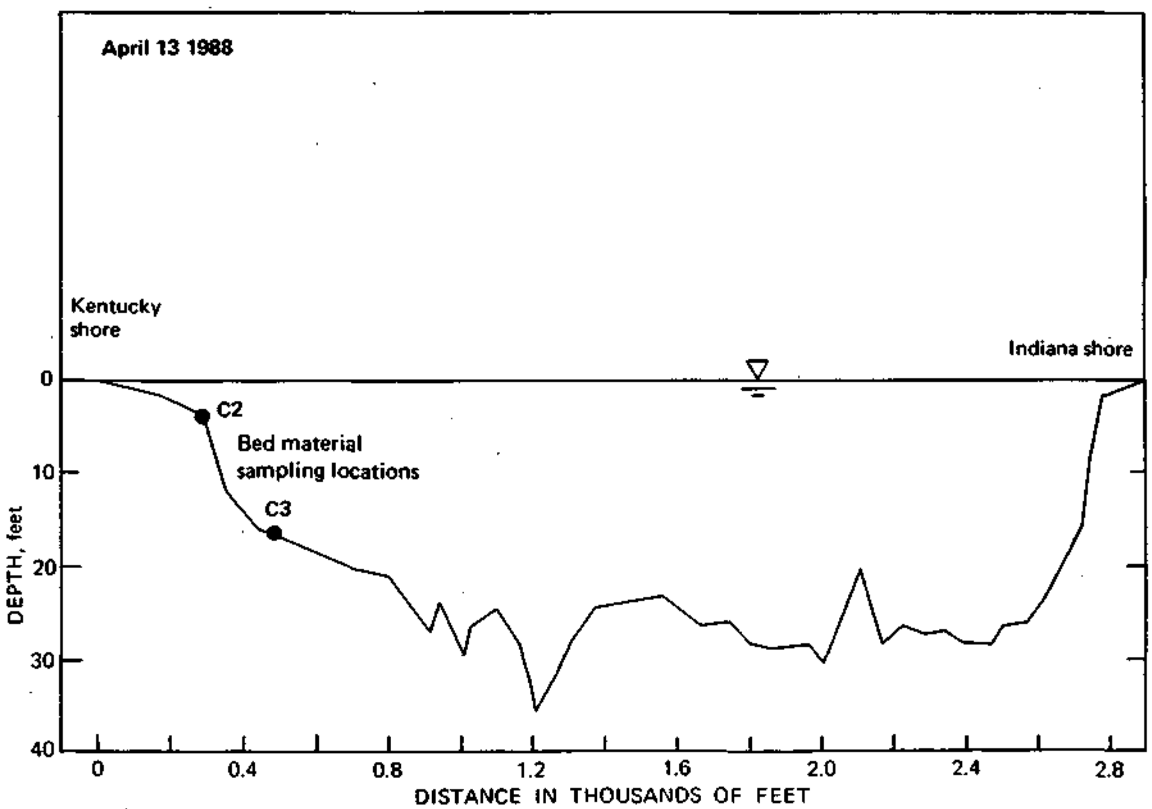


Figure 2. Typical cross-sectional profile at the test site

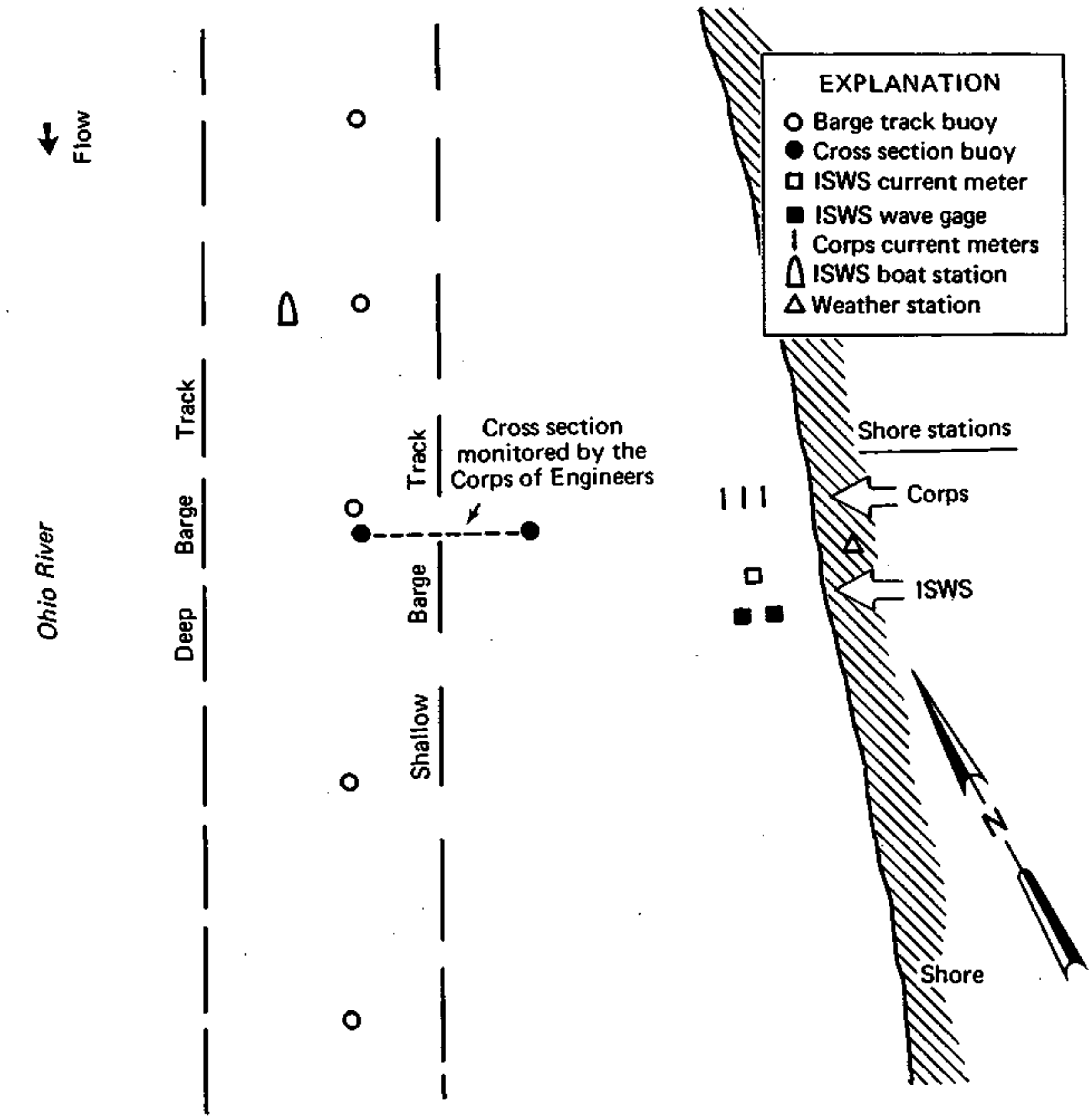


Figure 3. Plan view of project area at Ohio River, Mile 581
(buoy and boat locations shown for shallow barge track only)

shows a photograph of the ISWS shore station. Note the electrical facilities and electronic equipment, computer, and cables needed for the wave gage and current meter. Figure 5 shows a photograph of the empty barge used in the field experiment.

The ISWS research boat "Monitor" was located along the Corps' monitored cross section on the first day of 1500 horsepower (HP) runs and was located upstream and adjacent to one of the guide buoys on all subsequent days. This location of the sediment sampling boat close to the test sailing line subsequently impacted the collection of sediment samples immediately after the passage of the test barge because of waves generated by the moving barges.

The data collection program was conducted over three 2-day periods from July 28 to August 5, 1987. For each of these 2-day periods, commercial towboats leased by the U.S. Army Corps of Engineers, Louisville District, ran a prescribed series of passes through the test site. Three individual towboats were used for the field experiments. A 1500 HP towboat was used for the first 2-day period, a 4200 HP towboat for the second 2-day period, and a 5600 HP towboat for the final 2-day period. On five of the six days of the experimental runs, tows pushing one empty 35 x 195 foot barge were used. For the test runs of August 5 Oast day), several different barge configurations were used. The barge configurations used during the test runs are shown in figure 6.

The standard series of runs included the following:

1) Runs were generally made in sets of two (one upstream and one downstream). The tows always ran on the eastern side of the buoy line, and the boat sampling outside the barge track concentrated on the western side of the buoy line (see figure 3). With the exception of August 5, two buoy lines were set each day, with a shallow water track (16 feet deep) in the morning and a deep water track (22 feet deep) in the afternoon.

2) The first day that each tow operated, the Corps conducted water quality sampling. One set of runs was made on each track line with a 30-minute break between runs to allow the river system to stabilize.

3) The second day that each tow operated, the Corps conducted current meter measurements. Runs were made with only enough break between them to allow the tow to turn and come back. For the 1500 HP and the 4200 HP tows, three throttle settings were run per track line.

4) The second day of the 5600 HP tow was organized differently from the other day-2 runs. One track was used, and loads and throttle settings were varied. For each configuration, an upstream-downstream set of runs was made at 100 RPM (unless otherwise noted, all references to RPM in this report refer to propeller speeds), and another set was made at 150 RPM. The runs were made with:

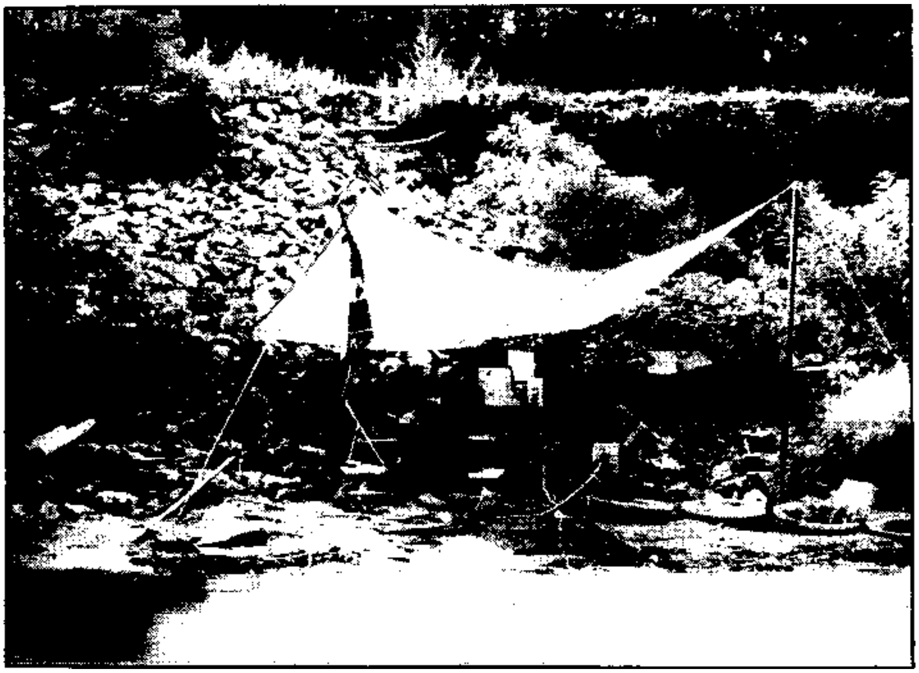


Figure 4. Shore station setup of the Illinois State Water Survey

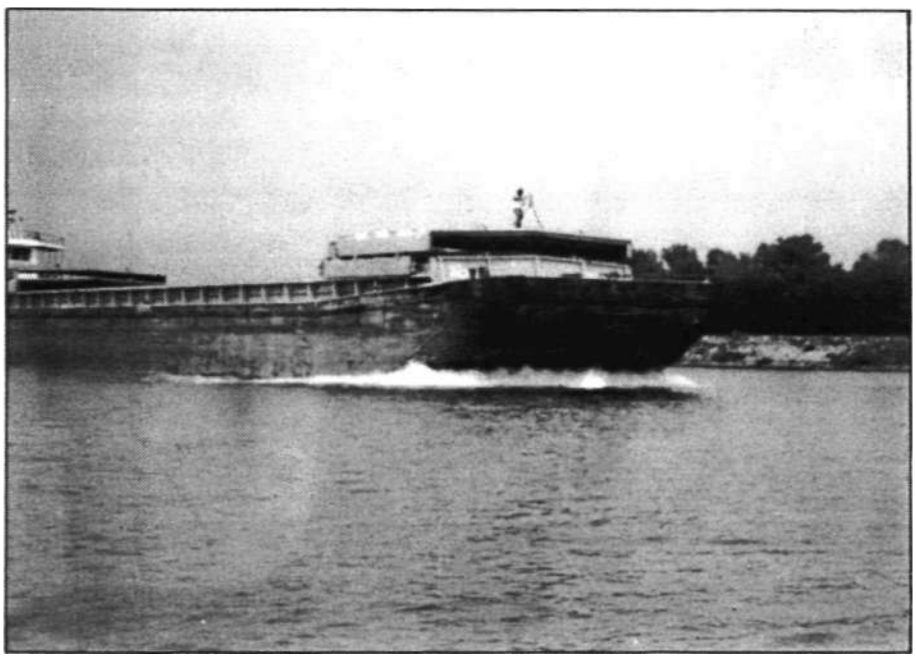


Figure 5. Empty barge used in the field experiment

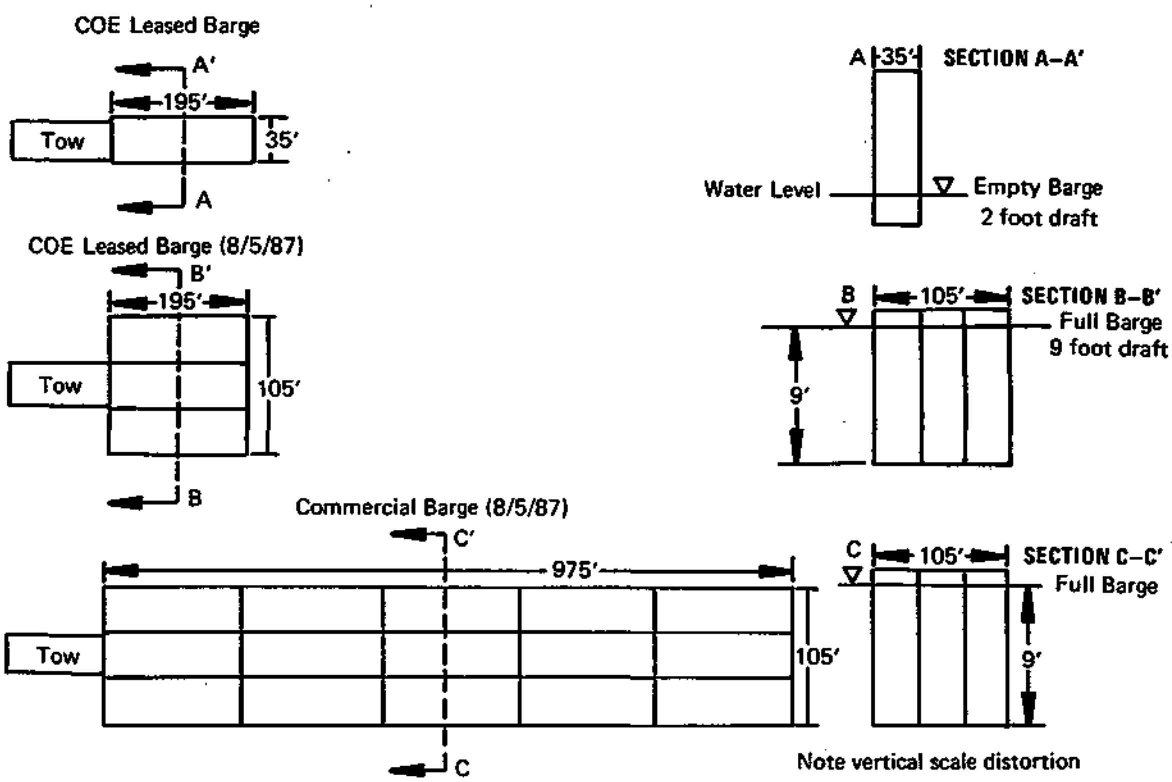


Figure 6. Barge configurations used in the field experiment

- one empty barge
- one full barge
- one commercial barge tow (downstream only, event 68)
- three full barges

Data from only one commercial barge tow were collected by both the Water Survey and the Corps. The configuration of this tow was 3 x 5 loaded, i.e., 3 barges wide, 5 barges long, and a nominal 9 foot draft. The total planform area was 105 feet by 975 feet, compared to a planform area of 35 feet by 195 feet for a single barge. A three-barge setup was used by the Corps for data collection on August 5, 1987.

All site surveying, including the locations of the buoy lines and the sampling boats, was conducted by the Corps. The Corps collected an extensive amount of data on velocity structure, turbulence, pressure fluctuations, scour, and water quality variations during the experimental runs.

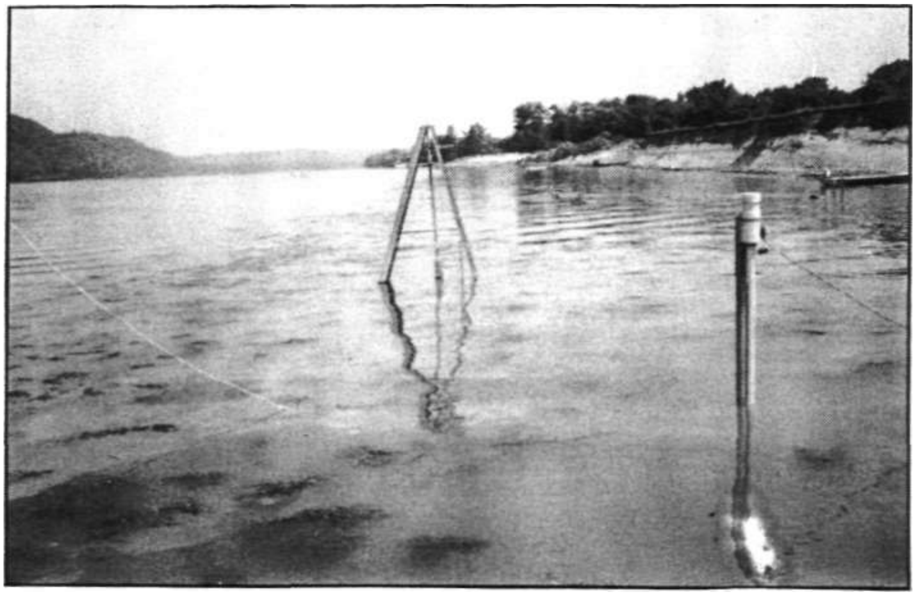
Waves and Drawdown

In this study an electronic wave measuring system was used to measure wave amplitude and period. This system is driven by a microcomputer, and data can be collected continuously at selected intervals and then saved on cassette tapes.

The wave profile was recorded ,as the fluctuating water surface made contact with electronic elements on the wave gage (figure 7). Two wave gages were used (figure 8), with a 3- or 5-foot span of sensing board. The sensing board has electronic probes at intervals of 0.05 feet and is mounted on PVC pipes. Mounting brackets are used to attach the gages to posts driven into the river bed. Detailed information on these wave gages is given by Bhowmik et al. (1982). Figure 9 shows the propagation of waves near the wave gages.

The wave gages generate electrical signals that are processed by interface units and recorded by a Commodore CBM 80032 microcomputer that also controls data logging rates. Processed data are stored on cassette tapes for later analysis. Figure 10 illustrates the units at the shore station. These components include a microcomputer and cassette tape recorder; a wave gage interface; a current meter interface; a current meter signal processor; and a power generator.

Each wave gage is attached to a fence post (figures 7, 8, 9), and a cable is connected between the wave gage and the wave interface. In this investigation, the two wave gages were placed in a line perpendicular to the shore at approximately 88 and 112 feet from the shore. Figure 11 shows a schematic diagram of the wave gage setup. The wave gage at each location was set so the wave fluctuations would not top over or go under the sensing board. The sampling frequency was set at 1-second intervals.



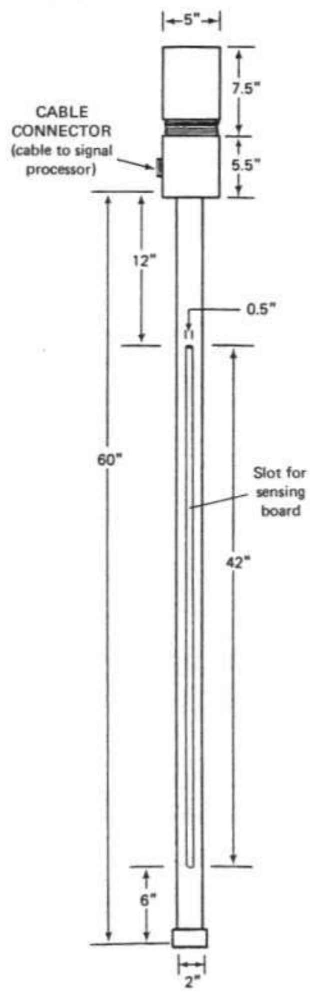


Figure 7. Field setup of the wave gage, and wave gage configuration

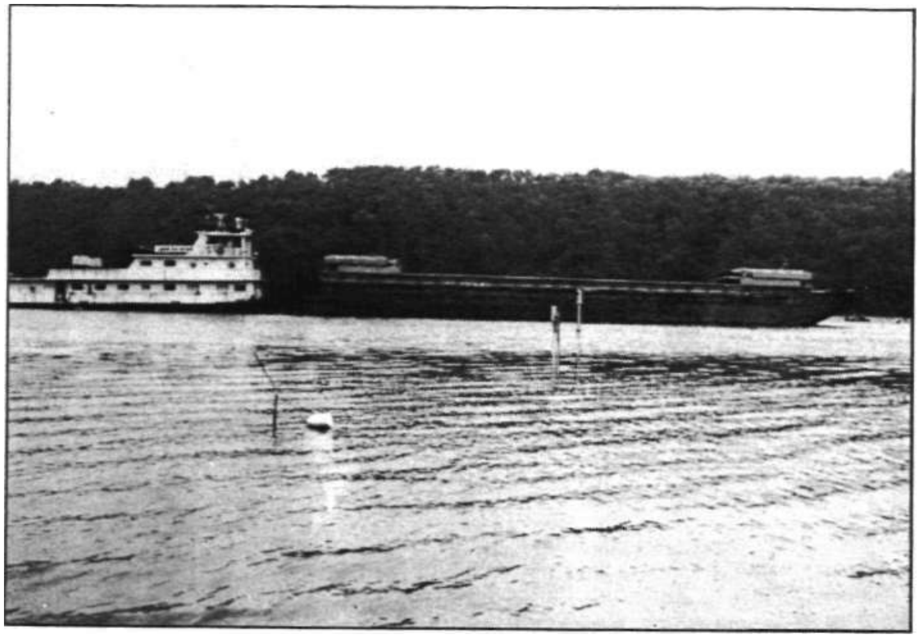


Figure 8. Wave gages used in the field

Figure 9. Tow-induced waves at the wave gages

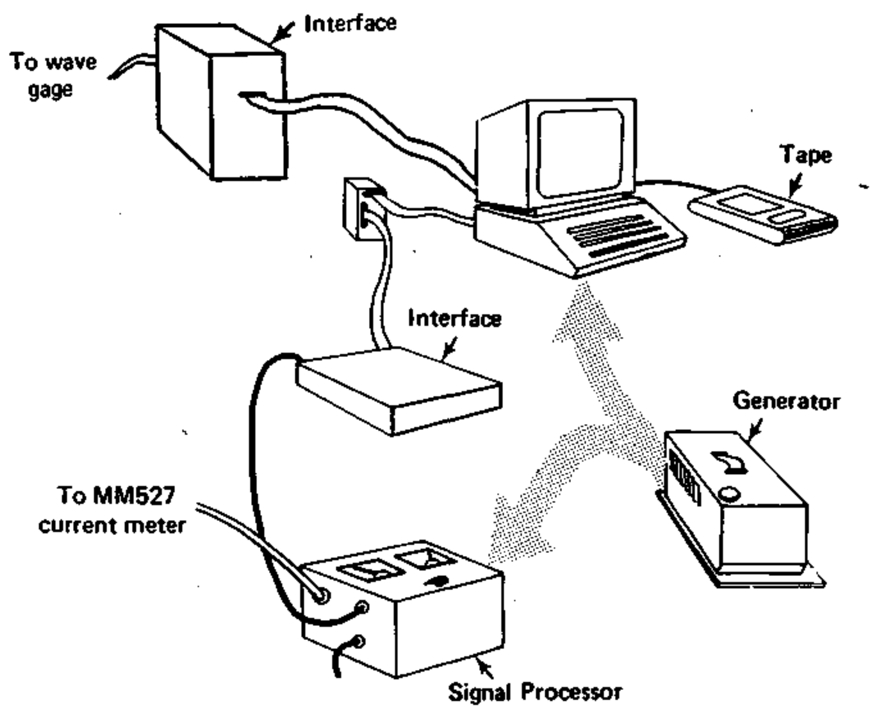


Figure 10. Shore station setup for the wave gages

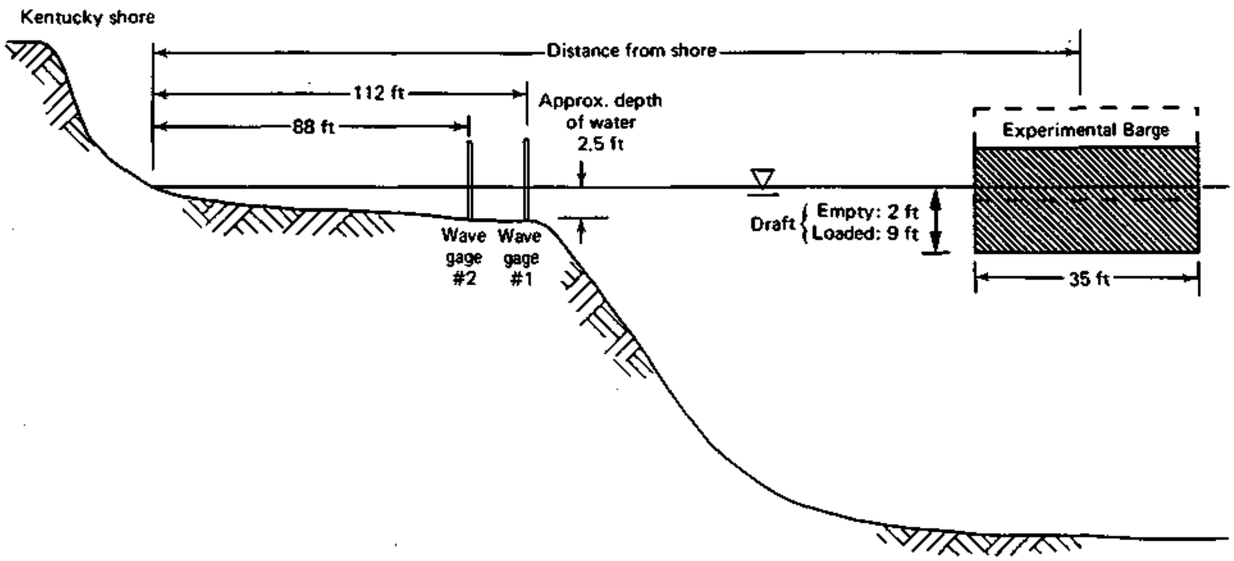


Figure 11. Schematic showing the wave gage setup

Data from 72 events were collected for this study. Table 1 lists these events. All the events are classified by the horsepower and propeller RPM of the towboat, distance from the shore line, number and load condition of the barges, and upstream or downstream direction. Of the 72 events, 58 (including one commercial barge passage) were fully monitored by the Corps, 11 were instrument calibration runs, and 3 were commercial barge passages monitored only by the ISWS shore station. For 5 of these 72 events, no data were collected by the shore station.

Suspended Sediment and Water Quality

Instream monitoring for the Ohio River Navigation Impact Study consisted of data collection for velocity changes, water quality changes, and changes in sediment concentration and particle size. The layout of the data collection equipment on the research boat "Monitor" is shown in figure 12. The current meter was deployed off the bow of the boat and monitored in the cabin; the Hydrolab water qualify sonde (temperature (T), dissolved oxygen (DO), pH, and conductivity) was deployed off the port side and monitored in the cabin; and the ISCO pump samplers were set on the aft-starboard gunwale above the trays of sampling bottles.

A total of 1026 pint water samples for suspended sediment were collected. Nineteen particle size distribution samples were collected (9 background and 10 event samples).

Particle size samples were generally collected in sets labeled background and event, with the background sample taken before the barge passage and the event sample taken immediately following passage. Each of the particle size samples took from 10 to 15 minutes to collect Except for the 5600 HP runs, only the 2-foot level was sampled for particle size. During the 5600 HP runs, background and event samples were collected for all three intake levels.

The Hydrolab system was used to determine variations in pH, dissolved oxygen, and conductivity with barge passage.

A summary of the types of instream data collected by the Water Survey is given in table 2. The event numbers in table 2 correspond to those in table 1.

ANALYSES OF THE DATA

This section describes the analyses that were performed on the data collected by the ISWS researchers. A description of the basic hydraulic and geomorphic characteristics of the Ohio River near the test site at RM 581 is also included.

Table 1. Types of Data Collected by ISWS from the Shore Station

Event no.	*Date*	*Time*	*Tow HP*	*Propeller RPM*	*U/S or* D/S[1]	*Distance from shore (ft)*	*Barge load*[2]	*Wave data*[3]
1	7/28/87	10:25:00	1500	310	U/S	348	1x1 empty	
2	7/28	11:05:00	1500	310	D/S	348	1x1 empty	
3	7/28	11:22:15	—	—		348		MWL
4	7/28	11:50:00	1500	310	U/S	348	1x1 empty	yes
5	7/28	12:00	1500	310	D/S	348	1x1 empty	yes
6	7/28		1500	310	U/S	348	1x1 empty	
7	7/28		1500	310	D/S	348	1x1 empty	
8*	7/28	12:25	unknown	unknown	U/S	other side of the river	2x4	
9	7/28	14:07:30	1500	310	U/S	709	1x1 empty	
10	7/28	14:40:45	1500	310	D/S	709	1x1 empty	yes
11	7/28	15:08:00	1500	310	U/S	709	1x1 empty	yes
12	7/28	15:17:45	1500	310	D/S	709	1x1 empty	yes
13	7/28	15:23:00	1500	310	U/S	709	1x1 empty	yes
14	7/28	15:32:00	1500	310	D/S	709	1x1 empty	yes
15*	7/28	15:56:45	unknown	unknown	U/S	other side of the river	loaded	
16	7/29	09:25:30	—	—	—			MWL
17	7/29	10:29:05	1500	155	U/S	444	1x1 empty	yes
18	7/29	10:52:00	1500	155	D/S	444	1x1 empty	yes
19	7/29	11:11:14	1500	230	U/S	444	1x1 empty	yes
20	7/29	11:25:23	1500	230	D/S	444	1x1 empty	yes
21	7/29	11:34:35	1500	310	U/S	444	1x1 empty	yes
22	7/29	11:50:11	1500	310	D/S	444	1x1 empty	yes
23	7/29	14:21:40	—	—	—			MWL
24	7/29	14:40:02	1500	155	U/S	702	1x1 empty	yes
25	7/29	14:59:20	1500	155	D/S	702	1x1 empty	yes
26	7/29	15:15:23	1500	230	U/S	702	1x1 empty	yes
27	7/29	15:34:38	1500	230	D/S	702	1x1 empty	yes
28	7/29	15:47:11	1500	310	U/S	702	1x1 empty	yes
29	7/29	15:57:06	1500	310	D/S	702	1x1 empty	yes
30	7/29	16:07:46	1500	310	U/S	702	1x1 empty	yes
31	7/30	09:00:45	—	—	—			MWL
32	7/30	10:10:54	4200	235	U/S	496	1x1 empty	yes
33	7/30	11:19:41	4200	235	D/S	496	1x1 empty	yes
34	7/30	15:05:10	4200	235	U/S	666	1x1 empty	yes
35	7/30	15:47:50	4200	235	D/S	666	1x1 empty	yes
36	7/31	09:20:35	—	—	—			MWL
37	7/31	09:36:55	—	—	—			
38	7/31	11:07:41	4200	100	U/S	422	1x1 empty	
39	7/31	11:23:08	4200	100	D/S	422	1x1 empty	
40	7/31	11:34:31	4200	160	U/S	422	1x1 empty	
41	7/31	11:50:08	4200	160	D/S	422	1x1 empty	
42	7/31	12:04:54	4200	225	D/S	422	1x1 empty	
43	7/31	12:20:00	4200	225	D/S	422	1x1 empty	
44	7/31	15:15:40	4200	—	—			MWL
45	7/31	15:31:14	4200	100	U/S	671	1x1 empty	yes
46	7/31	15:50:10	4200	100	D/S	671	1x1 empty	yes

Table 1. (Concluded)

Event no.	*Date*	Time	*Tow HP*	*Propeller RPM*	*U/S or D/S*[1]	*Distance from shore (ft)*	*Barge load*[2]	*Wave data*[3]
47	7/31	16:05:44	4200	160	U/S	671	1x1 empty	yes
48	7/31	16:17:00	4200	160	D/S	671	1x1 empty	yes
49	7/31	16:33:00	4200	225	U/S	671	1x1 empty	yes
50	7/31	16:47:34	4200	225	D/S	671	1x1 empty	yes
51	8/04	09:35:30	—	—	—			MWL
52	8/04	09:45:20	—	—	—			
53	8/04	10:29:58	5600	150	U/S	426	1x1 empty	yes
54	8/04	11:16:57	5600	150	D/S	426	1x1 empty	yes
55*	8/04	12:16:30	unknown	unknown	U/S	other side of the river	3x4 empty	
56	8/04	13:38:41	5600	100	U/S	654	1x1 empty	yes
57	8/04	14:25:19	5600	100	D/S	654	1x1 empty	yes
58	8/05	09:12:45	—	—	—			MWL
59	8/05	09:19:45	—	—	—			
60	8/05	11:18:44	5600	100	U/S	1306[4]	1x1 empty	
61	8/05	11:37:10	5600	100	D/S	1306	1x1 empty	
62	8/05	11:55:22	5600	150	U/S	1306	1x1 empty	yes
63	8/05	12:09:33	5600	150	D/S	1306	1x1 empty	yes
64	8/05	13:24:00	5600	100	U/S	1306	1x1 loaded	yes
65	8/05	13:40:51	5600	100	D/S	1306	1x1 loaded	yes
66	8/05	14:00:19	5600	150	U/S	1306	1x1 loaded	yes
67	8/05	14:15:23	5600	150	D/S	1306	1x1 loaded	yes
68*	8/05	15:17	5600	165	D/S	1293	3x5 loaded	
69	8/05	15:49:10	5600	100	U/S	1293	3x1 loaded	yes
70	8/05	16:08:32	5600	100	D/S	1293	3x1 loaded	yes
71	8/05	16:28:23	5600	150	U/S	1293	3x1 loaded	yes
72	8/05	16:44:52	5600	150	D/S	1293	3x1 loaded	yes

[1]U/S = upstream; D/S = downstream

[2]Configurations of barges are described as 1 x 1, 2 x 4, etc., denoting number of barges in width and length, respectively

[3]MWL = mean water level

[4]On August 5, the COE operated the experimental barge running in a south-north direction (and vice versa), thus intersecting the shallow and deep tracks as shown in figure 3

*Commercial barge

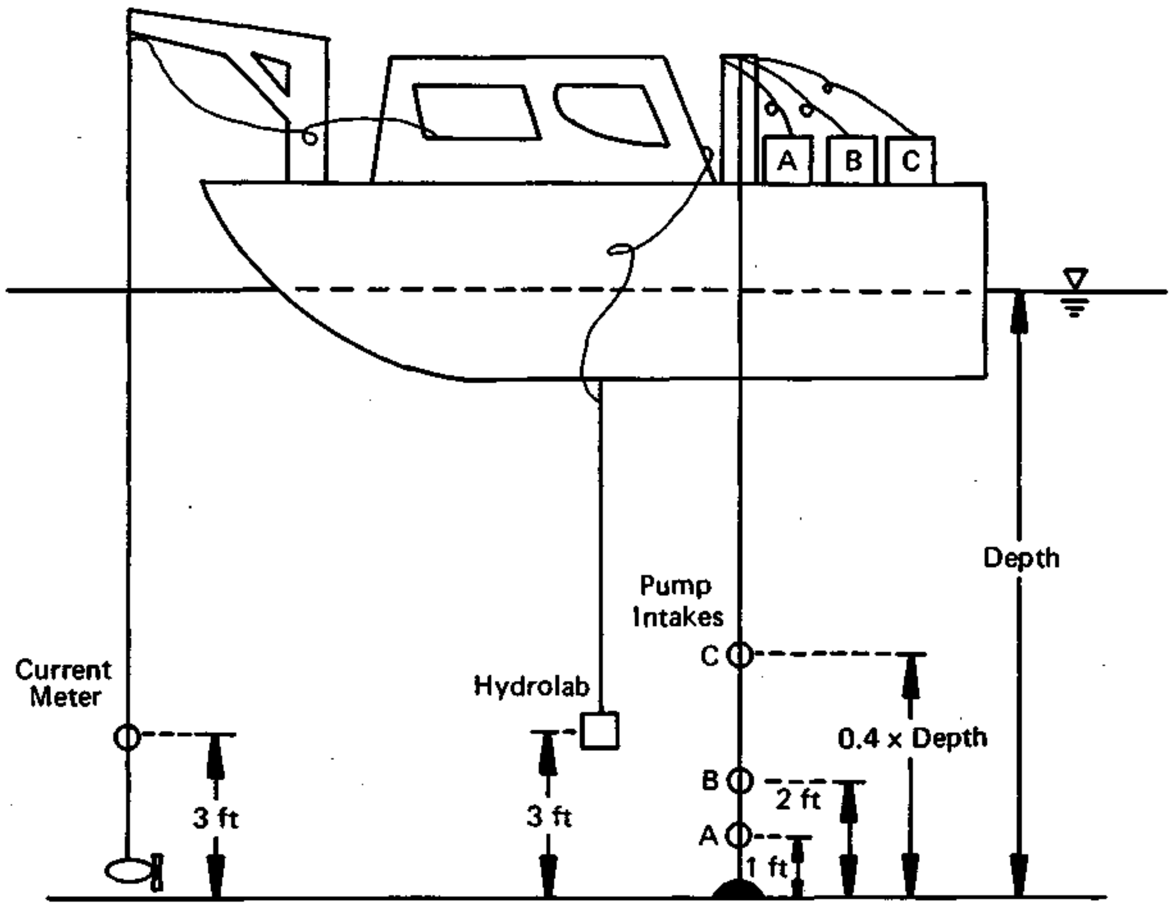


Figure 12. Profile view of the instream monitoring equipment

Table 2. Types of Data Collected by ISWS from the Boat Station

Event no.[1]	*Hydrolab* *Full*	*DO*	*Sediment concentration* *3 minutes*	*5 minutes*	*Particle size*[2] *1 point*	*3 point*
1						
2	x		x			
3						
4	x		x			
5	x			x		
6	x			x		
7	x			x		
8						
9	x		x[3]			
10	x		x			
11	x			x		
12	x			x		
13	x			x		
14	x			x		
15						
16						
17	x		x		x	
18	x			x		
19	x			x		
20	x			x		
21	x			x		
22	x			x		
23						
24	x		x		x	
25	x			x		
26	x			x		
27	x			x		
28	x			x		
29	x			x		
30	x			x		
31						
32	x		x		x	
33	x		x			
34	x		x			
35	x		x			
36						
37						
38		x	x		x	
39		x		x		
40		x		x		
41		x		x		
42		x	x			
43		x	x			
44						
45		x	x			
46		x		x		
47		x		x		
48		x		x		
49		x	x			

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Table 2. (Concluded)

Event no.[1]	*Hydrolab* *Full*	*DO*	*Sediment concentration* *3 minutes*	*5 minutes*	*Particle size*[2] *1 point*	*3 point*
50		x	x			
51						
52						
53			x			x
54			x			
55						
56			x			x
57			x			
58						
59						
60		x	x			
61		x	x			
62		x	x			
63		x	x			
64		x	x			
65		x	x			
66		x	x			
67		x	x			
68		x	x			
69		x	x			
70		x	x			
71		x	x			
72		x	x			

[1] For event descriptions, see table 1

[2] "1 point" indicates that one suspended sediment particle size sample set (background and event) was collected from pump intake B; "3 point" indicates that three sample sets (background and event) were collected, one from each pump intake.

[3] Only 2 pumps working

Physical **and Hydraulic** Characteristics

The planform of the Ohio River near KM 581 is shown in figure 1. As this figure indicates, at this location the river has a gentle bend, and the test site is just in the transition zone or beginning of the bend. A typical cross section at this location is shown in figure 2. Figure 13 shows the thalweg profile of the Ohio River near the test site. Other physical parameters at the test site are as follows:

Top width (ft)	2680	Hydraulic radius (ft)	23.7
Average depth (ft)	23.8	Cross-sectional area (ft^2)	63,900
Maximum depth (ft)	30.8	Estimated thalweg slope (ft/mile)	0.33

On April 13, 1988, discharge and velocity distribution were measured at the test site, and two samples for bed material size distributions were collected. The particle size distributions of these bed material samples are shown in figure 14. The sampling locations are shown in figure 2 as C2 and C3. The basic characteristics of these samples are:

Sample no.	d_{16}	d_{50}	d_{84}	σ	*U*
C2	0.21	5.0	NA	NA	41
C3	0.24	3.1	11.0	8.23	30

In this listing, the values shown for d_{16}, d_{50}, and d_{84} represent particle sizes in millimeters; their significance is that 16, 50, and 84% of the sample particles, respectively, are smaller than these sizes. The standard deviation **a** is defined by

$$\sigma = 1/2 \left[\frac{d_{84.1}}{d_{50}} + \frac{d_{50}}{d_{15.8}} \right] \quad (1)$$

and the uniformity coefficient U is defined by the ratio of d_{60}/d_{10}.

On April 13, 1988, the stage at the test site was about 4 feet above the stage from July 28 through August 5, 1987, and the hydraulic characteristics of the test site were as follows:

Discharge = 178,200 cfs

Average velocity = 2.8 fps

Flow duration was 22%; that is, about 22% of the time this flow will be exceeded.

Discharges for the study period generally ranged from 10,000 to 20,000 cfs (flow durations 85 to 95%), with the exception of August 4 when the discharge was 52,900 cfs (flow

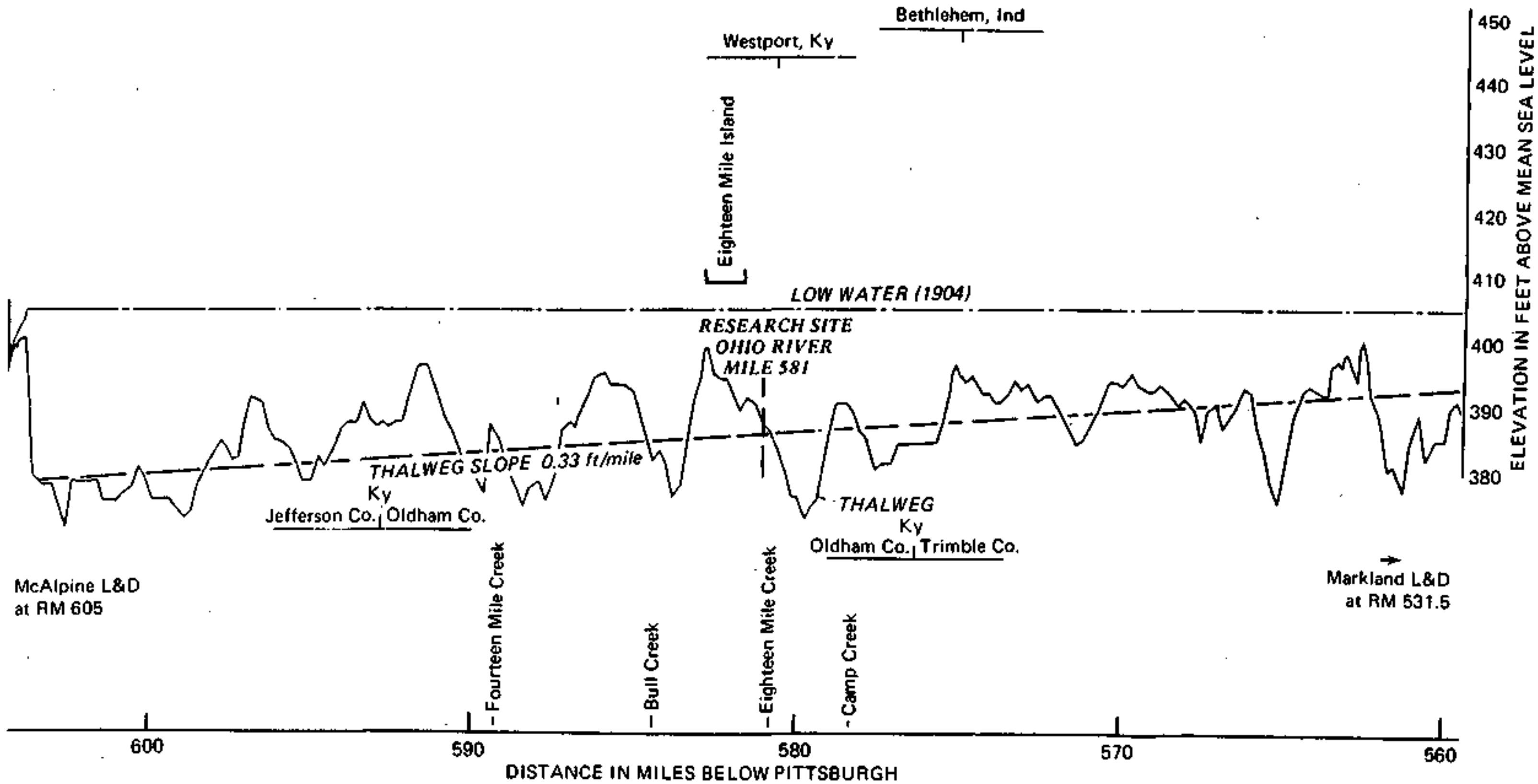

Figure 13. Thalweg profile of the Ohio River near the test site
(after U.S. Army Corps of Engineers)

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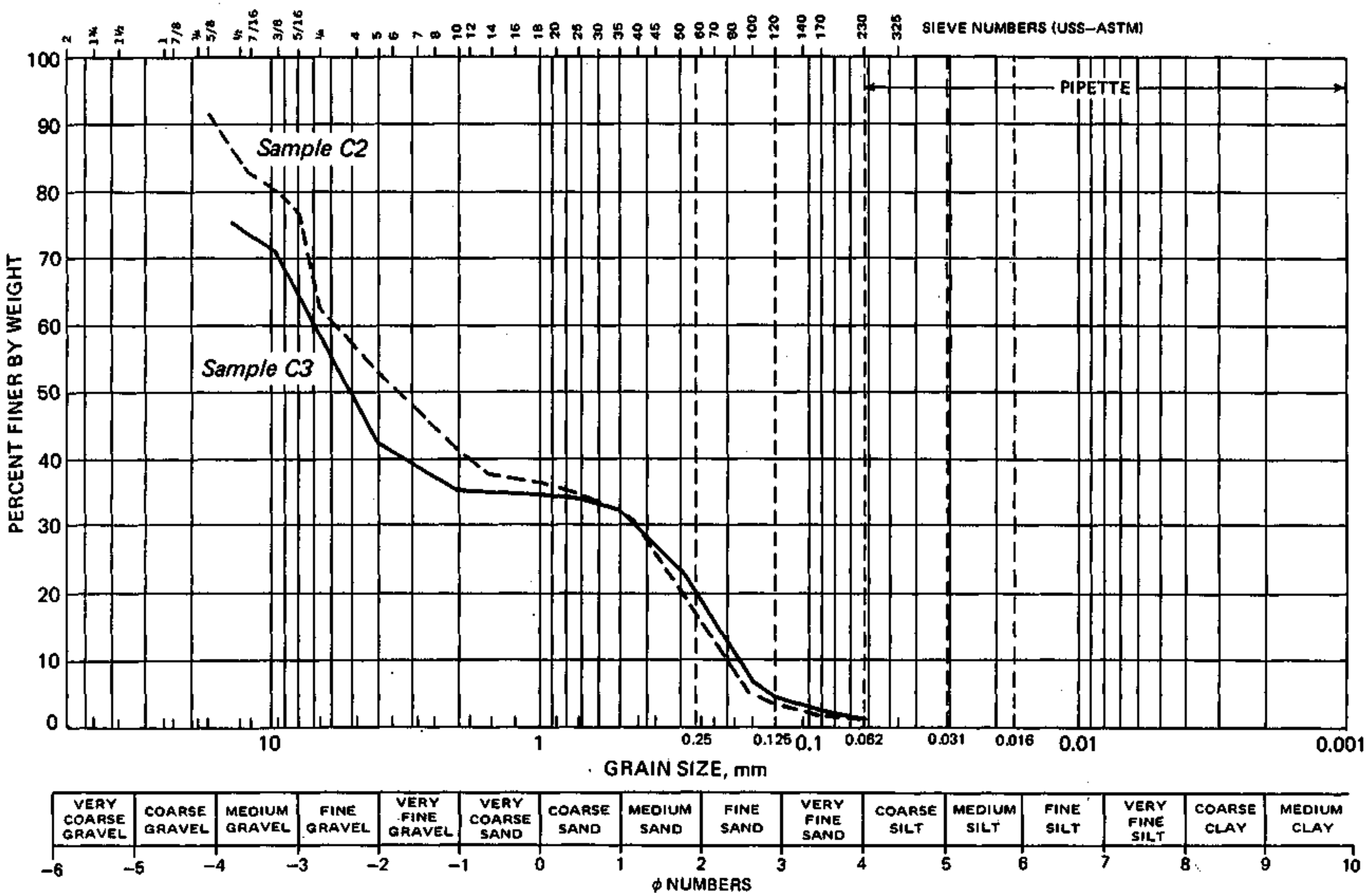

Figure 14. Particle size distributions of two bed material samples

duration 57%). Flow duration is a measure of the relative magnitude of a discharge when compared to all other daily discharges. As an example, the August 5 discharge of 52,900 cfs has been exceeded 57% of the time from 1928 to 1978. This information was estimated on the basis of flow duration curves at McAlpine Lock and Dam (RM 605) and Markland Lock and Dam (RM 531.5) on the Ohio River (USGS, 1989).

Water Quality

The Hydrolab sonde was suspended at a level 3 feet above the bed of the river (figure 12). It provided digital readouts of temperature, pH, conductivity, and dissolved oxygen (DO). Of these four parameters, only DO showed any short-term variability. Temperature changed from 29.1°C on the first day of data collection to 29.7°C on the last day. pH varied between 6.9 and 7.0. Conductivity varied from 362 to 371 µs/cm, but daily variation was less than 3 units. Typical water quality values are given in table 3.

The DO variability was over 1 mg/l during some event periods of up to 40 minutes. DO levels decreased overall during the project period from approximately 6.0 to less than 4.5 mg/l.

Suspended Sediment Concentration

Suspended sediment samples were collected by using three pump intakes as shown in figure 12. Intake A was 1 foot above the bed, Intake B was 2 feet above the bed, and Intake C was four-tenths of the depth above the bed. All the samples were taken to the sediment laboratory, where the sediment concentrations were determined.

Laboratory analyses of the suspended sediment concentration samples consisted of:

1) Weighing the full sample to determine the sample volume (sample containers were pre-tared).
2) Vacuum filtering of the samples through pre-tared Whatman 934AH glass micro-fiber filters.
3) Drying the filter papers at 105°C.
4) Weighing the dried sample/filter papers.

The dried sample weight was then compared to the full sample volume to determine sediment concentration in mg/1.

Sample numbers and concentrations were entered into a Lotus 1-2-3 database, sorted by sample number and pump intake, and plotted. Event plots of the sample concentrations versus either time or sample number for each pump intake are presented in Appendix A. Ranges of suspended sediment concentrations for a few selected events are given in table 4.

Table 3. Water Quality Data

Event number	*Temp °C*	*pH (standard unit)*	*Conductivity (micro-mHOS)*	*DO range (mg/l) min*	*max*
2	29.1	6.9	363	5.7	6.2
4	29.2	6.9	363	5.9	6.2
5	29.2	7.0	364	5.9	6.2
6	29.2	7.0	364	5.9	6.1
7	29.2	6.9	364	5.7	6.1
9	29.2	6.9	363	6.0	6.4
10	29.2	7.0	362	5.7	5.9
11	29.2	6.9	362	5.9	6.0
12	29.2	6.9	362	5.8	5.9
13	29.2	6.9	362		6.0
14	29.2	6.9	362	5.7	5.9
17	29.2	7.0	365	5.7	6.0
18	29.2	7.0	365	5.7	5.8
19	29.2	7.0	365	5.7	6.0
20	29.2	7.0	365	5.6	6.0
21	29.2	7.0	365	5.7	6.1
22	29.2	7.0	365	5.7	6.2
24	29.2	7.0	364	5.5	5.8
25	29.2	7.0	364	5.5	5.8
26	29.2	7.0	364	5.3	5.9
27	29.2	7.0	364	5.4	5.8
28	29.2	7.0	364	5.5	5.8
29	29.2	7.0	364	5.5	6.0
30	29.2	7.0	364	5.6	6.0
32	29.3	6.9	369	4.2	5.7
33	29.3	6.9	368	4.6	5.7
34	29.3	7.0	367	4.6	5.9
35	29.3	7.0	366	4.6	6.0
38	29.2	7.0	366	4.4	5.1
39	29.2	7.0	366	4.6	5.1
40	29.2	7.0	366	4.5	5.2
41	29.2	7.0	366	4.4	5.2
42	29.2	7.0	366	5.0	5.6
43	29.2	7.0	366	4.6	5.5
45	29.1	7.0	367	5.3	5.6
46	29.1	7.0	367	4.7	5.3
47	29.1	7.0	367	5.2	5.5
48	29.1	7.0	367	5.3	5.6
49	29.1	7.0	367	4.7	5.7
50	29.1	7.0	367	4.7	5.7
60	29.6	6.9	370	4.4	4.8
61	29.7	6.9	370	4.2	4.8
62	29.7	6.9	370	3.8	4.7
63	29.7	6.9	371	4.2	4.7
64	29.7	6.9	370	3.6	4.5
65	29.7	6.9	370	4.0	4.5

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Table 3. (Concluded)

Event number	*Temp °C*	*pH (standard unit)*	*Conductivity (micro-mHOS)*	*DO range (mg/l) min*	*max*
66	29.7	6.9	370	3.9	4.5
67	29.7	6.9	370	4.0	4.5
68	29.7	6.9	370	3.9	4.4
69	29.7	6.9	370	3.7	4.4
70	29.7	6.9	370	4.0	4.5
71	29.7	6.9	370	3.8	4.5
72	29.7	6.9	370	3.9	4.5

Table 4. Ranges of Suspended Sediment Concentrations for Selected Events (All Barges Unloaded)

Event	*HP*	*RPM*	*Direction of barge movement*	*Background range, mg/l*		*Maximum concentration at pump intakes, mg/l*		
				min	*max*	*A*	*B*	*C*
32	4200	235	upstream	5	15	53	20	9
33	4200	235	downstream	8	10	58	39	9
34	4200	235	upstream	6	12	26	17	13
43	4200	225	downstream	7	12	108	45	22
53	5600	150	upstream	9	15	39	53	33
54	5600	150	downstream	9	15	103	61	47
57	5600	100	downstream	9	17	50	47	20

Particle Size Distribution of the Suspended Sediment

Nineteen samples were collected for the determination of particle size distribution of the suspended sediments. Both background and event samples were collected. The background samples were collected during the 15-minute period immediately preceding a tow pass, and the event samples were collected in the 15-minute period immediately following the tow pass. Almost all the samples were collected from intake B, 2 feet above the bed (figure 12). Laboratory analysis consisted of wet sieving the full sample volume to determine the fine fraction. No distinction was made between the silt and clay fractions. The results of the sand/fine analysis are presented in table 5. The results indicate that more than 90 percent of the suspended sediment consists of silt and clay materials (less than 62 microns in size).

Waves and Drawdown

Wave and drawdown data were collected for 43 events, and data for 38 events were retrieved from the data cassettes. These data were transferred and stored on an IBM personal computer for processing.

Figure 15 is a plot of wave data collected in the field. This plot shows a sequence of increased depth just ahead of the drawdown, followed by drawdown and fluctuating waves before the water surface profile started to register the ripple characteristics due to winds. This figure also schematically illustrates how the values of the drawdown and maximum wave heights were determined. The maximum values of drawdown and wave height for all 38 events are given in table 6. Some typical wave and drawdown characteristics are shown in Appendix A.

DISCUSSION

This section discusses the data collected by the ISWS researchers for this study. It includes a comparison of the basic hydraulic and geomorphic characteristics of the Ohio River near the test site at RM 581 with those of the UMRS and the Illinois River.

Physical and Hydraulic Characteristics: Ohio River at the Test Site and Selected Pools along the UMRS

Geomorphic and Hydraulic Characteristics

Drainage area, discharge, and runoff characteristics of the Ohio River near the test site at Louisville and Warsaw, and at a few selected pools along the UMRS, are presented in table 7. These values were obtained from publications of the U.S. Army Corps of Engineers (not dated), U.S. Army Corps of Engineers (1980), and USGS (1988).

Table 5. Particle Size Distribution of the Suspended Sediments

Sample no.	*Date*	*Sample description code**	*%sand*	*% silt and clay*
1	7/29/87	BG17-2	6.1	93.9
2	7/29/87	E17-2	6.3	93.7
3	7/29/87	E24-2	10.4	89.6
4	7/30/87	BG32-2	2.2	97.8
5	7/30/87	E32-2	4.8	95.2
6	7/31/87	BG38-2	4.6	95.4
7	7/31/87	E38-2	18.0	82.0
8	8/4/87	BG53-1	4.6	95.4
9	8/4/87	BG53-2	3.7	96.3
10	8/4/87	BG53-(0.4D)	3.9	96.1
11	8/4/87	E53-1	3.5	96.5
12	8/4/87	E53-2	4.4	95.6
13	8/4/87	E53-(0.4D)	7.3	92.7
14	8/4/87	BG56-1	6.8	93.2
15	8/4/87	BG56-2	4.4	95.6
16	8/4/87	BG56-(0.4D)	5.9	94.1
17	8/4/87	E56-1	5.4	94.6
18	8/4/87	E56-2	5.2	94.8
19	8/4/87	E56-(0.4D)	2.3	97.7

* Sample description code:
BG = Background sample collected immediately before an event
E = Event sample
nn = Event number from table 1
-n = Sampling height above bed (4D = 0.4 x depth)
BG17-2 indicates background sample for event 17 (see table 1 for event description) from 2 feet above the bed. Similarly, E17-2 indicates event sample for event 17 from 2 feet above the bed, and BG53-(0.4D) indicates background samples for event 53 at four-tenths the depth (0.4D).

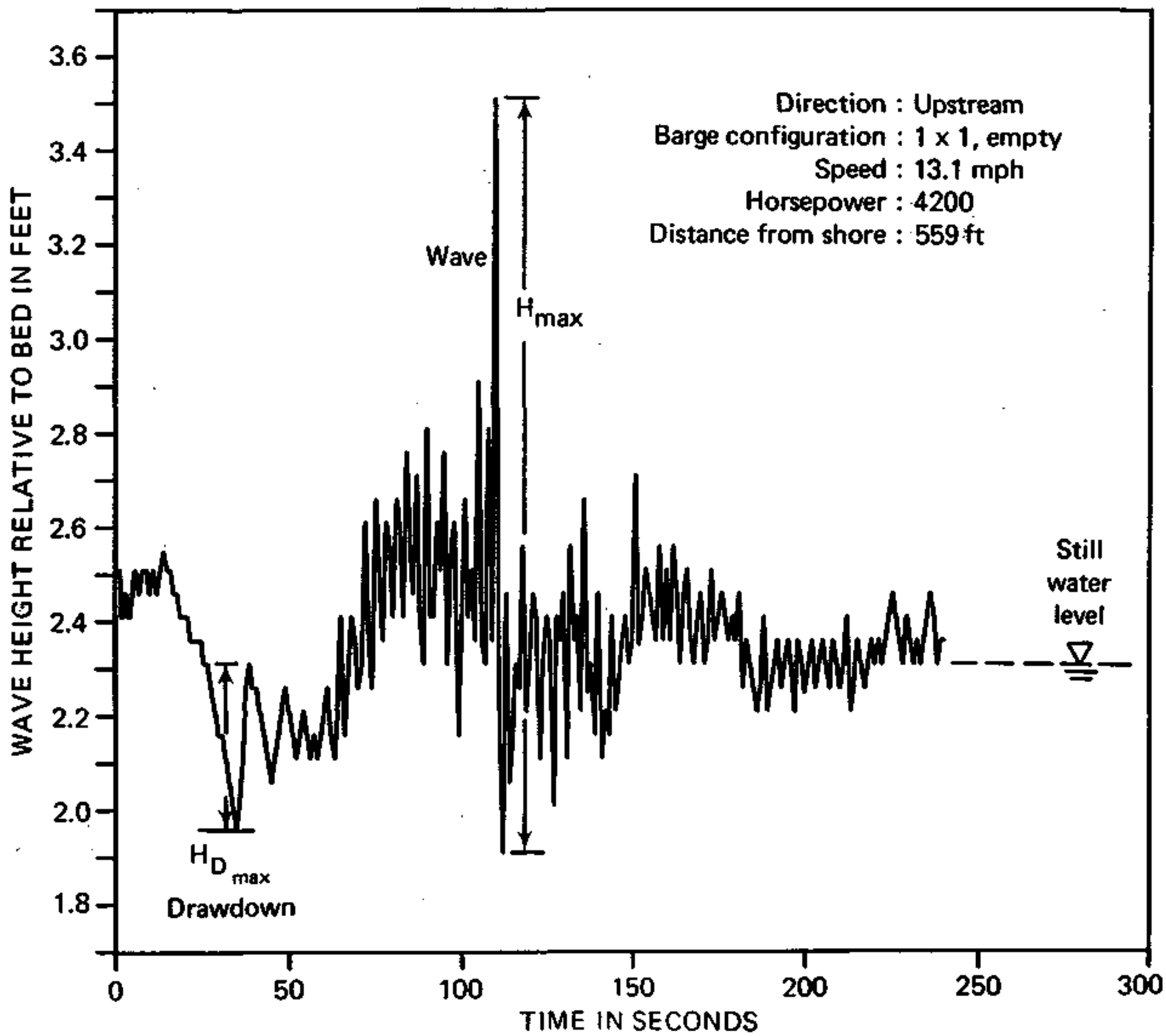

Figure 15. Typical wave and drawdown, event 49, gage 1

Table 6. Wave and Drawdown Characteristics at the Ohio River Site

Event	*Direct-ion*	*HP*	*RPM*	*Distance from wave gage, ft** #1	#2	*Speed VB mph*	*Gage 1* *Max wave ft*	*Max draw-down ft*	*Gage 2* *Max wave ft*	*Max draw down ft*	*Configur-ation*
4	U/S	1500	310	236	260	9.1	.50	.10	.50	.10	1x1 empty
5	D/S	1500	310	236	260	9.1	.40	.20	.35	.15	1x1 empty
11	U/S	1500	310	597	621	10.8	.45	.05	.45	.05	1x1 empty
12	D/S	1500	310	597	621	10.8	.55	.05	.40	.05	1x1 empty
13	U/S	1500	310	597	621	10.8	.45	.10	.35	.05	1x1 empty
14	D/S	1500	310	597	621	10.8	.55	.10	.50	.05	1x1 empty
17	U/S	1500	155	332	356	4.5	.05	.05	.05	.05	1x1 empty
19	U/S	1500	230	332	356	6.5	.15	.05	.15	.05	1x1 empty
20	D/S	1500	230	332	356	7.5	.20	.05	.15	.05	1x1 empty
21	U/S	1500	310	332	356	9.5	.50	.10	.40	.05	1x1 empty
22	D/S	1500	310	332	356	10.0	.50	.10	.30	.05	1x1 empty
24	U/S	1500	155	590	614	5.0	.05	.05	.05	.05	1x1 empty
25	D/S	1500	155	590	614	5.3	.05	.05	.05	.05	1x1 empty
26	U/S	1500	230	590	614	6.7	.05	.05	.05	.05	1x1 empty
28	U/S	1500	310	590	614	9.5	.30	.05	.35	.05	1x1 empty
29	D/S	1500	310	590	614	9.5	.45	.05	.35	.05	1x1 empty
30	U/S	1500	310	590	614	10.0	.40	.05	.40	.05	1x1 empty
32	U/S	4200	235	384	408	9.9	.50	.40	.80	.35	1x1 empty
33	D/S	4200	235	384	408	5.9	1.05	.35	1.00	.30	1x1 empty
34	U/S	4200	235	568	592	12.2	.65	.30	1.05	.20	1x1 empty
35	D/S	4200	235	568	592	8.1	1.20	.15	.75	.10	1x1 empty
45	U/S	4200	100	559	583	5.4	.05	.05	.05	.05	1x1 empty
46	D/S	4200	100	559	583	5.7	.05	.05	.05	.05	1x1 empty
47	U/S	4200	160	559	583	9.1	.25	.10	.30	.10	1x1 empty
48	D/S	4200	160	559	583	9.1	.30	.05	.35	.05	1x1 empty
49	U/S	4200	225	559	583	13.1	1.60	.40	.80	.25	1x1 empty
50	D/S	4200	225	559	583	13.1	1.20	.10	1.20	.15	1x1 empty
56	U/S	5600	100	542	566	8.7	.70	.55	.60	.40	1x1 empty
57	D/S	5600	100	542	566	10.4	.60	.25	.60	.15	1x1 empty
60	U/S	5600	100	***	***	9.1	.75	.15	.85	.10	1x1 empty
62	U/S	5600	150	***	***	11.4	.75	.15	.70	.10	1x1 empty
63	D/S	5600	150	***	***	11.4	.65	.05	.85	.05	1x1 loaded
64	U/S	5600	100	***	***	6.5	.05	.05	.05	.05	1x1 loaded
66	U/S	5600	150	***	***	10.8	.10	.30	.15	.25	3x1 loaded
67	D/S	5600	150	***	***	12.0	.70	.20	.85	.05	3x1 loaded
69	U/S	5600	100	***	***	6.1	.10	.10	.05	.05	3x1 loaded
70	D/S	5600	100	***	***	6.6	.05	.05	.05	.05	3x1 loaded
71	U/S	5600	150	***	***	8.4	.15	.15	.05	.05	3x1 loaded

* Distance is measured from the center of two buoy lines to two wave gages. Wave gage 1 is 112 feet from the shore, and wave gage 2 is 88 feet from the shore.

Note: *** = south to north direction; VB = velocity of the tow in mph; the resolution of the wave gage is 0.05 feet; wave and drawdown are measured in feet.

Table 7. Drainage Area, Discharge, and Runoff Characteristics of the Mississippi and Illinois Rivers, and of the Ohio River near Louisville

	Gaging station	*River mile*	*Length of record*	*Drainage area, sq mile*	*Daily discharge,, cfs* *Maximum* *Qmax*	*Minimum* *Qmin*	*Average* *Qavg*	*Ratio of discharges* *Qmax/ Qavg*	*Qmin/Qavg*	*Runoff, inches*	*Runoff without diversion, inches*
Mississippi **River**											
Pool 3	Prescott	811.4	60	44,800	226,000	1,380	17,404	12.98	0.079	5.27	
10	McGregor	633.6	52	67,500	276,000	6,200	35,696	7.73	0.174	7.18	
11	—	583.0	—	81,600	304,000	6,340	46,200	6.58	0.137	7.30	
12	—	526.7	—	82,400	304,000	6,340	46,200	6.58	0.137	7.36	
13	—	522.6	—	85,600	307,000	6,500	47,400	6.48	0.137	7.51	
	Clinton	520.0	114	85,600	307,000	6,500	48,029	6.39	0.135	7.61	
14	—	483.3	—	88,400	307,000	6,700	48,800	6.29	0.137	7.33	
15	—	482.9	—	88,500	307,000	6,500	48,800	6.29	0.133	7.33	
16	—	457.2	—	99,400	321,000	7,450	55,300	5.80	0.135	7.26	
17	—	437.1	—	99,600	321,000	7,450	55,300	5.80	0.135	7.26	
18	—	410.5	—	113,600	333,000	6,300	59,900	5.56	0.105	7.06	
19	—	364.4	—	119,000	344,000	5,000	62,487	5.51	0.080	6.98	
	Keokuk	364.0	109	119,000	344,000	5,000	64,602	5.32	0.077	7.37	
20	—	343.3	—	134,300	442,600	5,100	68,160	6.49	0.075	6.88	
21	—	324.9	—	135,000	408,000	6,400	68,570	5.95	0.093	6.88	
22	—	301.3	—	137,500	575,700	6,900	69,710	8.26	0.099	6.91	
	St. Louis	190.4	54	697,000	851,000	27,800	182,770	4.66	0.152	3.56	
Illinois **River**											
Marseilles	Marseilles	247.0	68	8,259	87,800	1,460	10,750	8.75	0.136	17.7	12.4
LaGrange	Kingston Mines	145.5	48	15,818	86,700	1.700	15,282	5.81	0.111	13.1	10.3
Pool 26	Meredosia	71.3	49	26,028	123,000	1,330	22,219	5.35	0.060	11.6	9.9
Ohio River											
McAlpine	Louisville	605	59	91,170	1,100,000	2,100	115,634	9.50	0.018	17.2	
Markland	Warsaw	531.5	17	83,170	542,000	4,320	117,525	4.61	0.037	19.2	

Consideration of the drainage areas shows that the Ohio River near Louisville is comparable to the Mississippi River between Lock and Dam 15 and Lock and Dam 16 (approximate drainage area 90,000 square miles). However, the average runoff at these locations on the Mississippi River is about 42% of the runoff volume on the Ohio River near Louisville. These differences become more pronounced when the drainage areas, discharges, and runoffs from selected gaging stations along the Ohio River (near the test site) and from stations along the Mississippi and Illinois Rivers are compared (table 7).

This comparison shows that the Ohio River passes significantly larger volumes of water per unit drainage area (17 to 19 inches) than either the Mississippi River (3.5 to 8.0 inches) or the Illinois River (11 to 18 inches). Note that the discharge data for the Illinois River are distorted by the diversion of Lake Michigan water at Chicago, which is 3200 cfs. The impacts of this distortion are reduced with increasing drainage areas from 5.3 inches at Marseilles to 1.7 inches at Meredosia. Without this distortion, the runoff rates would vary from 9.9 inches at Meredosia to 12.4 inches at Marseilles (table 7).

In general, greater variability exists between the maximum, minimum, and average flows on the Ohio River at the gaging stations at Louisville and Warsaw than exists on the Mississippi River near Lock and Dam 15 and Lock and Dam 16. The Ohio River at Lousiville has a low flow of about 1.8% of the average flows at this section. However, the maximum flow can be as much as 950% of the average flow. On the other hand, the variability of flows on the Mississippi River at Lock and Dam 15 ranges from 13.3% for low flows to 630% for maximum flows when compared with the average flows at the same location. Thus the Ohio River at the test site is subjected to much higher and wider variability in flows than the UMRS.

Higher peak discharges in the Ohio River most probably result from higher runoff rates and possibly from reduced off-channel storage areas. Off-channel storage and differences in geologic setting are likely factors in the lower low-flow rates in the Ohio River.

A comparison of the Ohio River at Louisville with the Mississippi River at Clinton, Iowa, shows that the drainage area at Louisville is approximately 5% larger than that of the Mississippi River at Clinton, but the peak discharge is three times larger, the average discharge is 2.5 times larger, and the minimum discharge is one-third less than at Clinton. These comparisons of the river flow characteristics near the test site with those in similar reaches of the Mississippi River indicate that these reaches of these two river systems are subjected to completely different flow regimes even though their drainage areas are approximately equal. Flow fluctuations on the Ohio River are much more prominent than flow fluctuations on the Mississippi River.

Table 8 gives average values of width, velocity, and thalweg slopes for the Mississippi River for Pools 11 through 22 and for the Ohio River at the test site. This table illustrates

Table 8. Hydraulic Characteristics of the Mississippi River, Pools 11 through 22, and of the Ohio River at the Test Site

		Width (feet)		Flow velocity ranee (ft / sec)		Thalweg slope
	min	*max*	*avg*	*min*	*max*	*(feet/mile)*
Mississippi River						
Pool 11	**1,000**	**7,000**		**3.0**	**6.0**	**1.07**
12	**6,000**	**8,000**		**3.0**	**6.0**	**0.26**
13	**2,000**	**20,000**		**3.0**	**6.0**	**0.33**
14	**2,000**	**3,000+**		**1.5**	**7.5**	**0.30**
15	**1,000**	**3,500**		**3.0**	**9.0**	**1.30**
16	**4,500**	**7,000**		**3.0**	**6.0**	**1.34**
17	**2,400**	**7,000**		**3.0**	**6.0**	**0.36**
18	**4,000**	**7,000**	**4,100**	**3.0**	**6.0**	**0.28**
19	**2,000**	**11,000**		**3.0**	**4.5**	**0.40**
20	**1,200**	**5,500**		**1.5**	**6.0**	**0.71**
21	**3,000**	**12,000**		**3.0**	**6.0**	**0.51**
22	**NA**	**NA**	**3,300**	**3.0**	**6.0**	**0.17**
Ohio River						
McAlpine Pool	**2,700**					**0.33**

Sources:

Mississippi River

Pools 11-18: USACOE (not dated)

Pools 19-22: USACOE (1980)

Ohio River

These values are based on field measurements and are not long-term average values.

quite vividly that in general the Mississippi River within these pools is much wider and probably is shallower than the Ohio River near the test site.

Bed Materials

The bed materials of the Ohio River near the test site are quite different from those found in the Illinois River and most of the Mississippi River. Data for two samples from the Ohio River near the test site indicated that the median diameters of these samples range from 3.1 to 5.0 mm. Moreover, during the field test, the field personnel from the Louisville District, Corps of Engineers, had considerable difficulty installing the support mechanism for the current meters because of the coarse-grained nature of the bed materials at this site. In contrast, Illinois and Mississippi River bed materials on or near the sailing line and also near the channel border areas are considerably smaller.

Figure 16 shows two histograms, one each for the Illinois River and the Mississippi River within Pool 26. The first histogram shows the variability of the median bed material sizes along the thalweg on the 80-mile length of the lower Illinois River (Bhowmik et al., 1981d). This plot indicates that the d_{50} size of the majority of the bed materials is in the range of 0.3 to 0.4 mm. However, these samples had coarser bed materials than the samples collected at one-half of the maximum depths on both sides of the channel and also at 2-foot depths in the same reach of the Illinois River. These data indicated that at one-half of the maximum depths, about 70% of the samples contained only silts (less than 0.062 mm in size), 15 to 18% contained mostly sands, and the remainder of the samples contained mostly shells. Similarly, most of the bed materials from the 2-foot depth were in the silty ranges, with the following distributions: 80% of the samples were silt, 15% were sand, and 5% were shells.

The variability observed in figure 16a was also shown to exist along the main channel of the Illinois River from its mouth at Grafton to near its origin at Joliet, Illinois (Bhowmik and Schicht, 1980). About 53 bed material samples were collected all along the sailing line of this river. Analyses of these samples indicated that the majority had median diameters ranging from about 0.1 mm to 0.5 mm. Thus the bed materials on Pool 26 along the Illinois River generally consist of sand, silt, and clay. On the other hand, bed material data collected from the Mississippi River from within Pool 26 (Goodwin and Masters, 1983) show that the majority of these samples have mean diameters of about 1 ϕ (figure 16b). Conversion from the ϕ scale to mm can be done as follows:

$$\phi = -\log_2 (d)\ \mathrm{mm} \tag{2}$$

Thus the 1 ϕ size translates to a size of 0.5 mm.

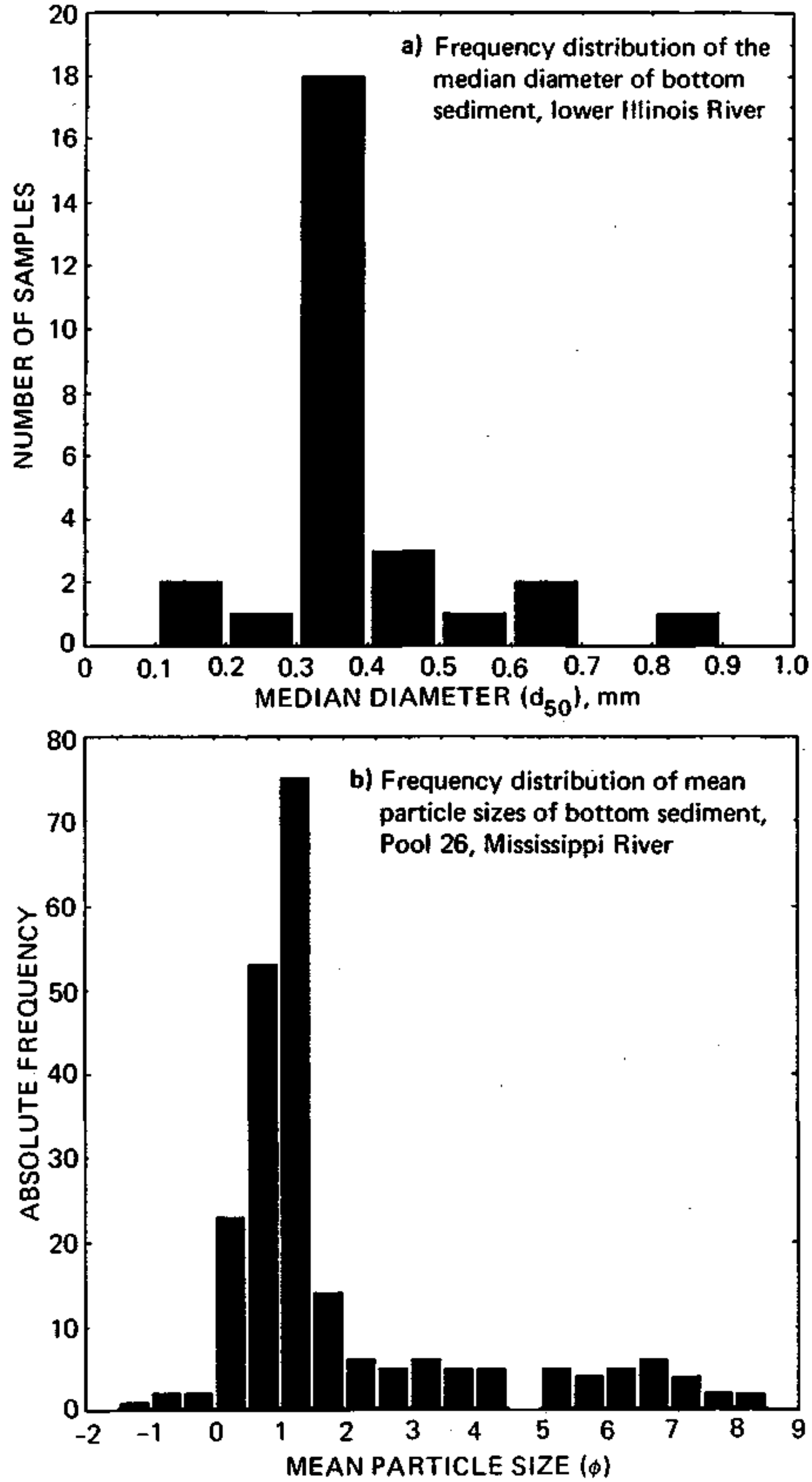

Figure 16. Frequency distributions of bed material sizes

Again, the mean diameters of the bed materials from the Mississippi River within Pool 26 are in the general category of the median diameters of the bed materials from the Illinois River from within the same pool.

The significant differences between the bed material sizes from the Ohio River at the test site and those from the major areas of the UMRS are exemplified by another set of data collected from Pool 19 on the Mississippi River. A summary of these data is given in table 9. Note that river miles decrease in the downstream direction.

This table shows bed material data that were collected by Casavant (1985) and by the authors and their associates in connection with the Long Term Ecological Research of the Illinois River. An examination of this table shows that the main channel of this pool has mostly sandy materials, and the non-vegetated main channel border areas have mostly silt and clay. There is also a significant difference in the bed material sizes between the upper and lower pools on this reach of the river. If the city of Nauvoo is taken to be the dividing line between the upper and lower pools, then the d_{50} size of the bed materials from the non-vegetated main channel border areas within the lower pool is almost always less than 0.062 mm (silt and clay range), and within the upper pool the d_{50} sizes are in the sandy fraction ranges.

This detailed description of the bed material size distributions from a few selected reaches of the UMRS indicates quite clearly that the UMRS flows on a bed consisting almost entirely of sand within the main channel area, and of silt and clay in the main channel border areas, whereas the test site on the Ohio River has bed materials in the coarse sand to gravel size ranges even within the channel border areas. This difference is extremely important when the resuspension characteristics of the bed materials due to the physical impacts of navigation are considered.

In general, whenever the velocity is altered, with an associated increase in its magnitude and variability (turbulence), the bed materials may be removed and resuspended within this high-velocity regime. The critical velocities needed to resuspend loose silt and fine to medium sands are much smaller than those needed to resuspend coarse-grained sands and gravels. Thus even if the altered velocity structure due to river traffic is similar in the Ohio River and the UMRS, the resuspension characteristics of the bed materials and their ultimate fates will be significantly different in these two systems.

In all probability, navigation on the Ohio River near the test site will resuspend much less bed material than may be resuspended in the Illinois River or the UMRS (within the reaches discussed here). These resuspension characteristics, including the potential implication of increased sedimentation rates within the channel border areas, backwater areas, or side channels on the UMRS due to navigation traffic, are the major difference between the Ohio River at the test site and the UMRS.

Table 9. Bed Material Size Distribution of Pool 19 along the Mississippi River

	Percent sand				*d_{50}, mm*			
Mile	*VMCB*	*NVMCB*	*MC*	*SCC*	*VMCB*	*NVMCB*	*MC*	*SCC*
364.5 (L&D 19)								
364.8	3	5	100		0.015	0.007	0.73	
365.2	3	0	100		0.02	0.007		
366.3*	4	4	6					
368.1		16	89			0.01	0.5	
368.3*		1	7					
370.5*		1	10				0.48	
372.8		35	93			0.025	0.55	
373.5	17	39	95		0.02	0.036	0.8	
374.9		1	57			0.018	0.4	
375.8		20	99			0.024	0.42	
376.5	16	25	95		0.027	0.043	0.36	
Nauvoo								
376.7*	8	3	1					
377.8		64	69			0.12	0.25	
378.5*		4	16					
380.6*		2	10		0.45	0.47		
382.4*		8	10				0.59	
384.3*						0.43	0.51	
386.4*		7	1				0.73	
388.4*		7	16			0.75	0.53	
390.4*		5	16	18			0.45	
392.0*		3	11				0.5	
394.6		76	90	100		0.08	0.38	0.43**
397.1		88	95	83			0.31	0.35**
400.6*						0.54	0.53	0.46**
402.2		99	100	100		0.37	0.49	0.44**
402.8*						0.48	0.56	
406.3*						0.54	1.09	
408.3*							0.98	
410.0 (L&D 18)				98				0.35

VMCB = vegetated main channel border
NVMCB = non-vegetated main channel border
MC = main channel
SCC = side channel
* Data collected by Casavant (1985); other data were collected by the authors and their associates
** Data collected from Shokokon Slough near Burlington Island

Water Quality

Water quality data collected by the Hydrolab did not show any changes in temperature, conductivity, or pH due to the navigation traffic at the test site. The dissolved oxygen content showed some variability, but it could not be clearly related to the towboat/barge traffic.

However, it must be remembered that water quality data were collected only from a single point at an elevation of 3 feet above the bed and on a substrate having a median diameter of about 3.1 mm to 5 mm. Therefore, very little resuspension of the bed materials can be expected at this location.

Suspended Sediment

Figure 17 shows the variations in suspended sediment concentration with time for ten events when the 1500 HP towboat was running at 310 RPM. As these plots indicate, the suspended sediment concentration did not vary much with time at any of the three intake points. Because the bed materials were coarse-grained, they were not resuspended and moved laterally by the movement of a single empty tow (figure 5).

Somewhat different variations in sediment concentration were observed when the 5600 HP towboat operated at 100 to 150 RPM. The variations of the suspended sediment concentrations with time are shown in figure 18 for events 54 and 57. At this time, the tow was running in the downstream direction at a constant speed with one empty barge. For both of these runs, the increase in suspended sediment concentrations at the lowest intake point A was higher than the increase in sediment concentrations at intake points B or C. Because intake point A was very close to the bed, it obviously was substantially impacted by the altered and increased velocity regime that resuspended the bed materials. As a matter of fact, for events 32, 33, 34, 43, 53, 54, and 57 with either the 4200 or 5600 HP towboat and with prop speeds ranging from 100 to 235 RPM, the variability of the sediment concentrations was quite substantial. These values are shown in table 4. Runs 53 through 57 may have been influenced by the slightly higher river discharge of August 4. This discharge of 52,900 cfs may have been a factor in keeping sediments in suspension. For many of the other events, an increase in suspended sediment concentration was either minimal or not detected. Appendix B shows plots of the suspended sediment concentrations with time.

Readers again must be cautioned against extrapolating these results to other riverine systems, especially the Illinois and Mississippi Rivers. As was pointed out in the last section, the bed materials of the Illinois and Mississippi River consist of silt, clay, and small quantities of sand, especially within the channel border areas, and thus the resuspension characteristics of these bed materials will be different from those observed on the Ohio River

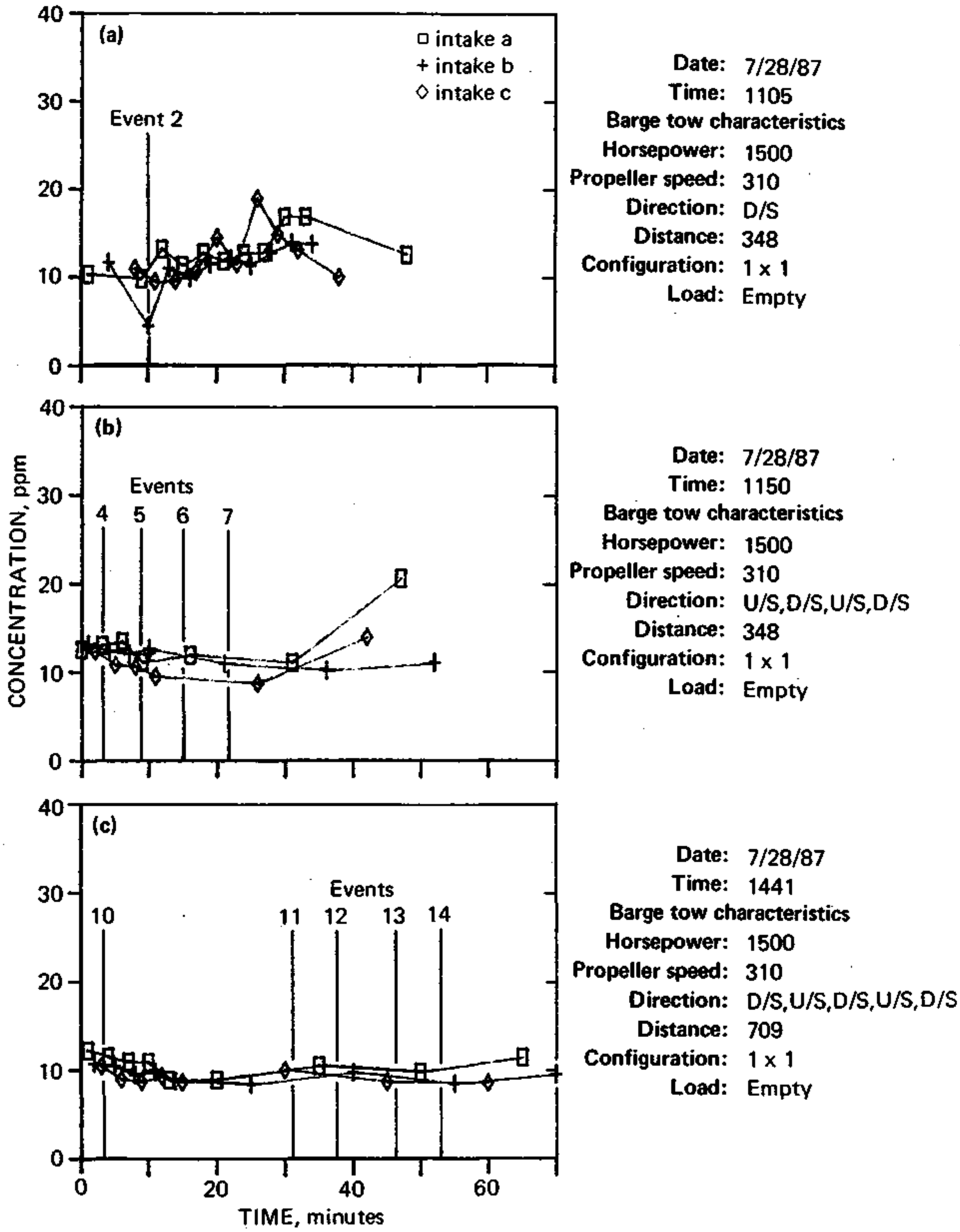

Figure 17. Variations in suspended sediment concentration with time for ten events

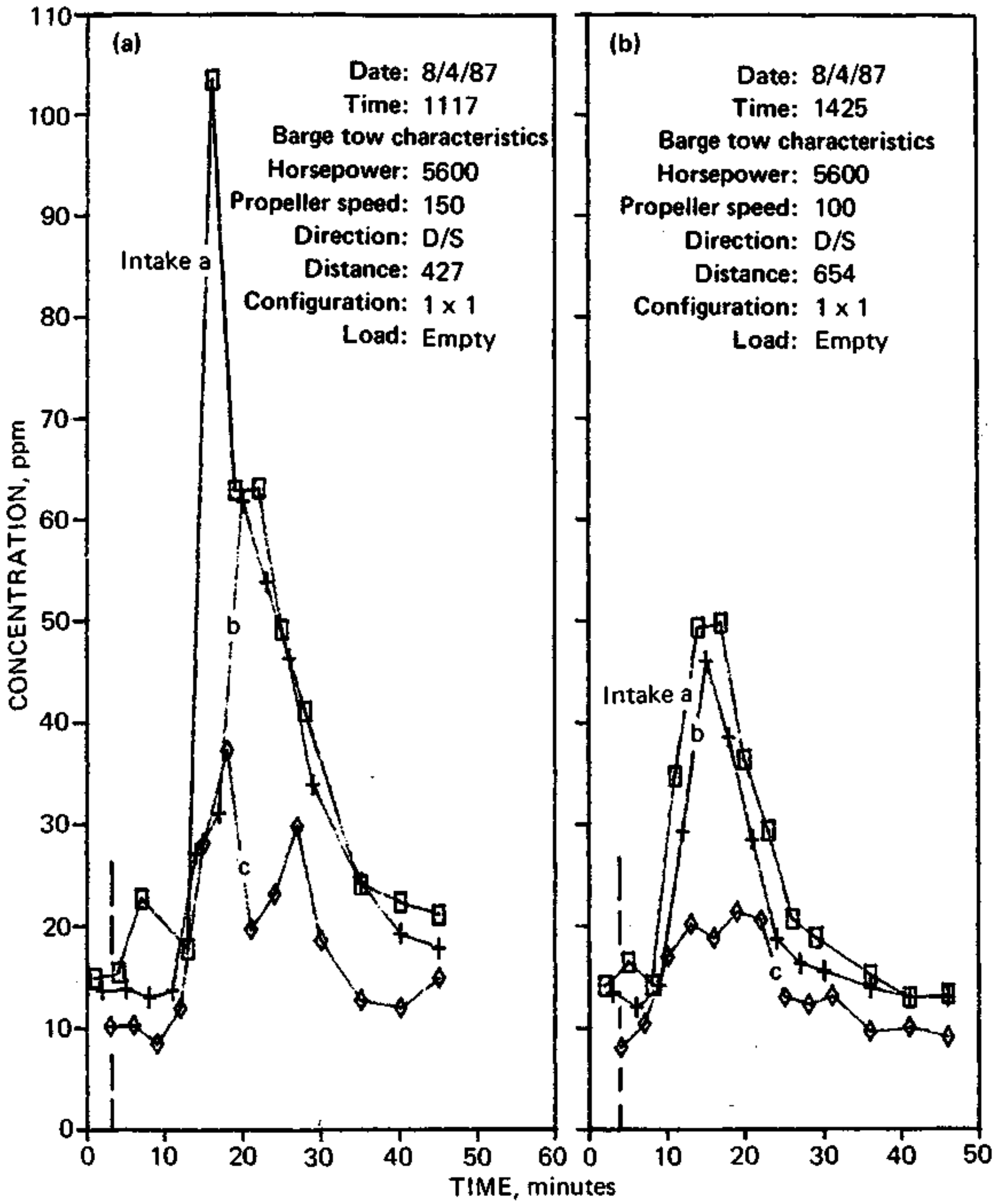

Figure 18. Variations in suspended sediment concentration with time for events 54 and 57

at RM 581 near the sampling point, where the d_{50} for the bed materials ranged from 3 mm to 5 mm for the two samples collected.

It is essential to point out that detailed data on sediment resuspension due to river traffic are needed for a wide range of hydraulic, geometric, bed material, and hydrologic variables. The minimum set of variables that should be considered is cross-sectional shape, width, depth, area, and roughness characteristics of the river; velocity and its vertical and lateral distributions, including an indication of whether or not secondary circulation is present; velocity fluctuation; ambient water temperatures; traffic characteristics, including distance, speed, length, draft, direction, and blockage factor of the vessel; the overall planform characteristics of the test reach, including its straightness and/or curvature; and the partical size distribution of the bed materials and suspended sediments.

The particle size distribution of the suspended sediments collected before and after six tow events indicated that suspended sediments on the Ohio River at this site consist mostly of silt and clay (table 5). For events 24, 32, and 38 (table 5), significant increases in the sand fractions were observed during these events over the background levels. Such an increase in the sand fraction size during a tow event is an indication of the resuspension of the bed materials. On the other hand, for the other three events, no substantial difference in the resuspended sediment characteristics was observed.

The Corps of Engineers collected velocity data in the immediate vicinity of the barge. These data are being analyzed by the Waterways Experiment Station and the Louisville District of the U.S. Army Corps of Engineers.

Waves and Drawdown

Some significant wave and drawdown events were generated and measured during this field experiment. The analyses show that higher wave amplitudes do not necessarily accompany a larger drawdown. The durations of drawdown and higher waves, and the magnitudes of maximum wave heights and drawdown, generally vary with HP, RPM of the tow, its distance and direction of movement, and its loading characteristics. The following generalized statements can be made on the basis of these data:

- Barges moving upstream generate larger drawdown than barges moving downstream having similar HP and RPM.
- Higher waves are generated by barges moving downstream.

- Values of drawdown and wave heights are related to characteristics of the tow and barge, and to local morphology. Table 6 presented the data collected on wave heights and drawdown. Maximum measured wave height was 1.6 feet for event 49. Maximum measured drawdown was 0.55 feet for event 56. Some general analyses of the maximum wave heights and drawdown are given in table 10.

Table 10. Average Values of Wave Heights and Drawdown

	Wave Gage No. 1		*Wave Gage No. 2*	
Tow characteristics	*Average wave height, ft*	*Average drawdown, ft*	*Average wave height, ft*	*Average drawdown, ft*
Upbound (for all)	0.39	0.15	0.37	0.11
Downbound (for all)	0.53	0.12	0.49	0.09
1500 HP up/down	0.33	0.07	0.29	0.06
4200 HP up/down	0.69	0.20	0.64	0.16
5600 HP up/down	0.42	0.18	0.44	0.12

Insufficient data exist to make any other generalized statements or to develop and/or validate any existing theoretical relationships on waves and drawdown due to navigation impact. However, these data can be used to get an approximate quantification of the wave heights and drawdown generated by tested barge tow configurations in a navigable waterway similar to the Ohio River.

SUMMARY

This report summarizes the data collected during a field trip made in July-August 1987 to the Ohio River near RM 581. During this time, the Louisville District of the U.S. Army Corps of Engineers conducted extensive field experiments with rented barges and towboats to determine the physical impacts of barge traffic on the Ohio River. Most of the experiments were conducted with a single unloaded barge. On a few occasions, a single loaded barge and three loaded barges tied abreast were used.

The data collected by the Illinois State Water Survey consist of suspended sediments at a single station, and waves and drawdown at two stations. Some water quality data were also collected at a single point.

During the data collection period, the river had a flow of between 10,000 and 53,000 cfs at this location, and the cross-sectional profile includes a terraced region near the channel border area. The bed materials near the sampling points were mostly coarse-grained sands and gravels.

Water quality data for pH, temperature, conductivity, and dissolved oxygen (DO) did not show variation except in DO. DO was observed to have been reduced slightly over several individual events.

Suspended sediment data collected at three elevations showed some variability during an event On a few occasions, with the 5600 HP towboat running at low RPMs, there was a clear increase in suspended sediment concentrations. The durations of these increases ranged from 25 to 30 minutes. Particle size distributions of the suspended sediment indicated that these are mostly of silt and clay sizes, with sand making up less than 10% of the total content

Wave and drawdown data were collected from two sampling verticals. Normally the water surface profile showed a gradual increase at the advent of a tow event followed by a prolonged drawdown just before the waves intercepted the wave gages. Most of the waves were of small amplitudes, with a few fairly high-amplitude waves. Maximum measured wave height was 1.6 feet, and the maximum drawdown was 0.55 feet. However, measured average maximum wave height was 0.45 feet at wave gage no. 1 (outer) and 0.42 feet at wave gage no. 2 (inner). Average drawdown was 0.14 feet for wave gage no. 1 (outer) and 0.10 feet for wave gage no. 2 (inner).

Hydraulic and geomorphic parameters for selected pools along the Illinois and Mississippi Rivers were compared with similar parameters from the Ohio River at the test site. These analyses indicated that on a relative scale and also for similar watershed areas, the Ohio River conveys much higher discharges than the UMRS. Moreover, the flows on the Ohio River show more extreme variations between low and maximum discharges than is found in most reaches of the UMRS (Illinois River and Pools 11 to 26 on the Mississippi River). Another difference between the Ohio River at the test site and the UMRS is in the overall composition of the bed materials. The lower reaches of the UMRS flow on a bed of sand, silt and clay extending from the main channel to channel border areas and side channels. This variability is quite different from the situation observed at the test site, where mostly coarse-grained particles were observed to exist These differences are significant with regard to the resuspension characteristics of the bed sediments. Fine-grained bed materials such as those present in the UMRS will be resuspended much more easily than those in the Ohio River at the test site for the same altered velocity regime.

The data presented in this report are not of sufficient quantity and content to permit generalized comments and evaluation regarding the impacts of navigation on the resuspension characteristics and waves and drawdown in a natural river. Moreover, caution must be exercised in extrapolating these data to other river systems that have different hydraulic and physical characteristics, especially if substantial differences in bed material sizes exist. Waves and drawdown may be similar for similar river cross sections and traffic

patterns, but the resuspension of the sediment will depend on the ambient suspended sediment concentration, the particle size distributions of the bed materials, and the relative positions of the sampling points and the sailing line. Detailed research is needed to quantify and predict the physical impacts of navigation in natural rivers with different geomorphic features.

Acknowledgments

The authors express their sincere appreciation to Jerry Rasmussen, Assistant Program Manger, Experimental Management Technical Center of the USFWS, who was the Program Manager for this project. Thanks are also extended to Gail Carmody of the USFWS for her support, encouragement, and review of this report. A hearty thank you to Terry Siemsen of the Louisville District of the Army Corps of Engineers, who was in charge of the Ohio River Navigation Impact Study field experiments and was always eager to assist the authors in their field data collection effort. Becky Howard typed the report, Linda Riggin and John Brother prepared the illustrations, and Gail Taylor edited the report.

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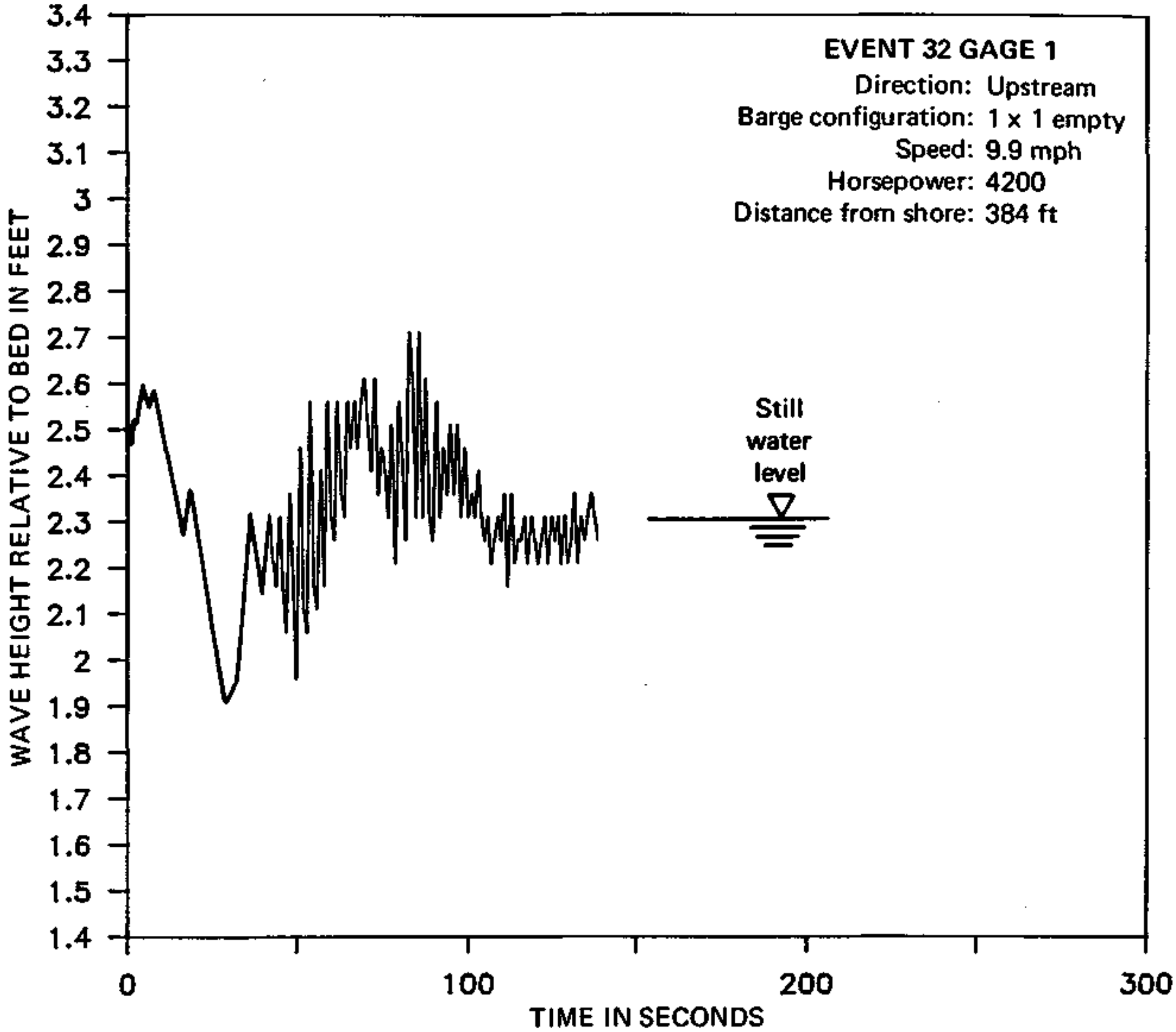
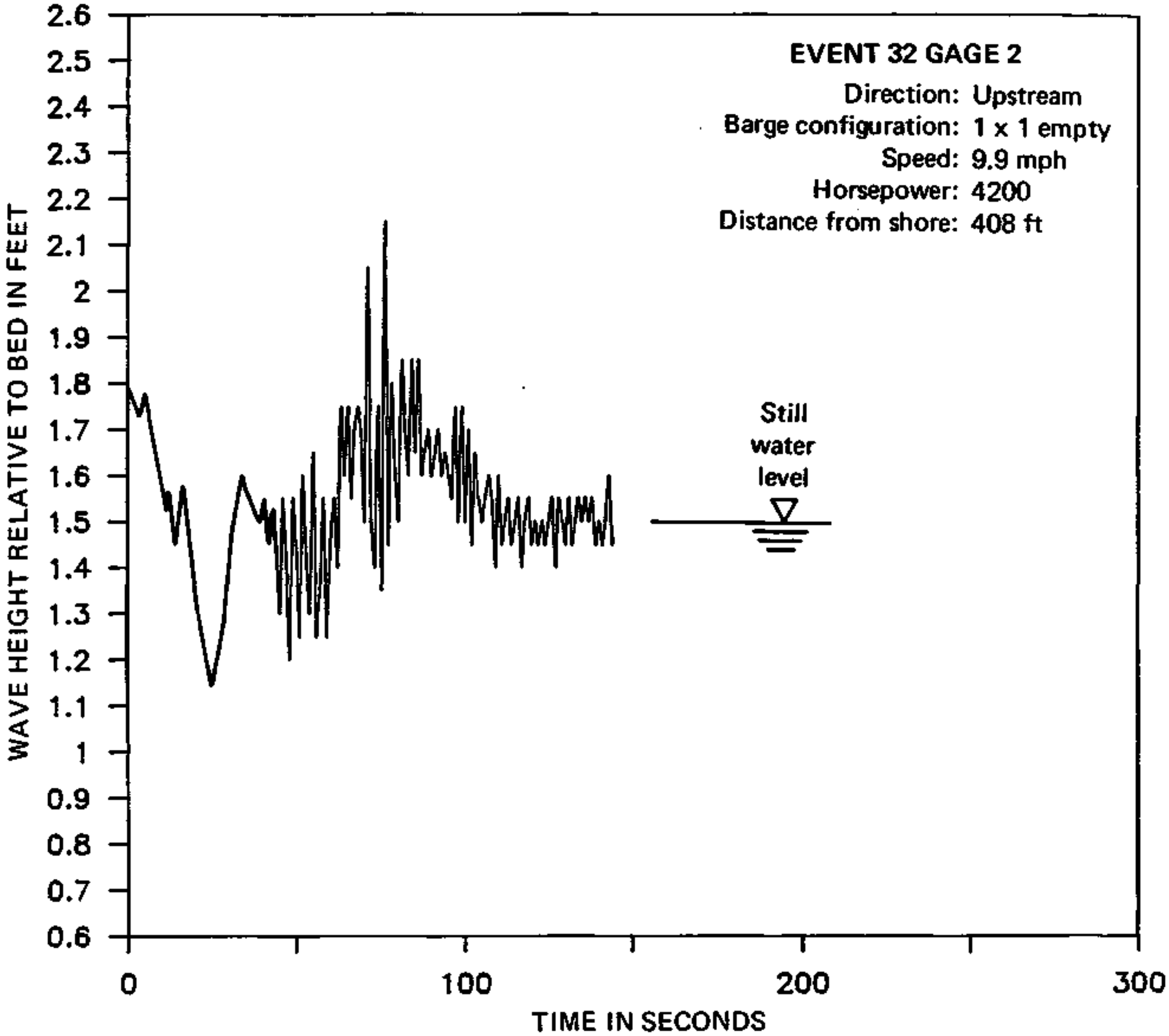
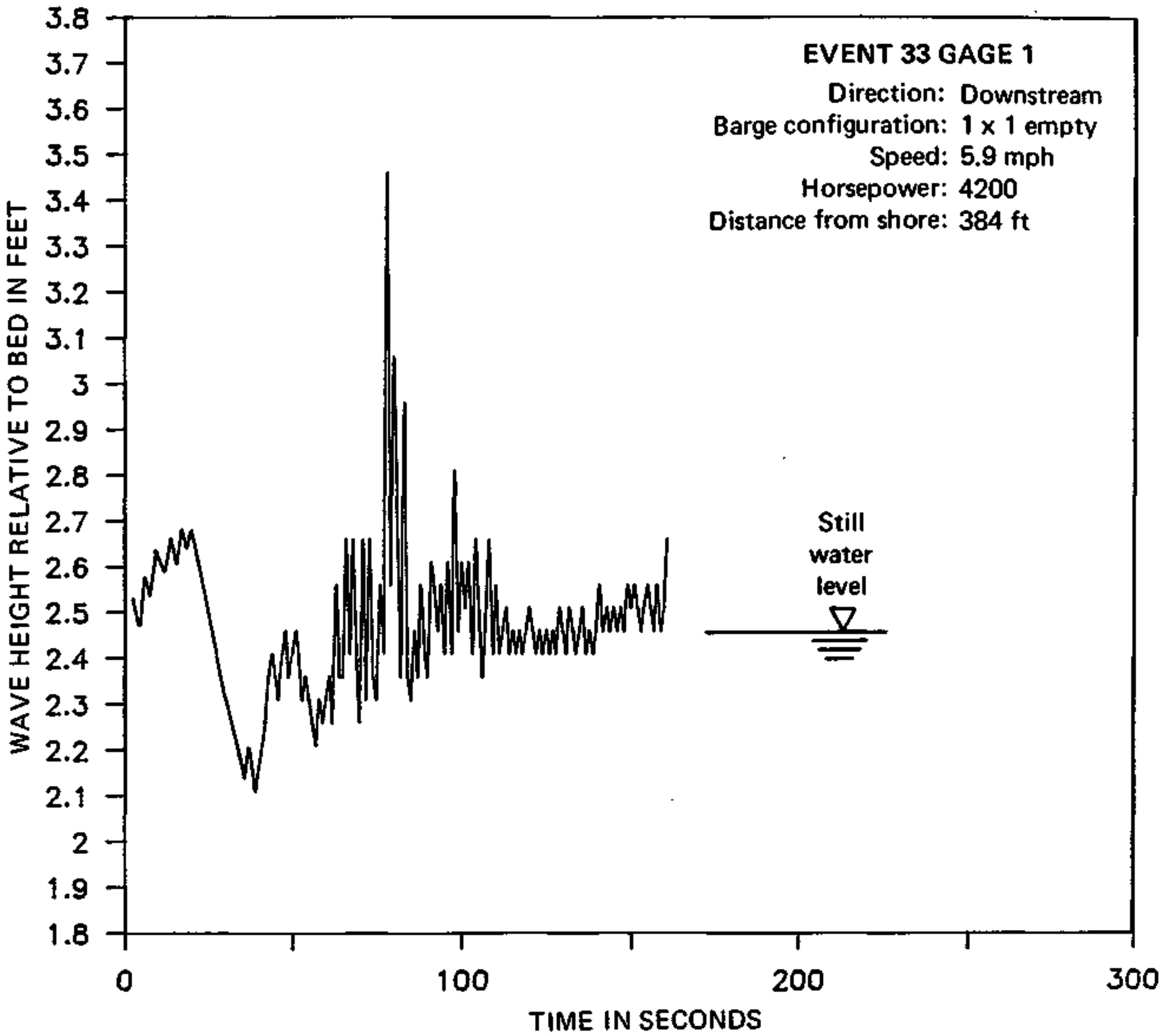
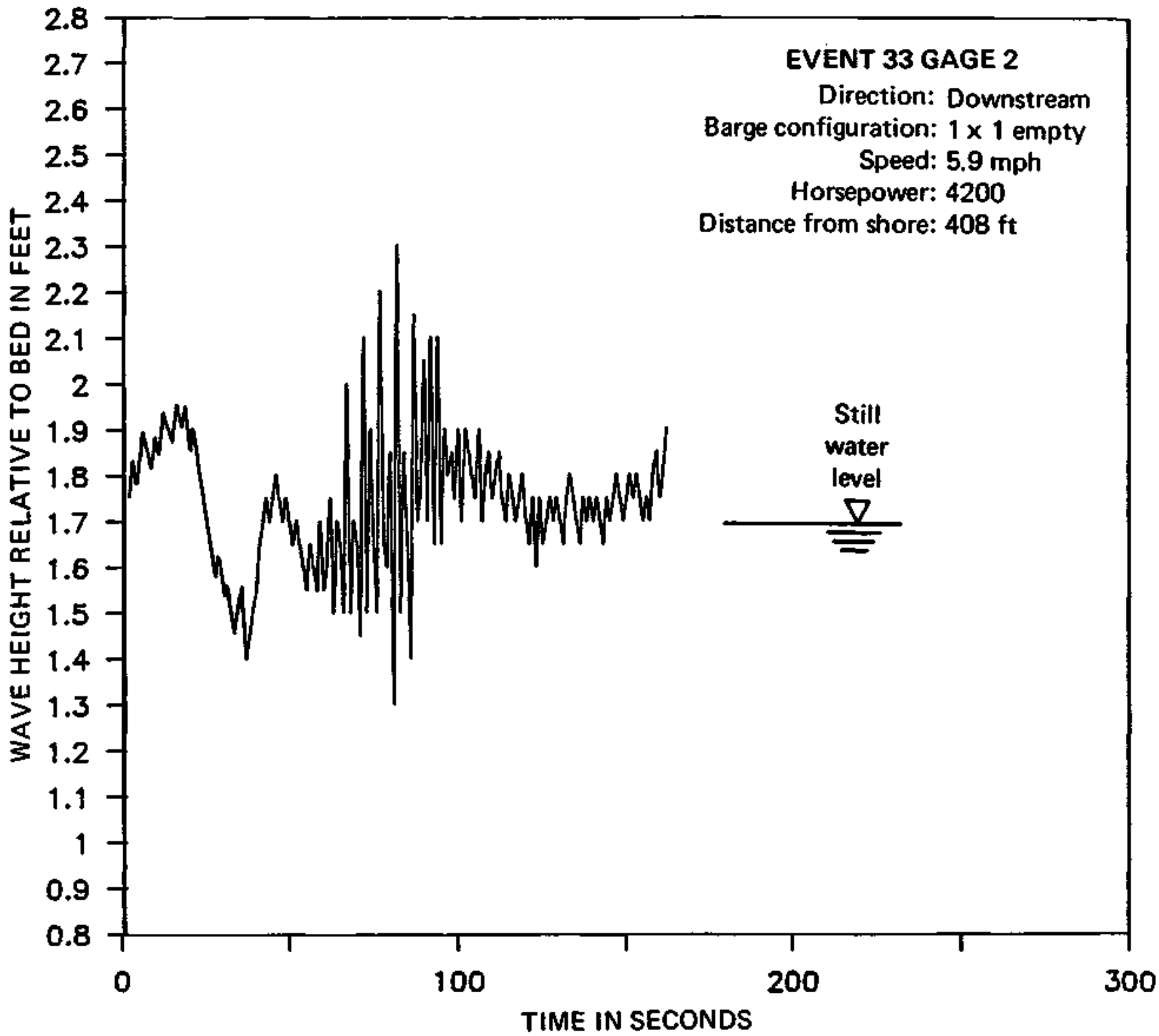
Appendix A. Selected Wave and Drawdown Characteristics of the Tow Events

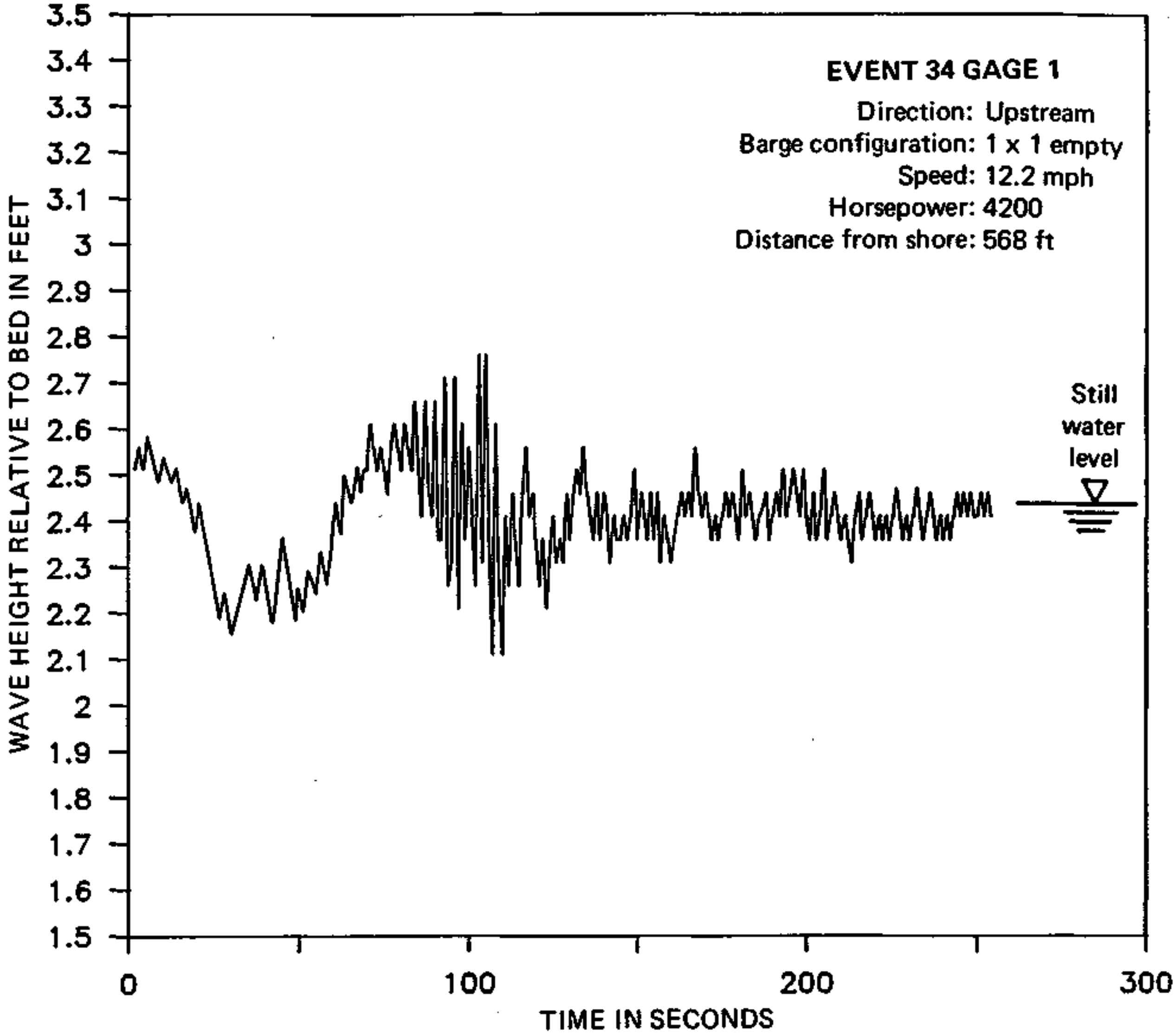

EVENT 32 GAGE 1
Direction: Upstream
Barge configuration: 1 x 1 empty
Speed: 9.9 mph
Horsepower: 4200
Distance from shore: 384 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
0
100
200
300
TIME IN SECONDS

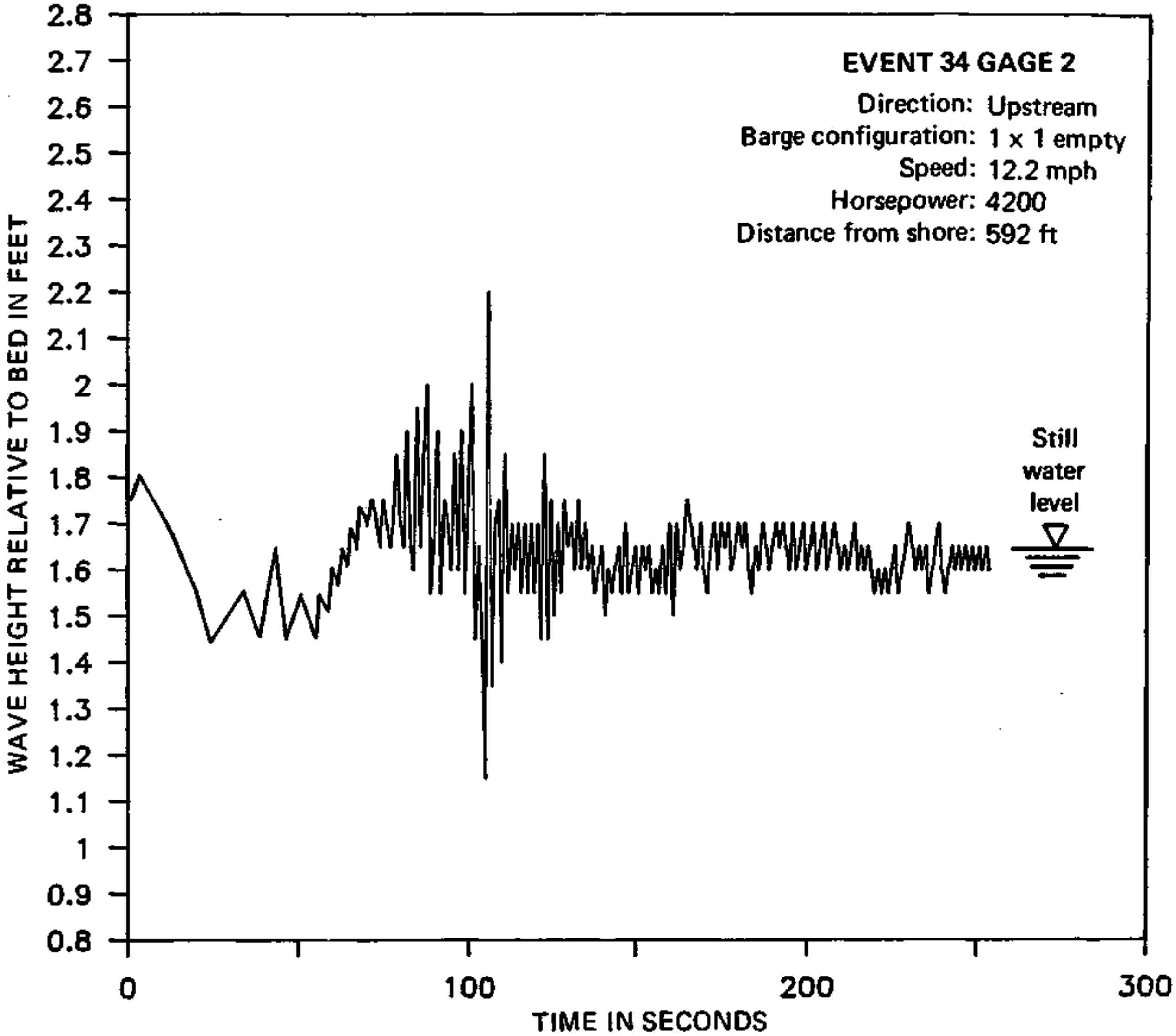


EVENT 32 GAGE 2
Direction: Upstream
Barge configuration: 1 x 1 empty
Speed: 9.9 mph
Horsepower: 4200
Distance from shore: 408 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
100
200
300
TIME IN SECONDS


EVENT 33 GAGE 1
Direction: Downstream
Barge configuration: 1 x 1 empty
Speed: 5.9 mph
Horsepower: 4200
Distance from shore: 384 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
0
100
200
300
TIME IN SECONDS


EVENT 33 GAGE 2
Direction: Downstream
Barge configuration: 1 x 1 empty
Speed: 5.9 mph
Horsepower: 4200
Distance from shore: 408 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
TIME IN SECONDS
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
100
200
300


EVENT 34 GAGE 1
Direction: Upstream
Barge configuration: 1 x 1 empty
Speed: 12.2 mph
Horsepower: 4200
Distance from shore: 568 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
0
100
200
300
TIME IN SECONDS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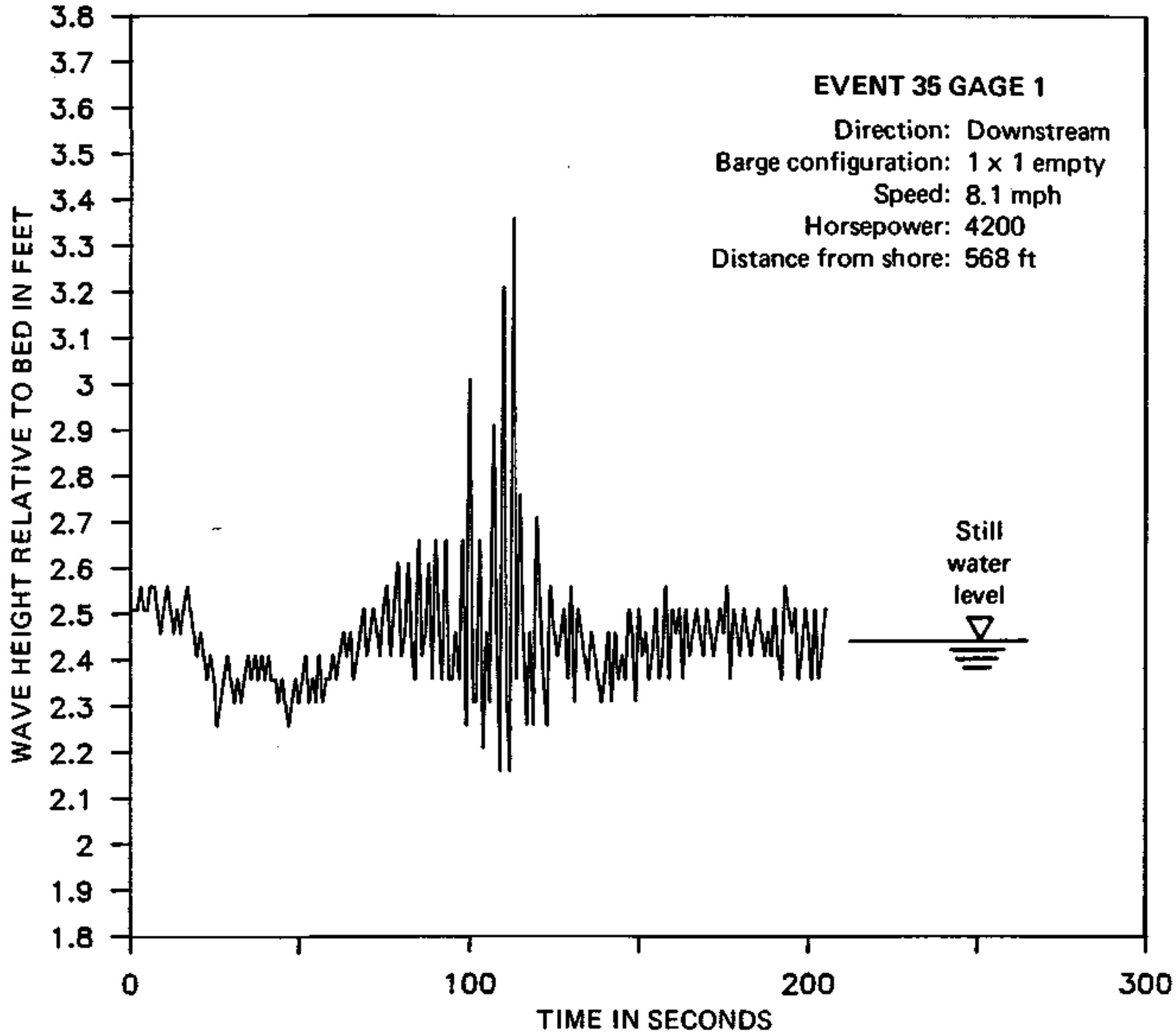
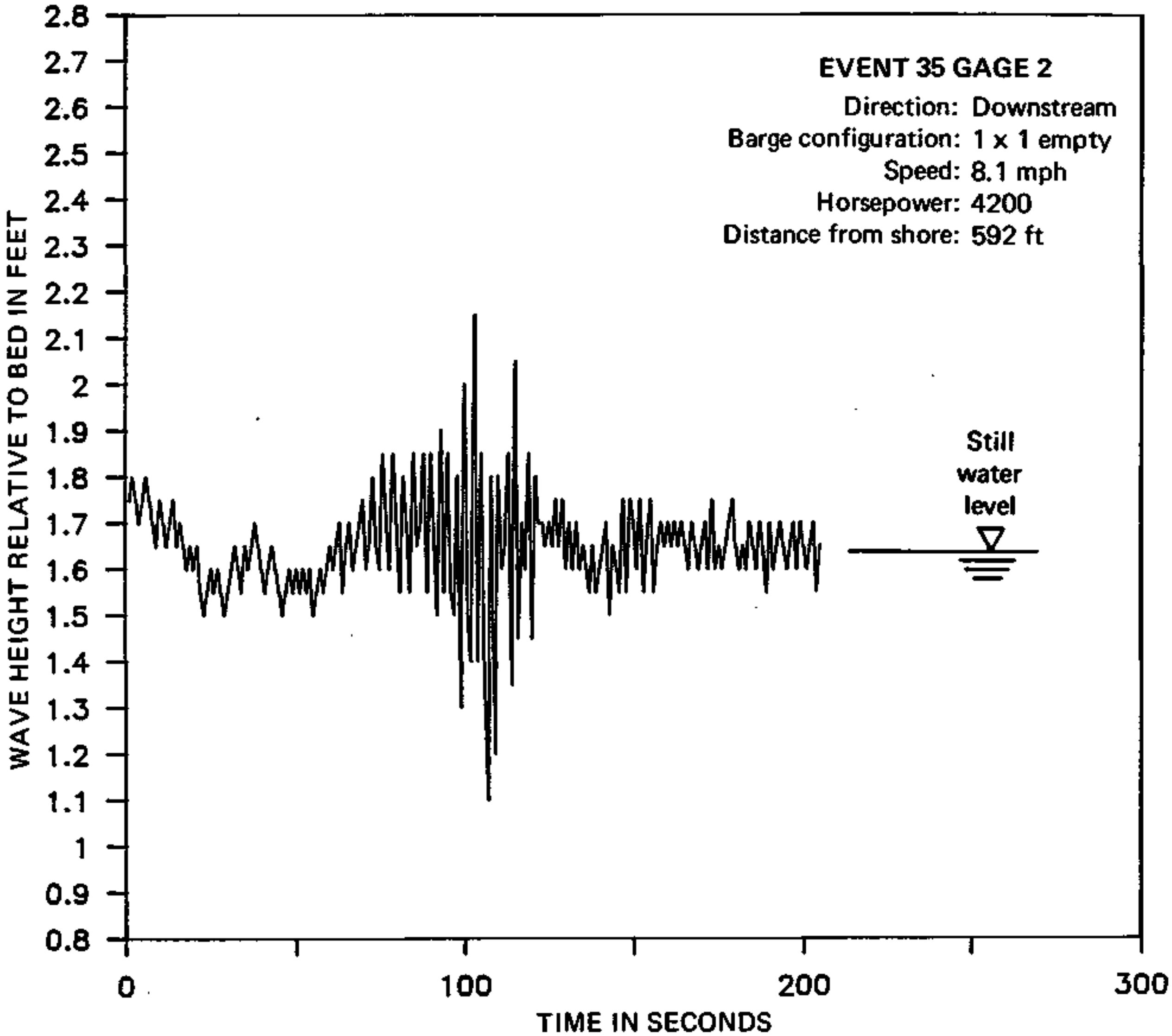
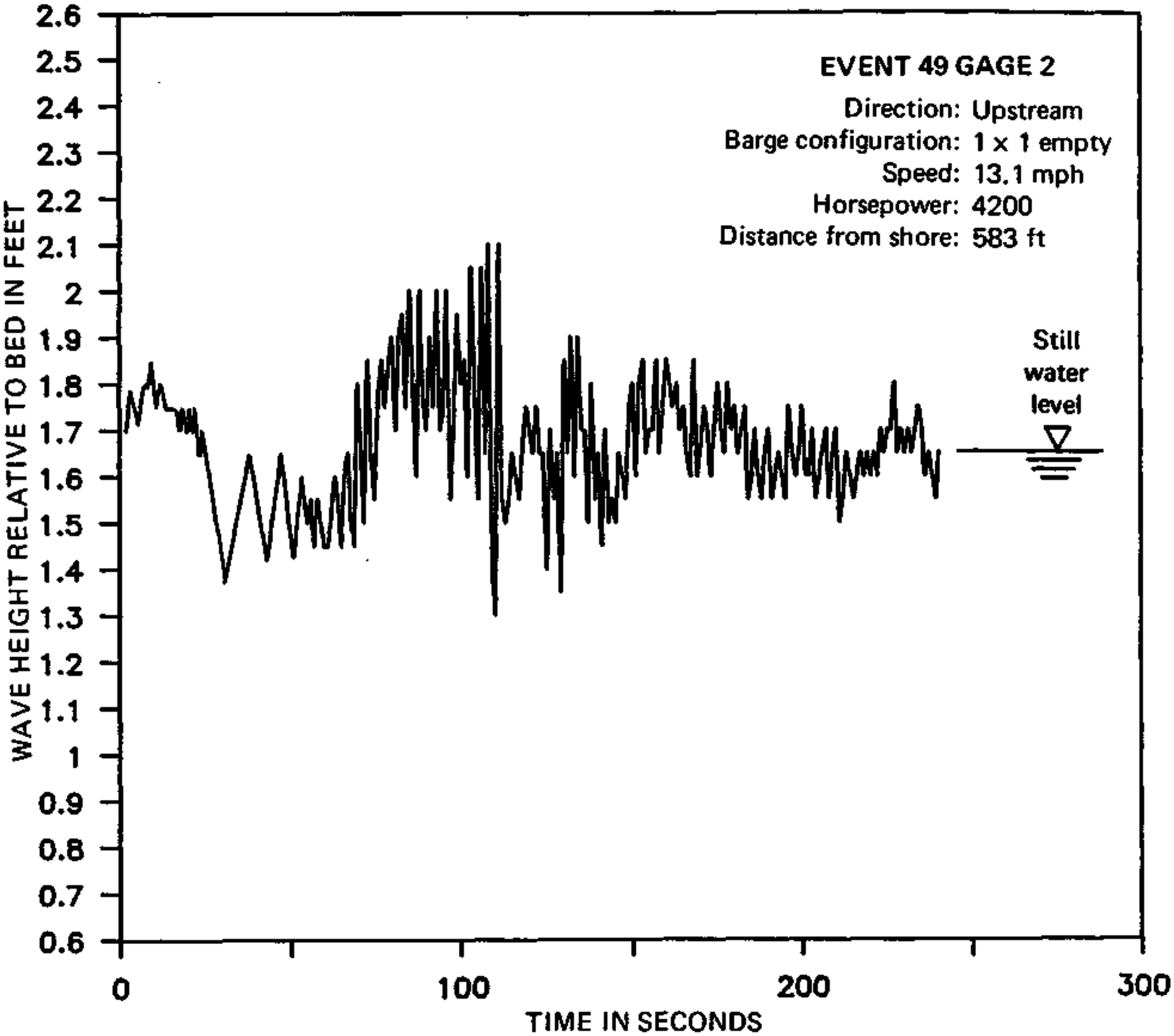
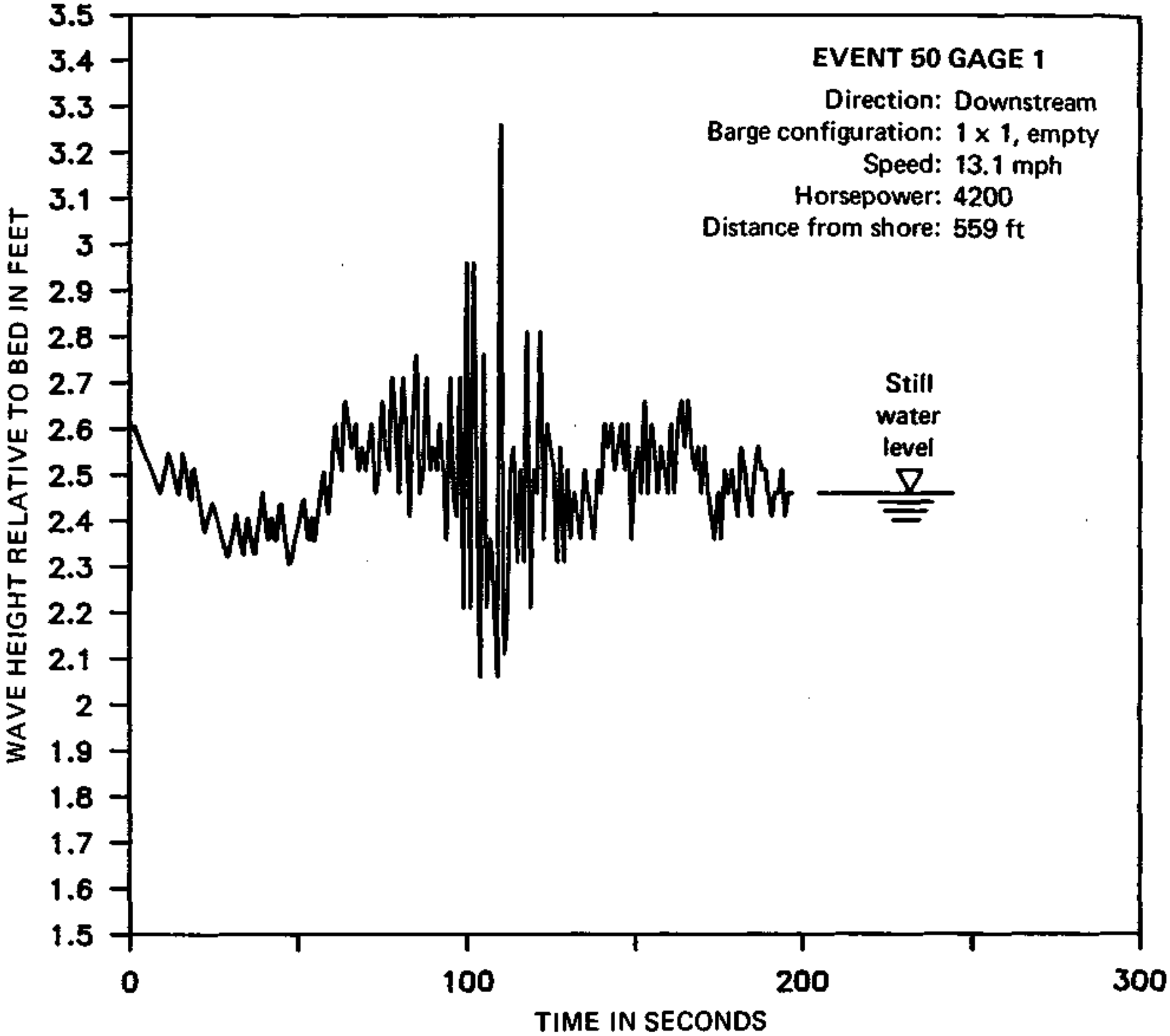
Direction: Upstream
Barge configuration: 1 x 1 empty
Speed: 12.2 mph
Horsepower: 4200
Distance from shore: 592 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
TIME IN SECONDS
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
100
200
300



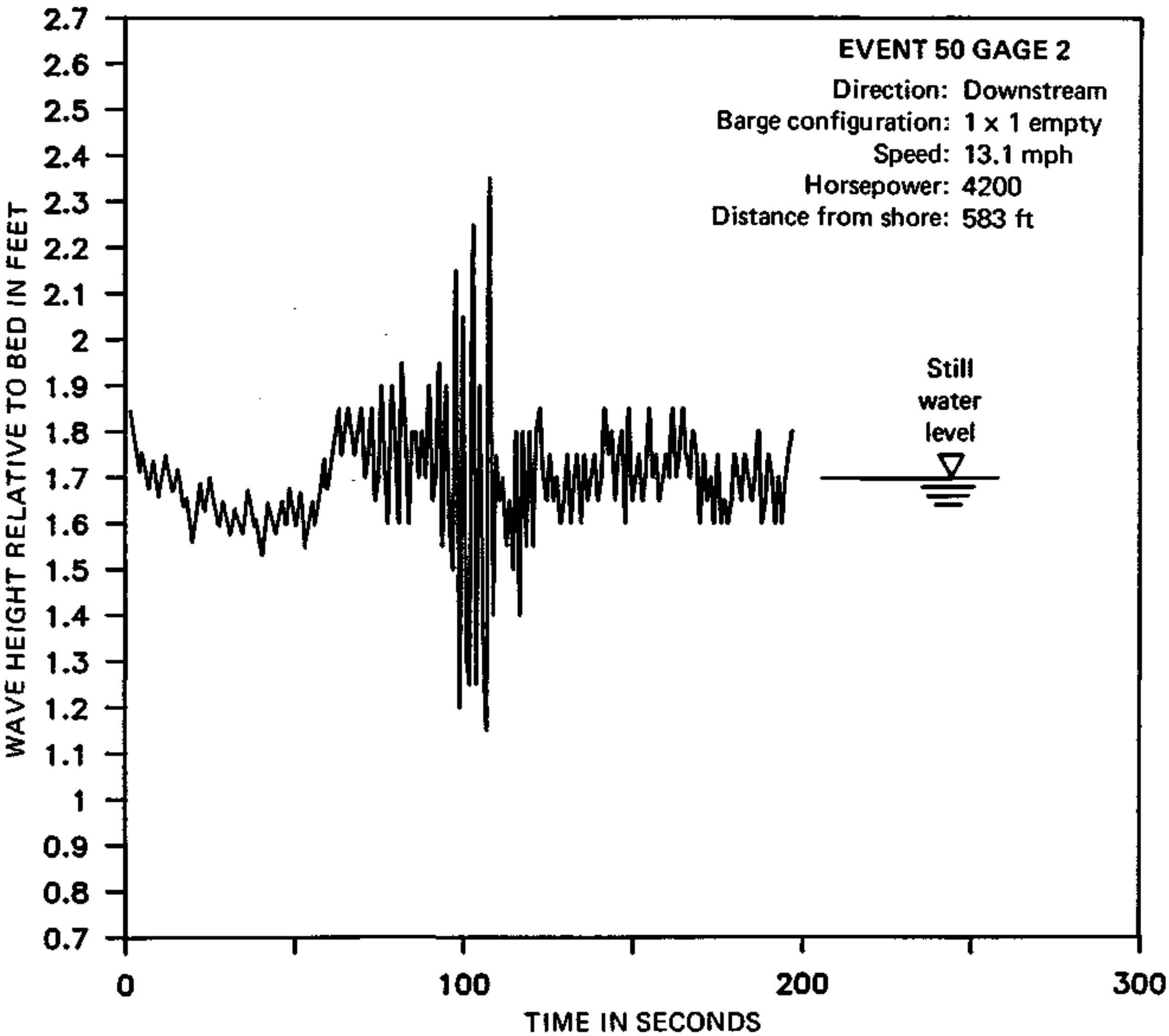
EVENT 35 GAGE 1
Direction: Downstream
Barge configuration: 1 x 1 empty
Speed: 8.1 mph
Horsepower: 4200
Distance from shore: 568 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
0
100
200
300
TIME IN SECONDS


EVENT 35 GAGE 2
Direction: Downstream
Barge configuration: 1 x 1 empty
Speed: 8.1 mph
Horsepower: 4200
Distance from shore: 592 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
100
200
300
TIME IN SECONDS

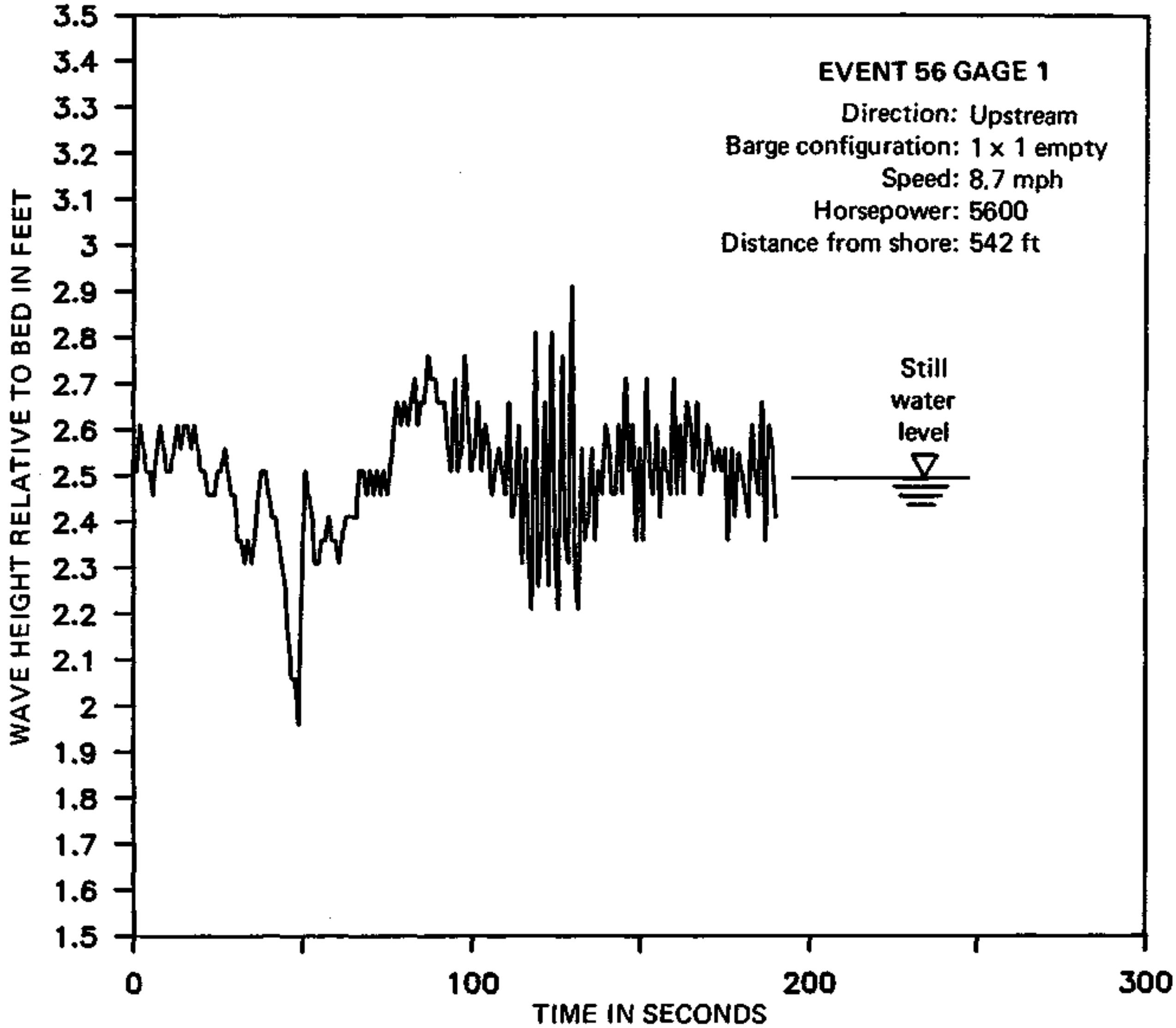

EVENT 49 GAGE 2
Direction: Upstream
Barge configuration: 1 x 1 empty
Speed: 13.1 mph
Horsepower: 4200
Distance from shore: 583 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
TIME IN SECONDS
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
100
200
300



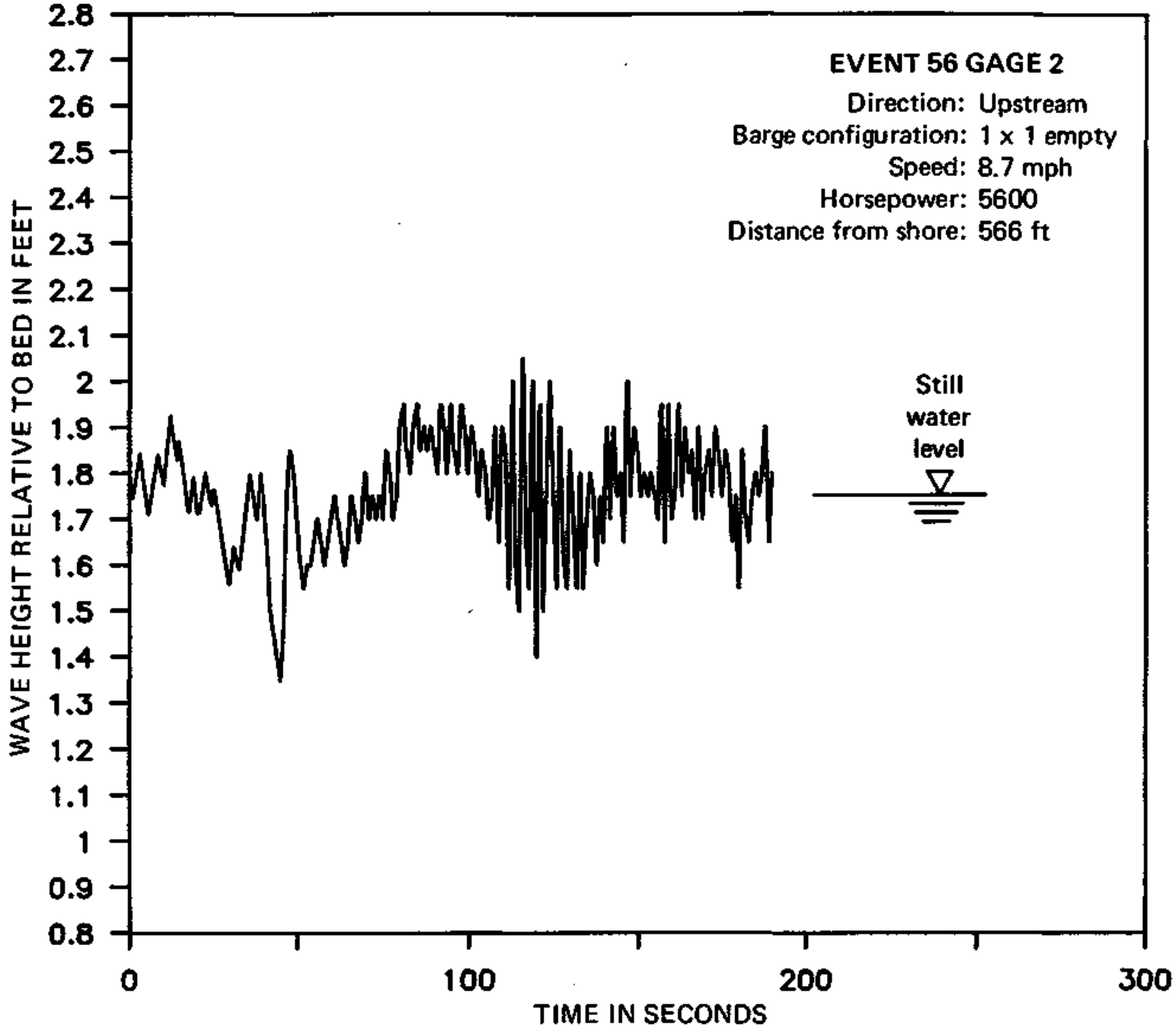
EVENT 50 GAGE 1
Direction: Downstream
Barge configuration: 1 x 1, empty
Speed: 13.1 mph
Horsepower: 4200
Distance from shore: 559 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
TIME IN SECONDS
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
0
100
200
300



EVENT 50 GAGE 2
Direction: Downstream
Barge configuration: 1 x 1 empty
Speed: 13.1 mph
Horsepower: 4200
Distance from shore: 583 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
100
200
300
TIME IN SECONDS



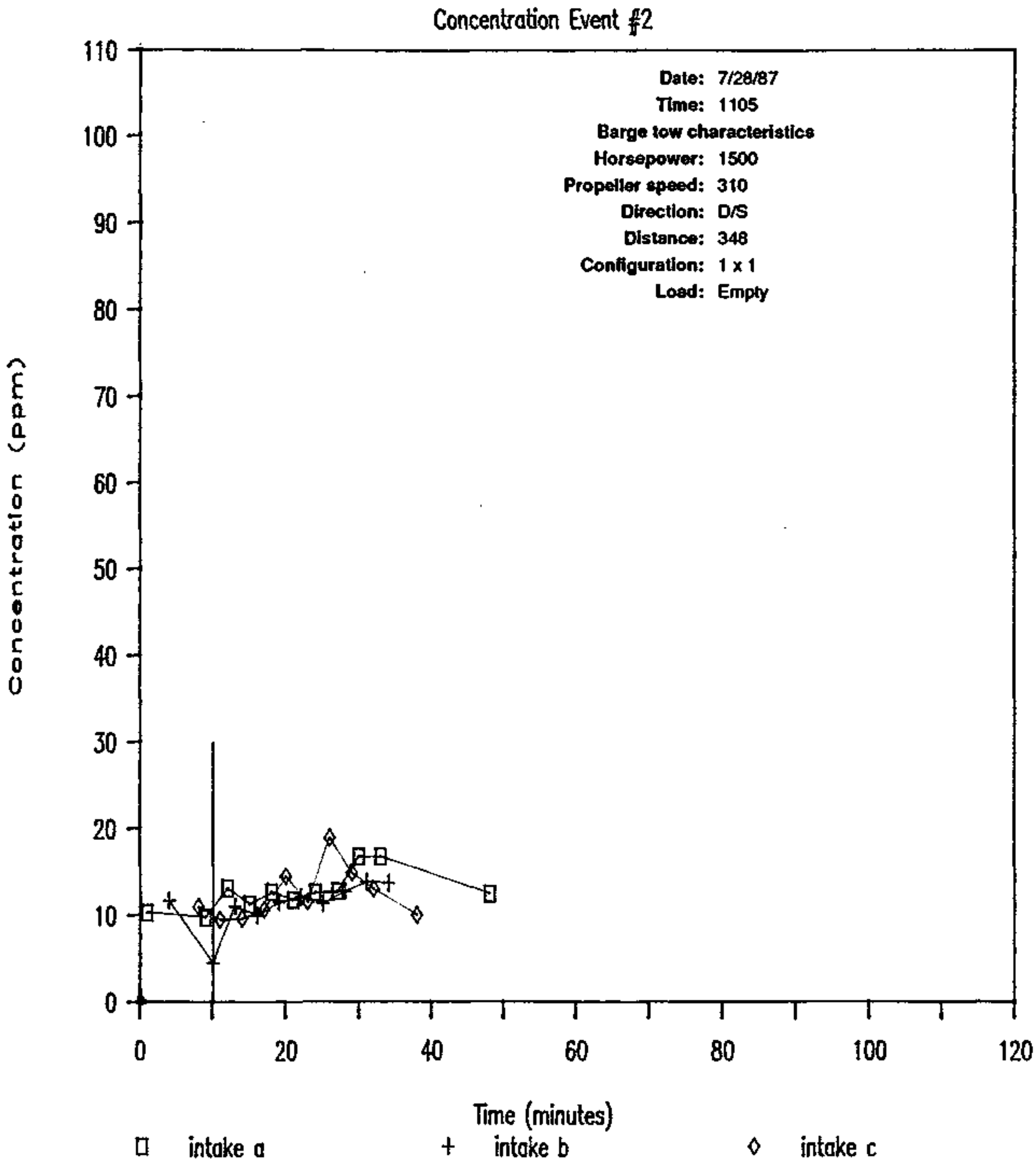
EVENT 56 GAGE 1
Direction: Upstream
Barge configuration: 1 x 1 empty
Speed: 8.7 mph
Horsepower: 5600
Distance from shore: 542 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
0
100
200
300
TIME IN SECONDS



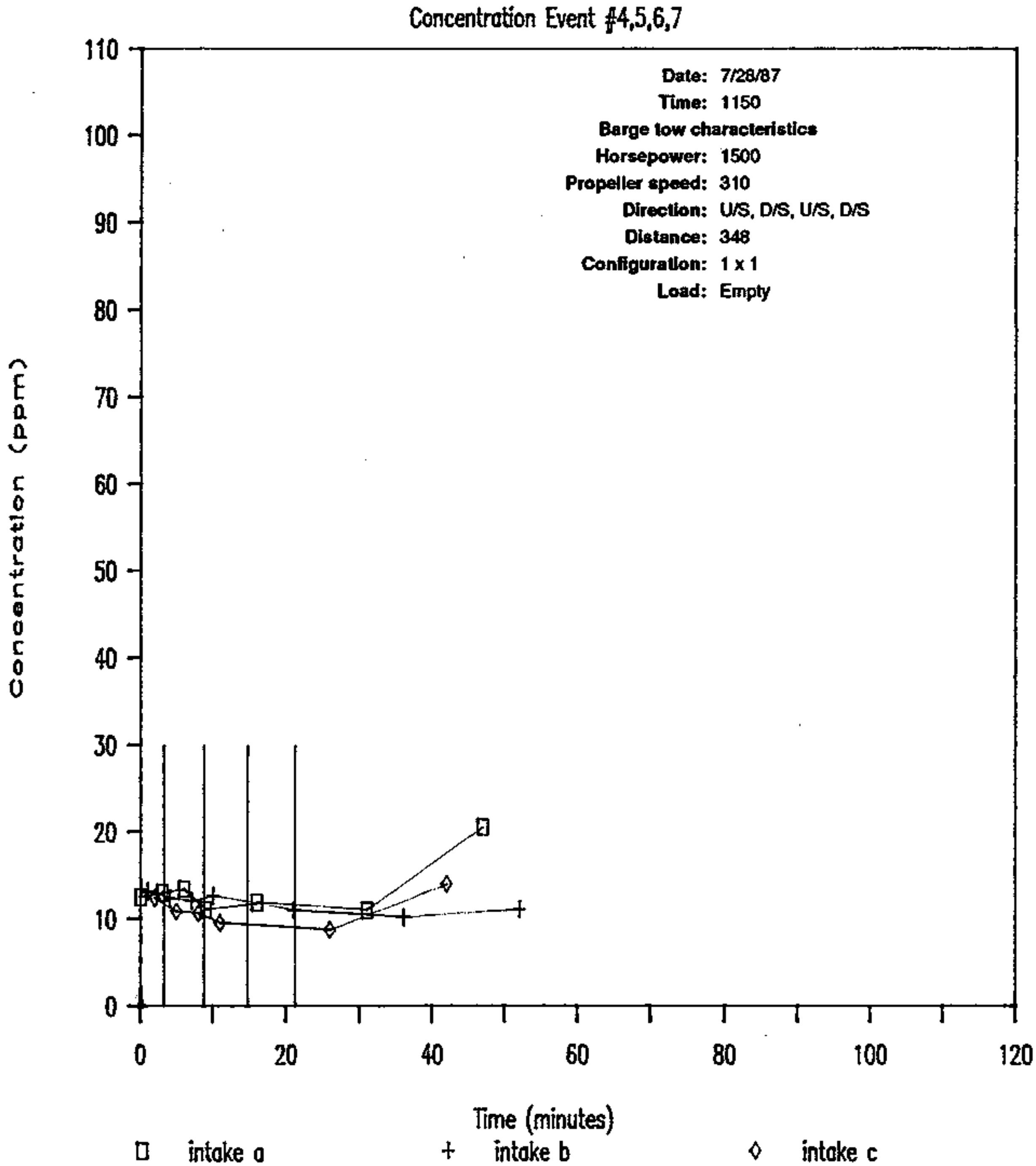
EVENT 56 GAGE 2
Direction: Upstream
Barge configuration: 1 x 1 empty
Speed: 8.7 mph
Horsepower: 5600
Distance from shore: 566 ft
Still water level
WAVE HEIGHT RELATIVE TO BED IN FEET
TIME IN SECONDS
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
100
200
300

Appendix B. Selected Resuspension Characteristics of the Sediments

OHIO RIVER NAV-IMPACT STUDY



OHIO RIVER NAV-IMPACT STUDY



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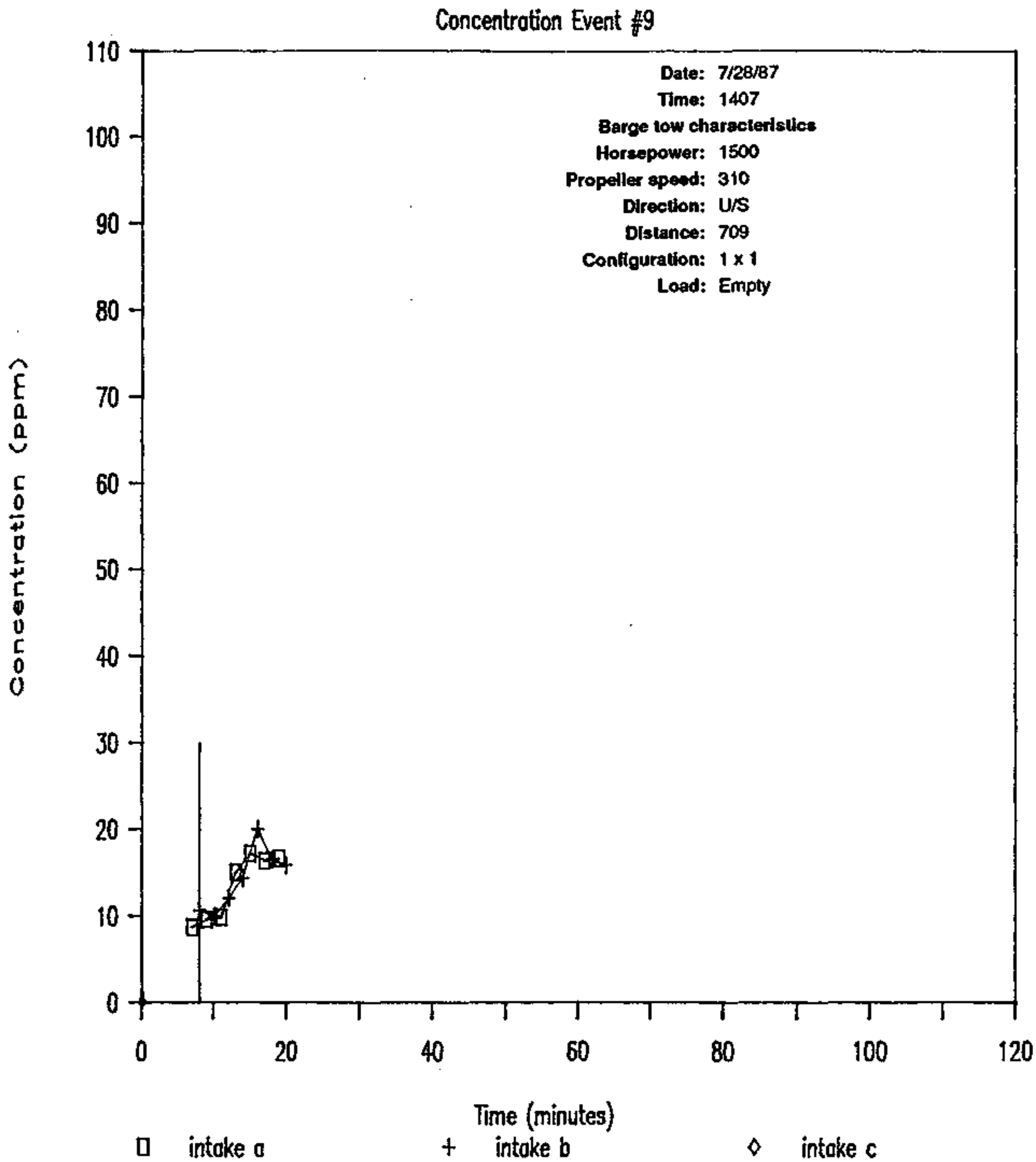
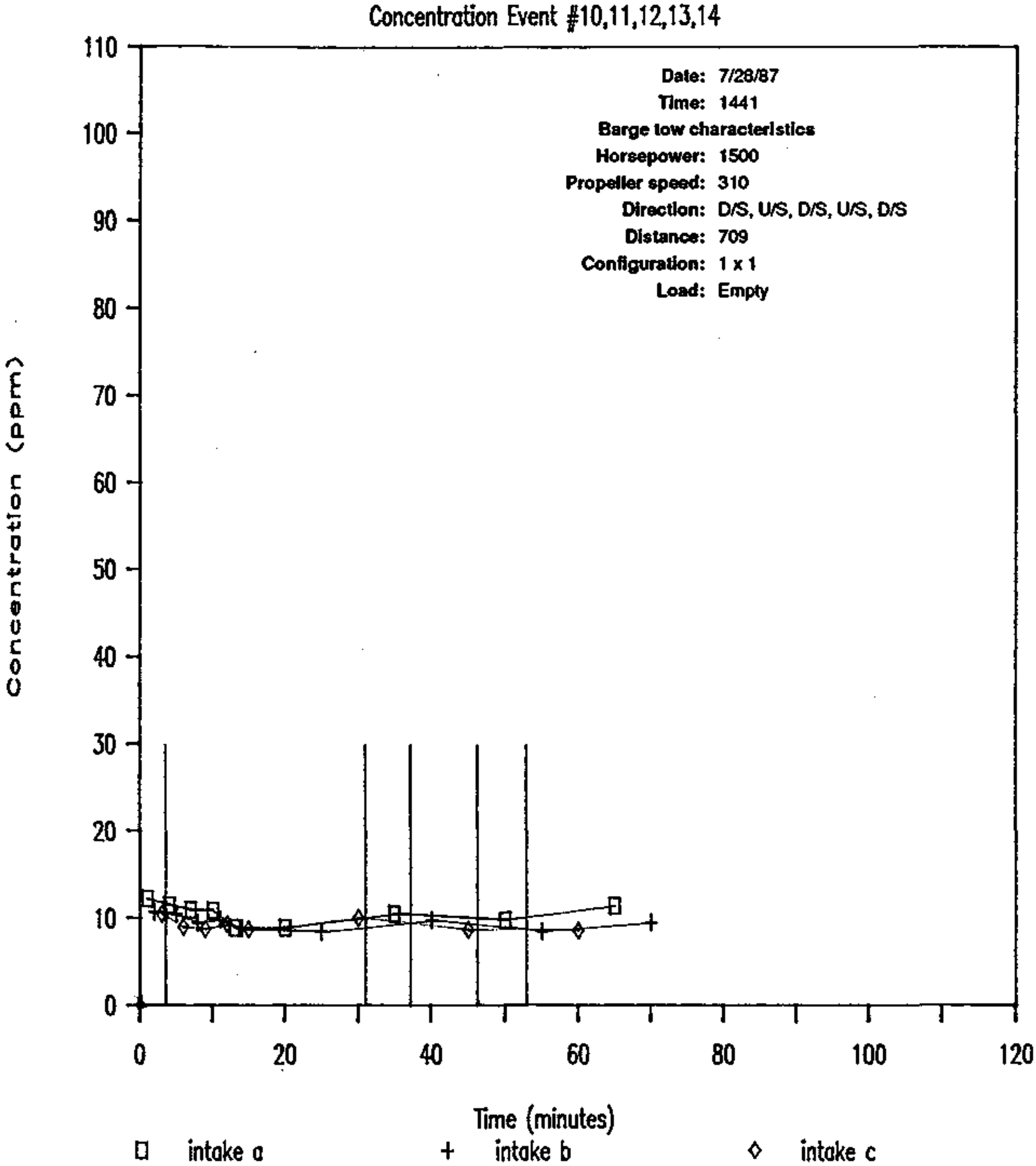
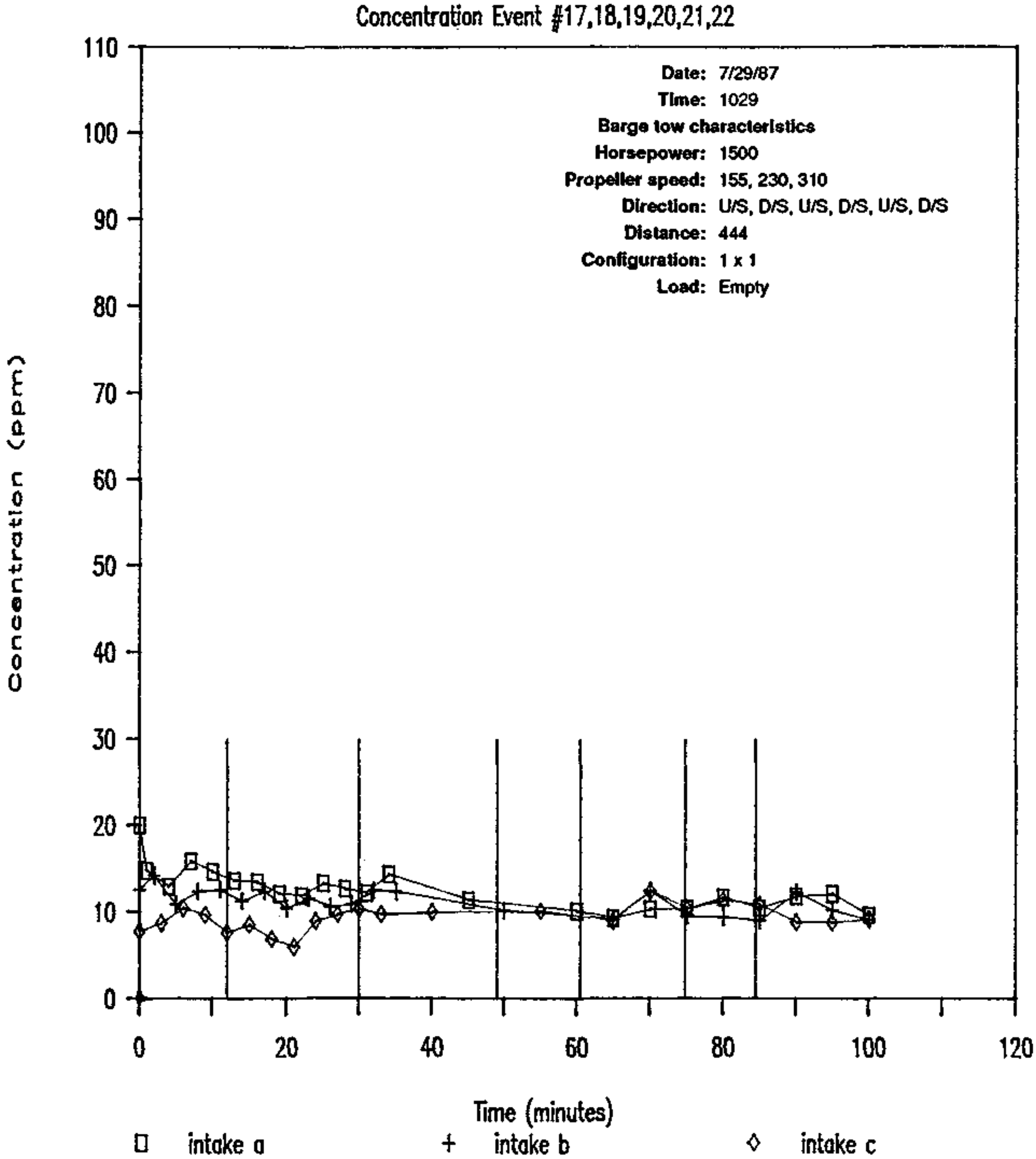


OHIO RIVER NAV-IMPACT STUDY

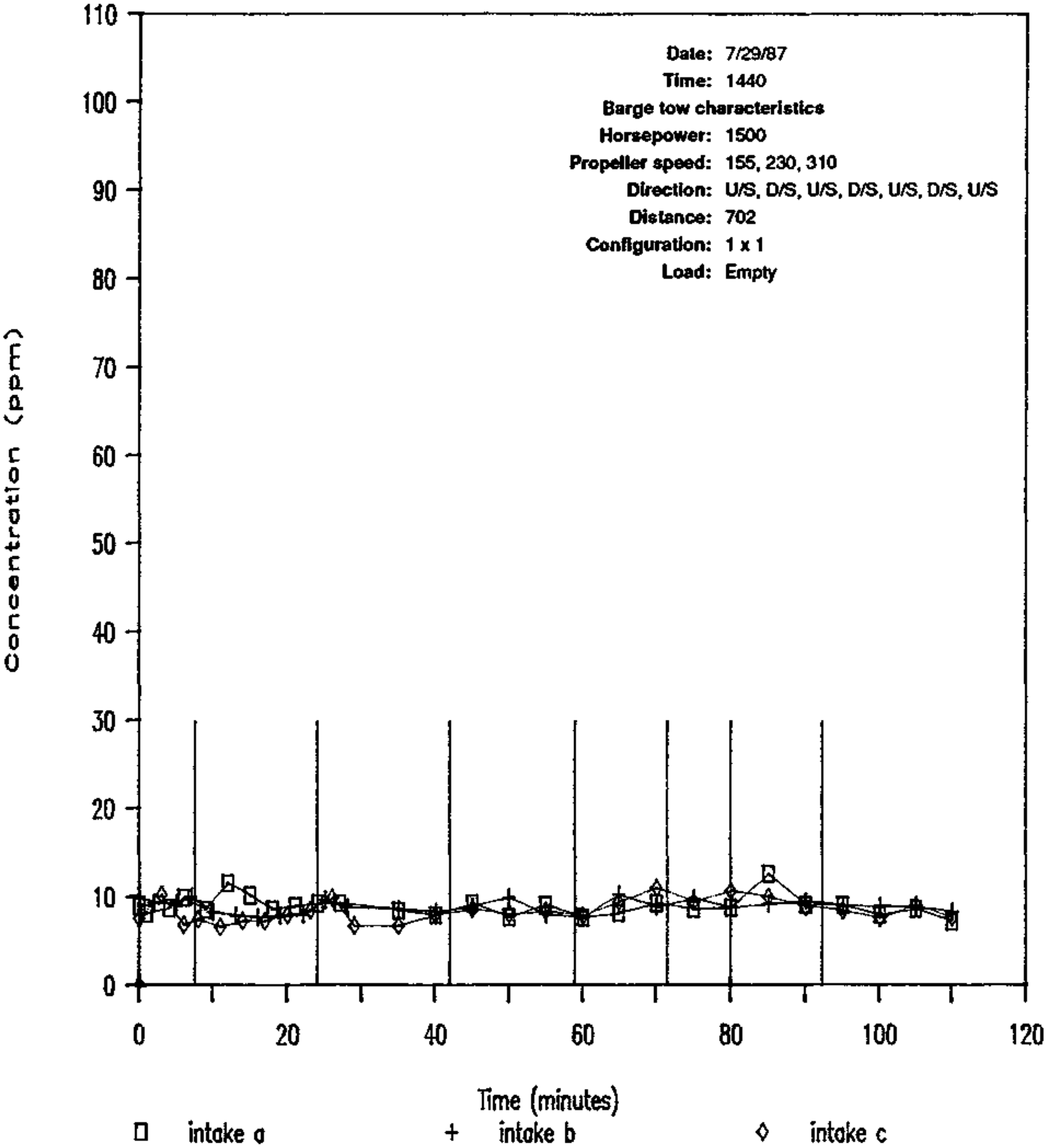


OHIO RIVER NAV-IMPACT STUDY

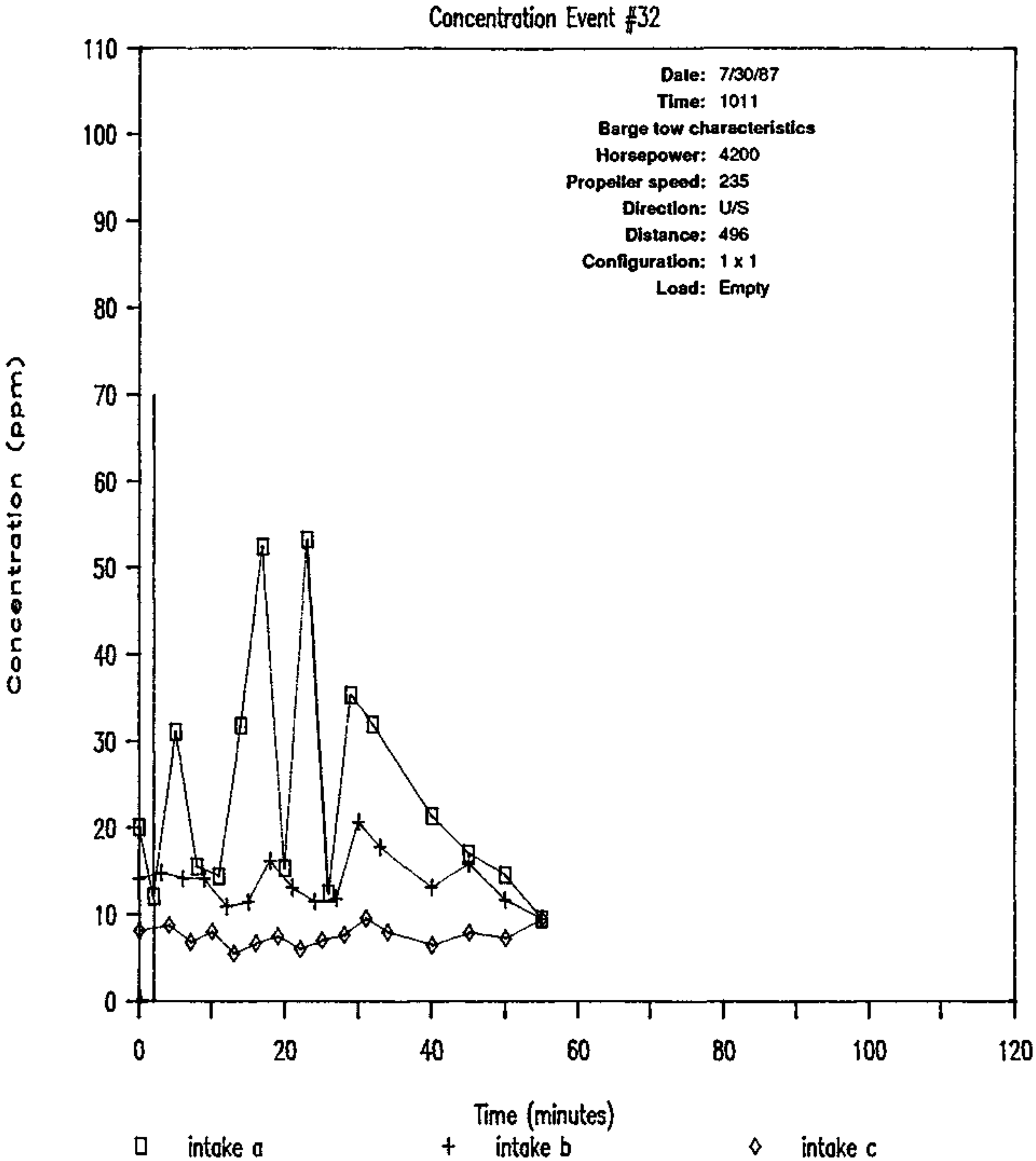


OHIO RIVER NAV-IMPACT STUDY

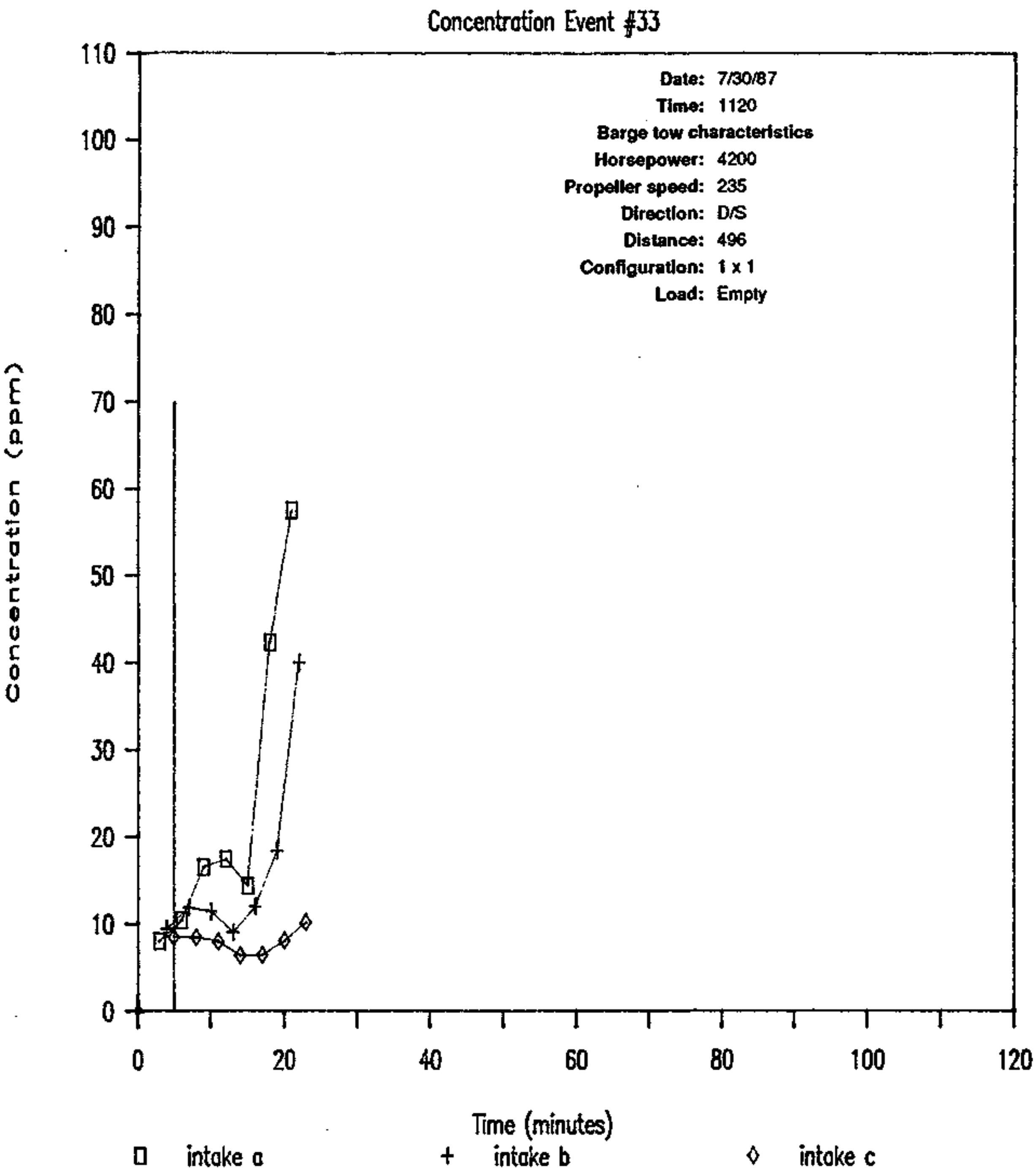
Concentration Event #24,25,26,27,28,29,



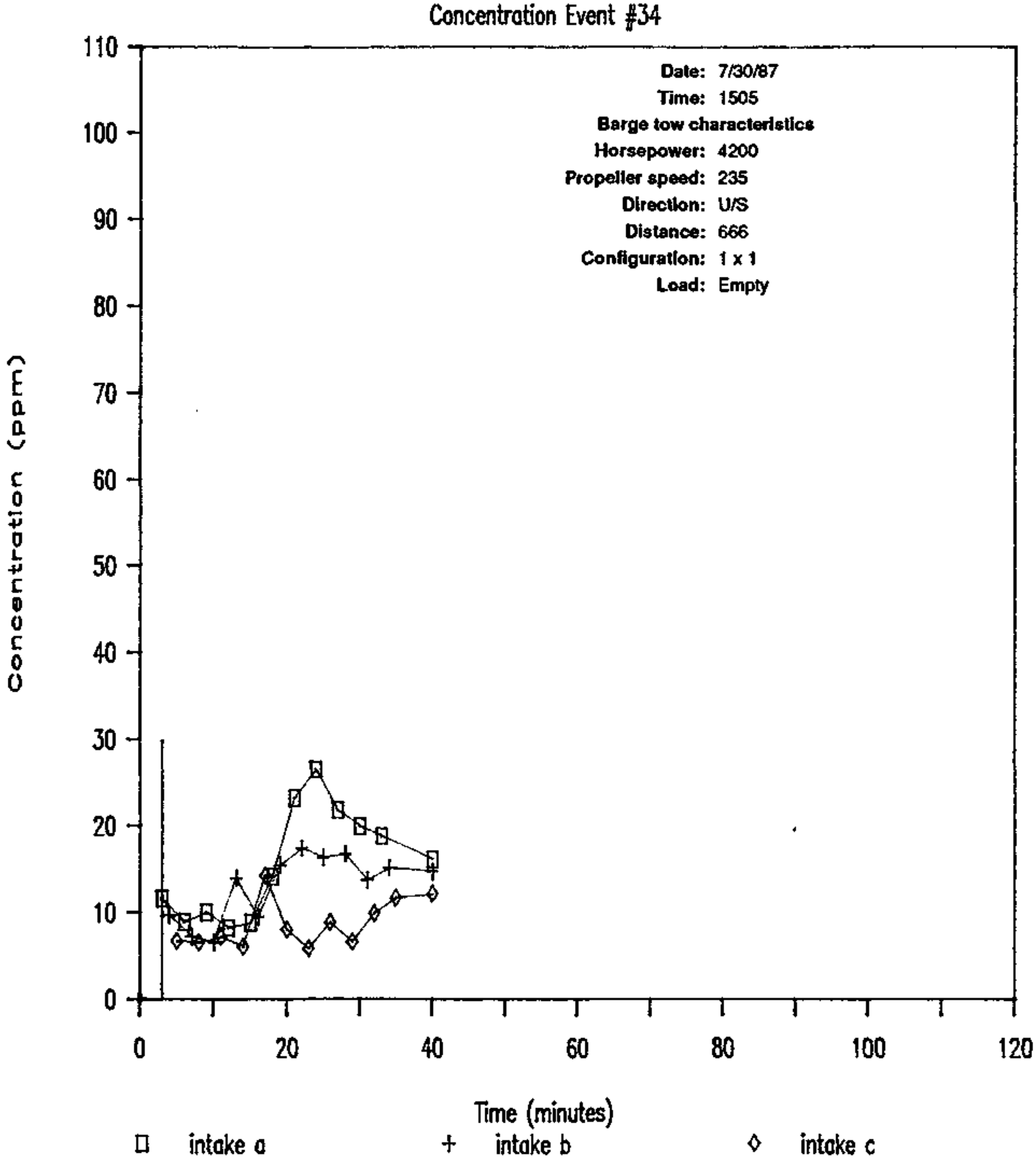
OHIO RIVER NAV-IMPACT STUDY



OHIO RIVER NAV-IMPACT STUDY

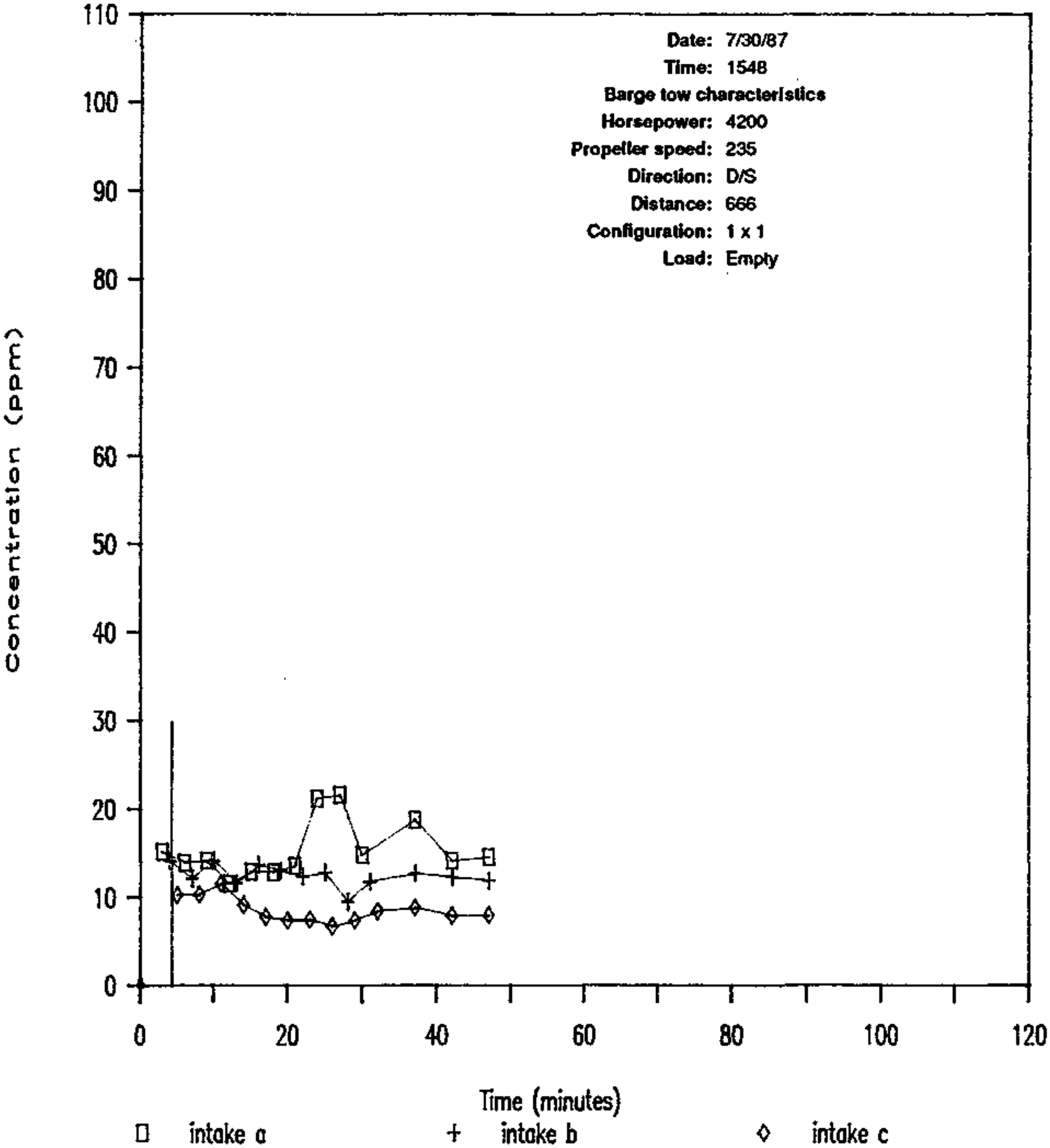


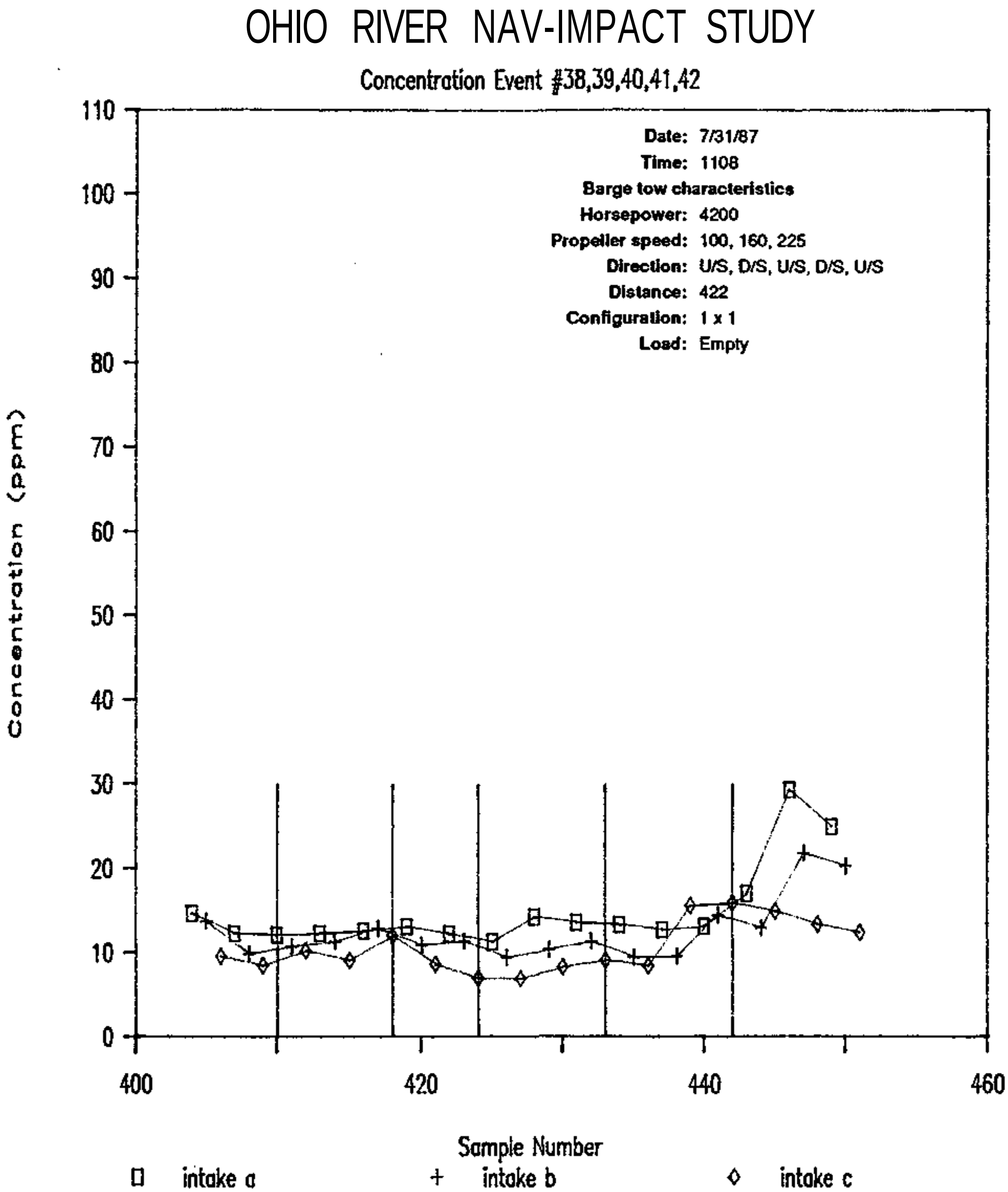
OHIO RIVER NAV-IMPACT STUDY



OHIO RIVER NAV-IMPACT STUDY

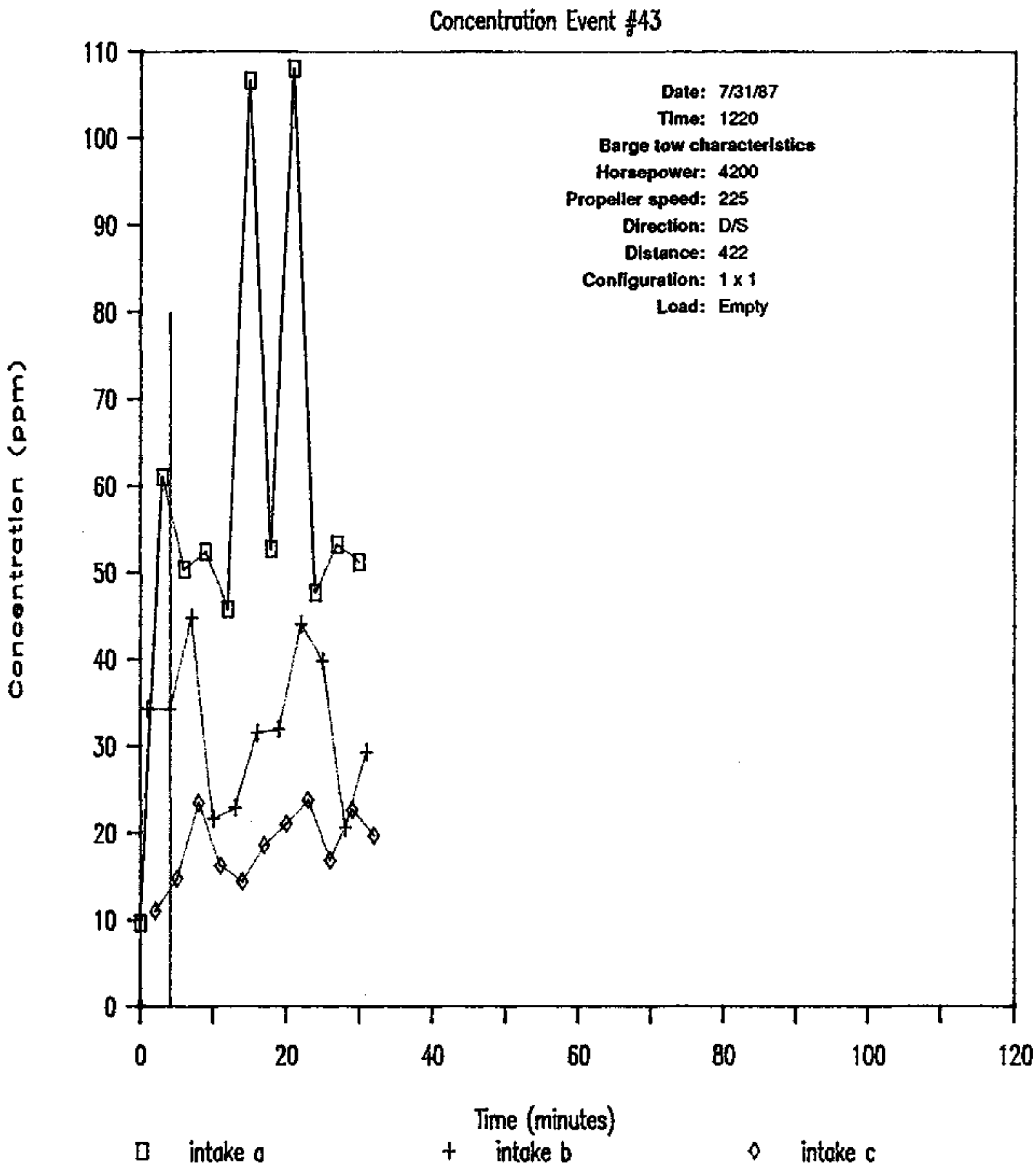
Concentration Event #35

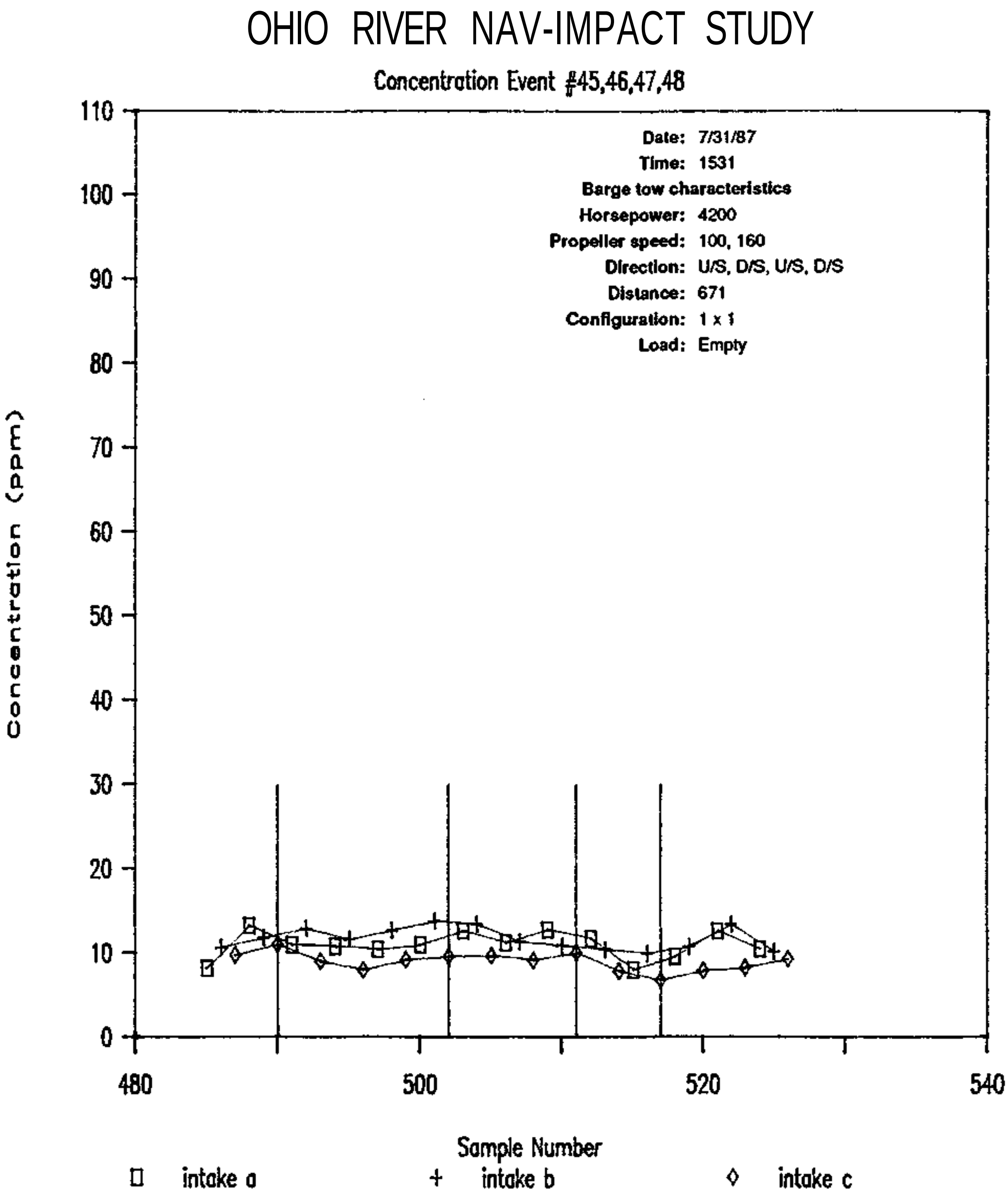




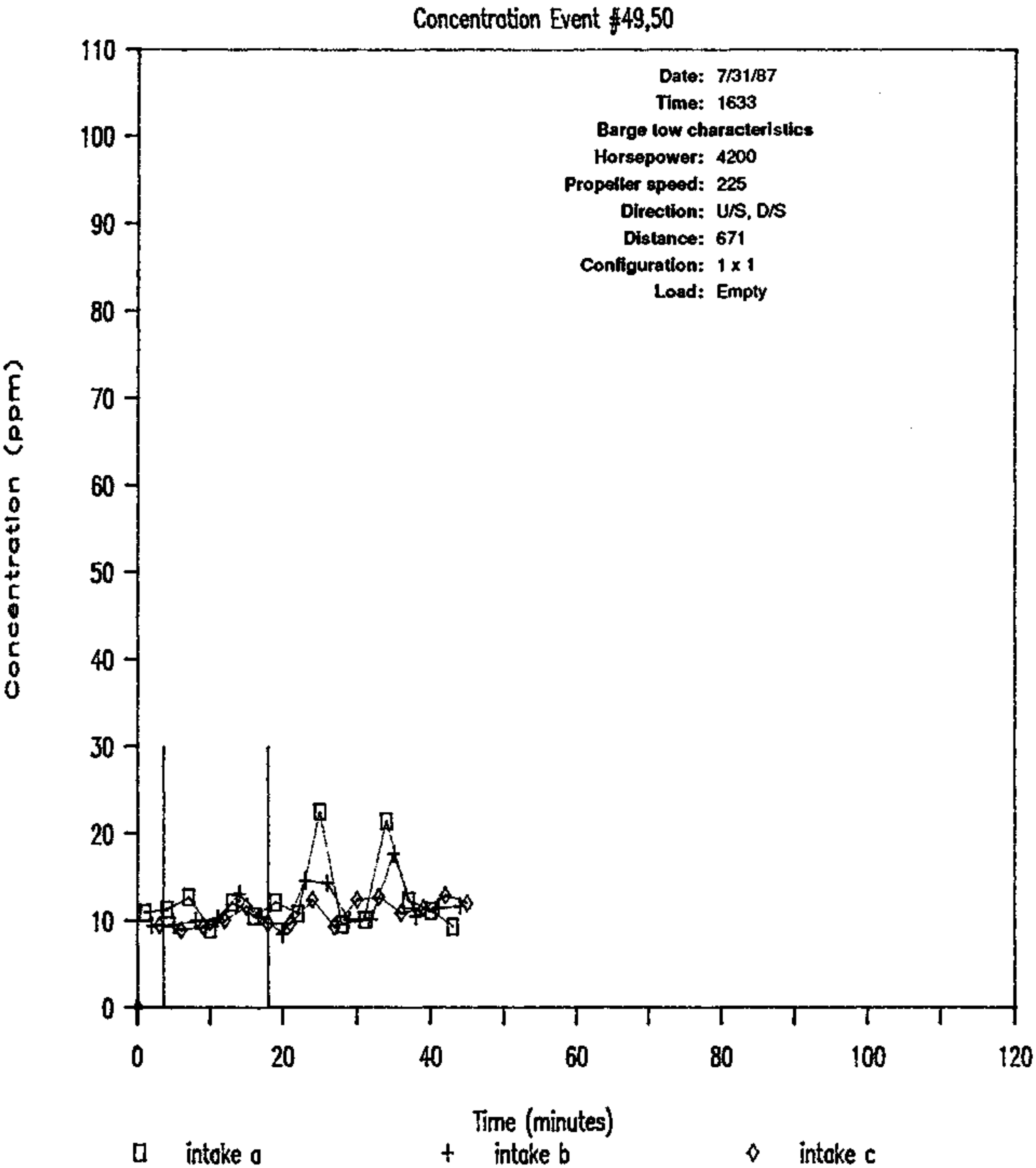
OHIO RIVER NAV-IMPACT STUDY
Concentration Event #38,39,40,41,42
Date: 7/31/87
Time: 1108
Barge tow characteristics
Horsepower: 4200
Propeller speed: 100, 160, 225
Direction: U/S, D/S, U/S, D/S, U/S
Distance: 422
Configuration: 1 x 1
Load: Empty
Concentration (ppm)
110
100
90
80
70
60
50
40
30
20
10
0
400
420
440
460
Sample Number
intake a
intake b
intake c

OHIO RIVER NAV-IMPACT STUDY

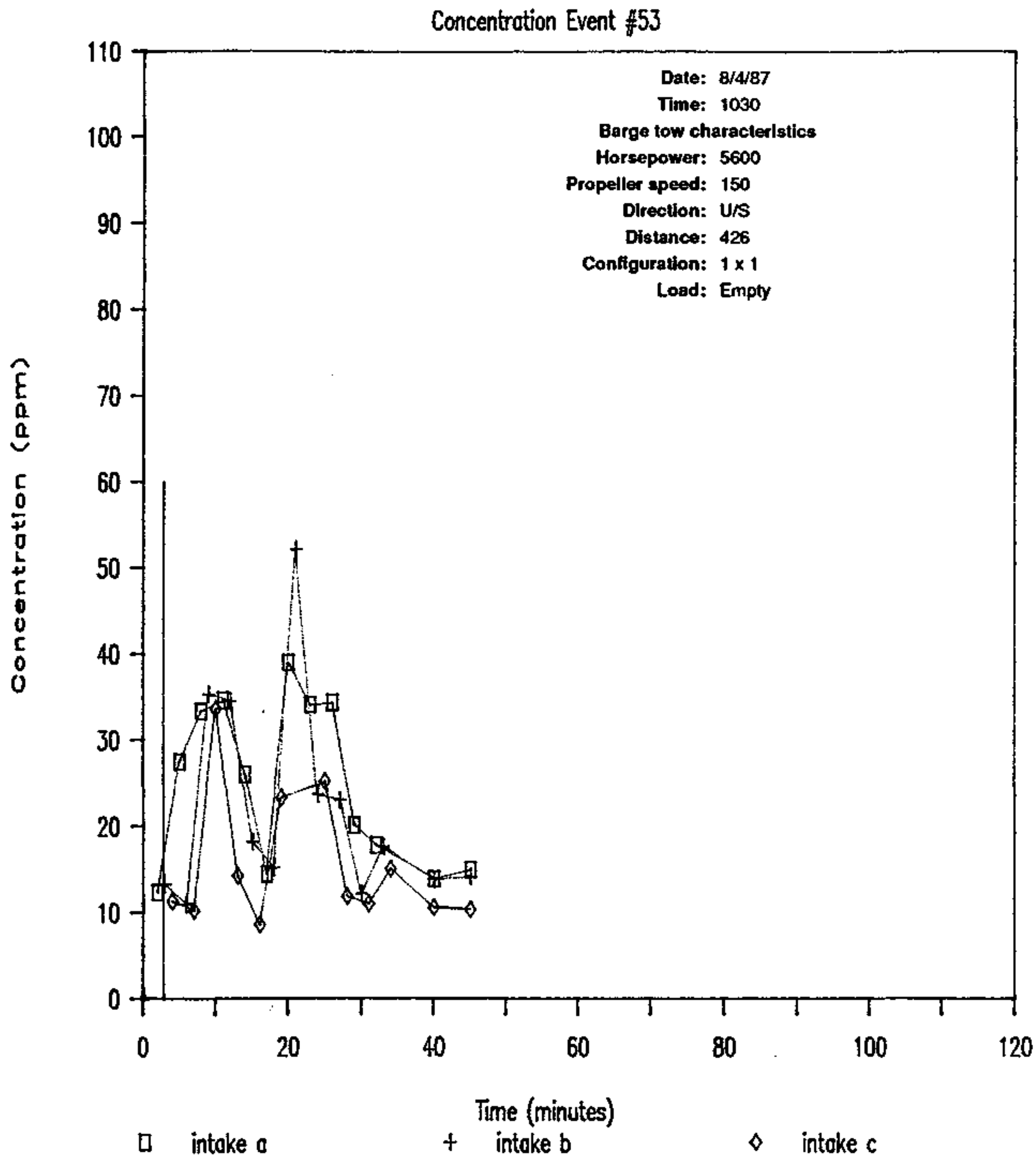



OHIO RIVER NAV-IMPACT STUDY
Concentration Event #45,46,47,48
Date: 7/31/87
Time: 1531
Barge tow characteristics
Horsepower: 4200
Propeller speed: 100, 160
Direction: U/S, D/S, U/S, D/S
Distance: 671
Configuration: 1 x 1
Load: Empty
Concentration (ppm)
110
100
90
80
70
60
50
40
30
20
10
0
480
500
520
540
Sample Number
intake a
intake b
intake c

OHIO RIVER NAV-IMPACT STUDY



OHIO RIVER NAV-IMPACT STUDY



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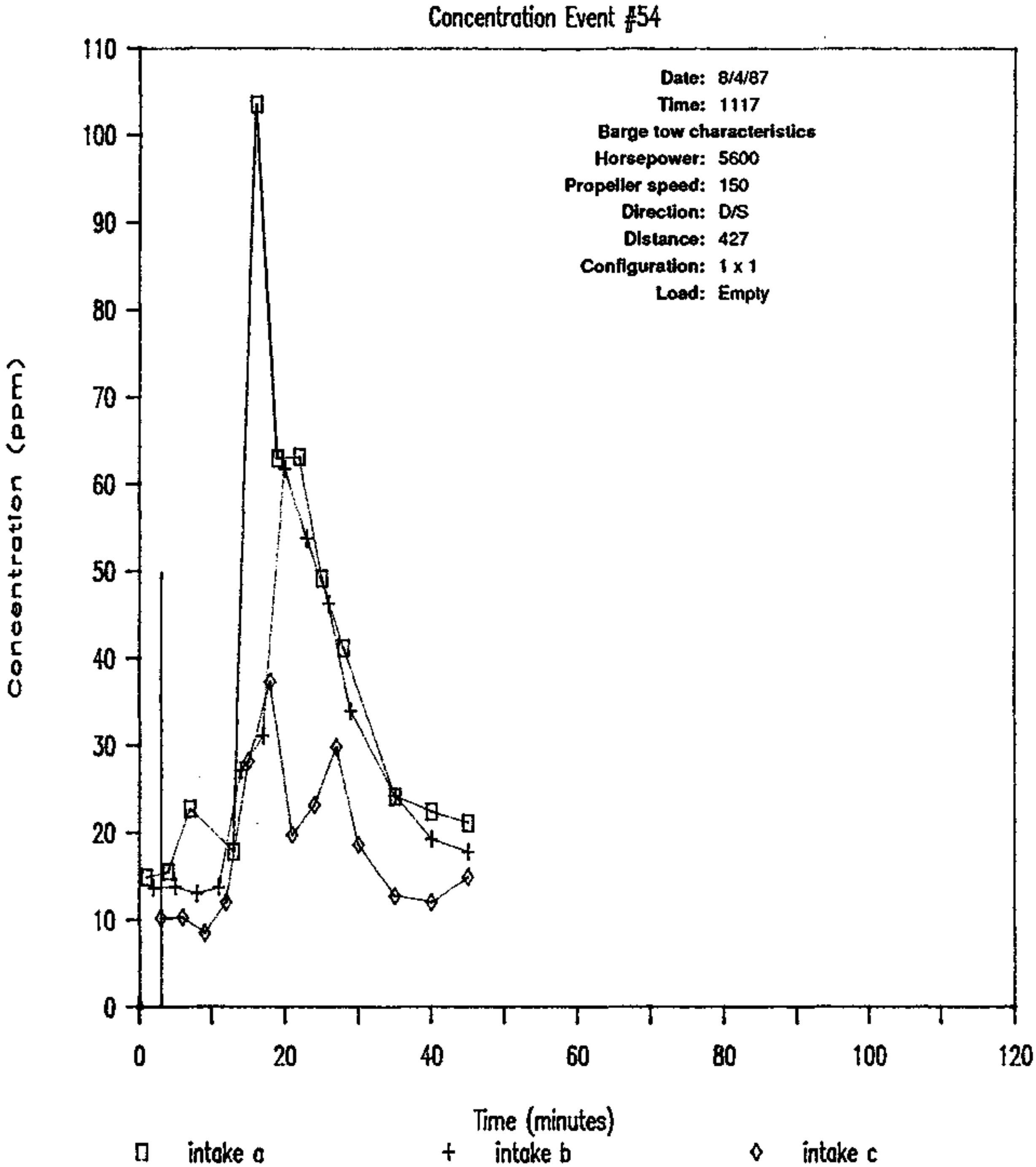

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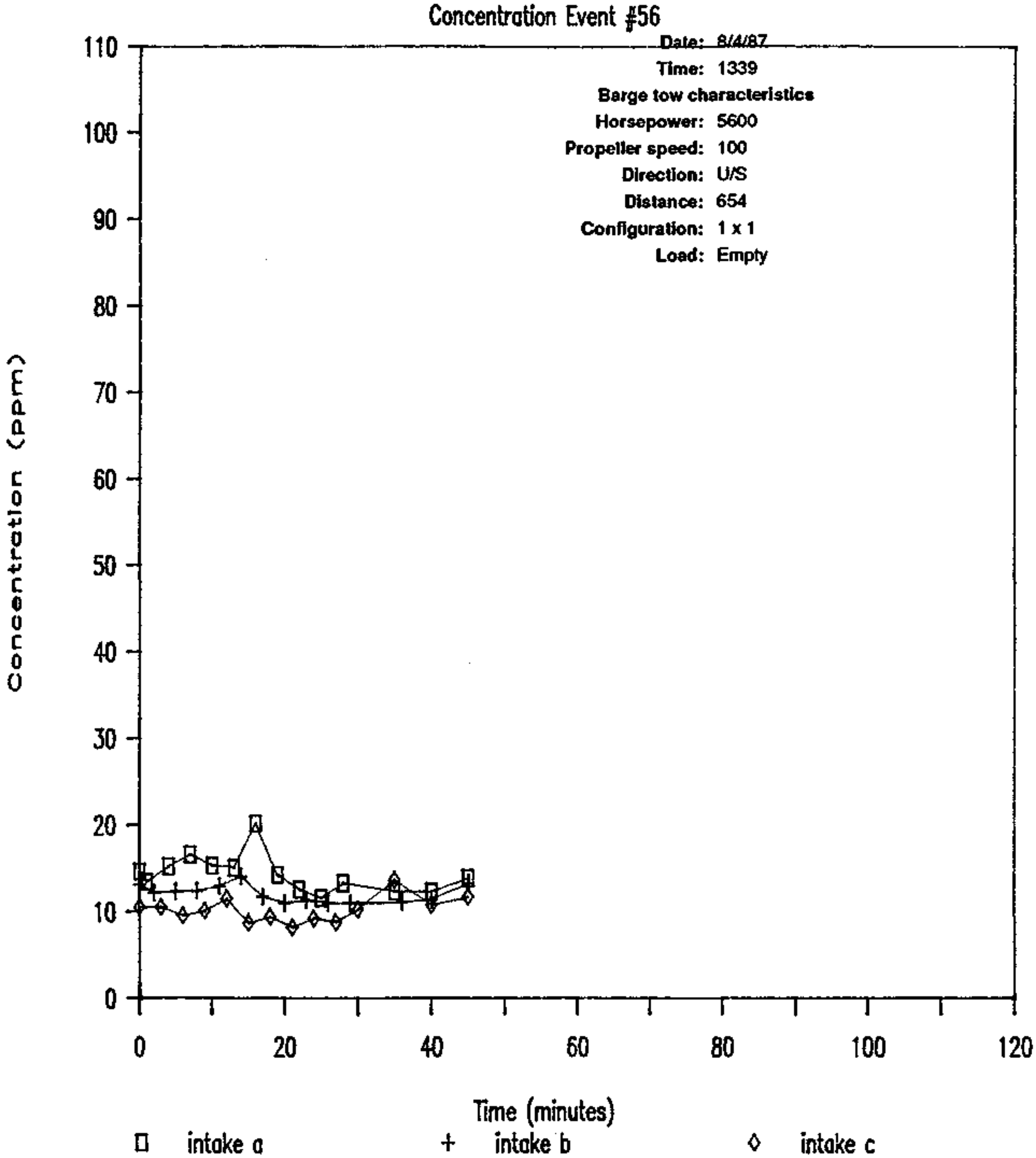
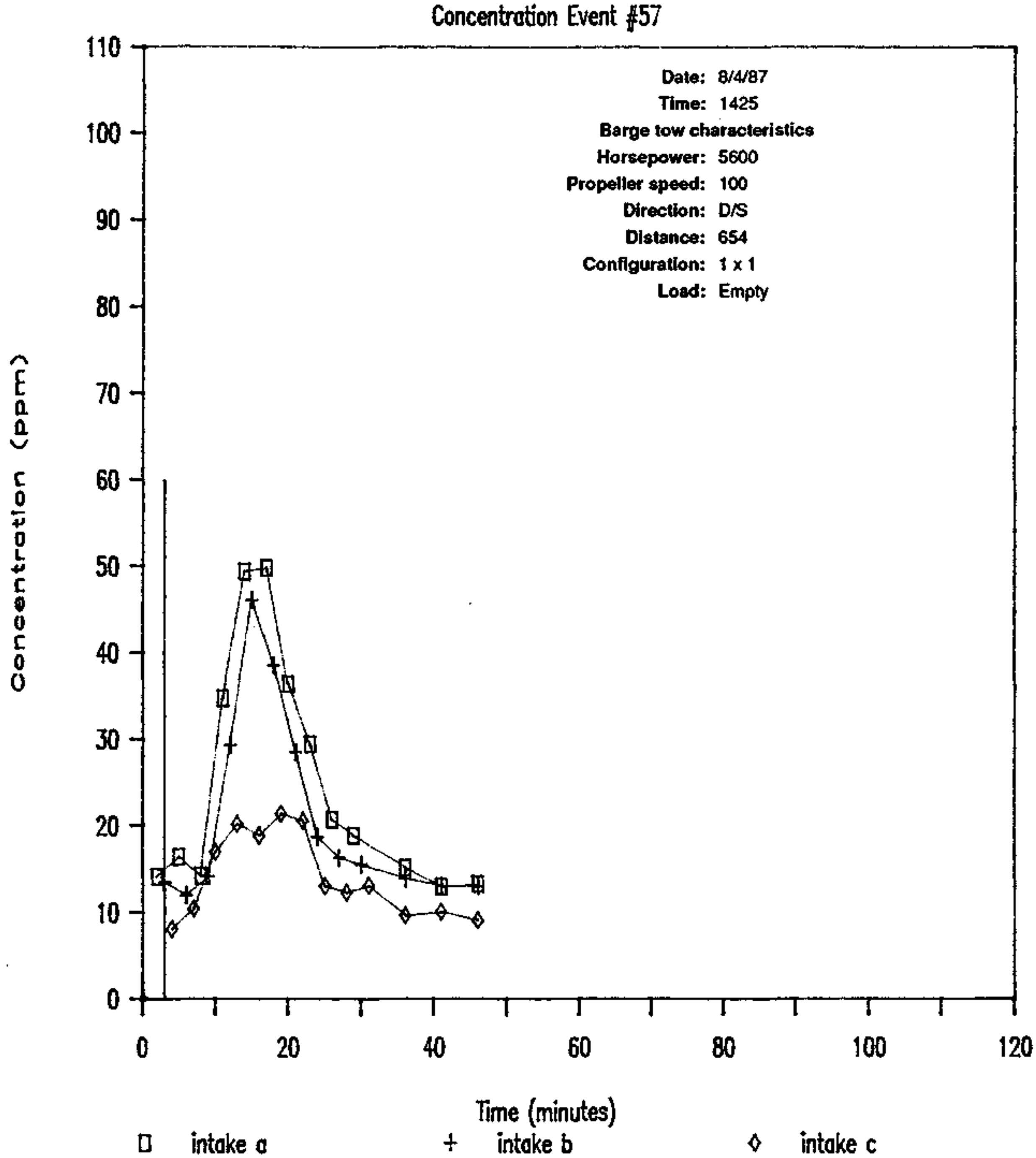


OHIO RIVER NAV-IMPACT STUDY



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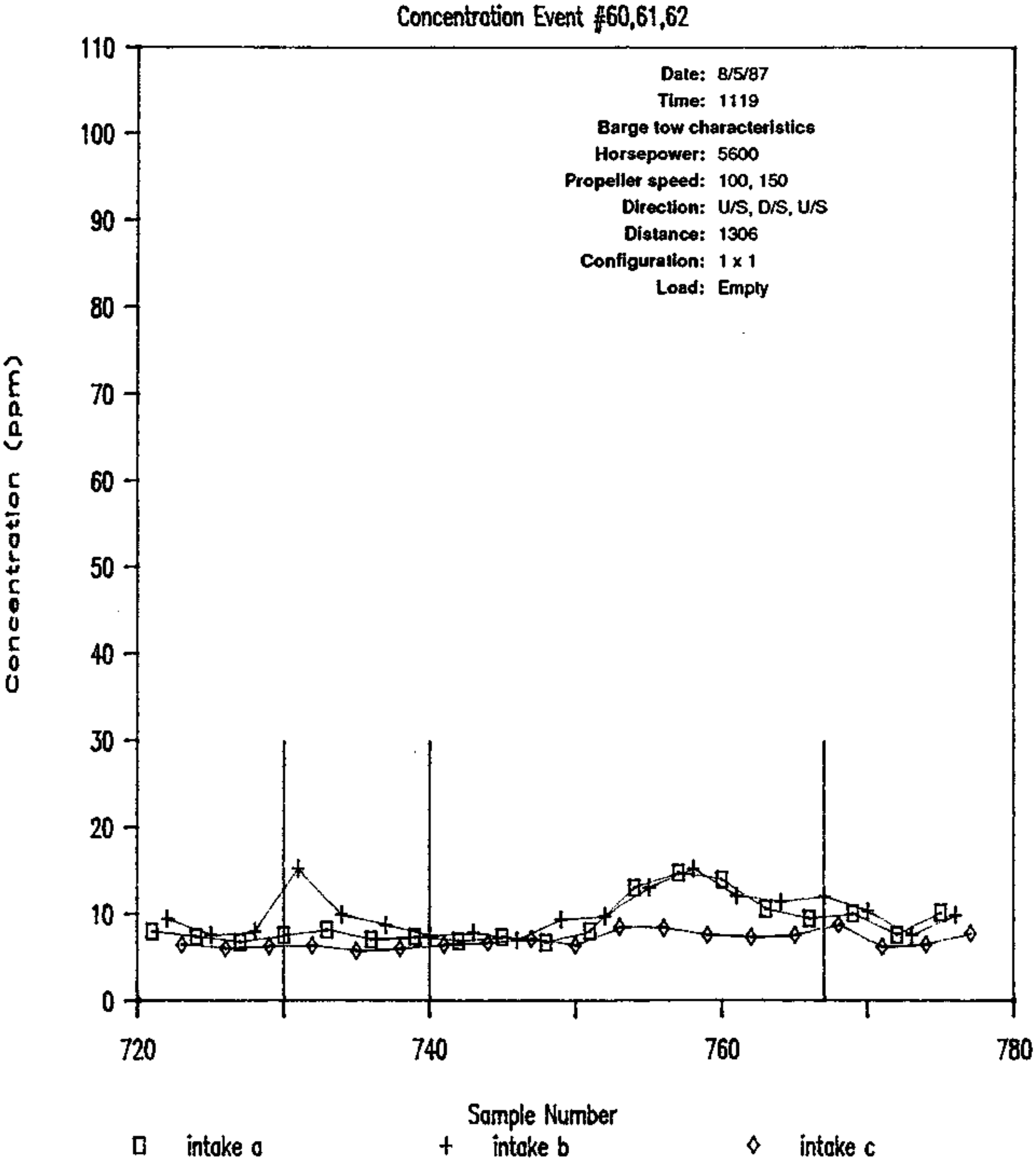
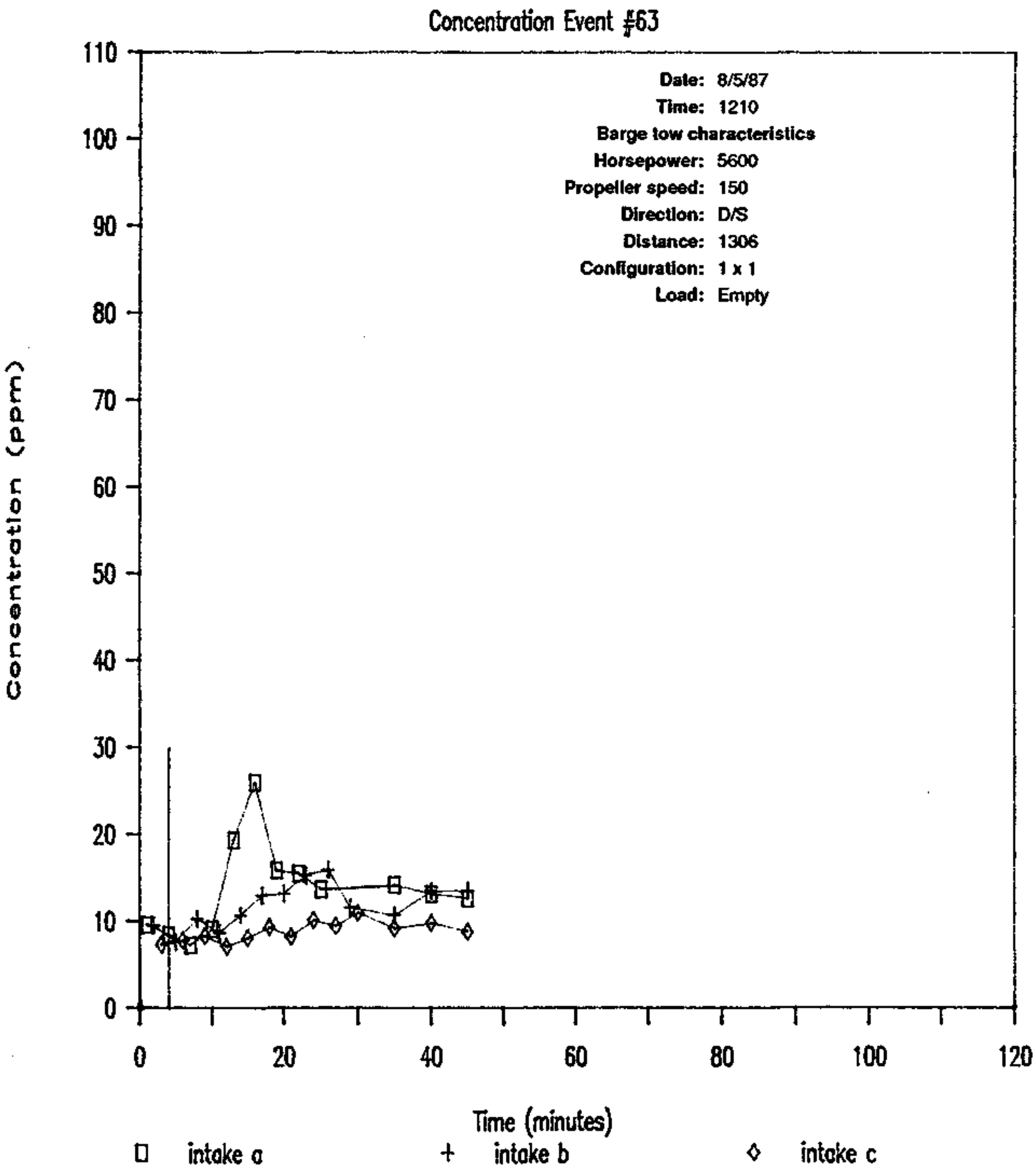
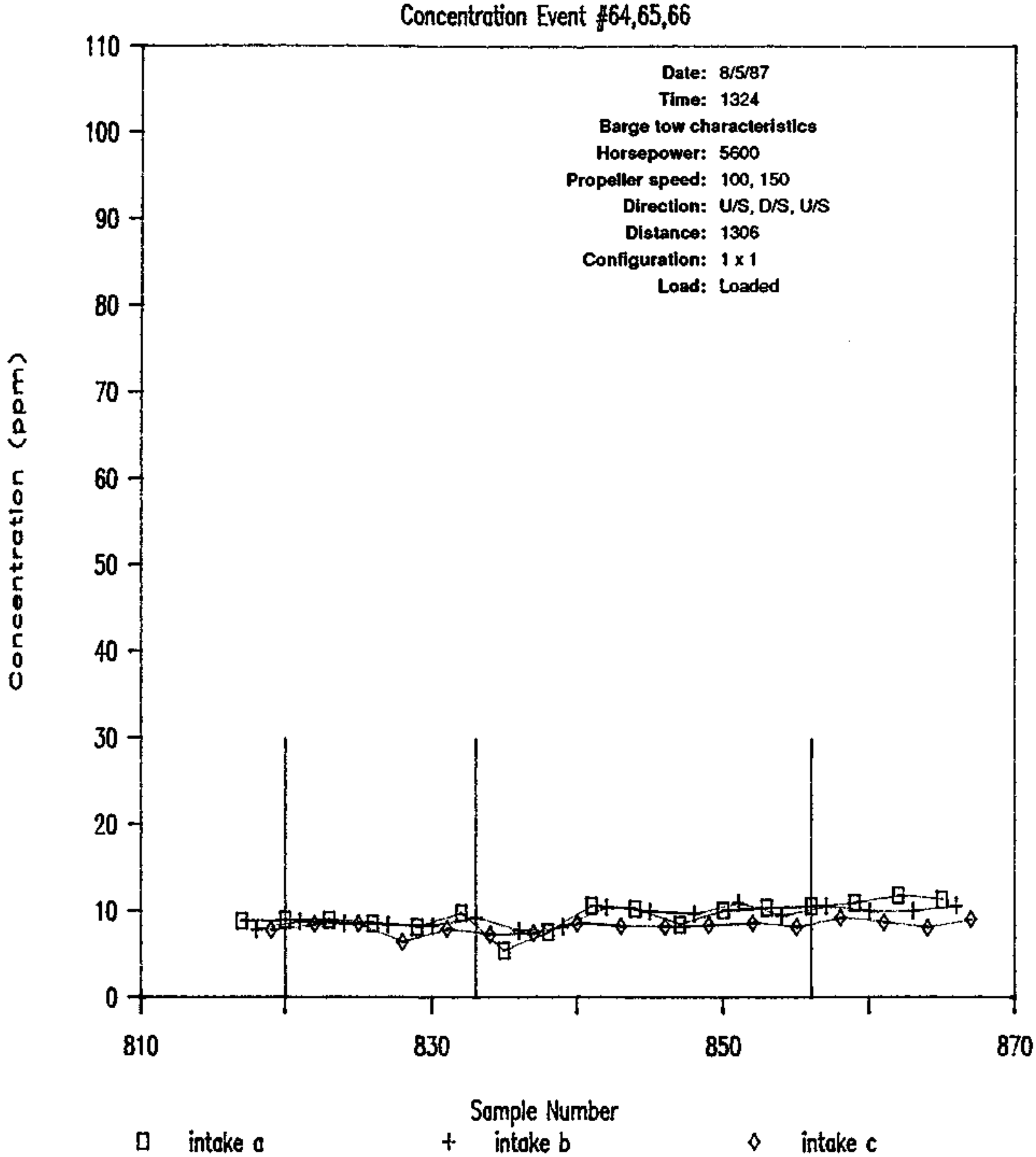


OHIO RIVER NAV-IMPACT STUDY



OHIO RIVER NAV-IMPACT STUDY



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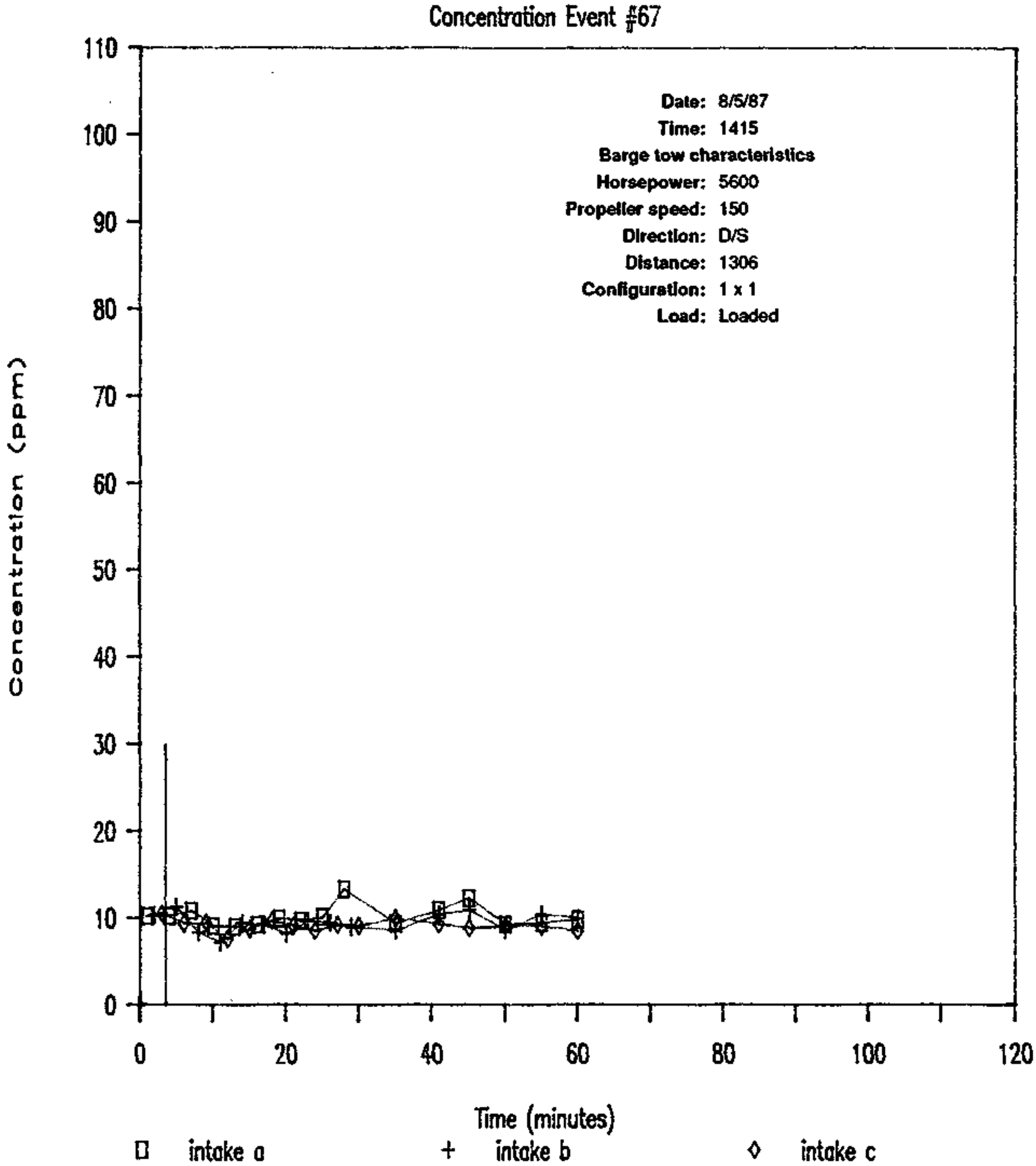

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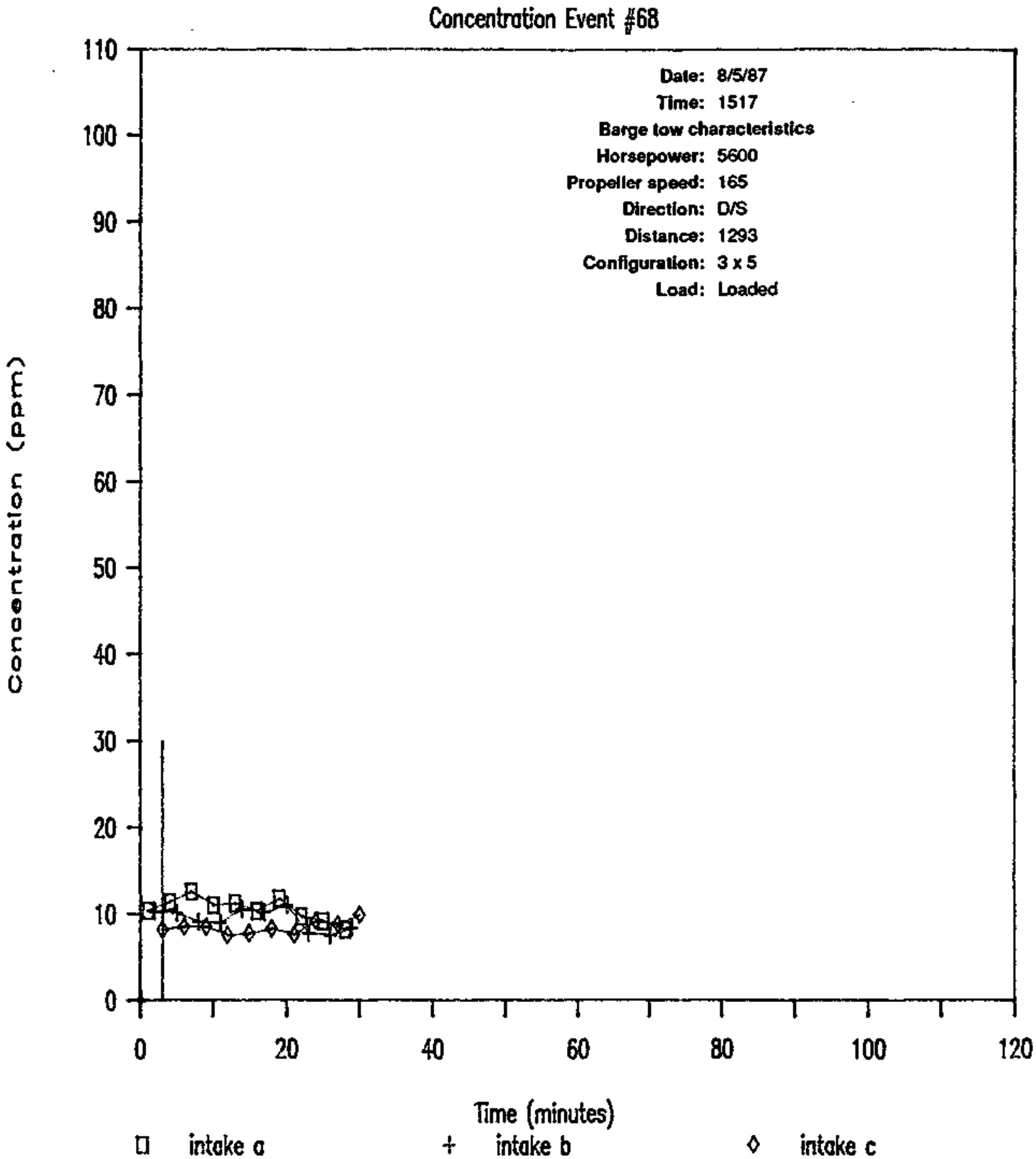
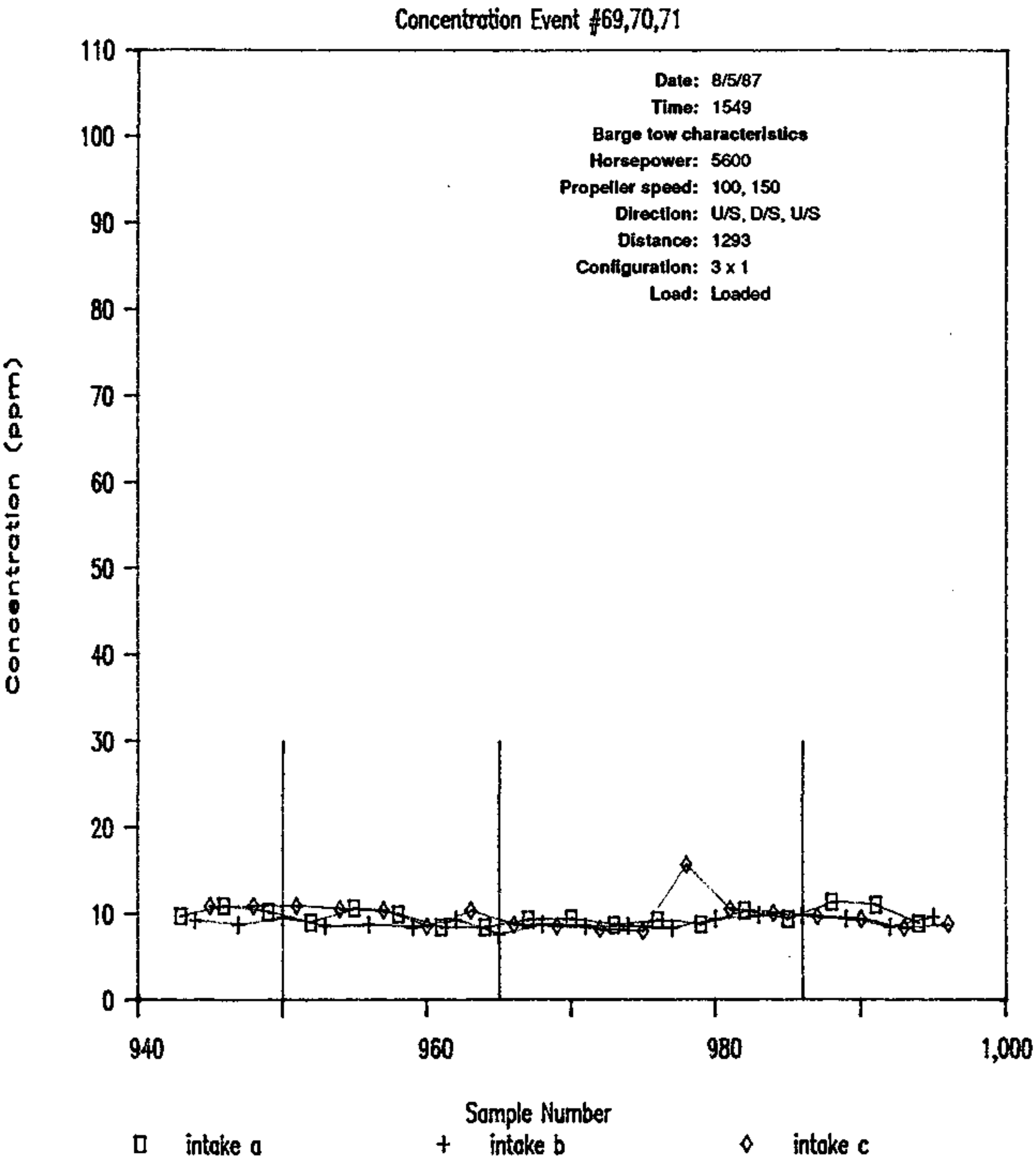
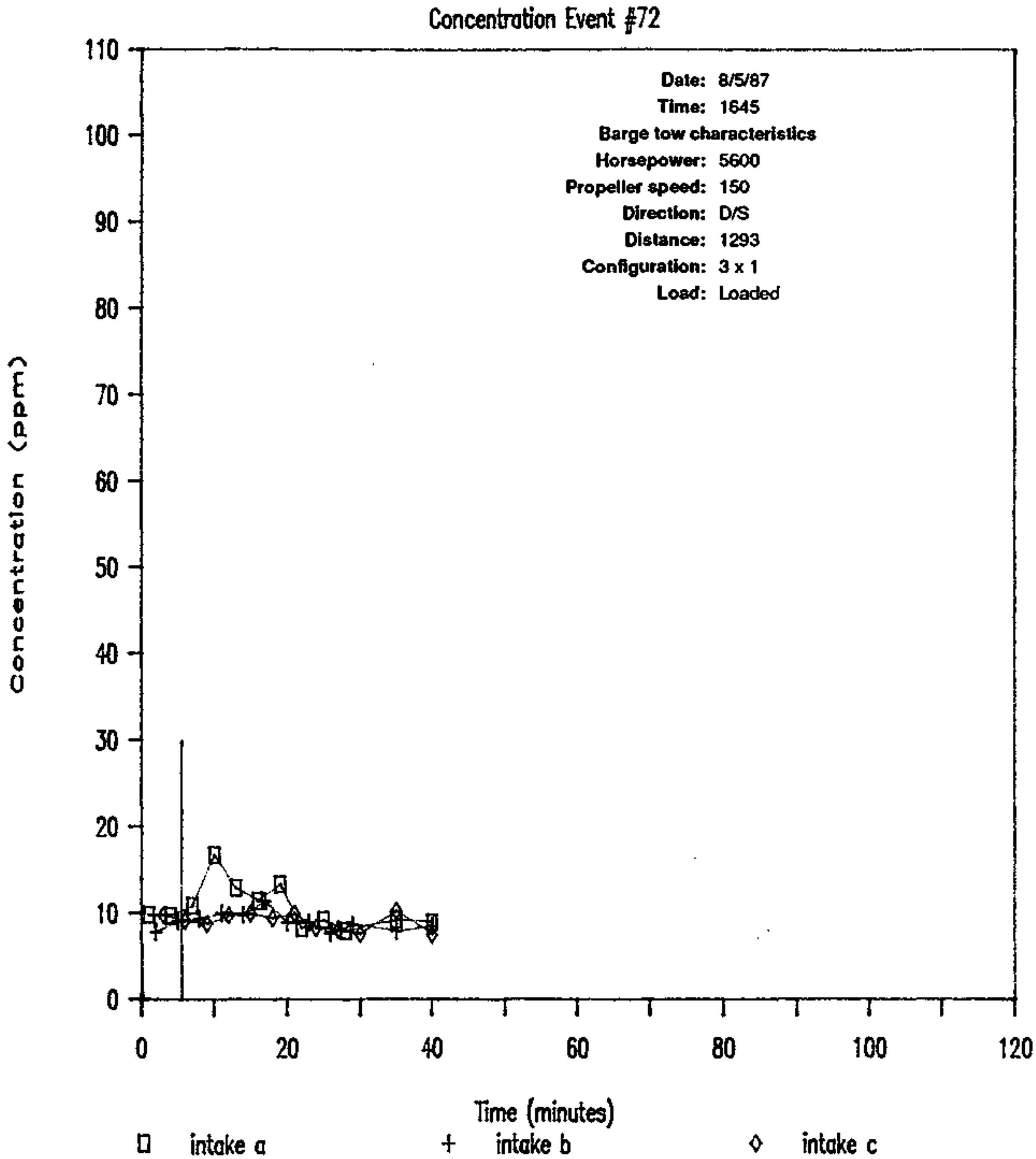


OHIO RIVER NAV-IMPACT STUDY



OHIO RIVER NAY-IMPACT STUDY



Appendix C. Comments and Responses on Draft Report

The draft copy of the report was forwarded to the Environmental Management Technical Center of the U.S. Fish and Wildlife Service (USFWS) for their review and comments. The USFWS sent copies of this draft to all members of the Ecological Advisory Team. Some of the EAT members in turn forwarded the draft report to their associate departments/agencies. All the comments thus received and the responses from the Illinois State Water Survey have been compiled in this appendix. It should be noted that the Water Survey collected this set of data from the Ohio River to supplement the main data collection effort undertaken by the Louisville District of the U.S. Army Corps of Engineers.

Comments with Water Survey Responses

Commentator: Iowa Department of Natural Resources
Dated: May 30, 1989
Signed by: Tom Boland, EAT Representative
Text: We have reviewed the draft report of the Impact of Barge Traffic on the Ohio River and have the following comments. Generally this report is very well organized and written. However, the overall purpose and objectives of the study are not clear. Thank you for the opportunity to comment.
Response: A section stating the objectives of the project has been added to the report.

Commentator: Illinois Department of Conservation
Dated: May 8, 1989
Signed by: Bill A. Bertrand, Streams Program
Text: I have read the draft Impacts of Barge Traffic on Waves and Suspended Sediments: Ohio River at River Mile 581. I have no specific comments or questions. I agree with the report authors that extrapolation of observations on the Ohio to the Mississippi and/or Illinois rivers is inappropriate as far as apparent magnitude of effects are concerned. The verification that certain impacts are occurring i.e. drawdown and material resuspension is useful however.
Response: No response is necessary.

Commentator: Missouri Department of Conservation
Dated: May 15, 1989
Signed by: Norman P. Stucky, Environmental Coordinator
Text: Thank you for providing our staff the opportunity to review the draft Impacts of Barge Traffic on Waves and Suspended Sediments: Ohio River at River Mile 581.
We view the report as informational and thus offer no specific comments at this time.
Response: No response is necessary.

Commentator: Wisconsin Department of Natural Resources
Dated: May 16, 1989
Signed by: John F. Wetzel, Mississippi River Biologist

Text: At your request we have reviewed the report titled Impacts of Barge Traffic on Waves and Suspended Sediment: Ohio River. Department reviewers were Mr. Mark Riebau and Dr. David Kennedy. If you have any questions about their comments, please contact David directly at xxxxxxxxx.

In general, their report is an excellent start on determining the physical effects of barge movement. Most of our comments are related to things that need to be accomplished in future studies. We are assuming that the results of this study will be used to design and carry out future studies.

Response: We also believe that the Ohio River data collection initiated by the Corps of Engineers and participated in by the ISWS is an initial step in the understandings of physical impacts of navigation on the UMRS.

Comment 1: Page 6 #1 - Define deep and shallow water: Maybe the average depth for these two tracks should be used?

Response: The design of the U.S. Army Corps of Engineers sampling program was to set the shallow water track in 16 feet of water and deep water track in 22 feet of water. These depths were set at the Corps' monitored cross section.

Comment 2: Page 6 #4 - Define the size, configuration, and if the commercial barge tows were loaded or unloaded.

Response: This information is provided in the text of the report.

Comment 3: Page 13 Event #15 - Tow horsepower and propeller size can be obtained from the "Inland River Record" (latest edition) published by the Waterways Journal.

Response: No identification was obtained for the commercial barges except for event **68.**

Comment 4: Page 13 Table 1 - I would also like to see the distance from the bottom of the barges to the bottom of the river in this table or elsewhere.

Response: These data were not collected by the Corps of Engineers. However for the experimental 1x1 unloaded barge with 2 ft draft, it is estimated that the bottom of the barge was about 14 ft above the bed of the Ohio River at the shallow track and 20 ft at the deep track. It should be noted that the depth of water at the shallow and deep track were about 22 and 16 ft, respectively.

Comment 5: Page 19 - I would like to see similar profiles at the same scale for similar areas on the Illinois and Mississippi Rivers (areas of similar discharge could be used).

Response: There are no areas of similar discharge on the UMRS until below the confluence of the Missouri River with the Mississippi River.

Comment 6: Page 25 Table 4 - Add loaded or unloaded to column for barge movement.

Response: All of the tests shown in Table 4 were unloaded barges, i.e., 1 x 1 configuration with a 2-foot draft.

Comment 7: Page 30 - End of paragraph just before section titled Bed Materials. Can you come up with an average sailing line depth for sections of the UMRS and Ohio Rivers?

Response: It will be very difficult to come up with an average depth at the sailing line for the entire UMRS. However, site specific data are available, e.g., Illinois River near McEvers Island, RM 50, average depth of water is 12-14 feet near the sailing line with a flow frequency of 90%, i.e., 90% of the flow on the Illinois River is equal to or greater than this value.

Comment 8: Page 40 - Summary 1st paragraph. "Most of the experiments were conducted with single unloaded barges." This was a good place to start, however, future experiments should be run with drafts and barge arrangements similar to what is actually found on the UMRS. More fully loaded barge tests need to be run. Data from actual tow events need to be collected.

Response: We agree. Our present investigation is designed to use run-of-the-river barge traffic, i.e., the traffic that normally moves on the river.

Comment 9: Will cold water (especially 4 degrees C) water cause different effect? Do we need to run tests in cold water or can effects be extrapolated?

Response: Cold water can increase the viscosity, which may change the sediment transport characteristics of the river. We hope to collect some cold-water data for our present research project to try to answer this and other related questions.

Comment 10: Overall, the summary and conclusions appear reasonable to me. Future work should help further define the physical effects of tow and barge movement. It appears to me that the Ohio River being generally much deeper and with few backwaters will have very different effects from tows than the Mississippi and Illinois Rivers. I am looking forward to similar data being collected from these rivers.

Response: No response is necessary.

Commentator: U.S. Army Corps of Engineers, Rock Island District

Dated: May 17, 1989

Signed by: Dudley M. Hanson, P.E., Chief, Planning Division

Text: This letter is in response to your request **for** comments on the submittal to our ecological Analysis Team (EAT) representative entitled DRAFT Impacts of Barge Traffic and Suspended Sediments: Ohio River at River Mile 581. Comments were solicited within the Corps of Engineers from the Ohio River Division, Louisville District, Lower Mississippi River Division, St. Louis District, Waterways Experiment Station, both St. Paul and Rock Island Districts within North Central Division. Comments are as follows:

Response: No response is necessary.

Comment 1: What were the objectives of the investigation? We recommend that the objective(s) be clarified such that the study effort is directed to either simply gather good data at a few points or that the study effort is to develop a predictive model. We anticipate that the intent of this effort is to develop a predictive model.

Response: A statement of the objectives of this project has been included within the text of the report.

Comment 2: What model or models were the data collected for? What are the input requirements of the model(s)? To what degree have the input requirements for full model development been met?

Response: These data were not collected for the development or verification of any specific mathematical model.

Comment 3: The extensive discussion of sediment resuspension at the site and comparisons with other rivers is speculative at best. Data from only two substrate samples collected at the test site and subjected to particle size analysis is presented. What was the pattern of substrate type distribution throughout the test reach of river? If more particle size data on substrate from the sailing lines and laterally away from the test site is available, it should be presented.

Response: The Illinois State Water Survey was involved in the field data collection from the Ohio River to supplement our understandings of the physical impacts of navigation. Our involvement was designed partially to supplement the major field data collection effort undertaken by the Army Corps of Engineers. When we realized that background data such as bed material and flow distribution data across the test section were not collected by the Army Corps of Engineers, we made an attempt in April 1988 to gather such a set of data. Due to equipment problems encountered while on the Ohio River, only two bed material samples could be collected. Also note that our effort was limited due to the availability of existing equipment and personnel.

Comment 4: Further clarification of the treatments and measurements conducted is needed. A matrix or combination of tables 1 and 2 is suggested. The following variables differed between treatments: towboat power, propeller rpm, tow speed, tow configuration (8), direction of travel, distance of sailing line from sensors, river discharge, ambient velocity, ambient suspended solids.

Response: We prefer to keep tables 1 and 2 as presented. Again, data on river discharge, ambient average velocity within the river cross section, and average suspended sediment concentration were not collected. See answer to Comment 3 above.

Comment 5a: Was there any replication of treatment?

Comment 5b: What were the actual tow speeds?

Comment 5c: What were the ambient velocities?

Response: Some repeat experiments were run by the COE. Please see the report to be published by the COE for these specific topic. Also some of this information is available in table 6.

Comment 6: What were the "shallow" and "deep" sailing lines? The river cross section figure does not indicate any extensive "shallow" area. Where were the sailing lines positioned in the river cross-section? Suggest including a bathymetric map of the test area with sailing lines and sensor positions indicated.

Response: Please see page 5 of the report for depths of water in the "shallow" and "deep" tracks. No current bathymetric map is available, and sounding data were not collected by the Corps of Engineers or the ISWS.

Comment 7: Much extraneous hydrologic data and discussion is presented to make the simple point that the Ohio River is different from the Illinois and Mississippi Rivers.

Response: We prefer to keep our discussions on the Illinois, Mississippi, and Ohio Rivers.

Comment 8: The sampling boat appears to have been anchored upstream from a crosscurrent. This would cause the sampling to miss a major part of the towboat plume.

Response: It is possible that a cross current could have existed at that sampling station. But based on our field observation, we felt that this was the logical point to collect data, which was essentially single-point data collected from a location that was at a safe distance from the barge track.

Comment 9: The report seems to present only selected data. The selection and presentation of the data indicates a bias toward maximum impacts and the need for more data while the data presented gives no indication of the significance of the measured quantities. The measurements should be presented in terms of impacts to the environment or compared to the magnitudes for natural conditions for a range of flood flow and wind conditions.

Response: All relevant data for waves, drawdown, and suspended sediment have been included in the report. Field data collection was not designed by the COE to cover a range of stream flows and wind conditions. However, we agree that this should be a major consideration of any field data collection program, and our present project with the USFWS is designed to address these and other related variables.

Comment 10: The tow velocities resulting in large waves and drawdowns are higher than normal average tow speeds expected in Pool 15 of the Mississippi River. Lower speeds seemed to result in much lower impacts.

Response: We agree that future studies should incorporate run-of-the-river barges.

Comment 11: Sediment impacts were addressed primarily by comparison of maximum differences in concentrations. The significance of this concentration over time, which is in the order of 15 to 20 minutes should be discussed.

Response: The impacts of increased sediment concentration on the river environment that may last for 15 to 20 minutes should be evaluated by biological scientists.

Comment 12: The authors quite properly point out that this study of the Ohio River should not be extrapolated to other streams. However, on page 35 for no apparent reason a discussion of the Illinois and UMRS is developed.

Response: The comparative discussion was included to show the major differences between the UMRS and the Ohio River.

Comment 13: Physical and hydraulic characteristics (pg. 16) appear to be for April 13, 1988 rather than during the test period. Need data for test period.

Response: Please see Comment No. 3.

Comment 14: John Matthews towboat was 4200 HP instead of 3000 HP.

Response: Corrected.

Comment 15: Table 8 and page 30 implies UMRS is larger than Ohio.

Response: In general, this is true with the exception of discharges.

Comment 16: Since much of this report is a comparison between the UMRS and the Ohio, someone from ORD should review this. It is our understanding that as of this date, Mr. Terry Siemsen of the Louisville District (ORD-ORL) has discussed the report with both EMTC and Illinois State Water Survey staff.

Response: Comments from Mr. Terry Siemsen of the Louisville District of the U.S. Army Corps of Engineer have been requested.

Comment 17: The discussion on velocity was based on a WES memorandum report to the Louisville District. It would be appropriate to wait until WES and Louisville District publish this information in a final document that reflects a more complete understanding of the data. Many of our concerns about the prototype data have been shown to be a result of an incomplete knowledge of the flow field around a moving tow.

Response: Reference to the WES memorandum has been removed from the report.

Comment 18: Page 39 - Prototype data beneath the tow were collected for all tows in the 1987 tests. Model data beneath the tow were collected for several different tow configurations.

Response: Reference to the WES memorandum has been removed.

Comment 19: Page 40 - Should note that 2.3 ft/sec velocity was in the same direction as the tow was moving.

Response: Reference to the WES memorandum has been removed.

Comment 20: Abstract should reflect that wave and drawdown data can be used interchangeably on rivers having similar cross-sections and ambient conditions.

Response: Has been included in the abstract.

Comment 21: Analysis of drawdown data should include comparison to existing water-level drawdown equations.

Response: Sufficient data are not available to make such a comparison.

Comment 22: Figure 6 shows 3-wide unloaded barges were used. Only 3-wide loaded were used.

Response: Figure 6 has been corrected.

Comment 23: Where are current measurements taken by ISWS referenced to in table 2?

Response: The velocity data collected by the Illinois State Water Survey could not be used because of marine band radio interference with the output signals of the Marsh McBirney 201 Current Meter and an unstable mounting system.

Comment 24: Observation that certain tests produced sediment while others did not fail to include the fact that tows near the bank traveling at high speeds were the ones producing increases in sediment concentration. These are the same tows that would produce the highest return velocity which is the mechanism that produced the sediment increase.

Response: We believe that this explanation is mostly true, however, we do not have sufficient data from the Ohio River to verify this concept.

Comment 25: Page 35, Last PP - 1500 HP should be 5600 HP.

Response: Corrected.

Comment 26: Page 41, 3rd PP - 1500 HP should be 5600 HP.

Response: Corrected.

Comment 27: Page 56 and 58 (formerly pp. 56 & 58; now pp. 70 & 72) - RPM not correct on plot.

Response: Corrected.

Commentator: U.S. Army Corps of Engineers, Lower Mississippi Valley Division

Dated: June 6, 1989

Signed by: Noel D. Caldwell for Edward A. Cohn

Text: Attached are comments on the draft report, Impacts of Barge Traffic on Waves and Suspended Sediments: Ohio River at River Mile 581 as requested in your letter of April 19, 1989. Mr. Jerry Rasmussen was notified on May 16, 1989, that comments would be late due to review delays. Questions concerning these comments should be directed to Mr. Eugene Buglewicz, a member of the Environmental Advisory Team.

Response: No response is necessary.

Comment 1: Abstract. The fifth sentence states that the "1500 HP" tow caused a clear increase in suspended sediment, while Figures 17 and 18 indicate that only the 5600 HP tow caused a clear increase in suspended sediment. The Abstract should indicate that these events were only a portion of the total number of events.

Response: Abstract corrected.

Comment 2: Abstract. The last sentence of the first paragraph should provide an indication of the average or median wave height and drawdown. Based on Table 6, maximum wave height average values were somewhat less (approximately one foot) than the 1.6 foot maximum wave height reported here. Likewise, the maximum drawdown figure reported in the Abstract does not reflect the data in Table 6, where average maximum drawdown values for different towboat horsepower tests were in the range of 0.06 to 0.2 feet.

Response: The average values of maximum measured drawdowns and wave heights have been included in the abstract.

Comment 3: Page 2. last paragraph. Three towboats were used to increase the tested horsepower. It is unclear if two tows of 1500 HP were used to provide the 3000 HP tow test, and three tows to provide 5600 HP, or, if three separate towboats, one 1500 HP, one 3000 HP and one 5600 HP were used. Combinations of towboats could influence results of these test.

Response: The last paragraph has been modified in an attempt to clarify any confusion.

Comment 4: Page 8. last paragraph. A discussion how the current meter was corrected for horizontal and vertical movements of the sampling boat as it was anchored at the sampling site should be provided.

Response: Please see response to Comment 23 of RID-COE.

Comment 5: Page 16. last paragraph. A statement is required to indicate the representativeness of the bed material in relation to that in the total cross section at the test site.

Response: Please see response to Comment 3 of RID-COE.

Comment 6: Page 25. Table 4. The table shows concentrations of suspended sediments taken at three different depths immediately following tow passage. A comparison shows a minimum to maximum range of suspended sediments taken prior to tow passage. It is unclear what the author is projecting into the comparison since, based on statements on the previous page, almost all of the background samples were taken from intake B or 2 feet above the bottom. If this is the case then it would be misleading to compare this one level's concentration with those taken at level A, B, and C shown in Table 4. The Table needs clarification.

Response: Probably the commentator misinterpreted the statement concerning samples collected for particle size distribution of the suspended sediments with those samples collected for the determination of the concentrations of suspended sediments. Concentration samples were collected for all intakes for the background period as well as the duration of the event.

Comment 7: Page 33, discussion of bed materials. Since only two bed material samples were collected at the test site, and they were taken near the bank line, the discussion of the comparison of bed materials in the Ohio River as compared with the Mississippi River or the Upper Mississippi River System in general seems to be grossly out of context. It is recommended the discussion be changed to reflect a generic discussion of sediment size in relation to potential suspension effects due to tow traffic. Alternatively, data on sediment sizes in the Ohio River from other sources could be used to compare and/or differentiate sediment qualities among various river systems.

Response: Please see response to Comment 3 of RID-COE.

Comment 8: Page 35. first and second paragraphs. Reference comment 7, above. As stated in the last sentence of the Abstract, it is inappropriate to make comparisons among rivers as is done in these two paragraphs without considerably more data than is presented in this report. There are several complex variables involved when considering the degree of resuspension that occurs in a stream and the effect this resuspension will have on the environment within the confines of that stream. The comparison has been made among three rivers while the amount of data collected on the Ohio River is only from one site taken on a steep bankline removed from the sailing line. It would seem that several areas would have been sampled prior to the subject tests to ensure the sediment samples represented the bed makeup of the reach of the river being discussed. It is noted that reference is made to backwater areas on the Mississippi River and the problem of resuspension in these areas. We do not agree that the results of this study can be related to the backwater areas on the Mississippi River.

Response: We do agree with the commentator about the multitude of variables that impact the resuspension characteristics of sediment in a river environment. However, a comparison of the test site with some selected areas of the UMRS has been made to illustrate the general dissimilarities between the Ohio River and the UMRS. If and when more data from the Ohio River and UMRS are available, a thorough and clear comparison of the physical impacts of navigation on these river basins can be made.

Comment 9: Page 35. Water Quality subparagraph, second paragraph. The meaning and intent of this paragraph is unclear. Sampling for characterization of sediments and resuspension of sediments after tow passage were taken at three levels; 1 foot and 2 feet over the bed, and at four-tenths of the total depth. On page 24 it is stated, "Almost all samples were collected from intake B, 2 feet above the bed". The apparent conflict should be explained. See comment 6, above.

Response: Please see response to Comment 6 given above. It should also be mentioned that the water quality changes were measured utilizing a Hydrolab at a single elevation.

Comment 10: Page 35. last paragraph. The first sentence refers to a "1500 HP" towboat operated at 100 to 150 RPM. As stated in the second sentence of this paragraph, the events related to this tow were events 54 and 57 which were run with a "5600 HP" tow.

Response: Corrected.

Comment **11:** Page 38. first incomplete paragraph. The effect of the increased discharge in the Ohio River to 52,000 cfs from 10,000 cfs to 20,000 cfs should be discussed as it relates to the discussion of variable water velocities on page 35.

Response: Additional explanation added.

Comment 12: Page 38. first complete paragraph. We concur with the admonition in this paragraph. A review of the discussion comparing sediment in the Ohio, Illinois, and Mississippi rivers occurring on pages 30, 33, and 35 is warranted.

Response: Data on sediment transport at or near the Ohio River site are not available for inclusion in an additional discussion beyond those in the report.

Comment 13: Page 38. second paragraph. Sediment size fractions should be added to this discussion of minimum data for resuspension evaluations.

Response: Has been incorporated.

Comment 14: Page 38. third paragraph, last sentence. The meaning of this last sentence is unclear. Fifty-eight tow events were sampled; three of the 58 events indicated an increase in suspended sediments; the last sentence states, "This was expected to happen for this site because the bed materials at this location consist mostly of coarse-grained materials." It is unclear if this last sentence is referring to events 24, 32, and 38, or the 55 events that did not indicate any substantial increase in suspended sediment.

Response: This paragraph has been modified. Also note that suspended sediment samples for particle size analyses were collected for six events only, not for 58 events.

Comment 15: Page 39. third paragraph. The fourth sentence hypothesizes that a towboat with a 9-foot draft would be expected to exhibit a bow effect of 300 feet in front of the tow similar to that exhibited with a 9-foot draft single barge. The basis for this supposition should be explained further.

Response: The reference to the velocity data collected by the Louisville District of the U.S. Army Corps of Engineers from the Ohio River and analyzed by WES has been removed.

Comment 16: Page 40. Waves and Drawdown paragraph. The generalizations which describe drawdown and waves should be accompanied by a minimum of range, mean, and median statistics. Inspection of Table 6 indicates maximum wave values average approximately 0.3 feet for the 1500 HP events; 0.7 feet for the 3000 HP events; and 0.4 feet for the 5600 HP events. Likewise, maximum drawdown only exceeded a value greater than 0.1 feet 21 times for the 72 measures of drawdown reported in Table 6. A breakdown by horsepower and RPM is even more revealing. This data should be reported in this summary section. There are no data to support the conclusion that "local morphology" had any influence over values of drawdown and wave height.

Response: Some more discussion on wave and drawdown data have been included.

Comment 17: Page 41. second paragraph. The use of the term "significant" should indicate whether or not it is in reference to statistical significance.

Response: Modification has been added within the text.

Comment 18: Page 41. third paragraph. The reference to the "1500 HP" test should be corrected to reflect that it was the 5600 HP test that indicated an increase in suspended sediments.

Response: Corrected.

Comment 19: Page 41, fifth paragraph and sixth paragraph. Based on the discussion in the sixth paragraph, and since only two bed material samples were taken at the test site, it is recommended that the fifth paragraph be deleted from the summary or additional data be used to support the discussion in the text (see comments 7 and 8).

Response: Please see responses for comments **7** and 8.

Commentator: U.S. Department of Transportation, Maritime Administration

Dated: June 12, 1989

Signed by: Alpha H. Ames, Jr., Great Lakes Regional Director

Comment 1: The Ohio River has few similarities to the Upper Mississippi River. Actual tests should have been made on the Mississippi in order to be conclusive.

Response: The Illinois State Water Survey participated in a field experiment initiated by the Louisville District of the U.S. Army Corps of Engineers. The ISWS was not a party in the selection of the site nor the type of barges to be used in the field experiments.

Comment **2:** The test site was on a bend in the river requiring increased towboat maneuvering and increased propeller RPM. This is not an acceptable test site. Adjustment should be made for towboat navigation requirements and wave differentials in river bends as well as straight sections for comparison.

Response: Again, the ISWS participated at this predetermined site to supplement our understandings of the physical impacts of navigation. It is of course true that the waves generated by navigation traffic within a straight reach will be somewhat different than those generated within a curved reach.

Comment **3:** The tow samples were generally one barge with a towboat. This sample might be considered acceptable for a fleeting operation - but has little value in determining the impact of a full line-haul barge compliment [sic].

Response: Again, the tow configuration was decided by the U.S. Army Corps of Engineers, Louisville District. However, it must be pointed out that it is extremely expensive to rent a fleet of fully loaded barges to conduct such a field experiment.

Comment 4: What wave impact differences can be identified in upbound versus downbound tows?

Response: Data on waves were not of sufficient quantities to make any statistically significant analyses on the differences in the waves generated by upbound versus downbound barges.

Comment 5: The river level was 4 feet above normal during the testing April 13, 1988. What other sample stages were tested? Was this test done during flooding conditions? What were the river sedimentation levels during these water level variances without the towboat?

Response: Refer to the response for Comment 3 of RID-COE. The data were collected for that 2-week period only. No background data exist at this site as to the sedimentation levels during various water discharges on the Ohio River.

Comment 6: Language such as "violent action of the waves generated by the moving barges" should be removed (page 2, paragraph 5), and replaced with less emotional wording. How violent can a wave be?

Response: The indicated sentence has been rephrased.

Comment 7: What was the speed (MPH), of the tow in up or downbound river samples? What was the river velocity (MPH) at the test site? Propeller RPM is meaningless!

Response: The speed of the tows for which data were collected has already been included in table 6. For the second part of the comment, please refer to response given for Comment 3 of RID-COE.