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EFFECTS OF TOW TRAFFIC ON THE RESUSPENSION OF SEDIMENTS AND ON DISSOLVED OXYGEN CONCENTRATIONS IN THE ILLINOIS AND UPPER MISSISSIPPI RIVERS UNDER NORMAL POOL CONDITIONS

by

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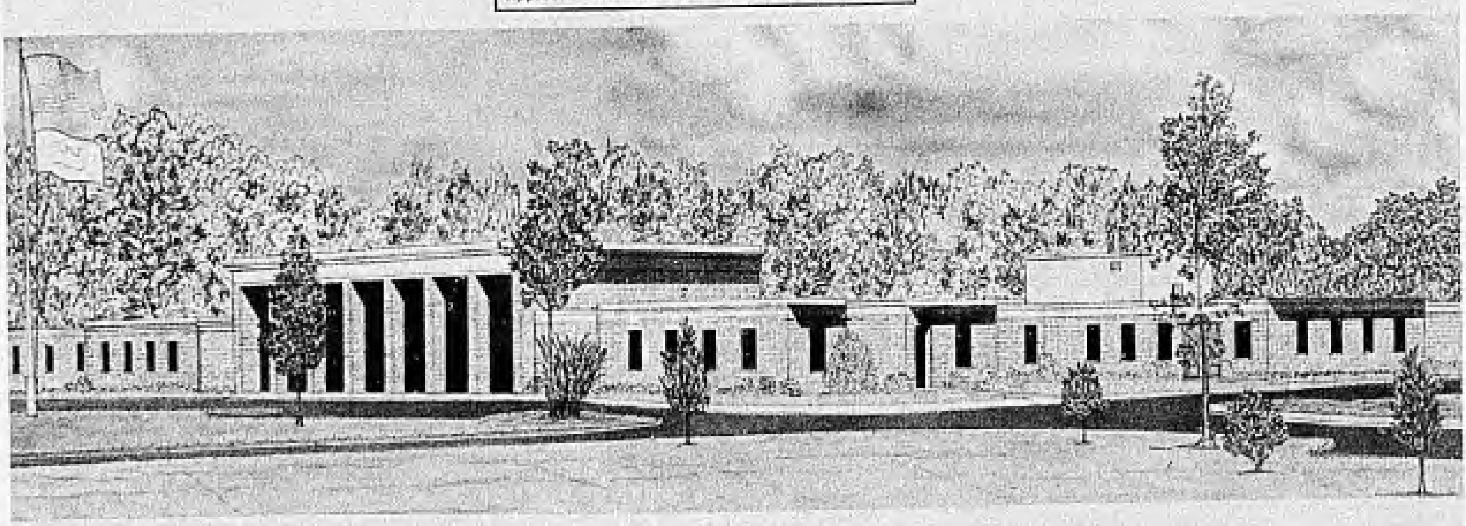

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This study was conducted to determine the effects of single and multiple tow traffic on the resuspension of riverbed sediments and on dissolved oxygen concentrations at several locations on the Illinois and Upper Mississippi Rivers during normal pool conditions. In total, 19 separate tows were monitored on the Mississippi River and 21 tows on the Illinois River at locations chosen to correspond to upper, middle, and lower river reaches. Specific sampling sites were selected so that maximum effects (changes in concentrations)
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of tow traffic on potentially productive side channel habitats could be tested. Besides side channel sampling stations, three other stations were positioned along a transect across the river proper to determine if sediments resuspended from the middle of the river move laterally to shoreward areas. Composite water-column samples were collected simultaneously at each sampling station at selected time intervals, consisting of immediately before the passage of a tow(s) and at specific time intervals up to 180 min after each tow passed. Current velocity profiles, water depth, water temperature, and river stage were also measured. Dissolved oxygen measurements were made in situ at surface, mid-depth, and near-bottom strata in the main channel only. Water samples collected in the field were analyzed in the laboratory for suspended solids (a gravimetric measurement) and for turbidity (an optical measurement). Two-way analyses of variance were performed on replicate samples for each variable (suspended solids, turbidity, and dissolved oxygen) monitored during each tow traffic event to test for differences among sampling stations and differences over time. To determine how the means differed, a mean contrast test (the least significant difference test) was performed. These analyses indicated that tow traffic on the Illinois and Upper Mississippi Rivers during normal pool conditions does contribute to existing levels of suspended sediment measured as both suspended solids and turbidity, and, furthermore, that sediments resuspended from the main channel do move laterally to shoreward areas, including potentially productive side channel areas. Based on the relative responses of suspended solids concentrations and turbidity levels following the passage of tow traffic on both the Illinois and Upper Mississippi Rivers, the Illinois River appears to be more susceptible to tow traffic effects than the Mississippi River. Comparison of past studies made during periods of high flow with the present study made during normal pool conditions, however, indicated that tow-generated turbidity levels in the Mississippi River are extremely small compared with natural turbidity levels occurring during annual flood stage conditions. With one exception, turbidity levels generated by tow traffic on the Illinois River were not elevated above flood stage turbidity levels. For multiple tow traffic events, additive effects (where the passage of additional tows added to those concentrations generated by a previous tow) were not observed for the Mississippi River but were noted for three of the six traffic events on the Illinois River. Recovery time (that time period during which concentrations generated by tow traffic returned to ambient levels) varied considerably with each traffic event for both rivers but was generally longer for the Illinois River than for the Mississippi River. Differences between minimum responses noted for the Mississippi River and maximum responses noted for the Illinois River appeared to be related to the more numerous and larger tows (number of barges) and characteristically narrower widths and finer bed material of the Illinois River. It was also shown that in most cases tow traffic did not reduce dissolved oxygen concentrations in the water column of the main channel of either river. In some instances, concentrations were reduced after tow passages, but in almost every case reductions were of a relatively low magnitude. During some tow traffic events monitored on the Illinois River, dissolved oxygen concentrations rose steadily after tows had passed. This phenomenon was not satisfactorily explained but may have been related to turbulence and subsequent reaeration caused by the tow traffic or to natural diel oxygen changes. Information collected about each tow (size, speed, draft, direction of travel, horsepower, and type--single or multiple) was examined and compared with elicited responses to see if any relationship existed. Although there were some apparent relationships, no clear predictive patterns were evident from inspection of these data because of the complexity of the problem and lack of control of the traffic monitored.

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PREFACE

This report presents the results of a study conducted to study the effects of tow traffic on the resuspension of bottom sediments and on dissolved oxygen concentrations at selected sampling locations on the Illinois and Upper Mississippi Rivers during normal pool conditions. The extent and duration of such effects are controversial concerns of Federal and State agencies as well as private organizations and citizens. The U. S. Army Engineer District, St. Louis (SLD) requested the Environmental Effects Laboratory (EEL) of the U. S. Army Engineer Waterways Experiment Station (WES) to design, coordinate, and conduct the study reported herein.

The work sponsored by SLD was conducted in two parts. The Mobility and Environmental Systems Laboratory (MESL), WES, conducted a complementary study to the EEL effort using remote sensing techniques to monitor the movement and dissipation of tow-generated suspended material plumes as a function of time. This work is documented in a separate report entitled "Use of Automated Remote Sensing Techniques to Define the Movement of Tow-Generated Suspended Material Plumes on the Illinois and Upper Mississippi Rivers."[1]

The work reported herein was conducted during the period of 5 October to 2 November 1975 by personnel from EEL and the Hydraulics Laboratory (HL) of WES and from the SLD. The report was written by Mr. J. H. Johnson under the general supervision of Mr. R. C. Solomon, Chief, Environmental Monitoring and Assessment Branch, Dr. C. J. Kirby, Chief, Environmental Resources Division, and Dr. J. Harrison, Chief, EEL.

Acknowledgement is made to all those individuals who assisted in the data collection, laboratory analysis, and report preparation and who made possible the timely publication of this report. Paramount among these were field coordinators Messrs. B. K. Colbert and C. R. Bingham, EEL; crew leaders, Messrs. D. A. Crouse, HL, and S. L. Hensley and J. E. Vaill, SLD; Chemist, Mr. T. J. Furdek, SLD; statisticians, Dr. C. B. Loadholt, Department of Biometry, Medical

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COL G. H. Hilt, CE, was Director of WES during the period of preparation and publication of the report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
quarts (U. S. liquid)	0.000946	cubic metres
horsepower	745.6999	watts
miles per hour	1.609344	kilometres per hour

one event, flood stage was exceeded by 2.5 ft; and for two events, river stages were 0.9 ft and 1.4 ft below flood stage), tow traffic on the Illinois River had little effect on increasing turbidity levels above ambient levels.

3. Although the above studies contribute to the understanding of the cause-and-effect relationship between tow traffic and resuspended sediment, several questions remain unanswered. For example, what is the temporal and spatial relationship of suspended solids concentrations generated by tow traffic in various reaches of both rivers? Does the sediment plume remain confined to the main channel or does it migrate laterally within the river proper or into potentially biologically productive side channel or backwater areas? Is there an oxygen demand exerted by riverbed sediments resuspended by tow traffic? Are the effects additive with multiple tow events? To answer these questions, the Engineering Division of the U. S. Army Engineer District, St. Louis (SLD) sponsored the study reported herein, which was designed by the Environmental Effects Laboratory (EEL) of the U. S. Army Engineer Waterways Experiment Station (WES) and was conducted by personnel from EEL and the Hydraulics Laboratory (HL) and from SLD.

Objectives

4. The following were objectives of this study. The study was to include single and multiple tow traffic events in upper, middle, and lower reaches of both the Illinois and Upper Mississippi Rivers.

- a. Determine if tow traffic significantly increases concentrations of suspended solids and turbidity above ambient concentrations at sampling stations located on a transect within the river proper.
- b. Determine if appreciable concentrations of suspended solids and turbidity generated by tow traffic enter side channels or backwater areas.
- c. Determine if multiple tow traffic events have an additive effect on elevating concentrations of suspended solids and turbidity in the immediate study area.

PART I: INTRODUCTION

Background

1. Considerable comments from Federal, State, and private organizations and citizens have been directed toward the lack of data on the resuspension of riverbed sediments generated by tow traffic occurring in the Illinois and Upper Mississippi Rivers in the "Draft Supplement Environmental Statement for Replacement of Locks and Dam No. 26."[2] Of particular concern is the expressed need to quantify the extent and duration of potential effects related to resuspended sediments generated by tow traffic during low and normal flow periods in several reaches of both rivers. Such information could be helpful in hypothesizing what potentially may result from the predicated increased tow traffic levels that would be allowed by the Locks and Dam No. 26 replacement project.

2. The studies that address the problem and that have been conducted on the two rivers under study are few and limited in scope. Karaki and van Hoften used infrared aerial photography to show that tow traffic did cause the resuspension of sediments in the Illinois and Upper Mississippi Rivers at several locations on both rivers during normal pool conditions.[3] Although informative, the study was more qualitative in nature since the authors did not attempt to correlate the imagery with suspended solids concentrations of the river water. Using data collected on two separate occasions in 1963, Sparks[4] reported surface turbidity increased and dissolved oxygen decreased in the main channel after tow traffic passed mile 25.9 on the Illinois River during normal pool conditions (river stages on both occasions were 418.5 ft* above mean sea level compared with normal pool stage of 419.0 ft at the Hardin Gage Station). The SLD monitored three tow traffic events by collecting surface water samples from a single boat on a transect across the Illinois River. They concluded that at flood stage conditions (for

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is given on page 6.

one event, flood stage was exceeded by 2.5 ft; and for two events, river stages were 0.9 ft and 1.4 ft below flood stage), tow traffic on the Illinois River had little effect on increasing turbidity levels above ambient levels.

3. Although the above studies contribute to the understanding of the cause-and-effect relationship between tow traffic and resuspended sediment, several questions remain unanswered. For example, what is the temporal and spatial relationship of suspended solids concentrations generated by tow traffic in various reaches of both rivers? Does the sediment plume remain confined to the main channel or does it migrate laterally within the river proper or into potentially biologically productive side channel or backwater areas? Is there an oxygen demand exerted by riverbed sediments resuspended by tow traffic? Are the effects additive with multiple tow events? To answer these questions, the Engineering Division of the U. S. Army Engineer District, St. Louis (SLD) sponsored the study reported herein, which was designed by the Environmental Effects Laboratory (EEL) of the U. S. Army Engineer Waterways Experiment Station (WES) and was conducted by personnel from EEL and the Hydraulics Laboratory (HL) and from SLD.

Objectives

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- a. Determine if tow traffic significantly increases concentrations of suspended solids and turbidity above ambient concentrations at sampling stations located on a transect within the river proper.
- b. Determine if appreciable concentrations of suspended solids and turbidity generated by tow traffic enter side channels or backwater areas.
- c. Determine if multiple tow traffic events have an additive effect on elevating concentrations of suspended solids and turbidity in the immediate study area.

d. Estimate the time required for concentrations of suspended solids and turbidity to return to ambient concentrations in the immediate study areas.

e. Estimate the magnitude and duration of the oxygen demand exerted by riverbed sediments resuspended in the main channel by tow traffic.

Scope

5. The geographical limits of this study spanned nearly 490 river miles on the Upper Mississippi River and approximately 190 river miles of the Illinois River. Within the study boundaries of both rivers, three sampling locations were chosen to correspond to upper, middle, and lower river reaches (Figure 1). The emphasis of this study was to monitor intensively two or more tow traffic events at each of the six sampling locations. Single tows or combinations of multiple tow traffic events at each sampling location could then be compared for response differences. In total, 19 separate tows were monitored on the Mississippi River and 21 tows on the Illinois River. Approximately 4000 water samples were collected in the field, and more than 6300 different analyses were performed during the study.

6. In other studies where tow traffic has been monitored,[2,3,4] only surface water samples have been collected. While such samples provide information relative to the surface strata, nothing can be said about total water-column concentrations. Under natural conditions, generally the concentration of suspended solids increases with depth. During the passage of a tow, one expects turbulence to alter this relationship. To account for the variations produced by tow traffic and to attempt to quantify and to test statistically for changes in the suspended solids concentrations in the total water column (and not just in surface strata), composite water-column samples were collected.

7. Water samples collected in the field were analyzed by the St. Louis Testing Laboratories for suspended solids concentrations and by the SLD water-quality lab for turbidity units (an optical property). Data collected and information recorded in situ included dissolved

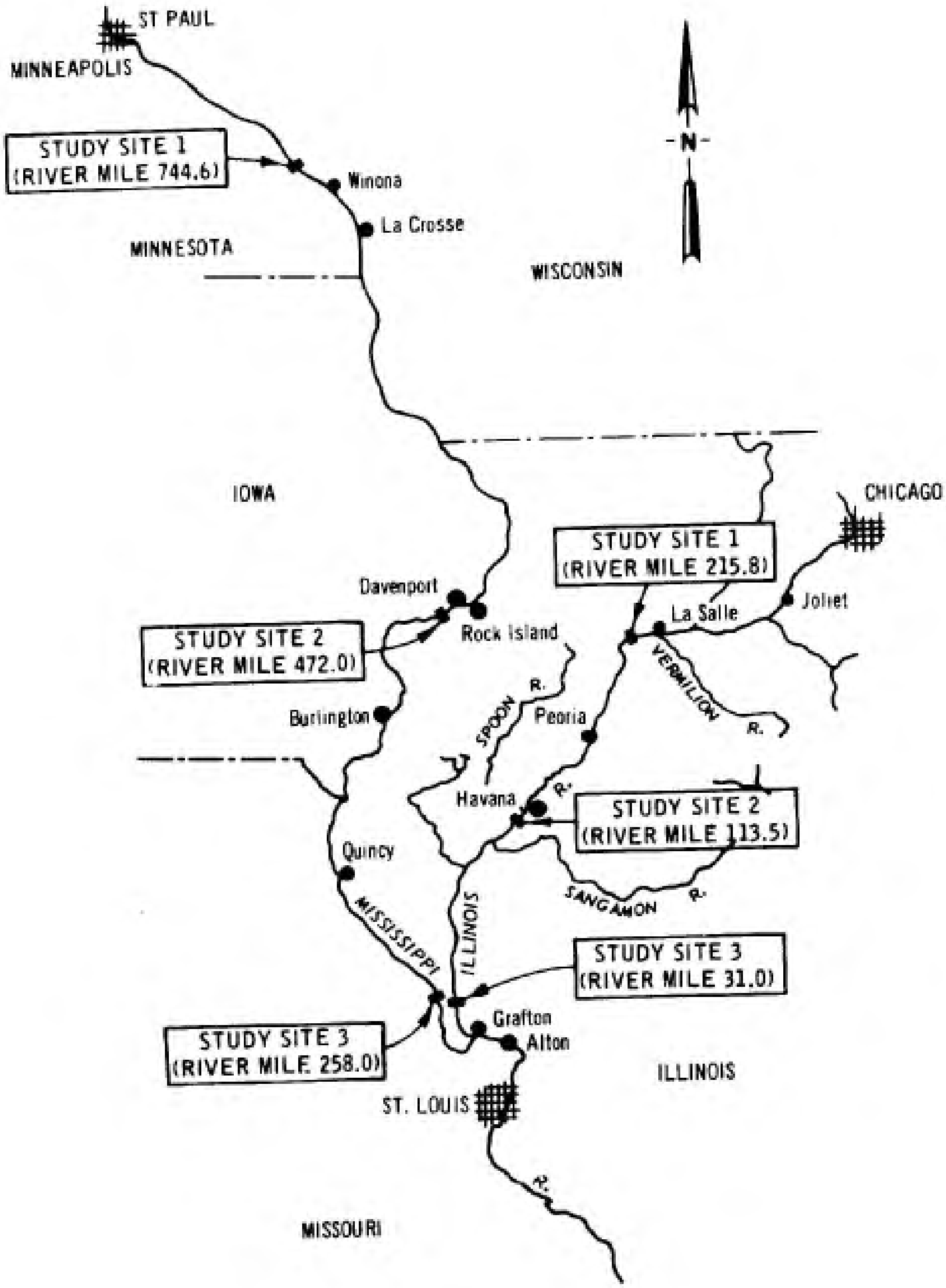

Figure 1. Location of study sites on the Illinois and Upper Mississippi Rivers

oxygen concentration, water temperature, current velocity profiles, water depths, river stages, and tow descriptions.

8. The report format for presentation and discussion of results consists of first treating the Mississippi River studies followed by those studies conducted on the Illinois River. Sampling locations are described for each river and for each tow event. The data (suspended solids, turbidity, and dissolved oxygen) are graphically presented and discussed.

PART II: METHODS OF MEASUREMENT

Selection of Sampling Areas

9. Because it is generally accepted that water quality degrades downstream from the headwaters of the Mississippi and improves downstream from Chicago, Illinois, on the Illinois River, representative reaches of both rivers were selected to conduct the study under varying water-quality conditions. For example, one could hypothesize that since water clarity is greater in the uppermost reaches of the Mississippi River than in its lower reaches, the potential impact of river sediments resuspended by tow traffic in the upper reaches is also greater.

10. Three sampling areas were chosen within both the Illinois and Mississippi Rivers for monitoring various tow traffic events. The areas selected on each river corresponded approximately to upper, middle, and lower river reaches. Selection of specific sampling locations was made according to the criteria described in the following paragraphs.

11. In order to determine if suspended solids enter potentially productive side channels or backwater areas as a result of tow traffic, areas were selected where side channels could be studied. Furthermore, an important selection criterion was establishing that water flowed into side channel areas during the time the studies were made. Current velocity profiles measured at preliminarily selected study areas provided this information. An additional consideration was the general morphology of the river, especially with respect to the position of the side channel. Selection of a side channel on the inside of a riverbend would probably bias the data since normally little flow would enter a side channel in such a location. Therefore sampling areas were selected in either straight reaches or on slight outside bends of the rivers.

12. Attention was also given to depth of water in main channel areas. An effort was made to avoid deep water areas because it was anticipated that the effect of disturbances on the riverbed would

be less there than in more shallow reaches. Other considerations included available and accessible boat landings and distance of travel between boat landings and sampling areas.

13. The sampling locations selected for the Mississippi River by river mile were 744.6, 472.0, and 258.0; for the Illinois River, river mile 215.8, 113.5, and 31.0. These locations are presented in Figure 1 and in detail in maps given in Appendices A and B for the Mississippi and Illinois Rivers, respectively.

General Sampling Scheme

Station locations

14. The basic sampling scheme followed during this study was designed so that temporal and spatial effects could be studied as they related to riverbed sediments resuspended by tow traffic. At each of the six study areas (three on the Illinois and three on the Upper Mississippi Rivers), four boats were positioned along a transect. Sampling stations in the river proper were positioned uniformly across the river and consisted of left bank, main channel, and right bank stations (left and right are oriented looking downriver). The fourth station, the side channel station, was located just inside the upstream entrance of the side channel.

15. In all cases the three stations in the river proper were positioned just upstream of the side channel station. All stations, except the main channel station, were marked with buoys so that the same areas could be returned to for the duration of the monitoring efforts at that site. The detailed maps of the study areas presented in Appendices A and B show the configuration of the sampling stations discussed above.

Sampling frequency

16. Three replicate composite water-column samples were collected simultaneously from each boat at selected time intervals. The time required to collect three replicate samples varied between 2 and 3 min.

Sampling time intervals consisted of immediately before the passage of a tow, and 10, 20, 40, 60, 90, 120, 150, and 180 min after the tow passed. The 180-min duration was chosen since Sparks[4] reported that in the Illinois River, 150 min were required before turbidity returned to ambient levels after passage of a tow. For the present study, in situations where a second tow or multiple tows passed the sample boats, the sampling frequency was started again with each tow passage and was normally continued until 180 min had elapsed after the last tow had passed.

17. Because of the lack of control of tow traffic on both rivers during the conduct of the study, an effort was made not to initiate monitoring efforts when tow traffic was known to have recently passed through the area because ambient concentrations may have been biased upward. The initial samples collected at all four stations prior to the passage of a tow were assumed to represent ambient concentrations. In some instances ambient concentrations differed statistically at some of the sampling stations. Differences in cross-sectional depths, related current velocities, and plankton densities probably accounted for the observed variations since river stage levels measured during the study were either stable or showed a slight drop. The important point is that those concentrations measured prior to the passage of a tow at each sampling station were considered to represent ambient levels and served as reference levels for subsequent comparisons made to assess whether or not tow traffic caused an increase in suspended solids concentrations at a particular sampling station.

Field Measurements

Composite water-column samples

18. Equipment. Composite water-column samples (surface to bottom) were collected using a sampling system that consisted of a small-capacity Jabsco pump powered by a 12-v d-c battery, a 50-ft length of 1/4-in. nylon tubing, a retractable aluminum A-frame and boom, a hand-operated sounding reel, 1/8-in. retrieval cable, and a 15-lb lead weight (called

the "fish" because of its gross shape). A direct-reading Gurley current meter was mounted above the lead fish. The basic features of the sampling system are shown in Figure 2. The base of the sampling unit was bolted to 3/4-in. plywood in the bottom of the sampling boat and secured by sandbags. Because the entire system was light and compact, it could be adapted to and easily operated from the small sampling boats.

19. Sampling procedures. Prior to the collection of water samples, each pump was calibrated to determine the time required for water to pass through the entire 50-ft length of tubing (the length was kept constant for each sampling station).

20. To collect a water-column sample, the lead fish, sensing unit of the current meter, and the attached length of the tubing were lowered to the bottom of the river. After waiting a short period of time to allow the river current to carry away any material resuspended during the lowering of the unit, the pump was run for a time period equal to or greater than its calibration time. The submerged unit was then slowly pulled to the surface while the pump was operating. The predetermined calibration time was allowed to elapse before initiating collection of the sample and after the unit reached the surface. The pumped water was collected in a plastic pitcher onboard the boat. The sample collected in this manner represented a composite of the water column from within about 0.3 m of the river bottom to the water surface.

21. Water contained in each pitcher was agitated and poured rapidly through a plastic funnel into pre-labeled quart-size plastic containers. The samples were then packed in ice and stored until transported to the laboratory for analysis of suspended solids concentrations and determination of turbidity units.

Dissolved oxygen, current velocity, and depth measurements

22. Three replicate dissolved oxygen measurements were made in situ for each of three strata (i.e., the surface, mid-depth, and near-bottom strata) in the main channel station only. It was felt that this station was the most appropriate to test for potential oxygen demand

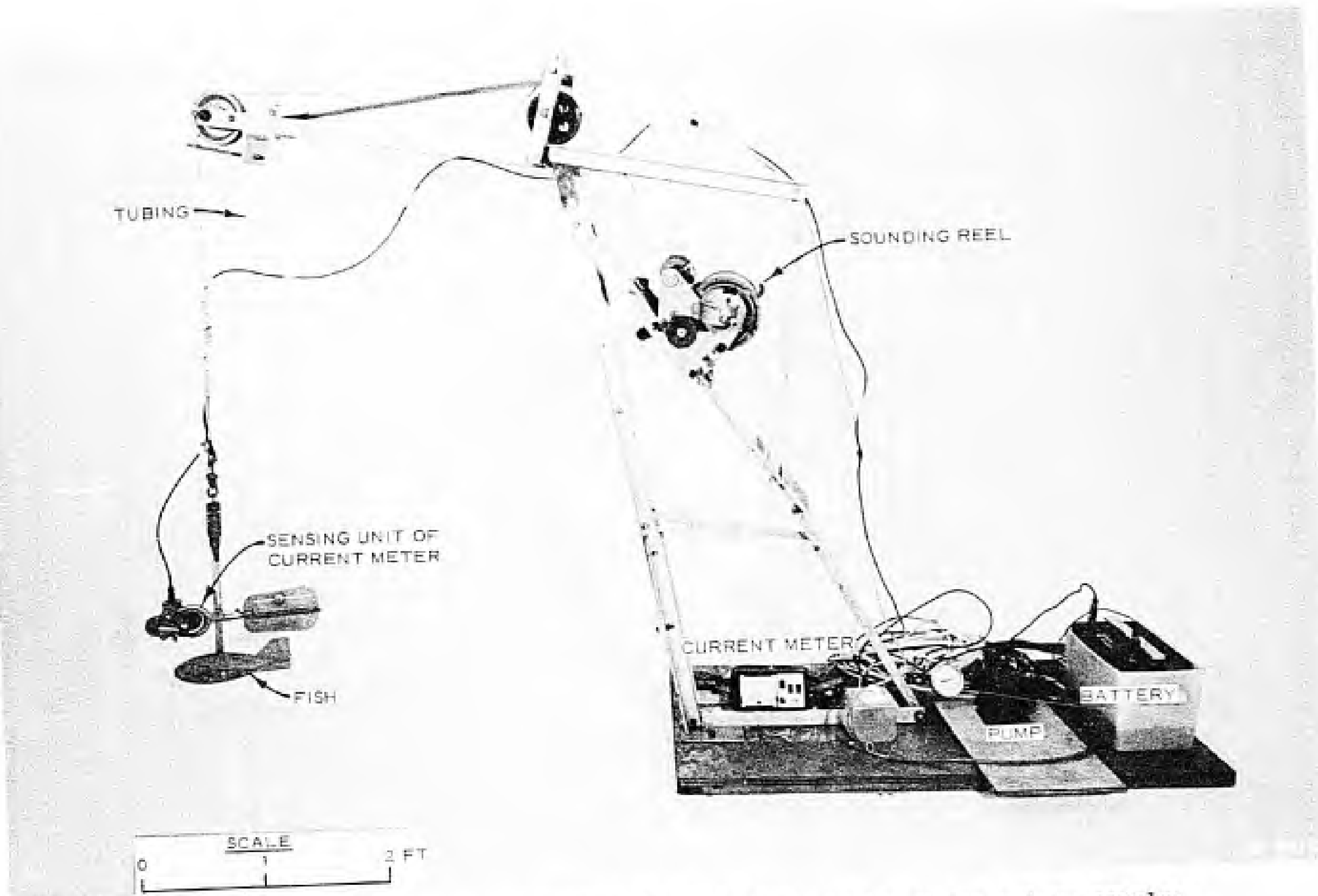

Figure 2. Sampling apparatus used to collect composite water column samples

exerted by sediments resuspended by tow traffic. The instrument used was a YSI Model 57 Dissolved Oxygen Meter and probe. Its accuracy is set at ±0.1 mg/ℓ by the manufacturer. The system was calibrated daily using the air calibration method. Sampling frequency was similar to that described for composite water-column sampling.

23. Current velocity profiles were measured at each of the four sampling stations using a Gurley No. 665 direct reading current meter. Profile depths included surface, mid-depth, and near-bottom strata. Velocities were measured in metres per second and were read directly. The sensing unit was mounted just above the lead fish (see Figure 2). Water depths at each station were read directly in feet (and later converted to metres) using the sounding reel that formed part of the sampling system (see Figure 2).

Tow Traffic and River Stage Information

24. Each tow that passed the study area during the monitoring efforts were contacted using marine band radio and the following information was noted: name of tow boat, name of towing company, number of loaded and empty barges, draft depth, tow velocity, and horsepower of the vessel's engine. The statistics given by the captains of the tows were subsequently confirmed using Reference 5, "Inland River Record." The information collected was considered important for a thorough interpretation of the results.

25. River stage data were obtained from the nearest gaging station for days prior to and during each sampling period for each sampling location. Corps Districts that provided the data for reaches of the Mississippi included St. Paul, Rock Island, and St. Louis. The Chicago District provided data for reaches of the Illinois River.

Laboratory Measurements

Suspended solids

26. Composite water-column samples collected in the field were

delivered to St. Louis Testing Laboratories within a 24-hr period after sampling. All samples were analyzed for suspended solids concentrations expressed in milligrams per litre. The U. S. Environmental Protection Agency (EPA) states that the practical range of the determination is between 10 and 20,000 mg/ℓ. The laboratory procedures followed those specified by EPA.[6] Standard glass fiber filters used were of the Reeve Angel type 934-AH. Pore size dimension of these filters ranged from 0.075 to 1.250μ. Aliquot volumes of water of either 100 and 250 ml were filtered depending on the concentrations of suspended solids.

Turbidity units

27. Although the emphasis of the study was to quantify suspended solids concentrations generated by tow traffic, it was also of interest to measure the optical property (i.e. turbidity) of samples collected during the monitoring efforts. Turbidity has been the primary measurement unit used in previous studies.[2,4] The nephelometric photoelectric method has been adopted as a standard and given preferred status in Standard Methods, American Public Health Association (APHA).[7] This method is used to measure the scattering of light through a water sample and is highly sensitive for measuring low levels of turbidity. Dissolved color in water samples does not register as turbidity using this method and may cause measured turbidities to be low.

28. Aliquots of the same water samples collected for suspended solids were analyzed for turbidity in the water-quality laboratory of the SLD using a Hach 2100 Turbidimeter. Turbidity units were the standard units of measurement and are used as the expression of turbidity in this study. Laboratory procedures followed were those listed in APHA[7] with the following exceptions. For turbidities exceeding 40 units, the samples were not diluted and readings were made directly from the appropriate scales. Also, since some sample sets were not refrigerated for between 1 and 2 days prior to turbidity analyses, the results may reflect positive or negative changes from initial turbidity levels. Generally, however, the same trends observed for the suspended solids concentrations (which were determined on refrigerated samples) were similarily observed using the turbidity data.

Statistical Analyses

29. Suspended solids concentrations and turbidity units measured from samples collected over time at four locations (main channel, right bank, left bank, and side channel) and dissolved oxygen concentrations determined in situ at different depths in the main channel formed the data base that was used to test the following major hypotheses.

- a. Single or multiple tows passing a given area on the river do not significantly increase suspended solids concentrations or turbidity units above ambient levels within the area or over time.
- b. No oxygen demand is exerted by riverbed sediments resuspended from the main channel area by single or multiple tows.

30. Two-way analyses of variance (AOVs)[8] were performed for each variable (suspended solids, turbidity, and dissolved oxygen) monitored during each tow traffic event to test the above hypotheses.

31. A significant F-test indicated only that there were differences among means. In order to determine how the means differed, a least significant difference (LSD) was calculated,[8] and any two means that were found to differ by more than the calculated LSD were then considered significantly different (probability, $P<0.05$). The LSD is a valid test criterion for planned comparisons of paired means and was used in this study to estimate the nature of the response over time. To allow visual inspection of how the means differed, the LSD interval was calculated for each particular tow traffic event and plotted on the figures presented in Part III. It is important to realize that the LSD was not used to make all possible comparisons and that the plotted LSD intervals in the figures do not represent the 95-percent confidence intervals commonly seen in the literature.

32. For the reader who is interested in the measure of variation, standard errors of the means[8] were calculated and are presented with the raw data in the appropriate appendices.

33. To quantify the relationship between suspended solids concentrations and turbidity units, correlation analyses were also performed. Correlation is a measure of the degree to which variables vary

together or a measure of the intensity of the association.[8] For each tow traffic event at each study site, suspended solids and turbidity data from all four sampling stations were used to calculate the correlation coefficient r . For values of r close to zero, there is no linear relationship; for values of r near ± 1, a very strong linear relationship exists. The calculated r's are presented in the discussion sections for each study site.

PART III: TEST RESULTS AND DISCUSSION

34. The results and discussions of the 15 different tow traffic events that were monitored during the study period are presented in this section of the report. Nine separate traffic events monitored within three different reaches (i.e., upper, middle, and lower reaches) of the Upper Mississippi River are discussed first, followed by discussion of the six traffic events monitored in corresponding reaches of the Illinois River.

35. Preceding the discussion of traffic events monitored at each of the six sampling sites, the sites themselves are briefly desscribed. Descriptions have been based on field observations, navigation charts for the Illinois[9] and Upper Mississippi Rivers,[10] and river stage data obtained from the various Corps Districts.

36. All of the six sampling sites were selected in locations where side channels occur. Among the six side channels, two were positioned in straight river stretches and four were positioned on slight outside bends. Although the locations of side channels vary considerably within the reaches of both the Mississippi and Illinois Rivers (i.e., inside or outside of bends or in straight stretches), the selection of side channels positioned on the outside of bends permits testing of possibly the most severe effects of tow traffic for these environments. (See paragraph 11 for selection criteria.)

37. In approaching the interpretation of the results of this study, a word of caution is in order. It is important to realize that effects, other than those related to tow traffic, may distract from clear interpretation of the data. Because of the emphasis and scope of this study, it was difficult to sort out any potential effects that may have been related to waves generated by large and small craft or by wind, or the effects of shoreline erosion caused by the same forces. When these effects were evident, they were noted.

38. Suspended solids concentrations and turbidity levels measured from samples collected over time at four stations (i.e., main channel, right bank, left bank, and side channel stations) and dissolved oxygen

concentrations determined in situ at different depths in the main channel formed the data base that was subjected to statistical analyses (results in Table 1). The reader is reminded that a statistical approach only provides the means for measuring the amount of subjectivity that goes into the researcher's conclusions. Ultimately, the researcher must base his conclusion on the total picture that comes from his overall knowledge of the situation. Throughout Part III of this report, the word "significant" is used in a statistical sense to refer to differences among means at a specified probability level. The reader should not associate its usage with "environmental significance," which was not within the scope of this investigation.

39. For each variable of the data base, the means of the replicate observations have been graphed along with the associated LSD intervals to allow the reader ease and rapid inspection of how the means differed. The amount of variation associated with each mean, and expressed as the standard error of the mean, has been tabulated and is included in appropriate appendices.

40. For each tow traffic event monitored, first the results of the suspended solids analyses are presented, followed by the results of the turbidity and dissolved oxygen analyses. The use of the least significant difference (LSD) is basic to the interpretation of the data for possible changes in concentrations of suspended solids, turbidity, and dissolved oxygen as a result of tow traffic; additive effects associated with the passage of multiple tows; and the time period required for elevated concentrations to return to ambient levels. Comparison of mean values with their associated LSD intervals allows one to make inferences about whether or not the means differed for the specific effects being tested. For example, one cannot simply compare the means by themselves to determine if a statistically significant increase in suspended solids concentrations occurred after the passage of a tow but must look to see whether or not the LSD intervals overlap. Means are not considered to differ in cases where the LSD intervals for two means overlap, but do differ when the LSD intervals are disjoint. This approach allows consistent treatment of all the data and was used throughout this report.

Table 1

Summary of Analyses of Variance Performed for Each Tow Traffic Event on the Mississippi and Illinois Rivers

Location		Event		Variable-Effects Tested								
				Suspended Solids			Turbidity Units			Dissolved Oxygen		
Study Site No.	River/Mile	No.	Description	Time	Habitat	T × H	Time	Habitat	T × H	Time	Habitat	T × H
			Mississippi River									
1	Miss./744.6	1	Multiple-2 upstream	R**	R**	A	R**	R**	R**	R**	R**	R**
		2	Multiple-3 downstream	R**	A	R**	R**	R**	R**	R**	R**	R*
		3	Multiple-1 up, 1 down	A	A	A	R**	A	R*	R**	R**	A
2	Miss./472.0	4	Multiple-1 up, 2 down	R**	R**	R**	R**	R**	R**	R**	R**	R**
		5	Single-downstream	R**	R**	R**	R*	R**	R**	R**	R**	R**
		6	Multiple-3 upstream	R**	R**	R**	A	R**	R*	R**	R**	R**
3	Miss./258.0	7	Single-downstream	R**	R**	R**	R**	R**	R**	R**	R**	R**
		8	Single-upstream	R**	R**	R**	R**	R**	R**	R**	R**	R**
		9	Multiple-1 up, 2 down	R**	R**	R**	R**	R**	R**	R**	R*	R*
			Illinois River									
1	Ill./215.8	1	Multiple-3 upstream	R**	R**	R**	R**	R**	R**	R**	R**	R**
		2	Multiple-4 up, 1 down	R**	R**	R**	R**	R**	R**	R**	R**	R**
2	Ill./113.5	3	Multiple-1 up, 1 down	R**	R**	R**	R**	R**	R**	R**	R**	R**
		4	Multiple-2 up, 2 down	R**	R**	R**	R**	R**	R**	R**	R**	R**
3	Ill./31.0	5	Multiple-3 downstream	R**	R**	R**	R**	R**	R**	R**	R**	R**
		6	Multiple-2 up, 2 down	R**	R**	R**	R**	R**	R**	R**	R**	R**

Notes: Two-way analyses of variance (AOVs) were made for three types of effects of each parameter:
(1) Time - AOV for differences among times accounting for habitat differences.
(2) Habitat - AOV for differences among habitats accounting for time differences.
(3) T × H - AOV for interaction between sampling times.

Column entries are as follows:
R - reject the hypothesis that effects were equivalent.
A - evidence indicates no significant differences.
* - effect significant at 5 percent level.
** - effect significant at 1 percent level.

41. In the interest of clarity, two concepts, additive effects and recovery time, are defined below. One objective of the study was to determine whether or not additive effects result from multiple tow traffic. Effects were not considered additive in cases where the passage of a successive tow(s) did not significantly add to the effects of a previous tow. Effects were additive in cases where the passage of a successive tow did significantly add to the effects of a previous tow. Again it should be emphasized that the basic criterion consistently used to differentiate between additive or nonadditive effects was comparison of the means and associated LSD intervals.

42. Another objective of this study was to estimate the time required, or recovery time, for concentrations of the response variables to return to ambient concentrations. To estimate recovery time, the initial time and terminal time were determined. The initial time was defined as that point along the axis (time) at or after the passage of a tow(s) where the mean concentration did not differ from the ambient concentration yet did differ from the maximum mean concentration or response. The terminal time was defined as that point along the axis (time) after the maximum response occurred where the mean concentration did differ from the maximum response but did not differ from the ambient concentration. Again this interpretation is based on the comparison of the means and associated LSD intervals.

Mississippi River

Description of study site 1 - river mile 744.6

43. The initial study site on the Mississippi River was located at river mile 744.6 about 19 river miles upstream from the town of Winona, Wisconsin, and directly opposite the town of Buffalo, Wisconsin. In this particular reach of the upper river, the study transect was positioned slightly downstream from an outside bend of the river that caused the longitudinal profile of the river or thalweg to swing nearer the right bank (Figure A1).

44. The width of the river across the study transect was

approximately 230 m. The off-channel opening, or what will be referred to as a side channel for convenience sake, was located on the right side of the river and opened into the Weaver Bottoms area near a marker light. The side channel station was positioned approximately 100 m downstream from the three upstream sample stations. Depths recorded for the sample stations were: main channel, 3.7 m; right bank, 1.5 m; left bank, 2.9 m; and side channel, 4.6 m. Mean current velocities were generally higher at the main channel (surface - 0.28 m/sec; bottom - 0.2 m/sec) and right bank stations (surface - 0.22 m/sec; bottom - 0.2 m/sec) than at the left bank station (surface - 0.18 m/sec; bottom - 0.2 m/sec) or the side channel station (surface - 0.13 m/sec; bottom - 0.1 m/sec).

45. Three separate multiple tow traffic events were monitored at this study site: two upstream tows; three downstream tows; and one upstream and one downstream tow (Table 2). River stage data measured at a gage located at river mile 748.8 indicated that prior to and during the period in which tow traffic was monitored, the river was at normal pool elevations (660.0 ft above mean sea level, MSL) (Table 3).*

Event 1**

46. The two tows monitored during this event were both moving upstream and passed the study site within 30 min of each other. Although pushing more loaded barges and powered by about twice the horsepower, tow 1 was noted to have a smaller draft depth and was moving slower than tow 2. Estimated difference between bottom of the channel and drafts for barges of tows 1 and 2 were 1.1 and 1.0 m, respectively.

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* All information relative to description of tow events is taken from Table 2 and all river stage data are from Table 3. No further reference to these two tables will be made.

** Passages of tow traffic (single or multiple) for each of the two rivers are numbered consecutively as event 1, event 2, etc.

Table 2

Description of Tow Traffic Events

Study Site No.	River/Mile	No.	Event Description	Date 1975	Vessel Name and Direction	Maximum Engine hp	Towing Company	[illegible]
					Mississippi River			
				October				
1	Miss./744.6	1	Multiple-2 upstream	8	Reliance*	2240	Wisconsin Barge Line	[illegible]
					Gateway*	1540	G. W. Gladders Towing	[illegible]
		2	Multiple-3 downstream	8-9	Mary Ann-	1200	Swingel Towing Co.	[illegible]
					Hugh [illegible]	5600	American Commercial [illegible]	[illegible]
					H. M. [illegible]	2800	Husband Towing Co.	[illegible]
		3	Multiple-1 up, 1 down	9	Prairie State*	3200	Midwest Towing Co.	[illegible]
					George Weathers-	[illegible]	Weathers Towing	[illegible]
2	Miss./472.0	4	Multiple-1 up, 2 down	13	[illegible]	2400	Inland Towing [illegible]	[illegible]
					DeRay Miller-	5600	American [illegible]	[illegible]
					Norma Christiana-*	[illegible]	----	[illegible]
		5	Single-downstream	13	[illegible]	[illegible]	Upper Mississippi Towing Co.	[illegible]
		6	Multiple-3 upstream	14	Jack H. [illegible]*	5600	American Commercial Towing	[illegible]
					Raven*	[illegible]	Wilkinson & [illegible]	[illegible]
					Clark Fromer*	3200	Southern Towing Co.	[illegible]
3	Miss./258.0	7	Single-downstream	27	Debbie Lou-	2200	Sandpan Towing	[illegible]
		8	Single-upstream	29	[illegible] H. Blaske*	5600	American Commercial Co.	[illegible]
		9	Multiple-1 up, 2 down	30	Elizabeth Ann*	2250	Missouri Barge Line	[illegible]
					John C. Byrd-	4200	Old Man River Towing Inc.	[illegible]
					[illegible]	4800	Upper Mississippi Towing Co.	[illegible]
					Illinois River			
1	Ill./231.8	1	Multiple-3 upstream	16	George W. Banta*	2400	Loughman Towing Co.	[illegible]
					[illegible]*	4200	Energy Transport Service	[illegible]
					Greenville*	3200	Williamson Towing Co.	[illegible]
		2	Multiple-4 up, 1 down	17	Richard F. [illegible]*	1800	Thomas Marine Co.	[illegible]
					Kenova*	2476	Ohio River Co.	[illegible]
					Lady Marjorie-	3200	Inland Oil & Transportation	[illegible]
					Dresden*	2140	Valley Line Co.	[illegible]
					Minnesota*	2600	Wisconsin Barge Co.	[illegible]
2	Ill./[illegible]	3	Multiple-1 up, 1 down	19	Della Ann-	2200	Robbins Towing Co.	[illegible]
					Terri Lynn*	2600	Thibodaux Marine Service	[illegible]
		4	Multiple-2 up, 2 down	20	Wisconsin*	3200	Wisconsin Barge Line	[illegible]
					Yankton*	1800	Sioux City & New Orleans	[illegible]
					Luke Gladders-	3200	G. W. Gladders Towing	[illegible]
					[illegible]-	2200	Houston Barge Line	[illegible]
3	Ill./[illegible]	5	Multiple-3 downstream	22	Molly M-	2400	Sandpan Towing Co.	[illegible]
					Caitlin Carrol-	2200	Sandpan Towing Co.	[illegible]
					Mariner-	4200	Marine Transport Co.	[illegible]
				November				
		6	Multiple-2 up, 2 down	2	Katherine L*	1800	Inland Waterways Inc.	[illegible]
					Luke Gladders-	3200	G. W. Gladders Towing	[illegible]
					Mary Ann-	1200	Swingle Marine	[illegible]
					[illegible] Hobart*	2400	Hobart & Trotter	[illegible]

*Drifted past transect

Table 3

River Stage Data Collected for Sampling Locations During Tow Traffic Monitoring

Related River Stage Data*							Tow Event		
					Daily Measurement				
Gaging Station	Record Low**	Normal Pool	Record High	Flood Stage	Date 1975	Reported Elevation	No.	Location River/Mile	Date Sampled
				Mississippi River					
					October				
Pool 5 Control Point Miss. RM 748.8	655.4	660.0	672.1	672.0	6	660.0			
					7	660.0			
					8	660.0	1,2	Miss./744.6	8
					9	660.0	2,3	Miss./744.6	9
					10	660.0			
Fairport, Iowa Miss. RM 436.6	533.3	545.0	558.7	549.1	10	545.8			
					11	545.4			
					12	545.5	4	Miss./472.0	12
					13	545.4	5	Miss./472.0	13
					14	545.5	6	Miss./472.0	14
					15	545.8			
Mosier Landing Miss. RM 260.3	427.9	434.0	451.5	441.0	20	434.2			
					21	434.1			
					22	434.0	7	Miss./258.0	22
					23	434.1			
					27	434.3			
					28	434.3			
					29	434.4	8	Miss./258.0	29
					30	434.3	9	Miss./258.0	30
					31	434.6			
				Illinois River					
Spring Valley Highway Bridge Ill. RM 218.4	-	440.1	459.6	451.0	14	440.6			
					15	441.2			
					16	441.0	1	Ill./215.8	16
					17	440.9	2	Ill./215.8	17
					18	440.5			
Havana Gage Ill. RM 118.4	-	429.2	451.7	438.7	17	430.9			
					18	430.8			
					19	430.7	3	Ill./113.5	19
					20	430.5	4	Ill./113.5	20
					21	430.0			
Hardin Gage Ill. RM 21.6	407.3	419.0	438.2	425.0	28	419.0			
					29	419.0			
					30	418.7			
					31	419.0	5	Ill./31.0	31
					November				
					1	419.0			
					2	419.0	6	Ill./31.0	2
					3	419.0			

*All river stage data expressed as elevation in feet above mean sea level.
**Dash entry indicates that no records were available.

47. Suspended solids. Ten minutes after the passage of tow 1, mean concentrations of suspended solids increased above ambient concentrations at all four stations (main channel, right bank, left bank, and side channel), but only increased significantly (5-percent level) at the left bank station (Figure 3). (Note that the LSD intervals for 1720 hr and 1745 hr overlap for all habitats except the left bank station.) Suspended solids concentrations at all stations began to decline 15 min after the passage of tow 1. Ten minutes after passage of tow 2, suspended solids concentrations increased slightly at all stations but only significantly at the main channel station (11.7 mg/ℓ over ambient). It is apparent that each tow did not have a uniform effect across the river; that is, the responses were different for each habitat. Based on the LSD, no significant concentrations of suspended solids entered the side channel during the monitored period and no additive effects observed.

48. The time required for the return to ambient levels varied according to sampling station: main channel, 45 min; right bank, 125 min; and left bank, 120 min.

49. Turbidity levels. While the turbidity data followed similar trends observed for suspended solids, the interpretation of the data differs because of the smaller calculated LSD value (less variability within replicates). The essential differences based on turbidity levels include the following points. The passage of the initial tow significantly increased turbidity at main channel and left bank stations, but increased turbidity due to the passage of tow 2 was not evident at right bank and side channel stations until 25 and 40 min, respectively, after the event. Also, the time required for the return to ambient levels for each of the stations was: main channel, 130 min; right bank, 65 min; left bank, 60 min; and side channel, 95 min (Figure 4). The passage of tow 2 did not have any additive effects on turbidity levels for event 1.

50. Dissolved oxygen. Figure 5 shows the relationship of dissolved oxygen concentrations at three depths and suspended solids concentrations measured in the main channel. Although the figure is presented, malfunction of the YSI dissolved oxygen meter during this

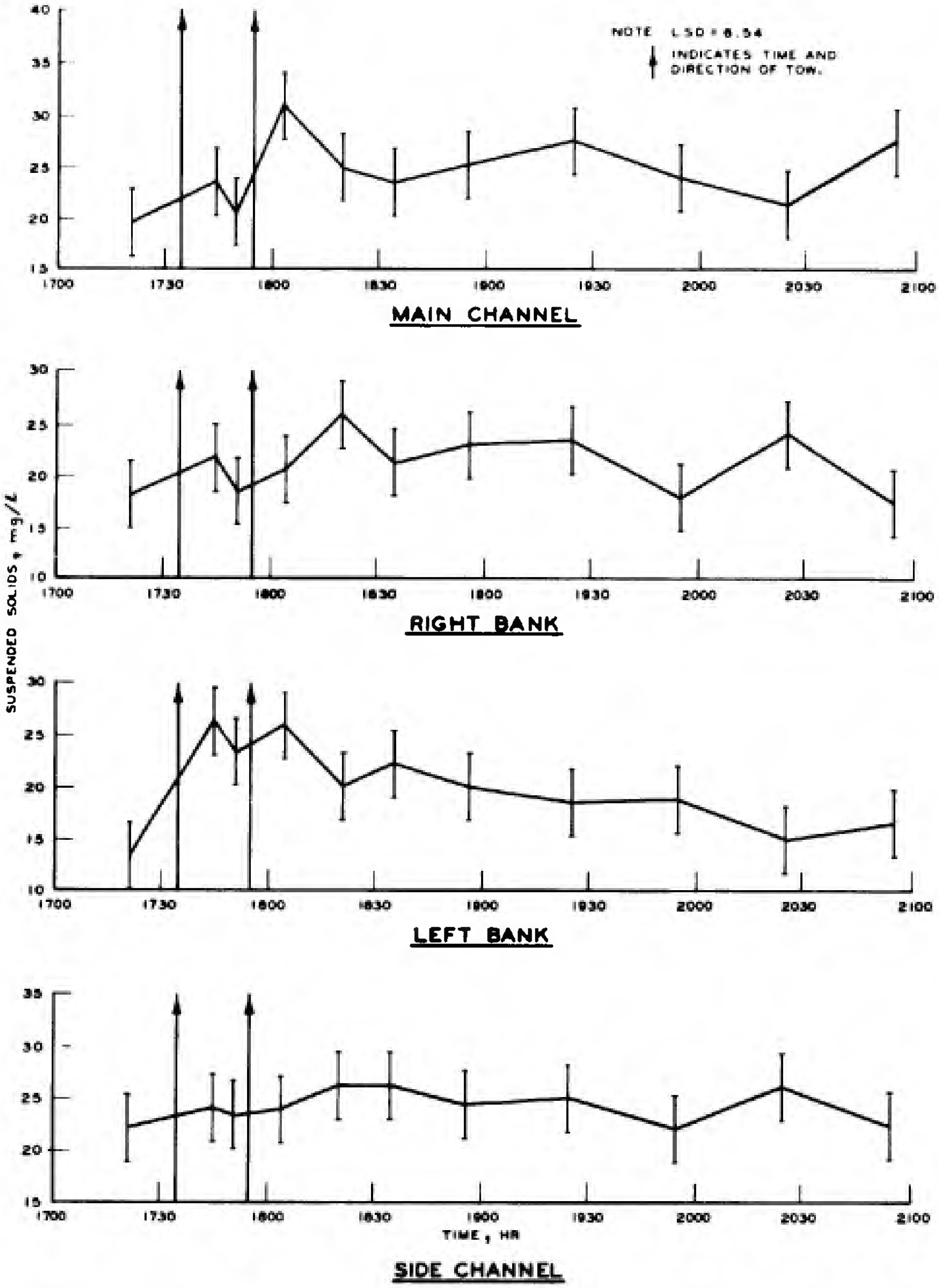

Figure 3. Effect of event 1 (multiple tow) on suspended solids concentration, Mississippi River sampled at RM 744.6, 8 Oct 75

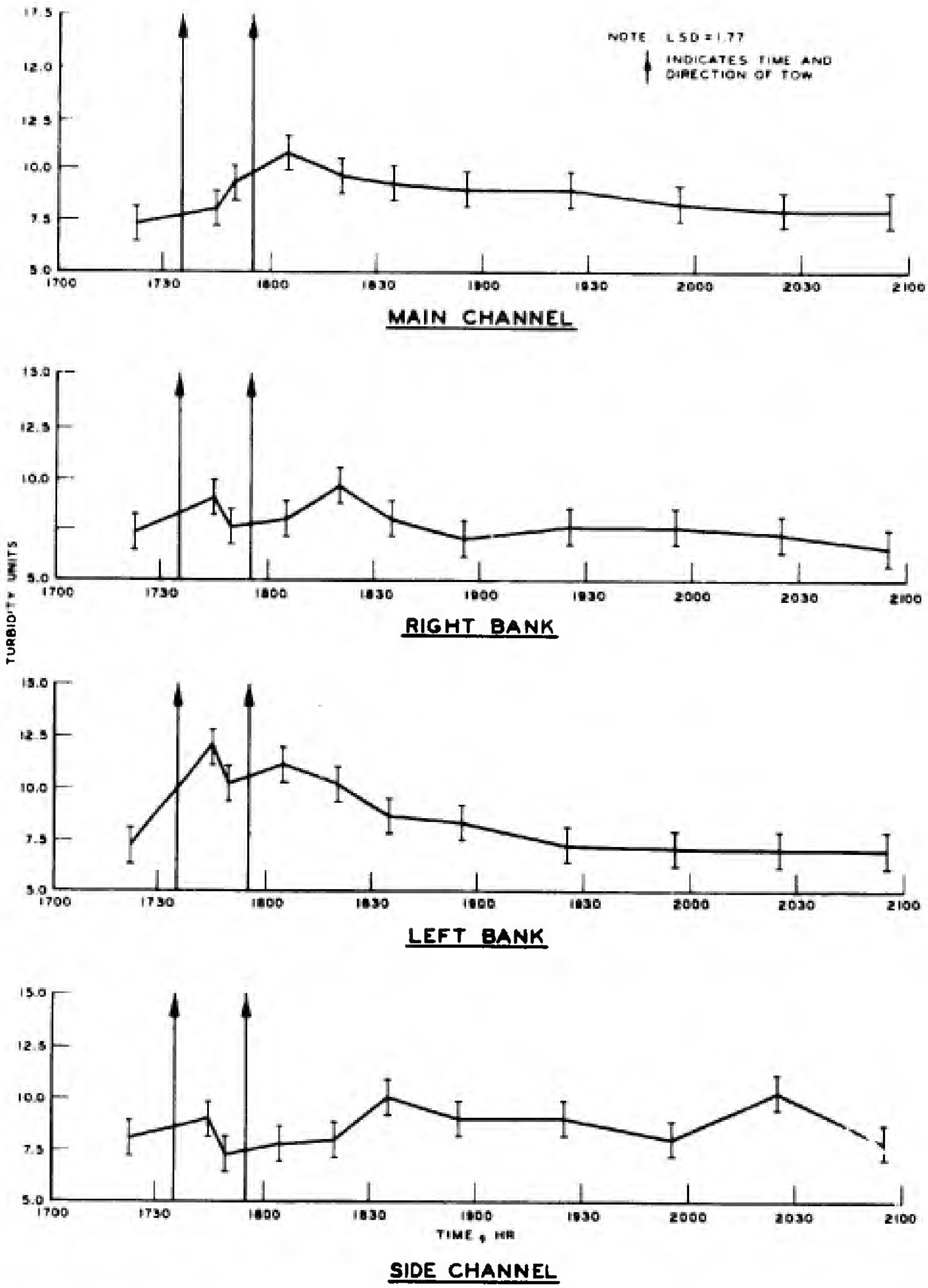

Figure 4. Effect of event 1 (multiple tow) on turbidity, Mississippi River sampled at RM 744.6, 8 Oct 75

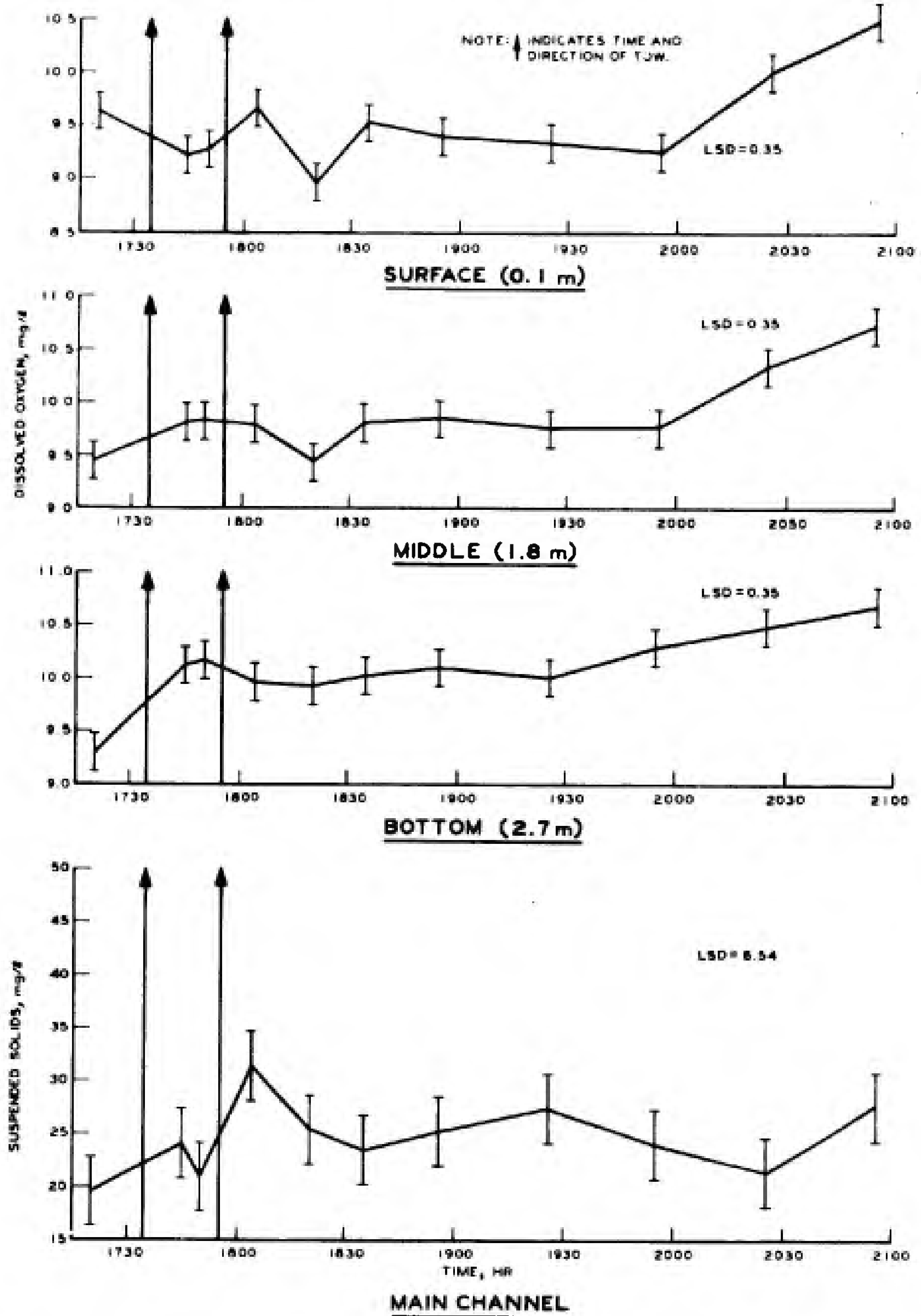

Figure 5. Effect of event 1 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 744.6, 8 Oct 75 (Note: Data are questionable due to equipment malfunction.)

initial monitoring effort precludes any interpretation of the data.

Event 2

51. This event consisted of monitoring three downstream tows, with the first two passing the study site within 10 min of each other, followed by the third tow 125 min later. Tow 1 was pushing two empty barges with draft depths of 0.45 m. Tows 2 and 3 were pushing 13 and 9 loaded barges, respectively, and both had draft depths of 2.7 m. Depth differences between barge drafts and bottom of the channel were 3.2 and 1.0 m.

52. Suspended solids. Thirty minutes after passage of the initial two tows, suspended solids concentrations increased significantly above ambient levels at main channel and left bank stations (Figure 6). While the mean for the right bank station showed a similar trend, it did not differ from the mean ambient concentration. In interpreting the response of the side channel station, ambient concentration was assumed to be immediately after the passage of tow 2. This assumption was made because the suspended solids level was higher prior to the passage of the tows. On this basis the side channel did not show any increase in suspended solids until 45 min after the passage of tows 1 and 2. This response somewhat lags the response observed at main channel and left bank stations. The time required for the return to ambient levels after the passage of the initial tows were: main channel, 50 min; left bank, 50 min; and side channel, 50 min. The right bank station was unaffected by any of three tows that passed through the area; the passage of tow 3 had no significant effect, additive or otherwise, on any sampling station.

53. Turbidity levels. The turbidity data generally followed the trends observed for suspended solids except for the following differences: turbidity levels measured at the side channel station showed a significant increase 15 min after tow 2 passed (Figure 7) and recovery times noted were 30 min for the main channel and 40 min for the side channel.

54. Dissolved oxygen. Figure 8 shows that while dissolved oxygen concentrations were unaffected by the passage of the initial two tows, the passage of tow 3 significantly decreased concentrations by 0.53 mg/ℓ

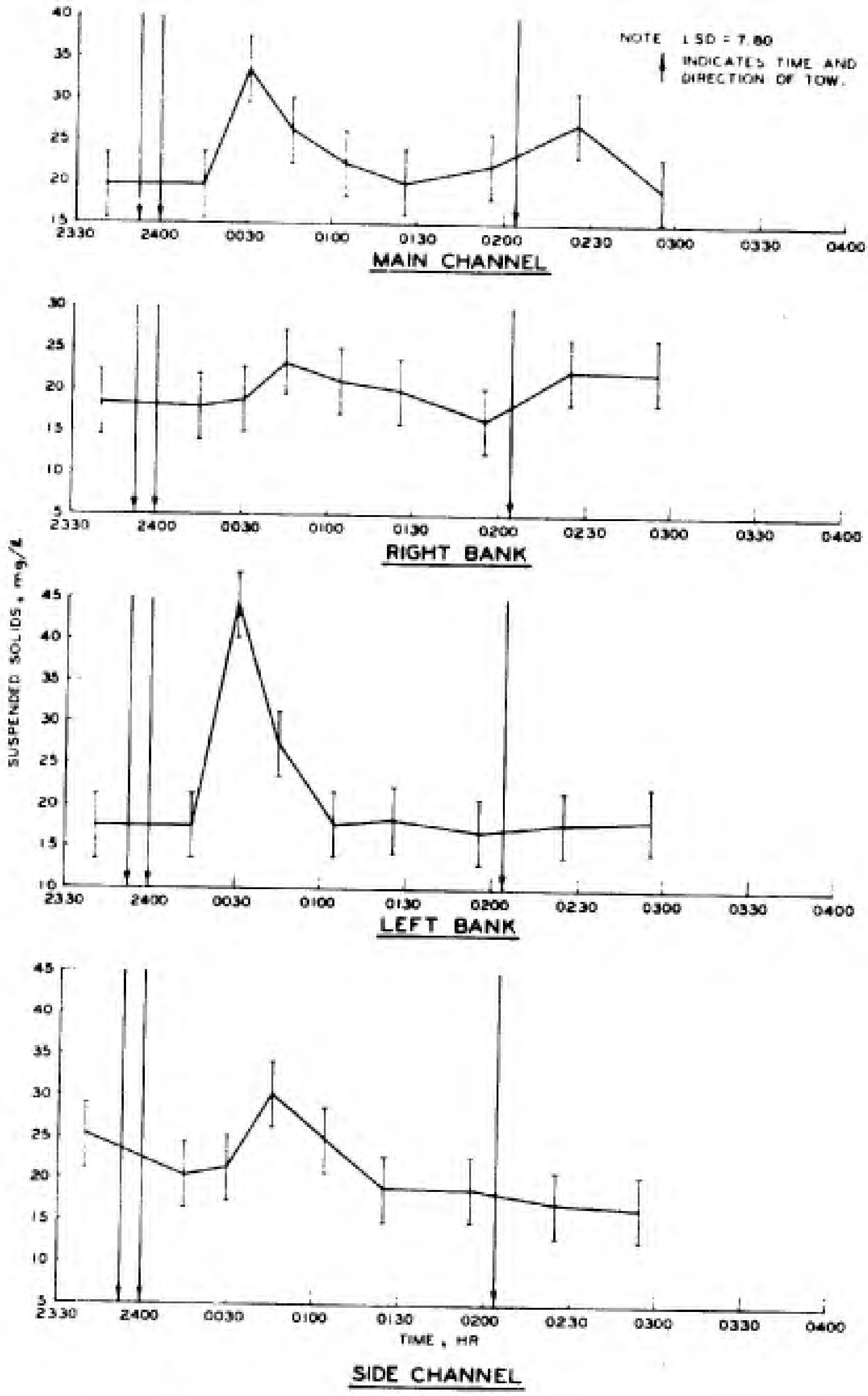

Figure 6. Effect of event 2 (multiple tow) on suspended solids concentration, Mississippi River sampled at RM 744.6, 8-9 Oct 75

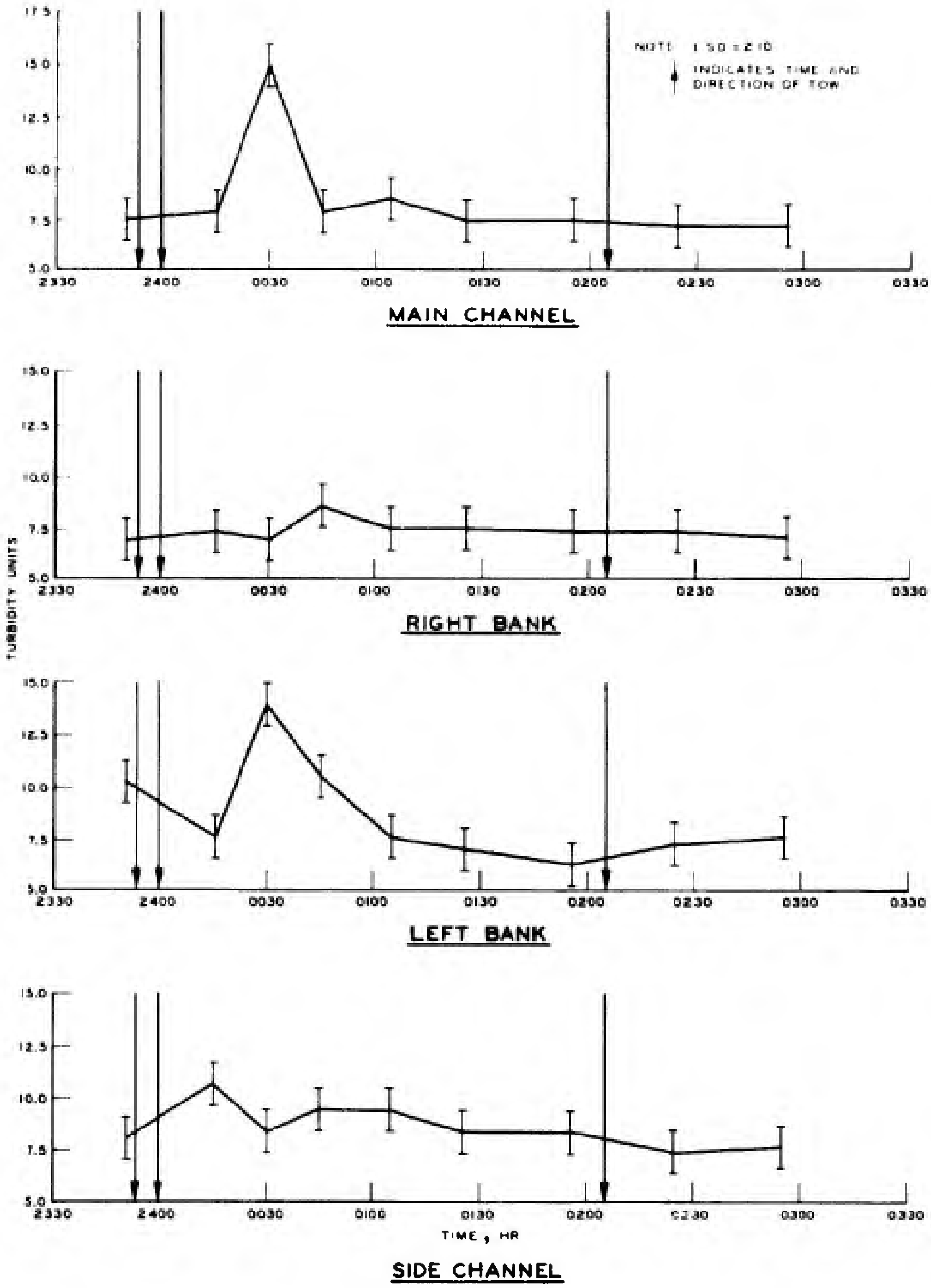

Figure 7. Effect of event 2 (multiple tow) on turbidity, Mississippi River sampled at RM 744.6, 8-9 Oct 75

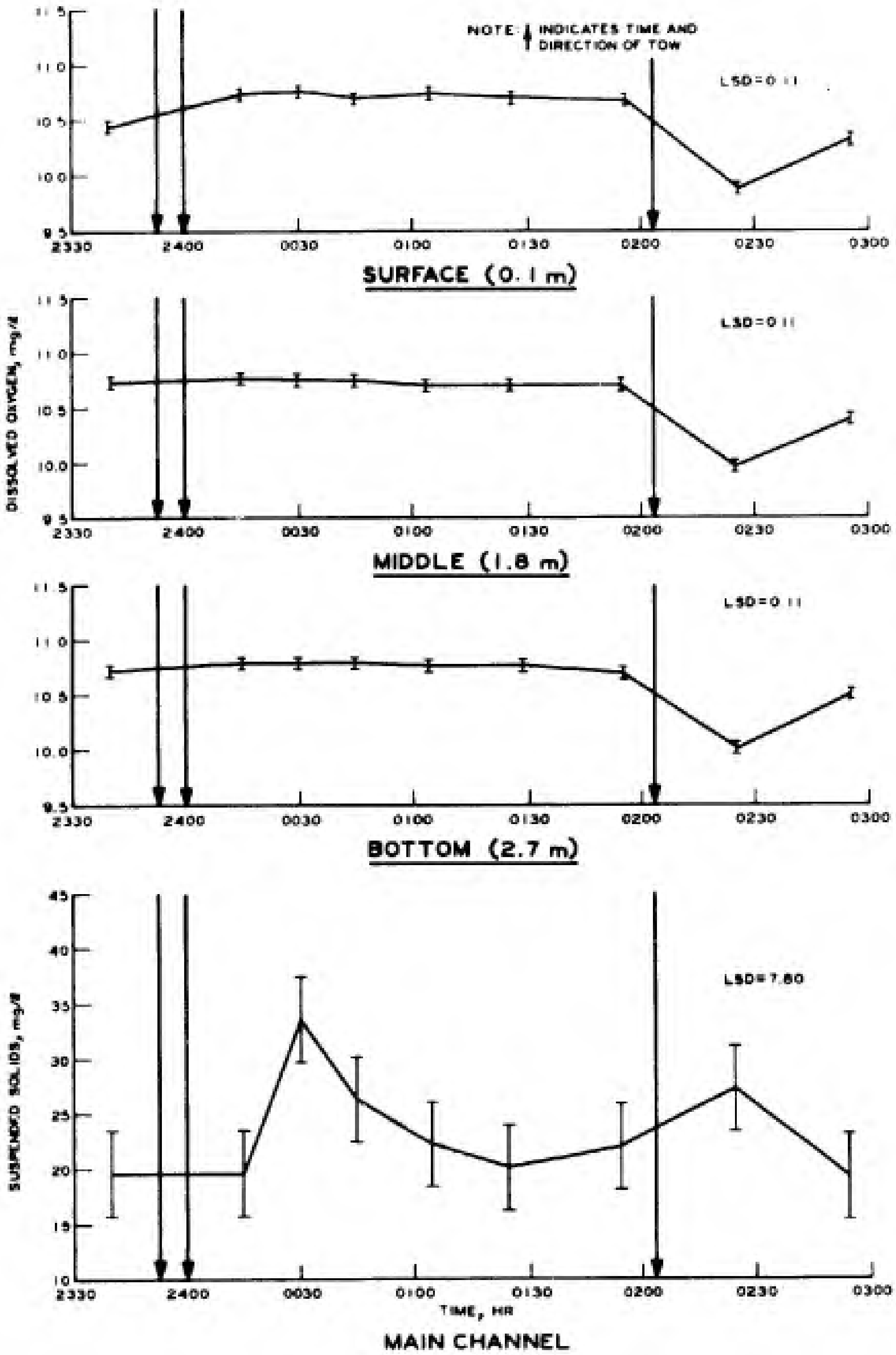

Figure 8. Effect of event 2 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 744.6, 8-9 Oct 75

at surface depth; 0.77 mg/ℓ at middle depth; and 0.73 mg/ℓ at bottom depth. Time required for concentrations to return to ambient levels was about 30 min.

Event 3

55. This particular tow traffic event consisted of one tow moving upstream followed by another tow moving downstream with a 30-min time period separating the two. The initial (upstream) tow was pushing two loaded barges; the second, nine loaded barges. The draft depth for each was 1.0 m less than the depth of the main channel in this area.

56. Suspended solids. The crossing of two tows at this site on the Mississippi River caused significant increases in suspended solids concentrations at the main channel, right bank, and left bank stations (Figure 9). In the main channel, concentrations increased to a maximum of 10.7 mg/ℓ over ambient levels 10 min after tow 2 passed; 120 min were required before suspended solids concentrations returned to ambient levels. The 120-min delayed response at the right bank station was unexplainable. It is important to point out that concentrations were still above the ambient concentration at the end of the sampling period. Standard errors calculated for sampling times 0750 and 0820 were within the range of those calculated for other times (Table D3). At the left bank station, concentrations of suspended solids increased slightly but (based on the LSD interval) significantly over the ambient concentration at 0700 hr. Recovery time for this station was 90 min. Although mean concentrations for the side channel stations showed a slight increase following the passage of both tows, these increases were not significant based on the LSD. No additive effects were observed at any station after tow 2 passed the study site.

57. Turbidity levels. Turbidity trends did not generally follow those trends observed for suspended solids (Figure 10). Maximum increased turbidity occurred 40 min after passage of tow 2 and returned to ambient levels 80 min later at the main channel station. No significant effects were observed at the right bank station. While no effects were noted for left bank and side channel stations based on suspended solids, there were significant effects at these stations based on turbidity

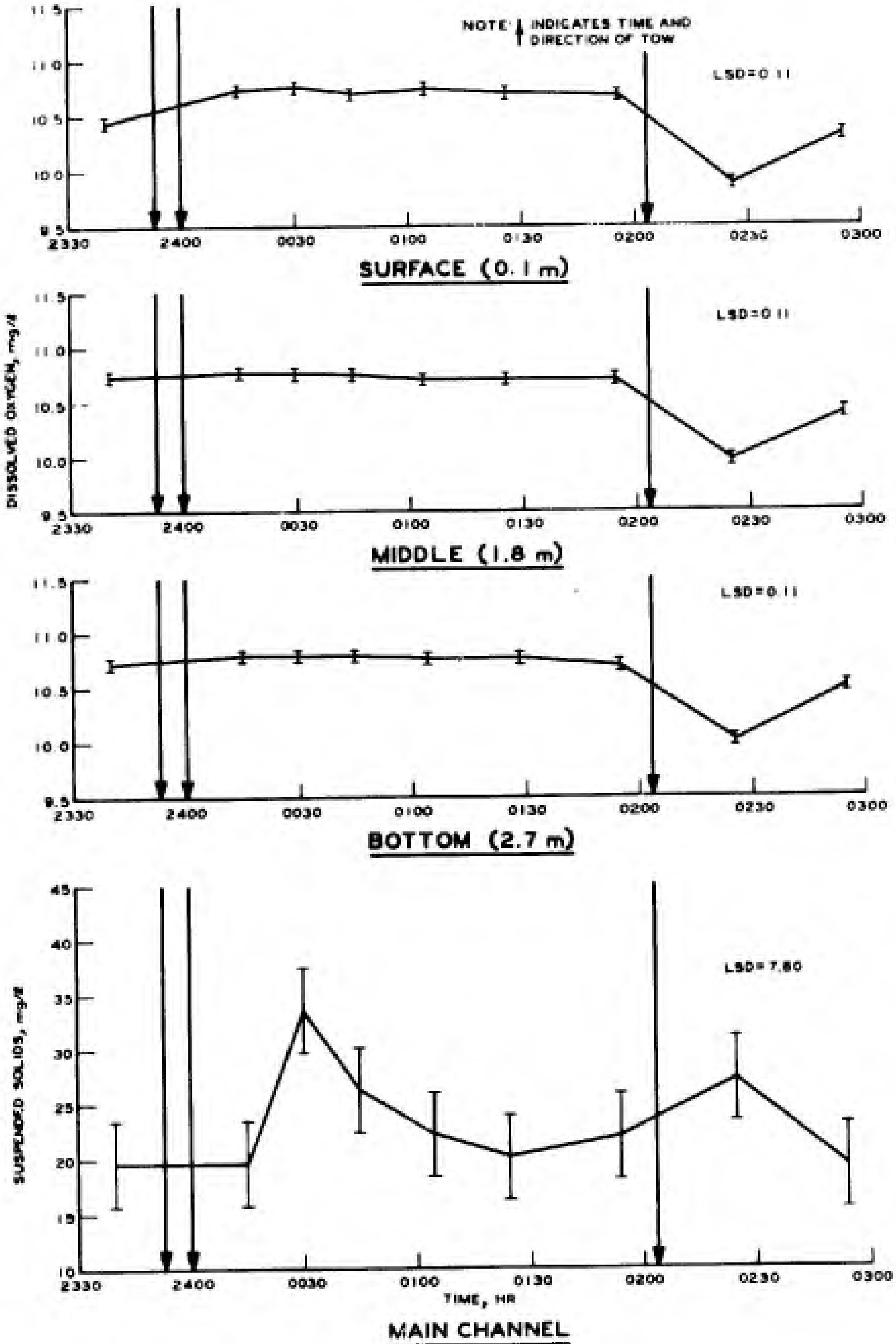

Figure 8. Effect of event 2 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 744.6, 8-9 Oct 75

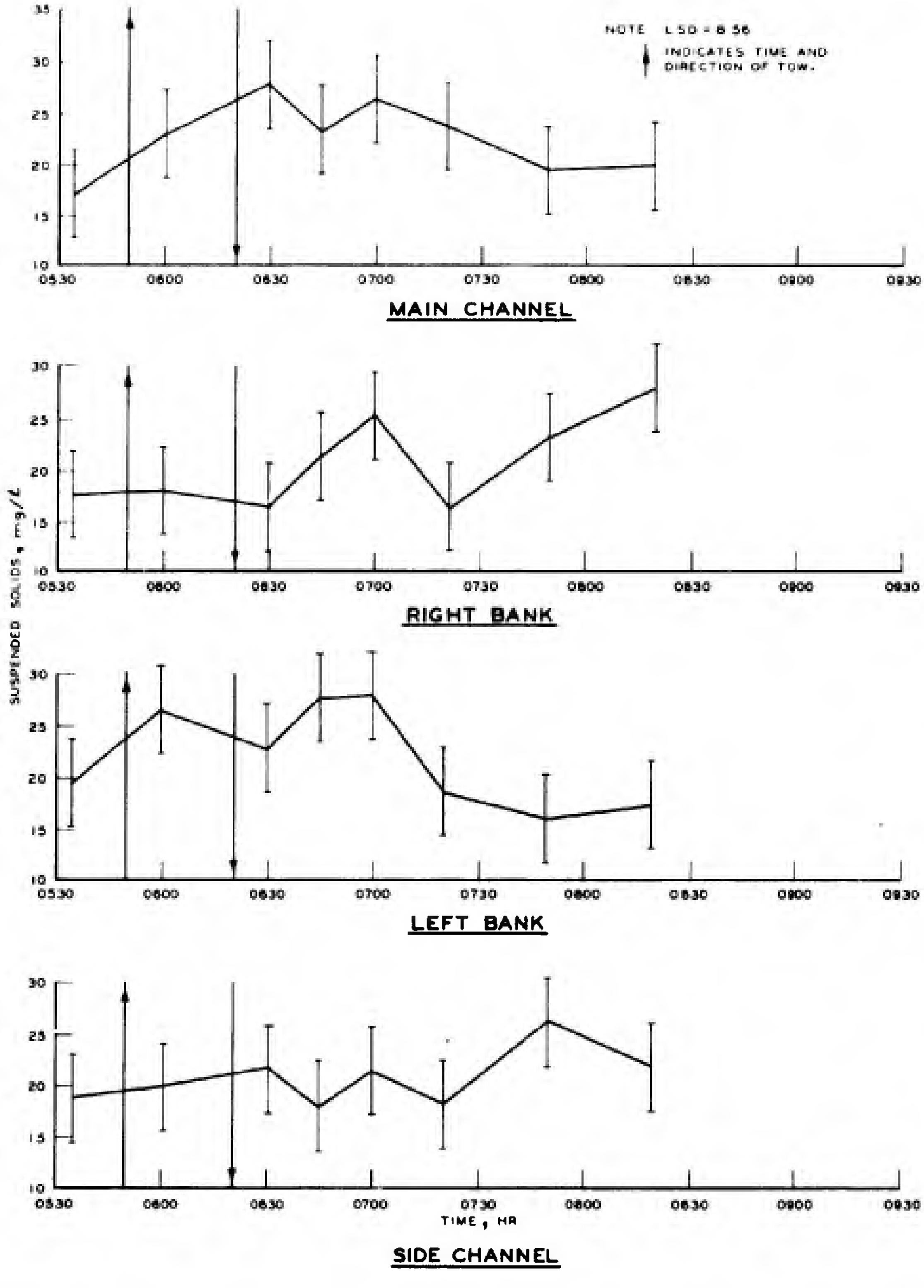

Figure 9. Effect of event 3 (multiple tow) on suspended solids concentration, Mississippi River sampled at RM 744.6, 9 Oct 75

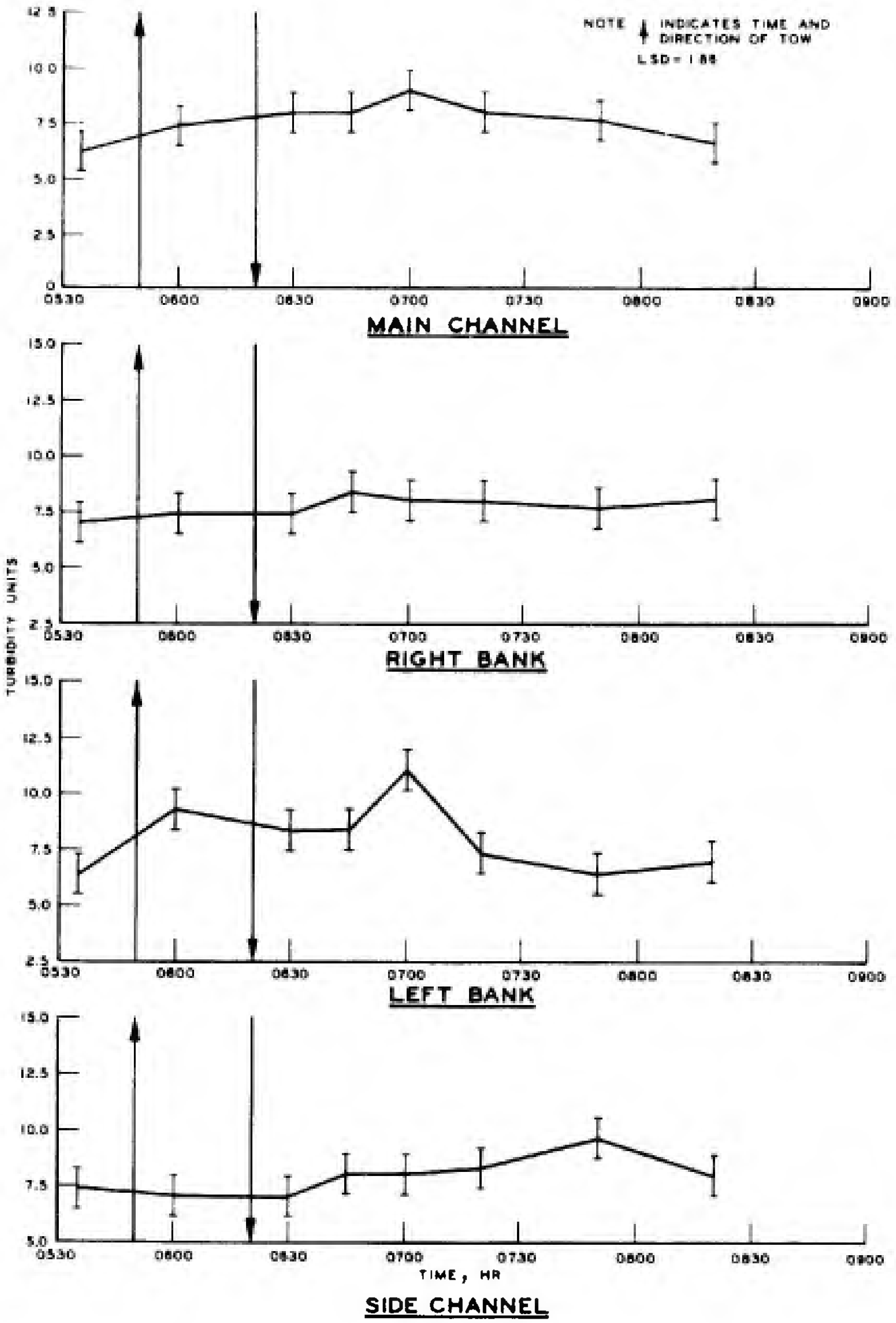

Figure 10. Effect of event 3 (multiple tow) on turbidity, Mississippi River sampled at RM 744.6, 9 Oct 75

data. The maximum turbidity increase over ambient levels at the left bank station amounted to 5.0 turbidity units and occurred 40 min after passage of the second tow. At the left bank station, 90 min were required for the return to ambient conditions. A significant increase in turbidity at the side channel station did not occur until 90 min after the passage of the second tow. Based on the definitions of initial and terminal times previously mentioned, 110 min was required before concentrations returned to ambient levels.

58. Dissolved oxygen. The suspended solids concentrations generated by the two tows during this event did not affect dissolved oxygen concentrations (Figure 11).

Discussion

59. During the 2-day period in which multiple tow traffic events were monitored at river mile 744.6 (site 1) on the Mississippi River, statistically significant effects related to tows passing through the study area were observed. The mean depth difference between tow drafts and channel bottom was 1.32 m. The responses noted were not consistent for each variable studied, nor were they the same for each station that was sampled.

60. Significant increases in suspended solids concentrations were consistently observed at the main channel and left bank stations over or near which the tows most frequently passed. However, increases were noted for other areas as well. The largest significant increases in suspended solids concentrations were noted at the left bank station where concentrations over ambient levels ranged from 8.7 to 26.7 mg/ℓ. The next largest increase was observed at the main channel station (10.7 to 14.0 mg/ℓ) followed by the right bank station (5.3 to 8.3 mg/ℓ). Increased suspended solids concentrations above ambient levels at the side channel station (5.0 mg/ℓ) were observed during only one of the three events monitored at this site.

61. The period of time required for suspended solids concentrations to return to ambient levels was less at the side channel (50 min) than at other stations. Recovery times for the main channel station ranged from 45 to 120 min and for the left bank station, from 50 to 120 min.

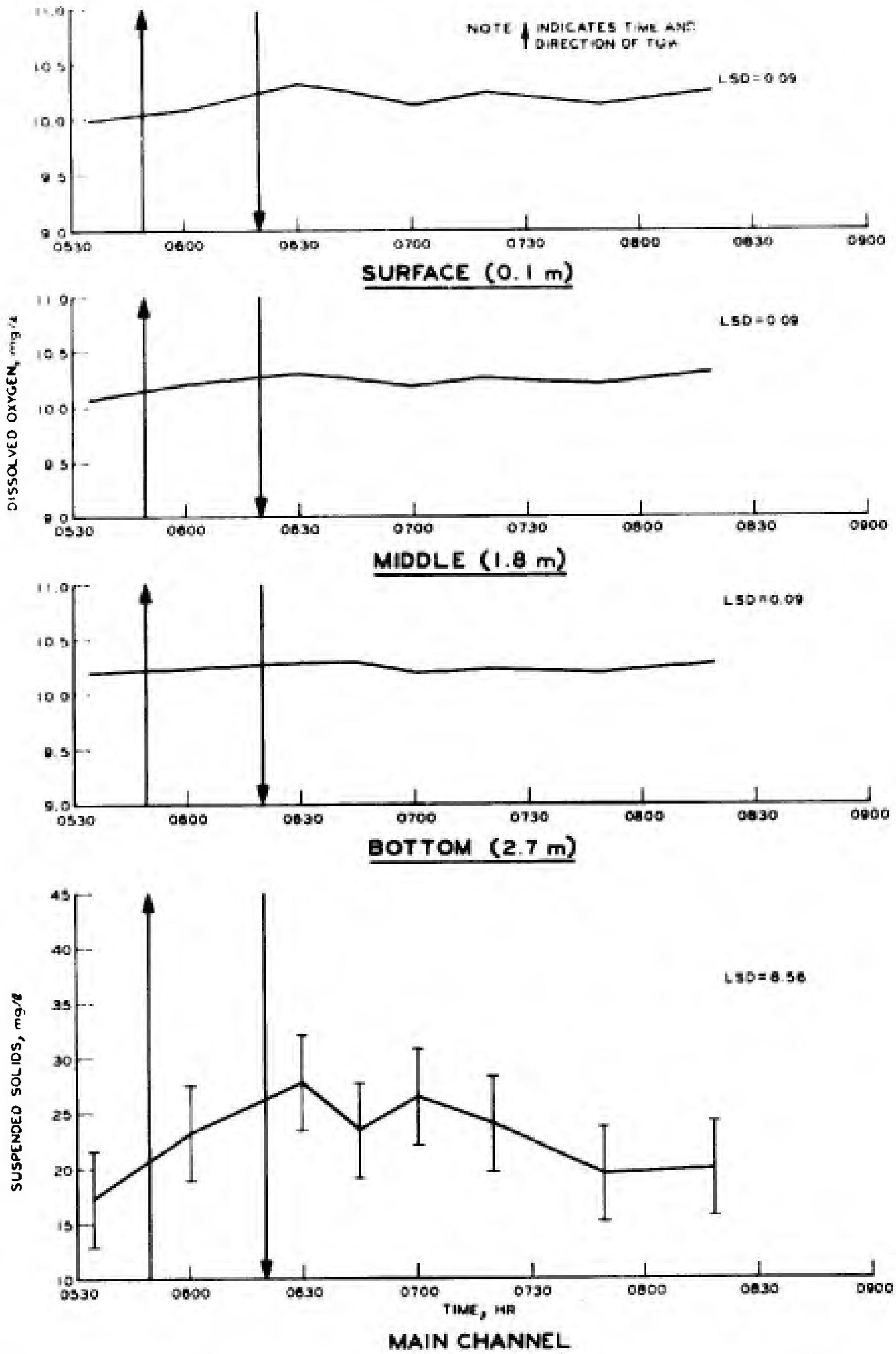

Figure 11. Effect of event 3 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 744.6, 9 Oct 75 (Note: LSD value for DO too small to graph)

During the third tow traffic event, suspended solids concentrations did not return to ambient levels at the right bank station for the duration of the 165-min sampling period.

62. Generally, the turbidity trends followed those noted for suspended solids; however, based on the statistical interpretation, a larger number of statistically significant increases of turbidity were observed. For example, it was shown that turbidity significantly increased above ambient levels in the side channel during all tow traffic events.

63. Ranges of significant increases in turbidity levels over ambient levels were largest at the main channel (2.7-7.4 units), followed by left bank (3.7-5.0 units), and side channel (2.3-2.6 units). Turbidity levels increased only 2.3 units above ambient levels at the right bank station during the single event wherein a significant increase was noted.

64. Recovery times based on turbidity units ranged from 30 to 150 min at the main channel; 40 to 110 min at the side channel; and 50 to 90 min at the left bank. Recovery time estimated for the right bank station was 65 min.

65. Because of an equipment malfunction, the effect of resuspended sediments on dissolved oxygen was monitored during only two traffic events. In one instance dissolved oxygen was reduced at all depths after the passage of a tow and recovered in a 30-min period. Reduction in concentrations ranged from 0.53 to 0.77 mg/ℓ. No significant effects were observed for traffic event 3.

65. There was no apparent relationship between observed effects and information related to tow direction, size, draft depth, or velocity.

66. As will be shown later, ambient concentrations of suspended solids and turbidity were relatively low in this upper reach of the Mississippi River when compared to other reaches. Also noteworthy is the relative magnitude of change related to increases in concentrations above ambient levels in those instances where effects were noted. These changes were considered small and may be related to the sediment characteristics of the area, which were not investigated in this study.

All the data indicated that passing tows did not have an additive effect on concentrations of suspended solids and turbidity levels. The time required for elevated concentrations of both suspended solids and turbidity to return to ambient levels varied considerably with each traffic event and within habitats.

67. For events 1, 2, and 3 at this site on the Mississippi River, there was a significant (at the 5-percent level) linear relationship between suspended solids concentrations and turbidity units. Calculated correlation coefficients (r's) for these events were +0.73, +0.75, and +0.65, respectively.

Description of study site 2 - river mile 472.0

68. Study site 2, representative of the middle reach of the Upper Mississippi River, was located at river mile 472.0. The site was located approximately 12 miles downstream from Rock Island, Illinois, and 1 mile downstream from Andalusia, Illinois. The study transect was in an area on the outside of a slight bend in the river just upstream from Tow Head Island, which formed the side channel where a station was located (Figure A2).

69. The width of the river across the study transect from the right bank station (near the small island) to the left bank station was about 435 m. The side channel station was located approximately 193 m downstream from the other three stations. Depths for the sample stations were as follows: main channel, 3.8 m; right bank, 2.7 m; left bank, 3.4 m; and side channel, 3.0 m. Mean current velocities were generally higher for main channel (surface - 0.29 m/sec, bottom - 0.19 m/sec) and right bank stations (surface - 0.27 m/sec, bottom - 0.19 m/sec) than for the side channel (surface - 0.15 m/sec, bottom - 0.11 m/sec) and left bank stations (surface - 0.25 m/sec, bottom - 0.10 m/sec).

70. At this particular study site, three different tow traffic events were monitored. The first consisted of one upstream and two downstream tows; the second, a single downstream tow; and the third, three upstream tows. During the 3-day period in which tow traffic was monitored, river stages were no more than 0.5 ft above normal pool conditions (545.0) and fluctuated very little (0.1 ft).

Event 4

71. Three tows passed the study site during the monitoring of event 4. The initial tow was moving in an upstream direction, while the two that followed were both moving downstream. Tow 3, pushing two empty barges with a draft depth of 0.5 m, drifted by the study site slowly. The speed at which it passed was not obtained from the captain of the vessel, but presumably was less than 2 mph. The time interval between tows 1 and 2 was 28 min; between tows 2 and 3, 64 min. Depth differences between drafts of the three tows and channel bottom were 1.2, 1.1, and 3.4 m, respectively.

72. Suspended solids. Significant increases in suspended solids concentrations over ambient levels were observed only at right bank and side channel stations (Figure 12). The first two tows passing the study site, which were pushing 4 and 15 loaded barges, respectively, did not initially cause any appreciable increase in suspended solids in the water column. About 60 min after the passage of tow 2 and just prior to the arrival of tow 3, the mean concentration of suspended solids increased significantly above the ambient level at the side channel station. This period may have represented the lag time required for effects caused by the initial tows to become evident. After tow 3 passed, concentrations increased at both the side channel station (12.3 mg/ℓ above ambient) and the right bank station (11.0 mg/ℓ above ambient). This increase was most likely attributable to sediments resuspended by the first two tows. Because tow 3 slowly drifted by the study site with shallow-draft barges, it is doubtful that it caused the observed increased concentrations, which returned to ambient levels within 80 min at the side channel station. Suspended solids concentrations at the right bank station still showed an upward trend as the sampling period ended. Additive effects were not noted for event 4.

73. In addition to the collection of the water-column samples that this report is based on, near-surface water samples (top 50 cm) were obtained at each sampling station coincident with overflights for aerial photographs. These near-surface samples were used to monitor the movement and dissipation of tow-generated suspended material plumes

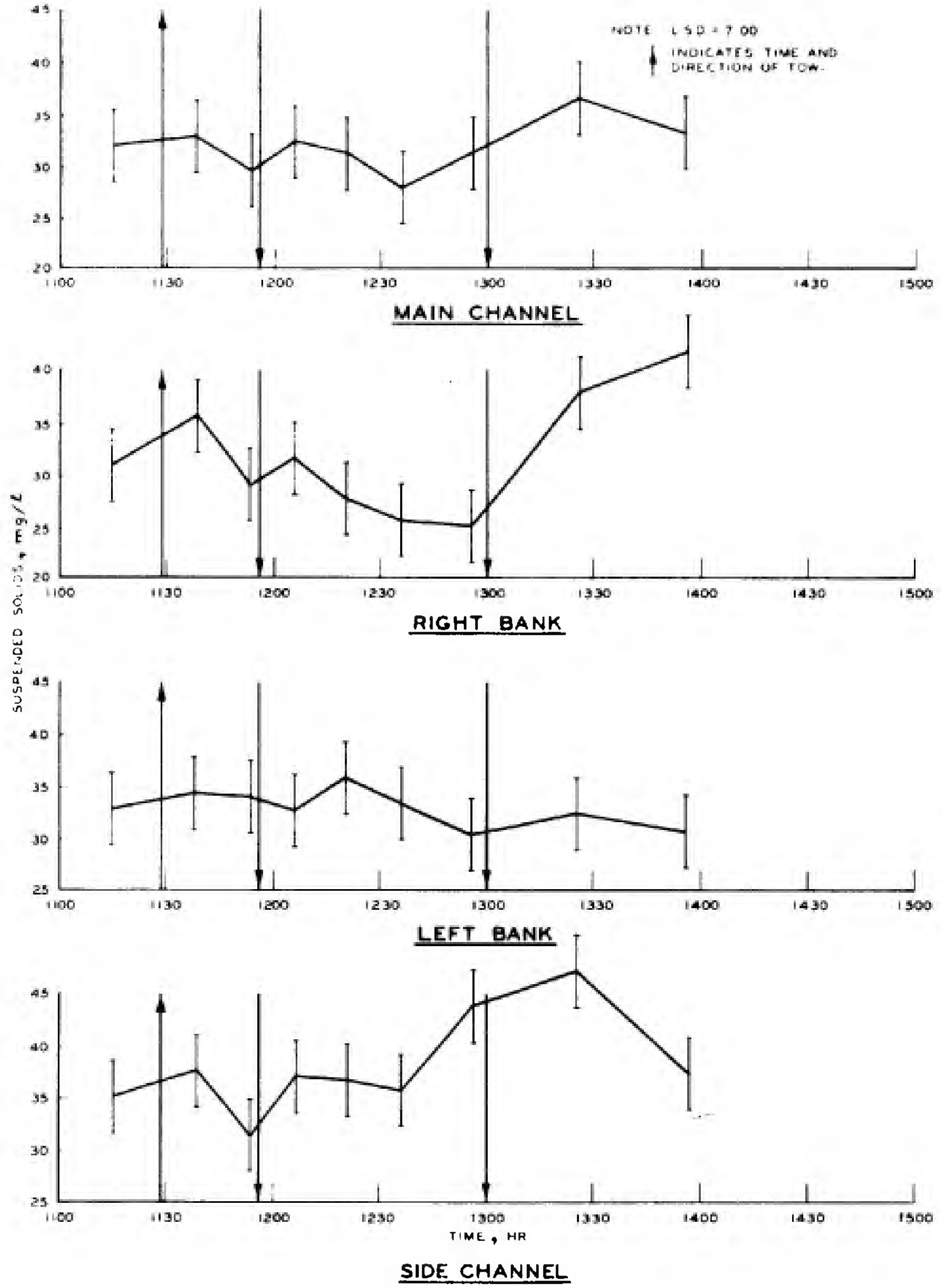

Figure 12. Effect of event 4 (multiple tow) on suspended solids concentration, Mississippi River sampled at RM 472.0, 12 Oct 75

as reported by Link and Williamson in Reference 1.* For this particular traffic event, computer-produced sequential photomaps for seven of the nine sampling times during the sampling period (1115 hr to 1356 hr) were interpreted for the movement and dissipation of the sediment plumes. Although conclusions based on changes in concentrations in "near surface" water samples versus "whole water column" samples might be expected to differ because different portions of the water column were sampled, the major conclusion drawn by Link and Williamson for this traffic event was also independently arrived at by the author for this study. Specifically, all interpretations were that between 40 and 60 min after the passage of tow 2 and just prior to the arrival of tow 3, increased concentrations of suspended solids were observed at the side channel sampling station.

74. Turbidity levels. As seen in Figure 13, portions of the turbidity data appear anomalous. In particular, the significant decreases in turbidity at main channel and right bank stations after the passage of tows 1 and 2 appear to be quite inconsistent. Even allowing for the fact that ambient concentrations were high prior to the arrival of the tows, it is highly improbable that tow traffic causes a reduction in turbidity levels. More reasonable is the significant increase (5.3 units above ambient) in turbidity at the side channel station after the passage of tow 3. The response at the side channel station was probably more related to the effects of the initial two tows than to the effects of tow 3. Responses in turbidity and suspended solids were similar at left bank and side channel stations (compare Figures 12 and 13). Recovery time for the side channel station was 60 min.

75. Dissolved oxygen. At least two of the three tows that passed the study site significantly decreased dissolved oxygen concentrations. Surface dissolved oxygen decreased 0.80 mg/ℓ 10 min after tow 1 passed

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* As mentioned in the Preface, Link and Williamson reported a complementary effort using remote sensing techniques to define the time variations of sediment plumes generated by tow traffic. (See Reference 1 for details concerning the remote sensing techniques used.)

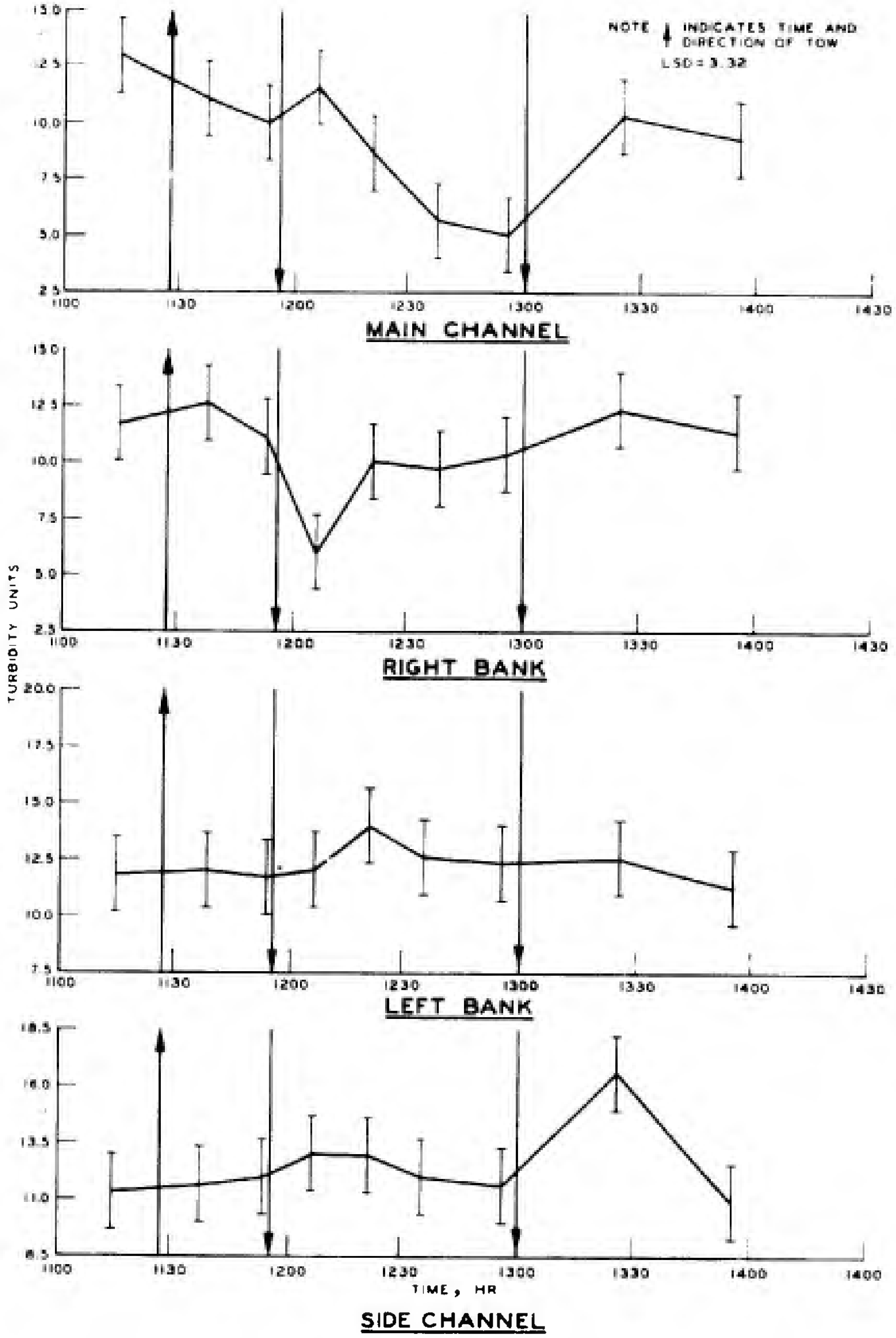


Figure 13. Effect of event 4 (multiple tow) on turbidity, Mississippi River sampled at RM 472.0, 12 Oct 75

the study site and 0.74 mg/ℓ after tow 3 passed (Figure 14). Although there was a corresponding reduction in surface dissolved oxygen after passage of tow 2, the change was small. Dissolved oxygen measured at mid-depth and bottom strata essentially followed the trend observed for the surface although the relative changes in concentrations were less. Recovery time for surface and mid-depth dissolved oxygen concentrations after tow 3 passed was about 56 min. It should be pointed out that although changes in dissolved oxygen were observed, these changes were relatively small. Maximum range of all the concentrations was only 1.0 mg/ℓ. In general, responses in dissolved oxygen concentrations were inversely related to suspended solids concentrations, indicating that suspended solids exert a demand on oxygen concentrations.

Event 5

76. While most of the events that were monitored were multiple combinations of tows, this event consisted of a single downstream tow. The vessel was pushing 15 loaded barges with a recorded draft depth of 2.8 m and a single empty barge. Based on the depth of the channel in this area, there was approximately a 1.0-m-depth difference between the bottom of the channel and draft of the barges.

77. Suspended solids. Ambient concentrations for main channel, left bank, and side channel stations were higher prior to the passage of the tow than after it had passed (Figure 15). For this reason, samples at 1443 hr, collected 10 min after the tow passed, were assumed to represent ambient levels and were used as such in the interpretation of effects. Based then on the LSD intervals, significant increases occurred at main channel, right bank, and side channel stations. No change was noted for the left bank station. Maximum suspended solids concentrations (7.0 mg/ℓ above ambient) at the main channel station occurred 25 min after passage of the tow and decreased within a 15-min period. The right bank station showed a different response--a steady increase in concentrations that continued throughout the entire sampling period. The maximum increase in suspended solids concentrations at the right bank station amounted to 15.6 mg/ℓ. On the other hand, while concentrations in the side channels increased significantly 25 min after

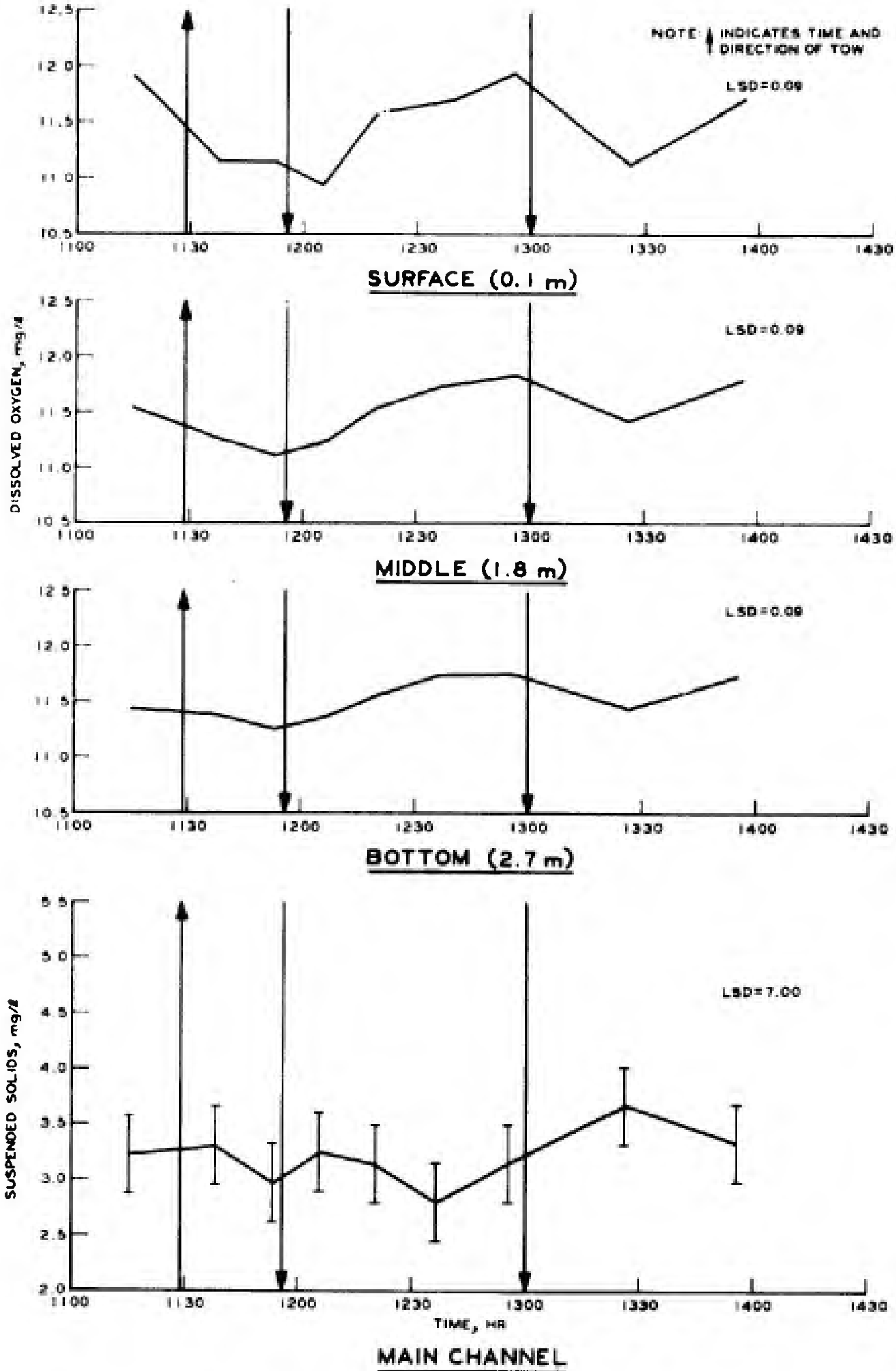


Figure 14. Effect of event 4 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 472.0, 12 Oct 75 (Note: LSD value for DO too small to graph)

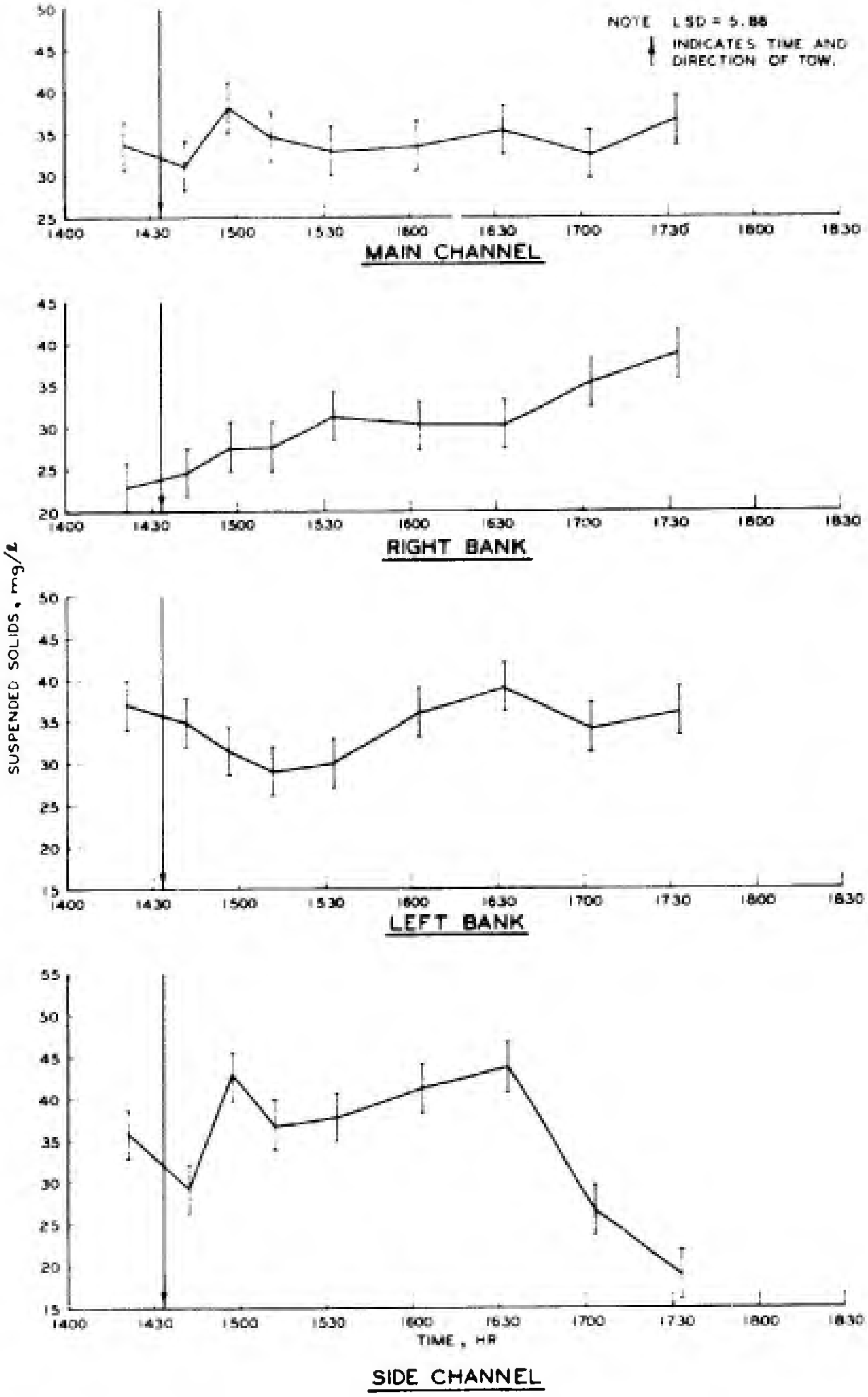


Figure 15. Effect of event 5 (single tow) on suspended solids concentration, Mississippi River sampled at RM 472.0, 13 Oct 75

the tow passed, ambient levels were recovered within 140 min. Although this single downstream tow caused some significant increases in concentrations of suspended solids, overall the changes were small.

78. Turbidity levels. Turbidity levels measured in main channel and left bank stations generally followed the trends observed for suspended solids (Figure 16). Unlike the trend of increasing concentrations noted for the right bank station using suspended solids data, turbidity levels remained fairly uniform at this station. There was no apparent trend for turbidity measured in the side channel. It should be noted that turbidity for all stations never increased more than 2.3 units above ambient levels with no significant increases being detected.

79. Dissolved oxygen. The passage of the single downstream tow had no effect on dissolved oxygen concentrations at surface, mid-depth, or bottom depth strata (Figure 17).

Event 6

80. Three upstream-bound tows passed the study site within a period of 75 min during this monitoring event. The number of loaded barges pushed by each were tow 1, 13 barges; tow 2, 1 barge; and tow 3, 4 barges. Time intervals between the tows were: tows 1 and 2, 58 min; and tows 2 and 3, 17 min. Depth differences between channel bottom and drafts of the three tows were 1.1, 1.7, and 1.0 m, respectively.

81. Suspended solids. Significant increases in concentrations of suspended solids above ambient levels were observed for two stations (main channel and side channel) of the four stations sampled (Figure 18). In the main channel the effect of tow 1 was greater than the effect of the other two tows. Mean suspended solids concentration increased from 25.6 mg/ℓ at 1145 hr, prior to the arrival of the tow, to 34.3 mg/ℓ at 1219 hr after the tow had passed. Tows 2 and 3 did not have an additive effect on those levels observed as a result of tow 1. Recovery time for the main channel station was 129 min. No effects were noted at right bank and left bank stations. Ten minutes after tow 1 passed, increased concentrations were observed at the side channel station; the level of suspended solids remained above ambient level for about 40 min. The passage of tows 2 and 3 maintained the side channel concentrations above

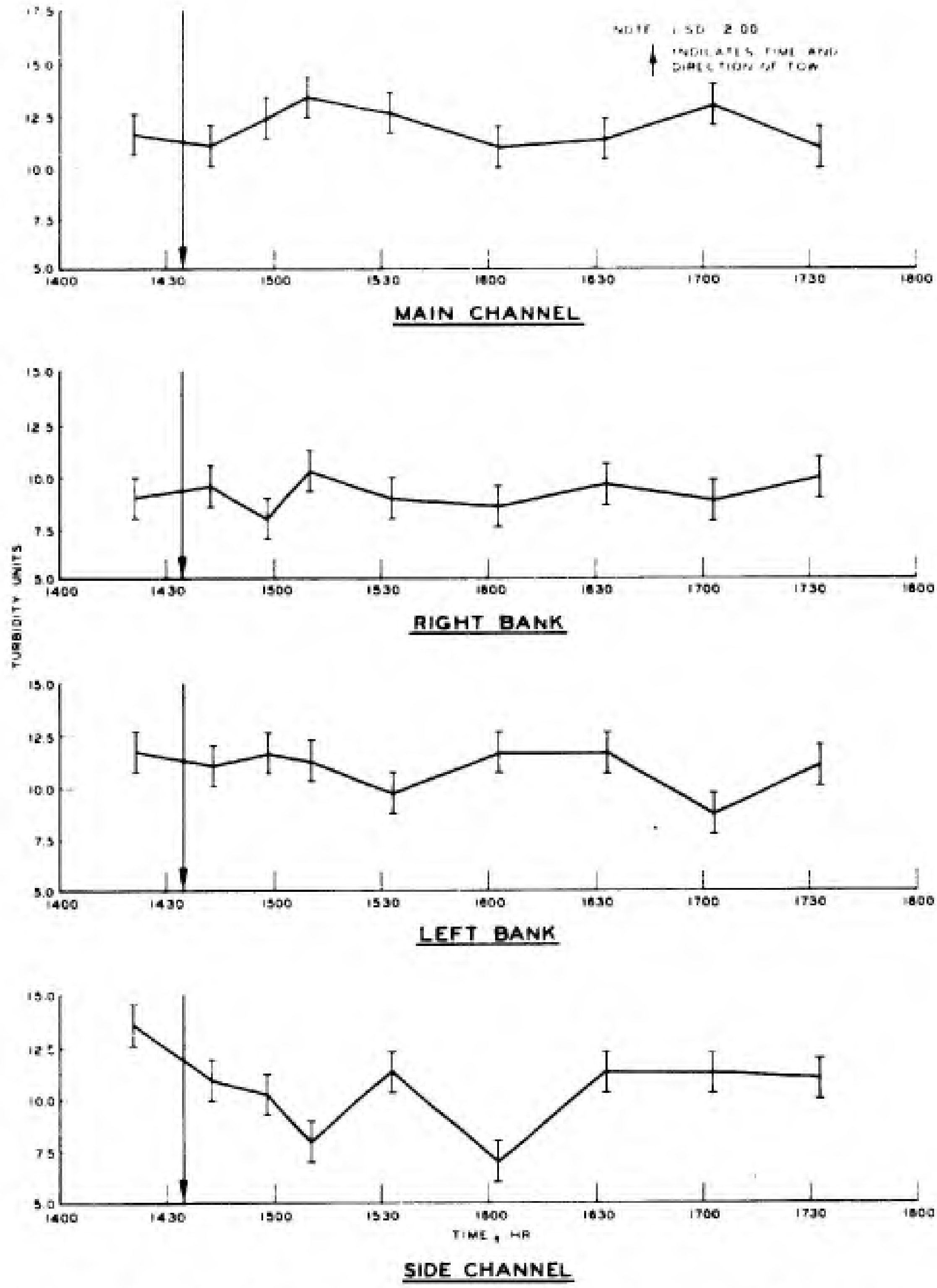


Figure 16. Effect of event 5 (single tow) on turbidity, Mississippi River sampled at RM 472.0, 13 Oct 75

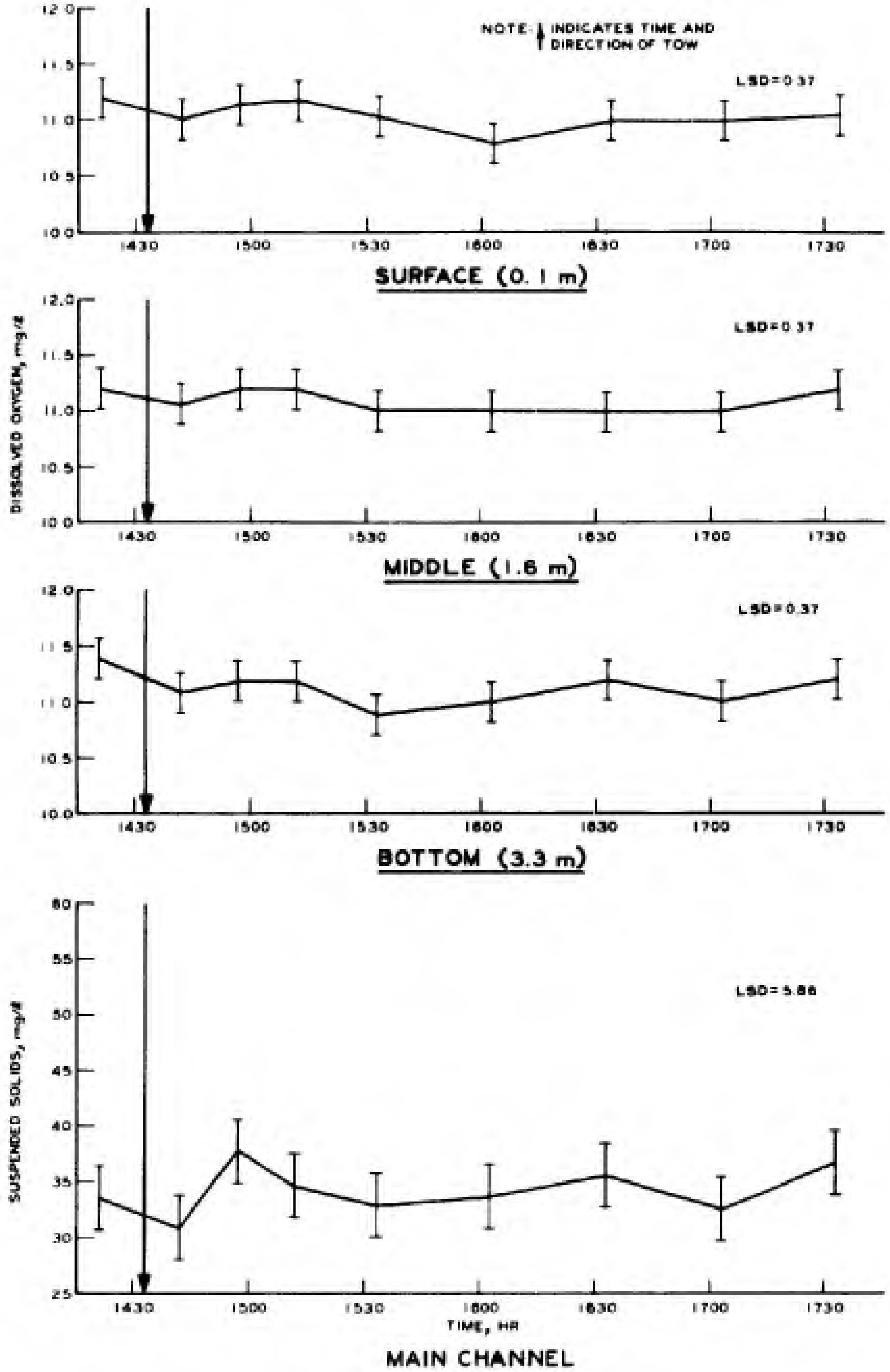


Figure 17. Effect of event 5 (single tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 472.0, 13 Oct 75

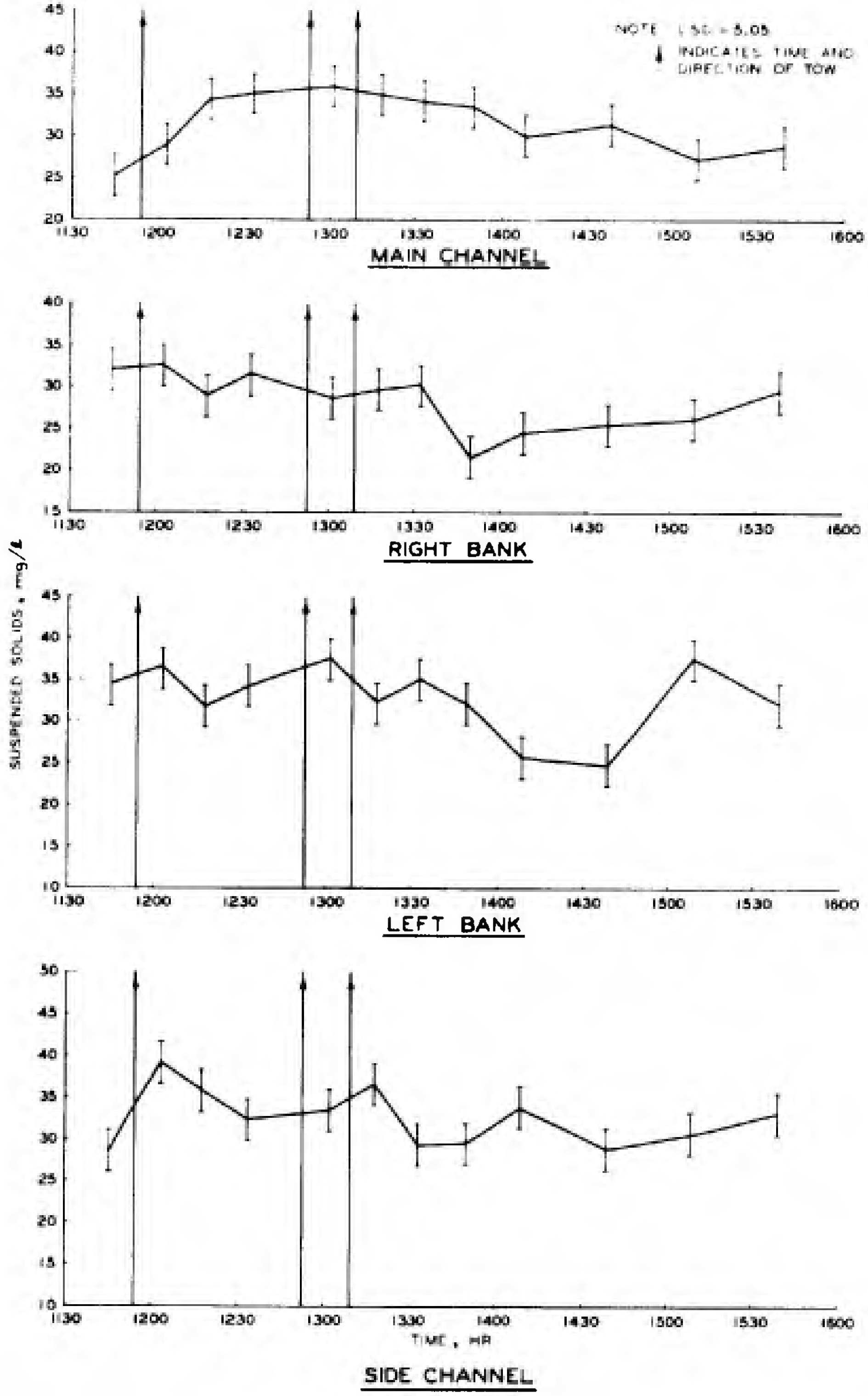


Figure 18. Effect of event 6 (multiple tow) on suspended solids concentration, Mississippi River sampled at RM 472.0, 14 Oct 75

ambient levels for a short period, although the effects were not additive. The observation of effects at the side channel station and not at the left bank station may be attributable to the differences in flow patterns: that is, the side channel station may be in a more favorable position to receive directly the upstream flow of water than the left bank station.

82. Turbidity levels. The turbidity trends followed the suspended solids trends only at left bank and side channel stations (Figure 19). Different responses were observed at main channel and right bank. Though significant increases were noted for the main channel station using the suspended solids data, no significant increases were observed based on turbidity changes. The reverse trend was noted for the right bank station. Recovery time was 40 min for the right bank station and 208 min for the side channel station.

83. Dissolved oxygen. Mean surface concentrations of dissolved oxygen were reduced 0.4 mg/ℓ after tow 1 passed with reductions at mid-depth and bottom strata slightly less (Figure 20). The time required for concentrations to return to ambient levels was about 40 min after tow 1 passed. The passage of tows 2 and 3 did not have the immediate effect on dissolved oxygen concentrations as did tow 1. Dissolved oxygen content at all depths showed a slow decline and reached a low at 1409 hr or 75 min after tow 3 had passed. This reduction amounted to about 0.4 mg/ℓ. An additional 100 to 130 min were required before concentrations returned to ambient levels. Dissolved oxygen concentrations were generally inversely related to suspended solids concentrations. The changes in concentrations that were observed were relatively small, amounting to less than a 0.50 mg/ℓ change from ambient.

Discussion

84. During the 3 days that tow traffic events were monitored at river mile 472.0 (site 2) in the Mississippi River, significant changes in suspended solids, turbidity, and dissolved oxygen concentrations were attributable to the passage of tows. As would be expected, different tow traffic events (single and multiples) produced different responses for those variables measured. The mean depth difference between drafts

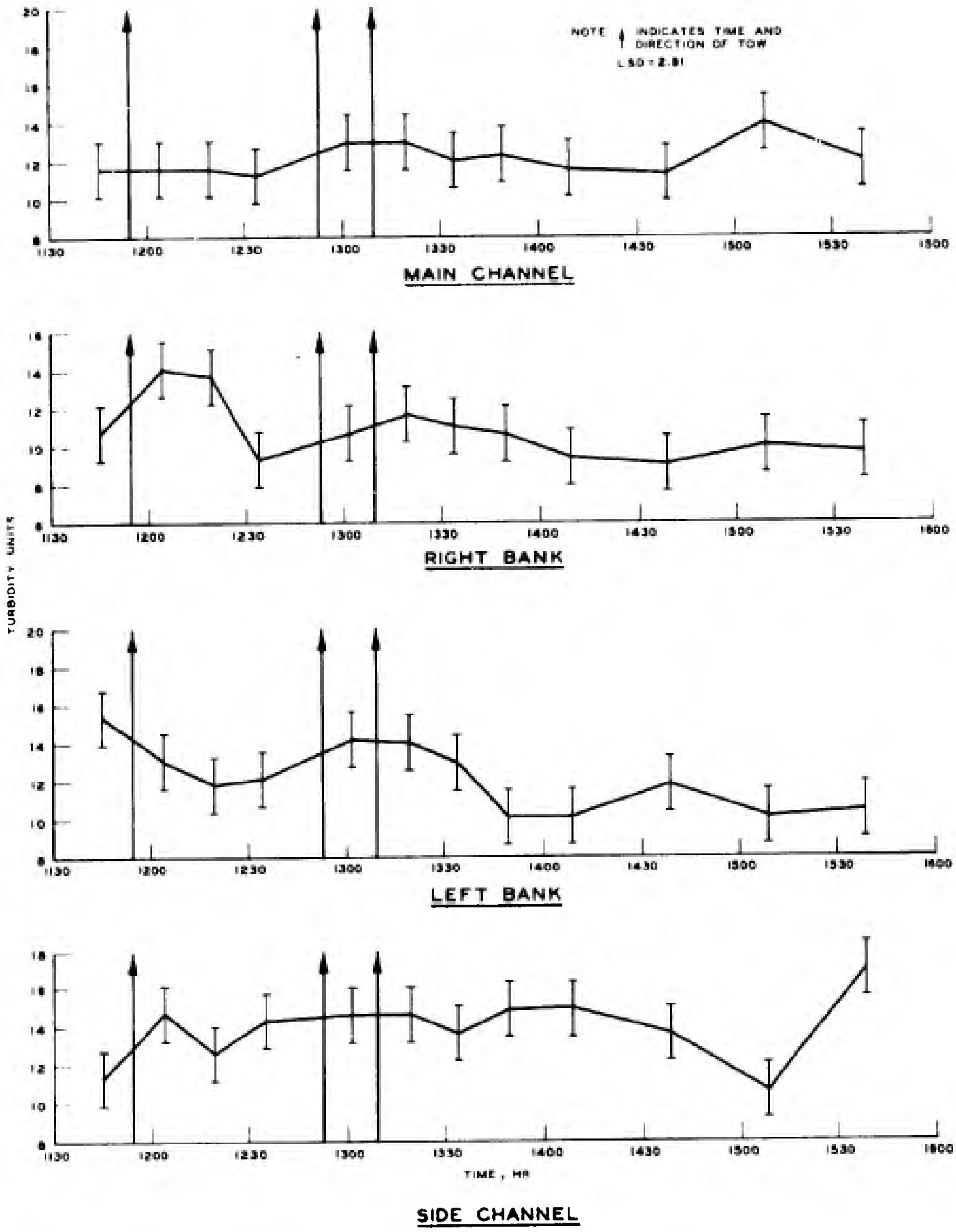
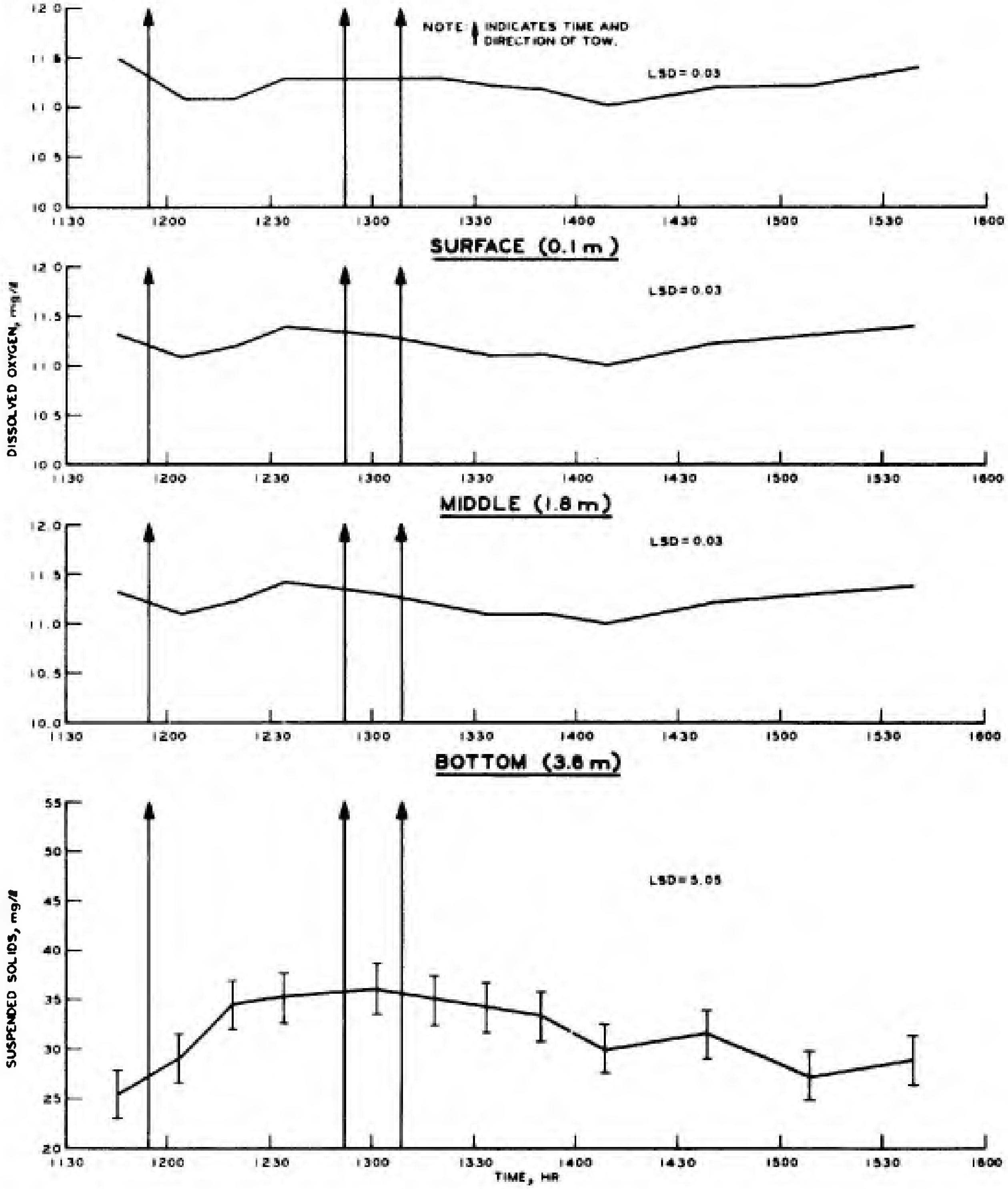


Figure 19. Effect of event 6 (multiple tow) on turbidity, Mississippi River sampled at RM 472.0, 14 Oct 75



MAIN CHANNEL

Figure 20. Effect of event 6 (multiple tow) on dissolved oxygen concentrations, Mississippi River sampled at RM 472.0, 14 Oct 75 (Note: LSD value too small to graph). Related suspended solids concentrations in the water column also shown.

of all the tows for this site and channel bottom was 1.48 m.

85. The single downstream tow event caused suspended solids concentrations to increase at all stations except the left bank station. Maximum response was noted for the main channel station where concentrations increased 15.6 mg/ℓ above ambient and remained above ambient for the duration of the sampling period. During this event turbidity levels were not significantly increased above ambient levels at any of the sampling stations. The single tow had no effect on dissolved oxygen concentrations measured in the water column.

86. The multiple (three tow) upstream event produced significant increases in suspended solids concentrations at main channel and side channel stations, but the effects were not additive: that is, the passage of more than one tow did not add to the effects of the first tow. The same conclusion was drawn for the effects of the three upstream tows on turbidity levels. Dissolved oxygen concentrations were reduced after passage of the tows, but the reductions were small, amounting to a change of less than 0.4 mg/ℓ. It was apparent that the first tow pushing the larger number of barges produced a larger effect than the successive tows pushing fewer barges.

87. The remaining tow traffic event, consisting of one upstream tow and two downstream tows, was comparable to the other multiple event in that although effects were noted, they were not additive.

88. Based on both the suspended solids and turbidity data, the majority of significant effects were observed at the side channel station, followed by the right bank station and then the main channel station. On two occasions suspended solids concentrations at the right bank station remained above ambient levels for the duration of the sampling period. No effects were noted for the left bank station. The absence of any observable effects at the left bank station could not reasonably be explained, although perhaps it may have been related to deviations in the flow patterns of the area. Considering all three traffic events at this site, significant increases above ambient suspended solids concentrations ranged from 11.0 to 15.6 mg/ℓ at the right bank station, 11.0 to 14.3 mg/ℓ at the side channel, and 7.0 to

10.4 mg/ℓ at the main channel. Maximum significant responses above ambient levels based on turbidity units consisted of 5.7 and 4.0 units at the side channel and right bank stations, respectively. Maximum recovery times based on suspended solids data were noted for the right bank station, which on two occasions did not recover during the sampling periods, and for the side channel station (140 min). A period of 208 min was required before ambient turbidity levels were regained at the side channel station.

89. A significant linear relationship between concentrations of suspended solids and turbidity units was determined for the two multiple events at this study site. Calculated correlation coefficient r was +0.49 for event 4 and +0.47 for event 6. For the single downstream tow (event 2), the r value was +0.14 and was not significant at the 5-percent level.

90. Generally, ambient concentrations of suspended solids and turbidity were lower at this sampling site in the middle reach of the Upper Mississippi River (study site 2) than those concentrations at river mile 744.6 (study site 1) in the upper reach of the river.

Description of study site 3 - river mile 258.0

91. The third study site, in the lower reach of the Upper Mississippi River, was at river mile 258.0 and was located directly downstream from Hamburg, Illinois. This particular area of the river has a characteristic straight configuration following a slight eastward bend seen at Mosier Island (Figure A3).

92. The river's width across the study transect measured about 340 m. Both left and right bank stations were positioned about 30 m from the shoreline. The side channel station was positioned inside the entrance to Westport Chute approximately 1110 m downstream from the other sampling stations. Depths of water at the sample stations were: right bank, 2.2 m; left bank, 4.1 m; and side channel, 2.0 m. Depth of water initially recorded for the main channel station was 5.7 m; 9.1 m was recorded for the remaining two sampling dates. Because it was impractical to mark the main channel station with a buoy, a considerable difference in depth (3.4 m) was observed between the first sampling date

and the remaining two sampling dates. Mean current velocities were highest at the main channel station (surface - 0.43 m/sec, bottom - 0.33 m/sec) and next highest at the side channel station (surface - 0.27 m/sec, bottom - 0.22 m/sec). Velocities measured at left bank station (surface - 0.21 m/sec, bottom - 0.19 m/sec) and right bank station (surface - 0.12 m/sec, bottom - 0.12 m/sec) were lower.

93. Another salient feature of this study site was the presence of the Hamburg ferry, which crossed the river approximately 270 m upstream of the study transect. It could be assumed that if the ferry disturbed the riverbed sediments along its crossing, ambient levels of suspended solids and turbidity would be higher than normal. However, a cross-channel depth profile was run and the information gained indicated that the ferry would probably have little effect on elevating ambient levels of suspended solids and turbidity. At the crossing, the main channel was 12.8 m deep, with depths of 3.5 m associated with shoreward areas. The draft of the ferry measured 1.1 m fully loaded; the engine was rated at 100 hp.

94. The three traffic events monitored at this site consisted of a single downstream tow, a single upstream tow, and a multiple tow (one upstream tow and two downstream tows). River stages for those days that tow traffic was monitored ranged from normal pool elevation to 0.4 ft above normal pool elevation.

Event 7

95. The single downstream tow that was monitored during this event was pushing 1 empty and 11 loaded barges and was traveling between 7 and 8 mph. Draft of the loaded barges was 2.7 m, and the engine was rated at 2200 hp. The difference between tow draft and channel bottom was estimated at 3.0 m.

96. Suspended solids. The single downstream tow that passed the study site had no significant effect on suspended solids concentrations (Figure 21). Mean concentrations over time for main channel, left bank, and side channel stations varied less than 10 mg/ℓ. The initial concentrations associated with the right bank station were considerably higher than those observed for the other stations. In fact, the trend

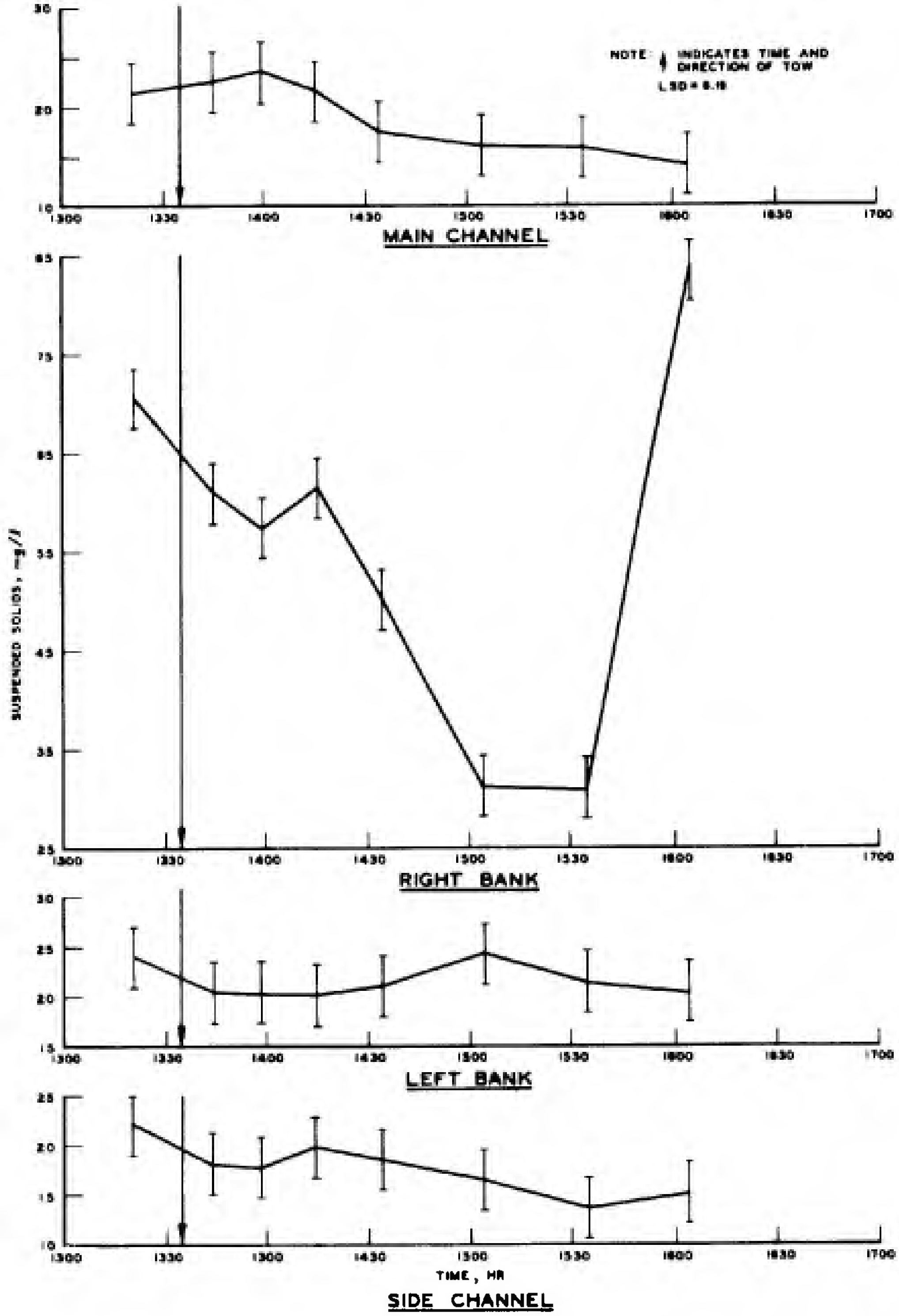


Figure 21. Effect of event 7 (single tow) on suspended solids concentration, Mississippi River sampled at RM 258.0, 22 Oct 75

shown in Figure 21 for the right bank station indicates the strong possibility that shoreline turbulence caused the observed elevated concentrations. Although the depth of the right bank station was about 2.2 m, proximity of the station to the shore could account for the possibility of shoreline turbulence.

97. Turbidity levels. The discussion in paragraph 96 related to suspended solids similarly applies to the turbidity measurements. No significant effects of the tow were observed, and the right bank station essentially followed the same trend noted for suspended solids concentrations (Figure 22).

98. Dissolved oxygen. Dissolved oxygen concentrations were not affected by the passage of the single tow during this event. The fluctuations shown in Figure 23 are exaggerated because of the scale used. Maximum fluctuation in surface concentrations was 0.53 mg/ℓ; in mid-depth concentrations, 0.36 mg/ℓ; and in bottom concentrations, 0.30 mg/ℓ. The anomalous responses at 1434 hr and 1534 hr were assumed to be related to operator error.

Event 8

99. Passage of a single upstream bound tow pushing 15 loaded barges was monitored at river mile 258.0. The tow passed the study site traveling between 5 and 6 mph and was powered by a 5000-hp engine. Draft depth of the barges was 2.7 m; the channel depth measured 9.1 m for this event. The difference between tow and channel bottom was estimated to be 6.4 m.

100. Suspended solids. No effects were noted at any of the stations except the left bank station (Figure 24). Ten minutes after the single upstream tow passed the study site, suspended solids concentrations increased 6 mg/ℓ at the left bank station and returned to ambient levels 15 min later. A second significant increase of a similar magnitude was noted about 80 min later. Since the data indicate that no sediments were resuspended in the main channel, the effects observed at the left bank were most likely attributable to shoreline wavewash that was possibly caused by the passing of the tow or some other force. Generally, concentrations at all stations varied less than 10 mg/ℓ.

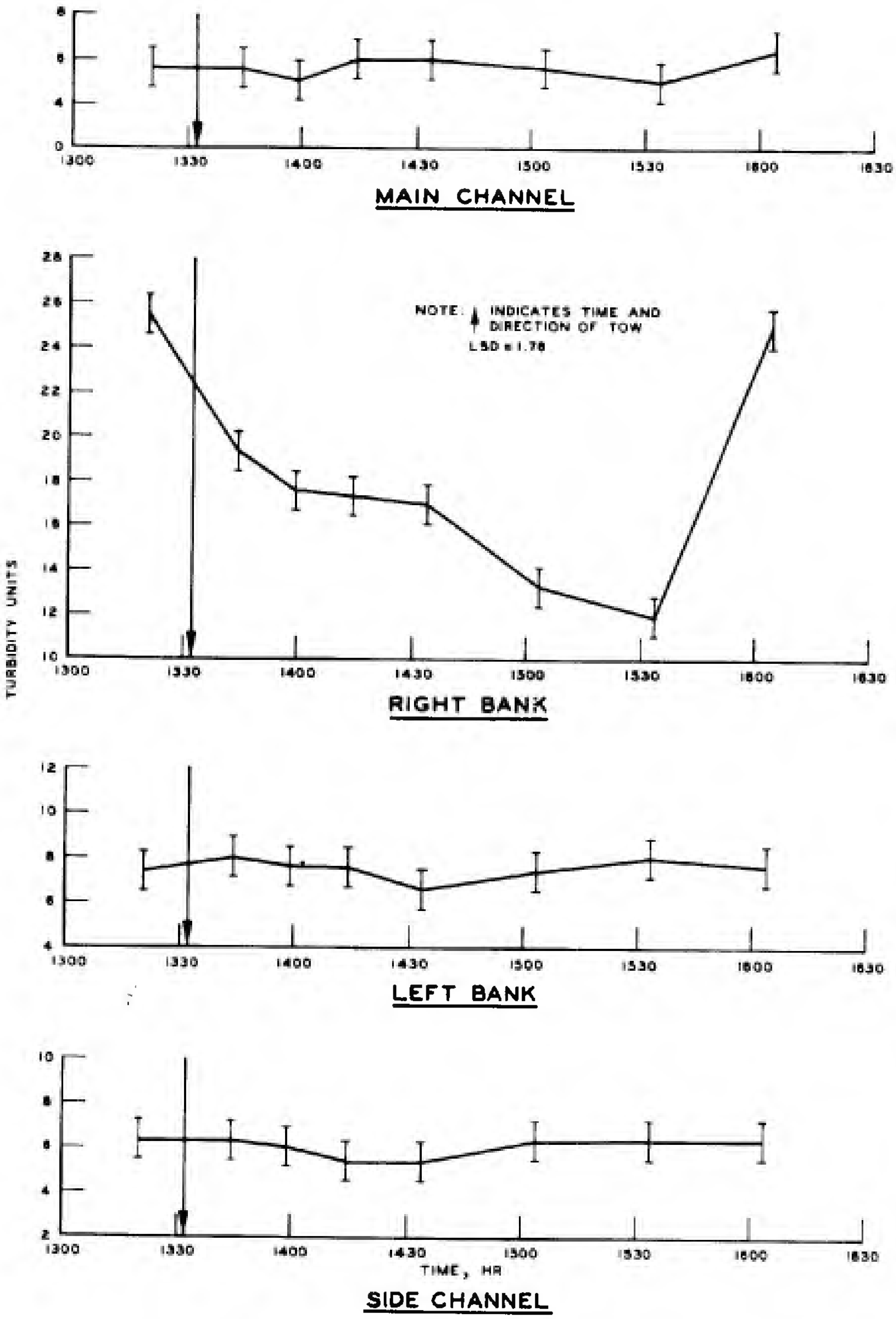


Figure 22. Effect of event 7 (single tow) on turbidity, Mississippi River sampled at RM 258.0, 22 Oct 75

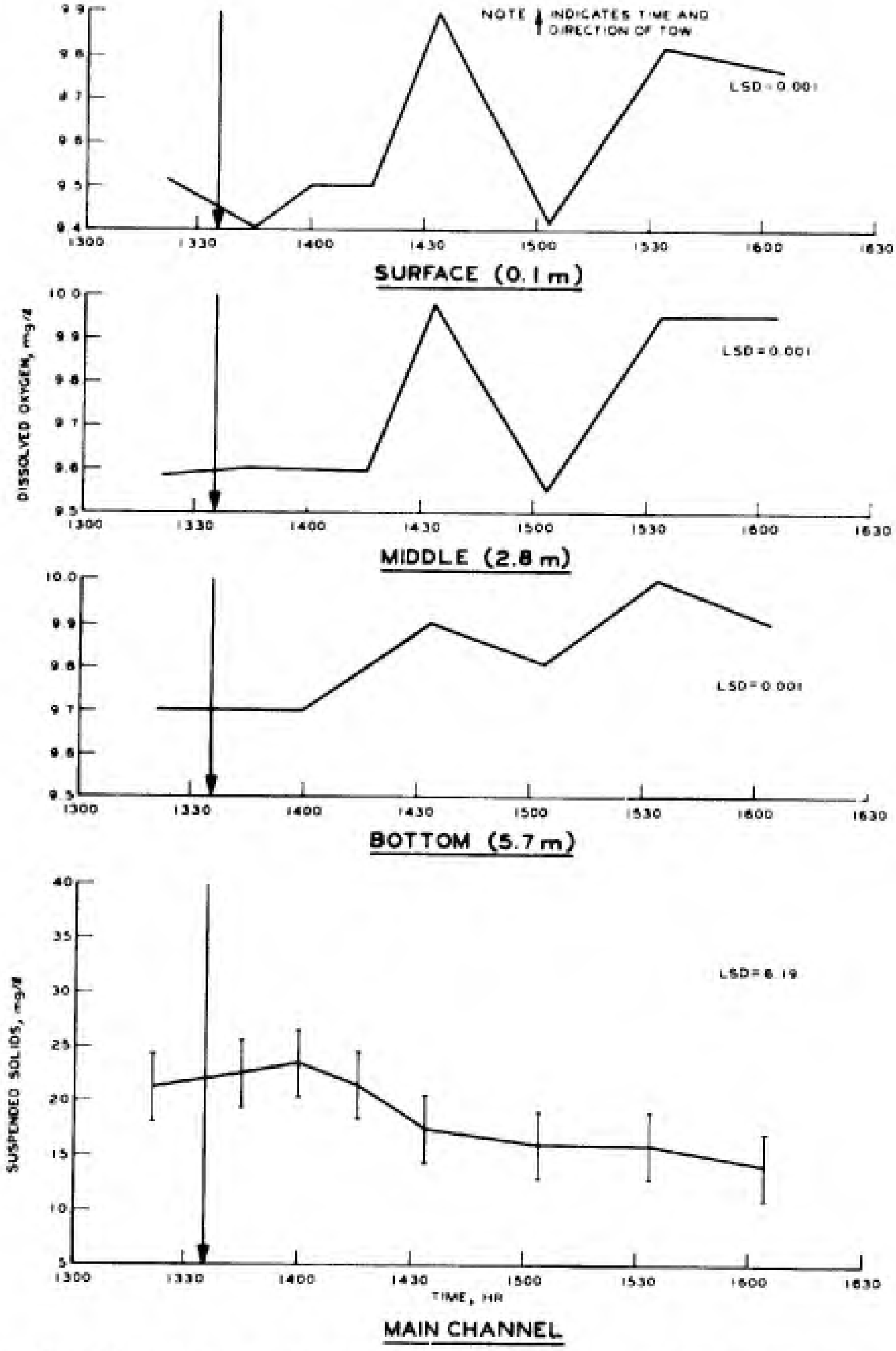


Figure 23. Effect of event 7 (single tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 258.0, 22 Oct 75 (Note: LSD value for DO too small to graph)

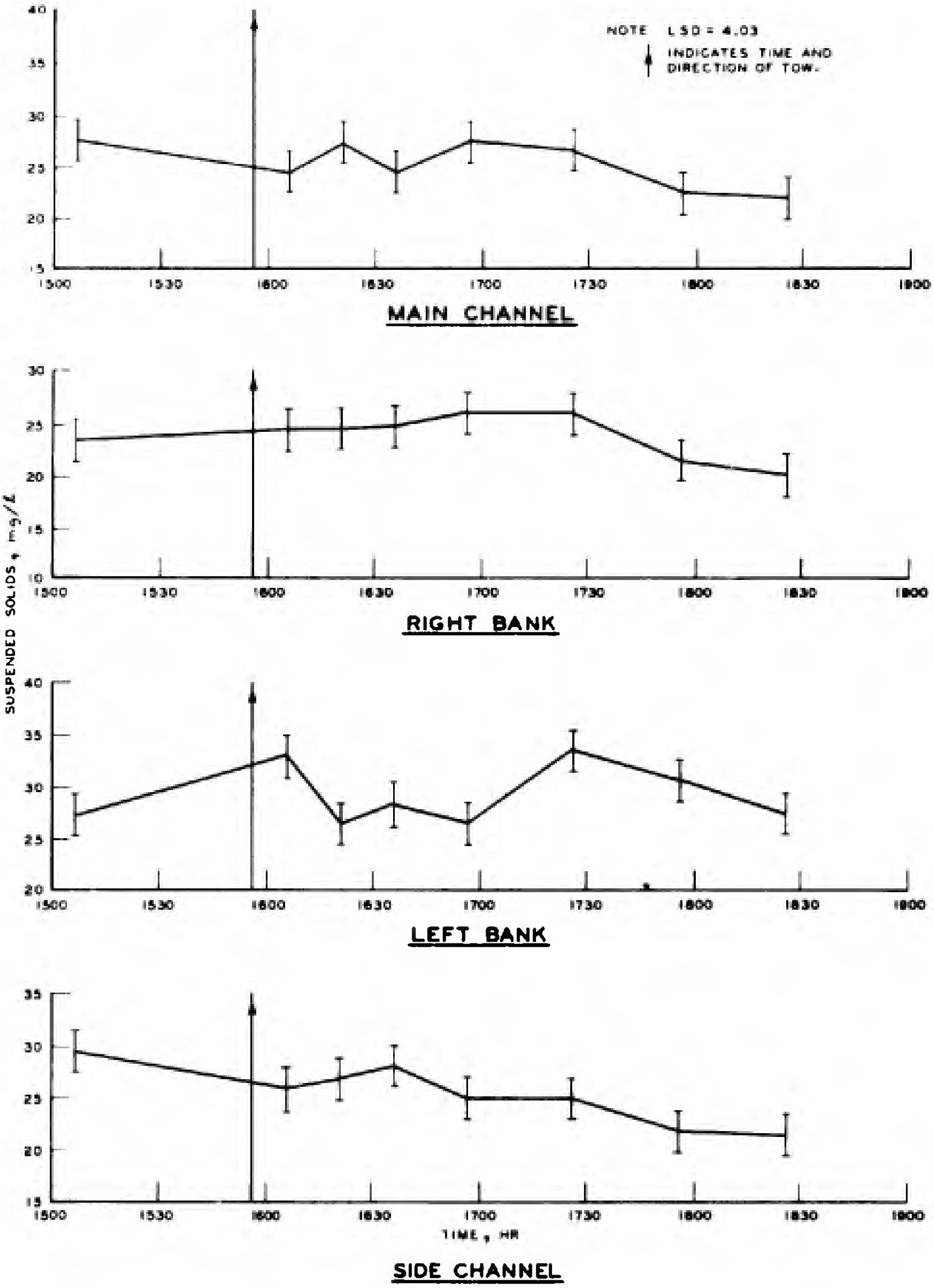


Figure 24. Effect of event 8 (single tow) on suspended solids concentration, Mississippi River sampled at RM 258.0, 29 Oct 75

101. Turbidity levels. Similar to the observations made for the suspended solids data, the single upstream tow had no apparent effect on turbidity levels (Figure 25). The increased turbidity shown at 1621 hr at the side channel station could have been caused by the tow as it passed that station. However, the reader should be aware that the difference between the ambient turbidity level and the maximum concentration recorded at the side channel was only three turbidity units. Even though comparison of the LSD intervals indicates a significant statistical increase, the change over the ambient level was quite small.

102. Dissolved oxygen. Dissolved oxygen concentrations measured at all three depths did not show any change after the tow had passed (Figure 26).

Event 9

103. This multiple tow traffic event consisted of one upstream tow, followed by another tow passing downstream 31 min later, and by still another downstream tow passing the study site 12 min after the second tow passed. Draft depths of the barges being transported were similar (ranging from 2.7 to 2.8 m); however, the number of loaded barges varied. The mean depth difference between tow drafts and channel bottom was 6.34 m. Tow 1 was pushing 3 loaded barges; tow 2, 15 loaded barges; and tow 3, 15 loaded barges.

104. Suspended solids. While the passage of tow 1 apparently had no effect on suspended solids concentrations at any of the stations, significant increases were noted at main channel and right bank stations after tows 2 and 3 passed the study site (Figure 27). No effects were noted for left bank and side channel stations. In interpreting the response at the main channel station, ambient concentration was assumed to be that mean (20 mg/ℓ) associated with 0826 hr, for reasons that have previously been discussed. Based on this assumption, the effect of the two tows that passed over the main channel station was to increase suspended solids concentrations from 20.0 mg/ℓ to a maximum of 27.3 mg/ℓ. Ambient concentrations were not recovered until 155 min after tow 2 passed. A similar response was noted for the right bank station, although generally the concentrations were higher. These

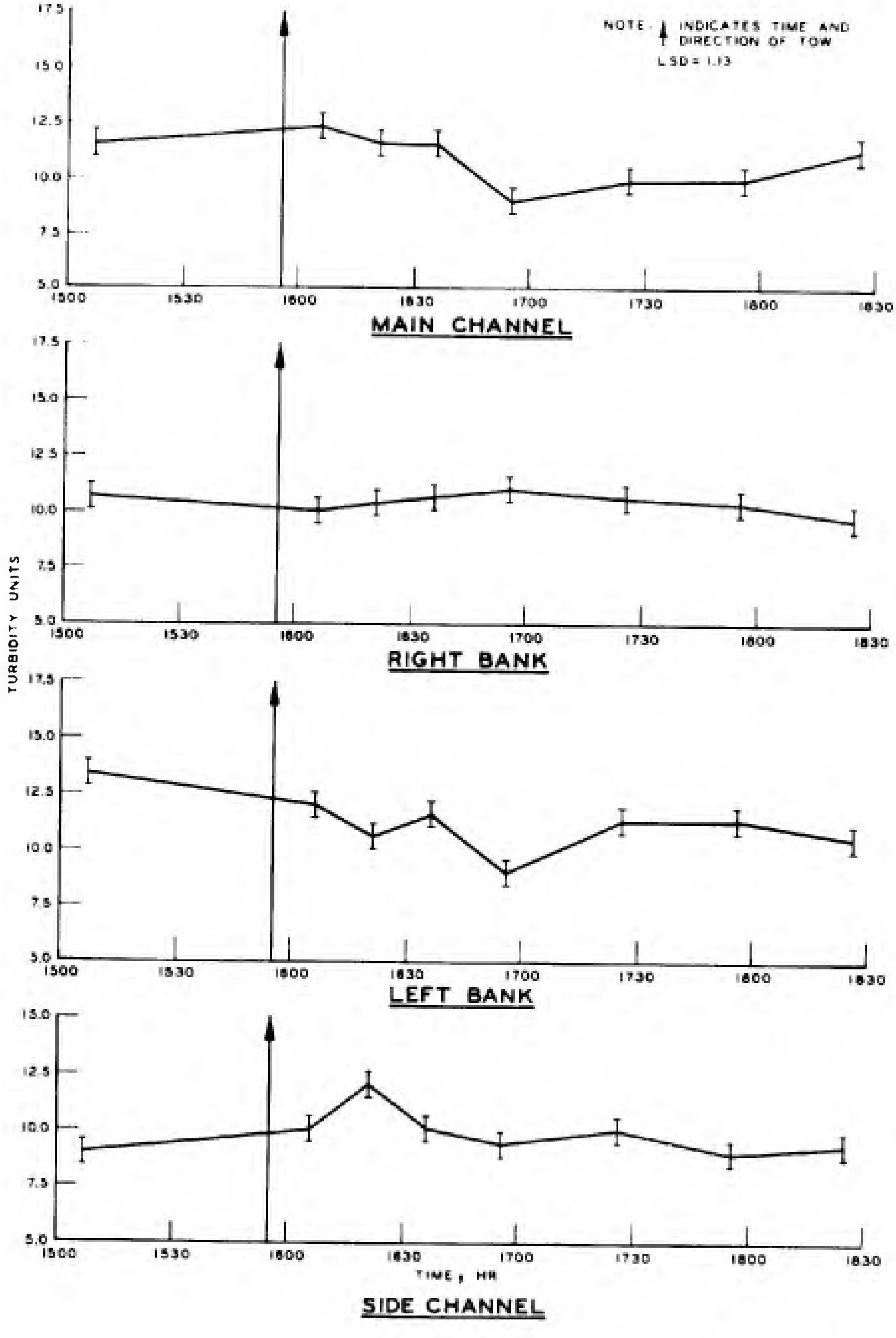


Figure 25. Effect of event 8 (single tow) on turbidity, Mississippi River sampled at RM 258.0, 29 Oct 75

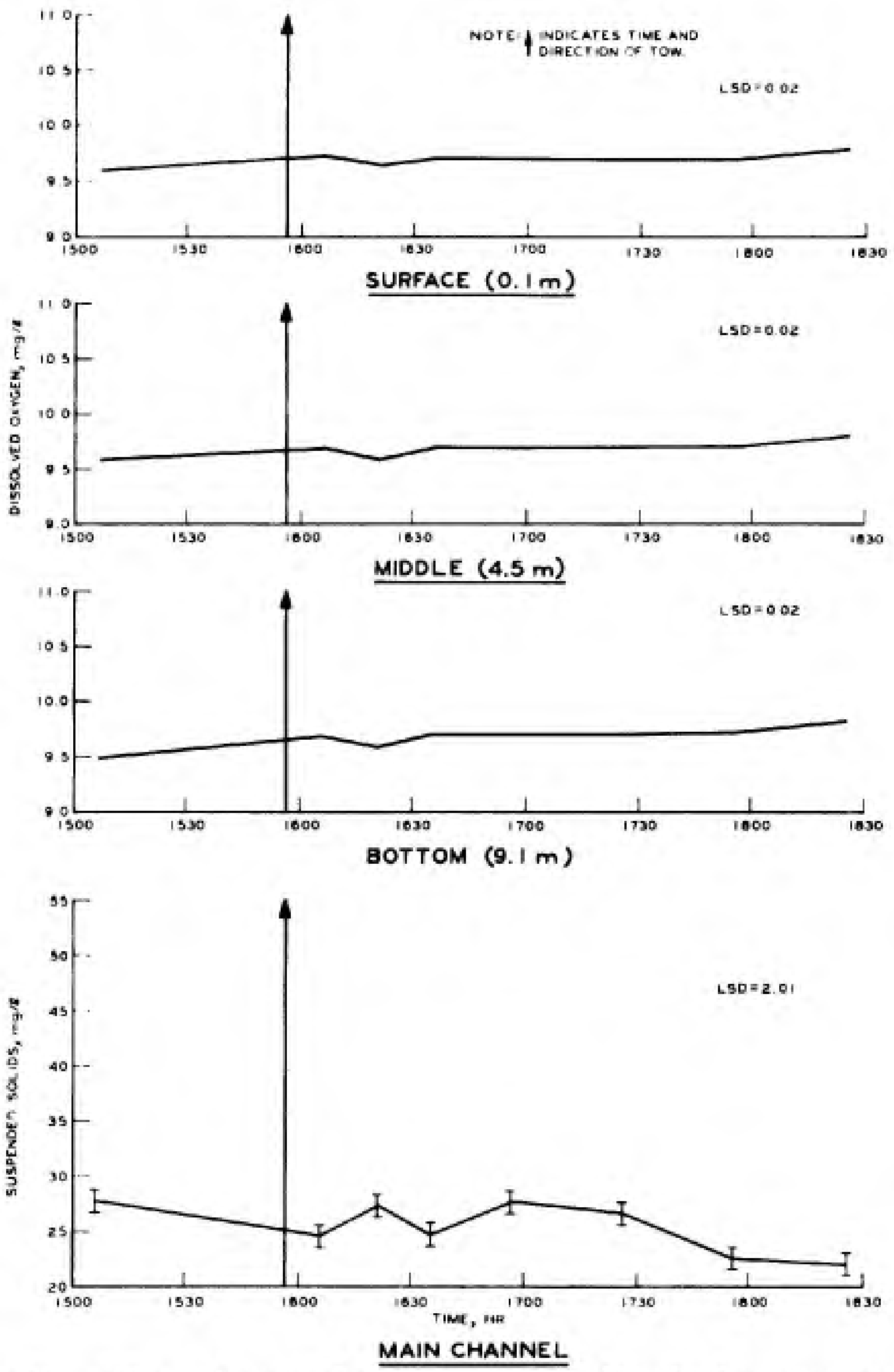


Figure 26. Effect of event 8 (single tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 258.0, 29 Oct 75 (Note: LSD value for DO too small to graph)

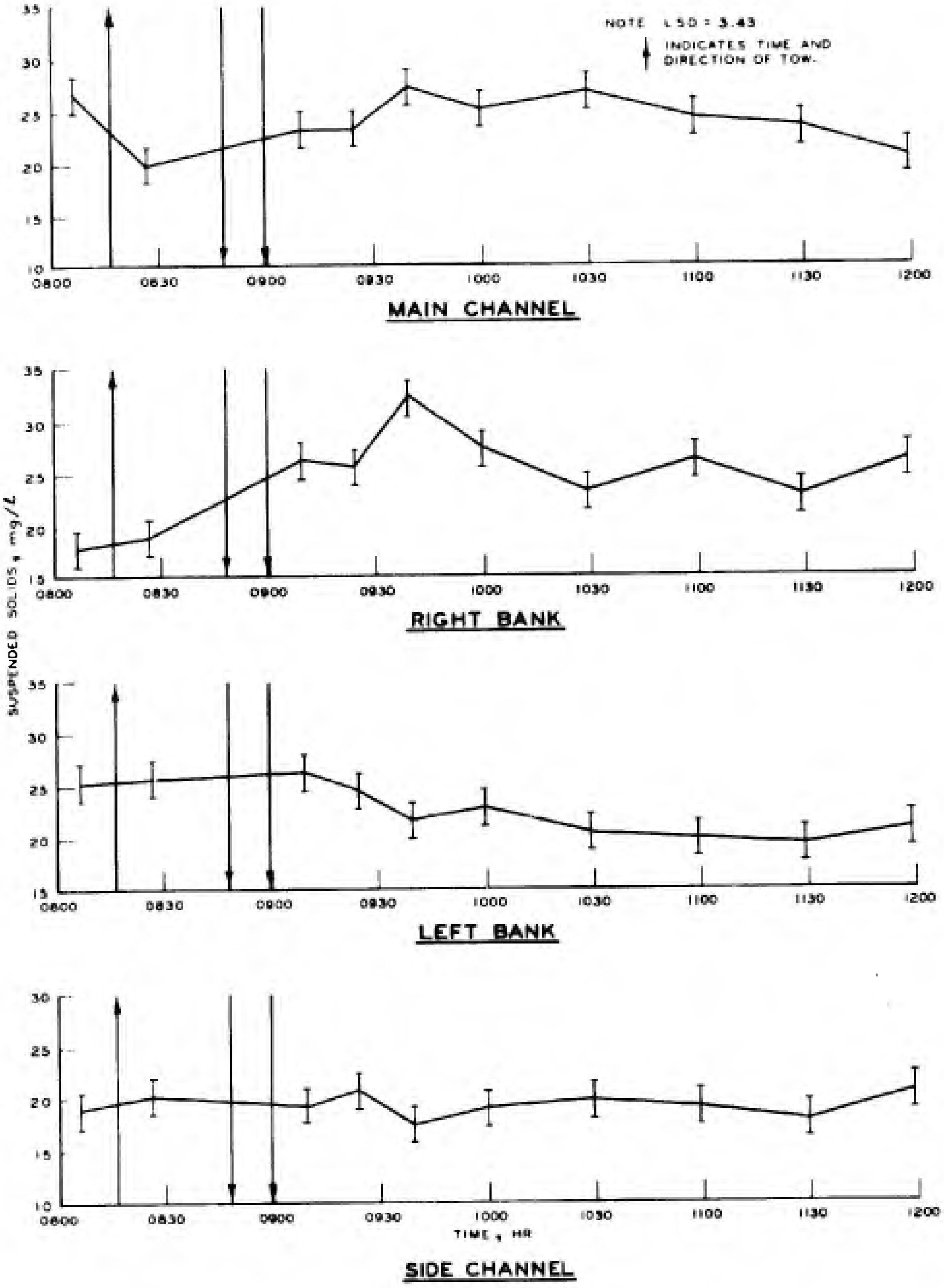


Figure 27. Effect of event 9 (multiple tow) on suspended solids concentration, Mississippi River sampled at RM 258.0, 30 Oct 75

higher concentrations could have been contributed to by shoreline turbulence caused by surface waves. The difference between ambient level and the maximum recorded concentration at the right bank station was 14.5 mg/ℓ. Since no samples were collected between the passage of tows 2 and 3, it was impossible to evaluate any potential additive effects produced by the two tows. For the duration of the sampling period, suspended solids concentrations measured at the right bank station never returned to ambient level.

105. Turbidity levels. Turbidity levels increased at right bank and left bank stations but not at main channel or side channel stations after the passage of tows 2 and 3 (Figure 28). After tow 3 passed, both stations showed an initial recovery that was followed by a slight increase in turbidity levels. At the end of the sampling period, turbidity levels at both right bank and left bank stations remained above the ambient level. The maximum increase above ambient levels observed at right bank and left bank stations amounted to about five and four turbidity units, respectively. These changes were statistically significant; however, the very small magnitude of these changes should be considered carefully in drawing any conclusions. The effects at right and left bank stations could have also been related to wave effects on the shoreline.

106. Dissolved oxygen. As shown in Figure 29, none of the three tows that passed the study site affected concentrations of dissolved oxygen at surface, mid-depth, or bottom depths.

Discussion

107. Based on the data, minimal effects (increases in suspended solids concentrations and turbidity and decreases in dissolved oxygen concentrations) were noted during the monitoring of three tow traffic events at river mile 258.0 (site 3), located within the lower reach of the Upper Mississippi River.

108. Event 7, consisting of a single downstream tow, had no significant effect on suspended solids, turbidity, or dissolved oxygen concentrations at any of the sampling stations.

109. During event 8, which consisted of a single upstream tow, a

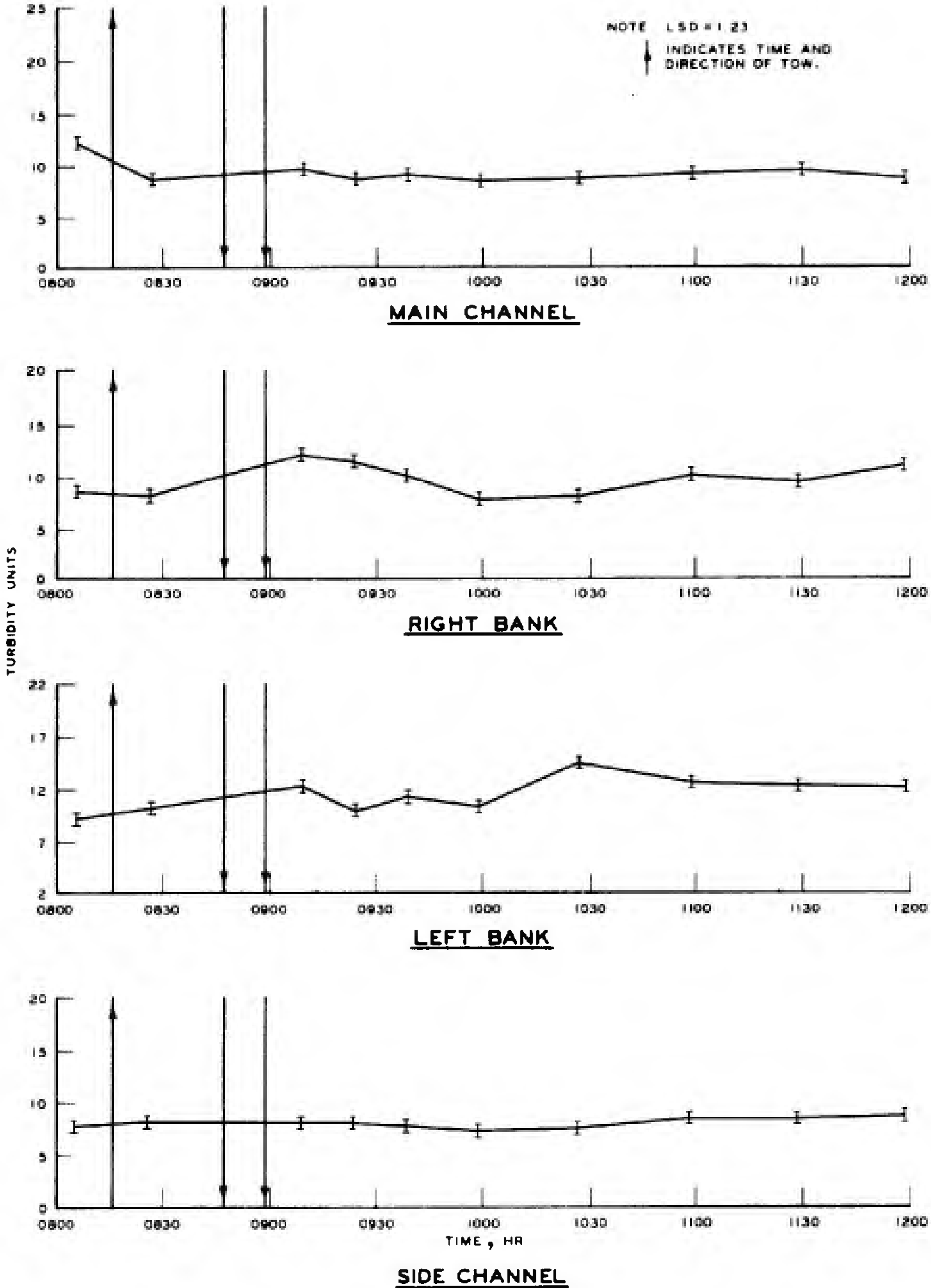


Figure 28. Effect of event 9 (multiple tow) on turbidity, Mississippi River sampled at RM 258.0, 30 Oct 75

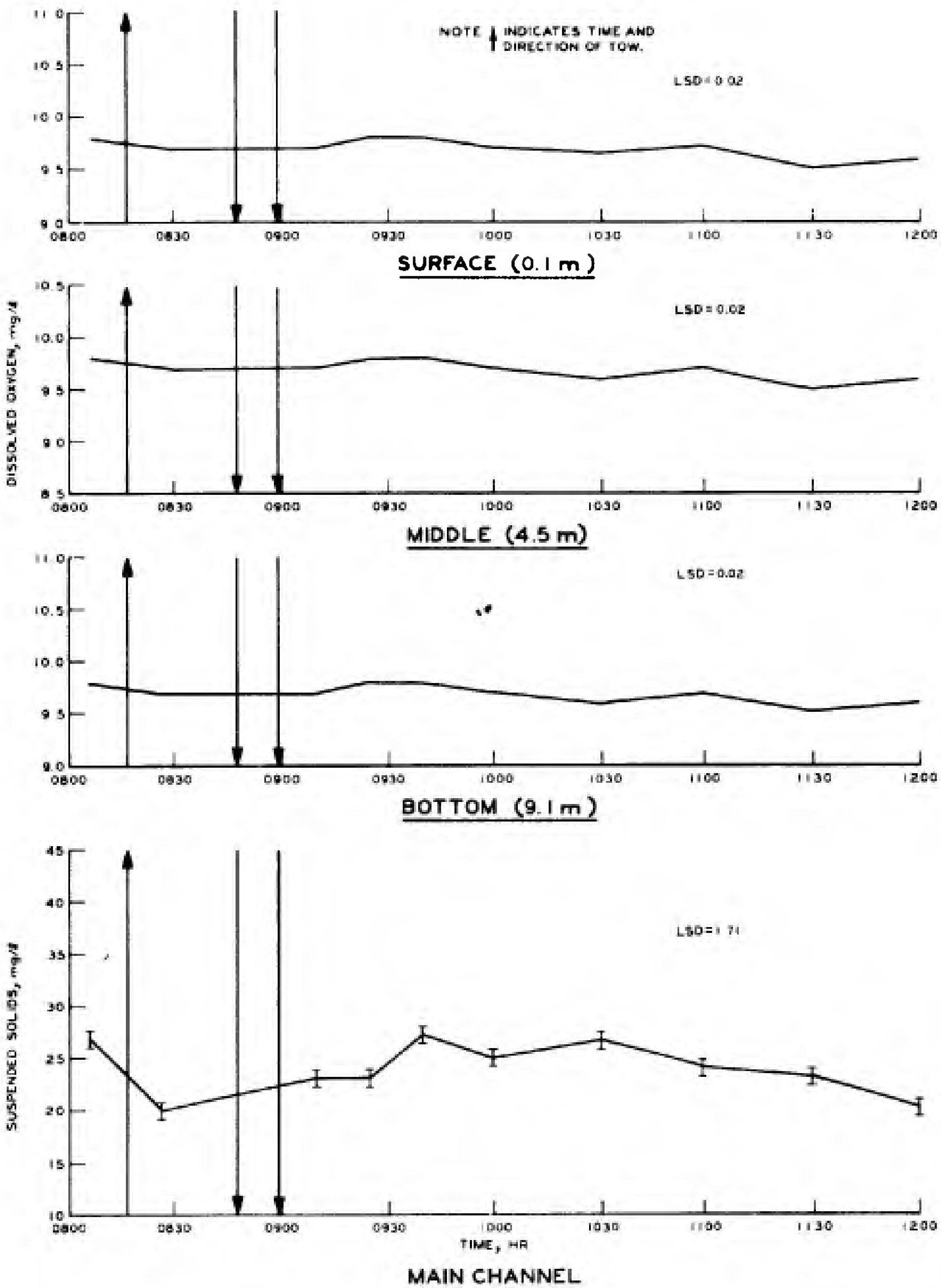


Figure 29. Effect of event 9 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Mississippi River sampled at RM 258.0, 30 Oct 75 (Note: LSD value for DO too small to graph)

binodal increase in suspended solids concentrations was noted at the left bank station, although this presumably resulted from shoreline turbulence probably caused by wave activity. Because the evidence indicates that no sediments were resuspended by the tow in the main channel area, this interpretation appeared reasonable. Recovery times determined for the binodal maxima at the left bank station were 25 and 90 min. The single upstream tow had no apparent effect on dissolved oxygen concentrations.

110. Event 9, consisting of a single upstream tow and two downstream tows, apparently did have some effect on suspended solids concentrations in the main channel (which recovered within a 155-min period) and right bank stations (which did not recover). The higher suspended solids concentration noted at the right bank (14.6 mg/ℓ above ambient) was probably contributed to by shoreline turbulence, created by the tows passing the study site. The turbidity data conform to those observations made related to suspended solids concentrations but also indicate that some effect occurred at the right bank station. Although significant effects were noted, the relative changes caused by the passage of the tows were considered small. During the multiple tow event, no changes in dissolved oxygen were observed.

111. The overriding characteristic of this particular study site was the deep water in the main channel, which undoubtedly accounted for the lack of direct effects of the traffic events. The depth of the main channel in the study area varied between about 5.7 and 9.1 m. The overall mean difference between tow drafts and depths of the main channel was 5.7 m. It appeared that single tows moving through this area have little effect on the resuspension of sediments in the main channel. Multiple tows may have some slight effects, including wavewash in shoreline areas.

112. Where effects were noted, an important point to consider was the relative magnitude of the changes in the concentrations of suspended solids and turbidity. In every case these changes were relatively small even though they differed significantly in a statistical sense.

113. A significant linear relationship between suspended solids and turdibity was noted only for event 7 (single downstream tow) at this

study site on the Mississippi River. Correlation coefficients for events 7, 8, and 9 were +0.97, +0.34, and +0.25, respectively.

Illinois River

Description of study site 1 - river mile 215.8

114. The first study site on the upper Illinois River was located about 2.5 miles downstream from Spring Valley, Illinois, at river mile 215.8. The study transect was in a relatively straight reach of the river (Figure B1).

115. The river's bank-to-bank width was about 240 m. The side channel station, positioned approximately 200 m downstream from the three upstream stations, was inside the entrance to Clark Island Chute. Depth of water recorded for the main channel station was 3.4 m. Other station depths were: right bank, 1.1 m; left bank, 1.8 m; and side channel, 1.5 m. Current velocities were generally uniformly low for all stations but were markedly affected by tow traffic, especially at the side channel station. Mean current velocities recorded for each station were: main channel (surface - 0.23 m/sec, bottom - 0.17 m/sec); right bank (surface - 0.18 m/sec, bottom - 0.17 m/sec); left bank (surface - 0.18 m/sec, bottom - 0.09 m/sec); and side channel (surface - 0.21 m/sec, bottom - 0.13 m/sec).

116. Two multiple tow traffic events were monitored on different days at this study site. The first tow event consisted of three upstream tows with the duration of sampling being 6-3/4 hr. The second event consisted of four upstream tows and a single downstream tow, and the sampling period lasted for nearly 7 hr. River stages fell 0.1 ft during the 2-day sampling period.

Event 1

117. The first tow traffic event monitored in the upper reaches of the Illinois River at river mile 215.8 was a multiple event consisting of three upstream tows. All three tows passed the study site within a 58-min period. The number of barges pushed by each were: tow 1, four loaded barges; tow 2, two loaded barges; and tow 3, three loaded

and five empty barges. Draft of the barges varied between 2.4 and 2.7 m. Clearance between tow drafts and channel bottom ranged from 0.7 to 1.0 m. Tow speeds were between 5 and 7 mph.

118. Suspended solids. The passage of tow 1 produced significant increases in suspended solids concentrations at main channel and right bank stations but not at left bank and side channel stations (Figure 30). The largest increases in concentrations were noted for the main channel station, which recovered 40 min after tow 1 had passed. Concentrations still exceeded ambient levels at the right bank station immediately prior to the arrival of tows 2 and 3. The passage of tows 2 and 3 increased concentrations at all stations, with highest concentrations noted for the main channel. For the interpretation of potential effects at the side channel station, ambient concentration was assumed to be the lowest of the two initial time measurements. The increases observed at left bank and side channel stations could possibly represent the accumulative effects of all three tows. Additive effects were not noted at either the right bank, left bank,or side channel stations. Recovery times for main channel and left bank stations after tows 2 and 3 passed were 58 min each; recovery time for the side channel station was 183 min. Ambient concentrations were still exceeded at the right bank station at the end of the sampling period.

119. Turbidity levels. Based on turbidity measurements, the initial tow caused significant increases in turbidity levels at all stations, except the left bank station (Figure 31). Turbidity levels at the main station increased significantly 25 min after tow 1 passed and remained elevated above ambient level for 198 min after the remaining tows passed. The same initial response was observed at the side channel station and to a lesser extent at the right bank station. Recovery times for right bank and side channel stations were 73 and 200 min, respectively. No increase in turbidity levels was observed for the left bank station until 90 min after all the tows had passed the site; recovery time was 140 min. Although significant increases were observed, most of these amounted to only about 10 turbidity units above ambient. No additive effects were noted at any of the sampling stations.

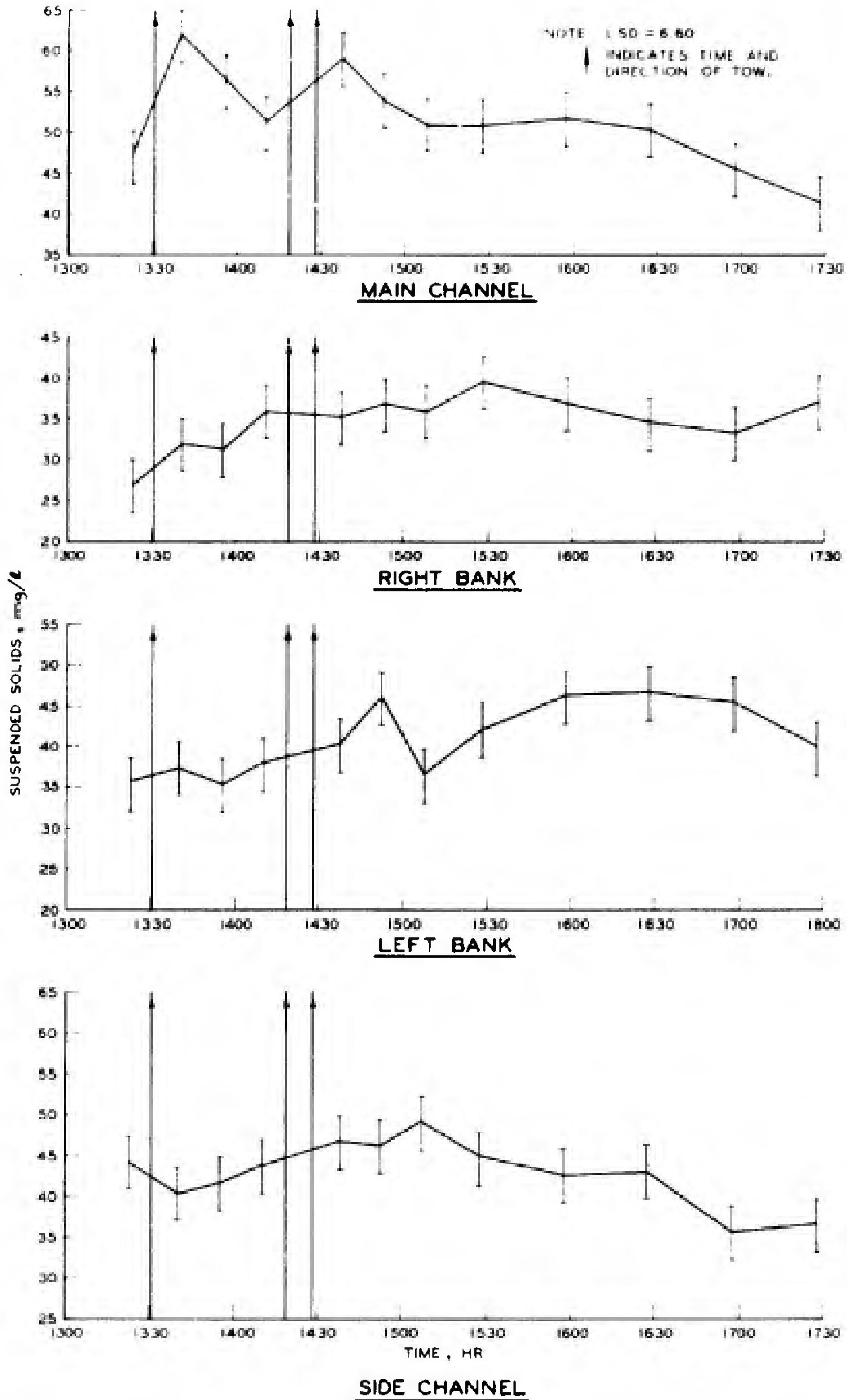


Figure 30. Effect of event 1 (multiple tow) on suspended solids concentration, Illinois River sampled at RM 215.8, 16 Oct 75

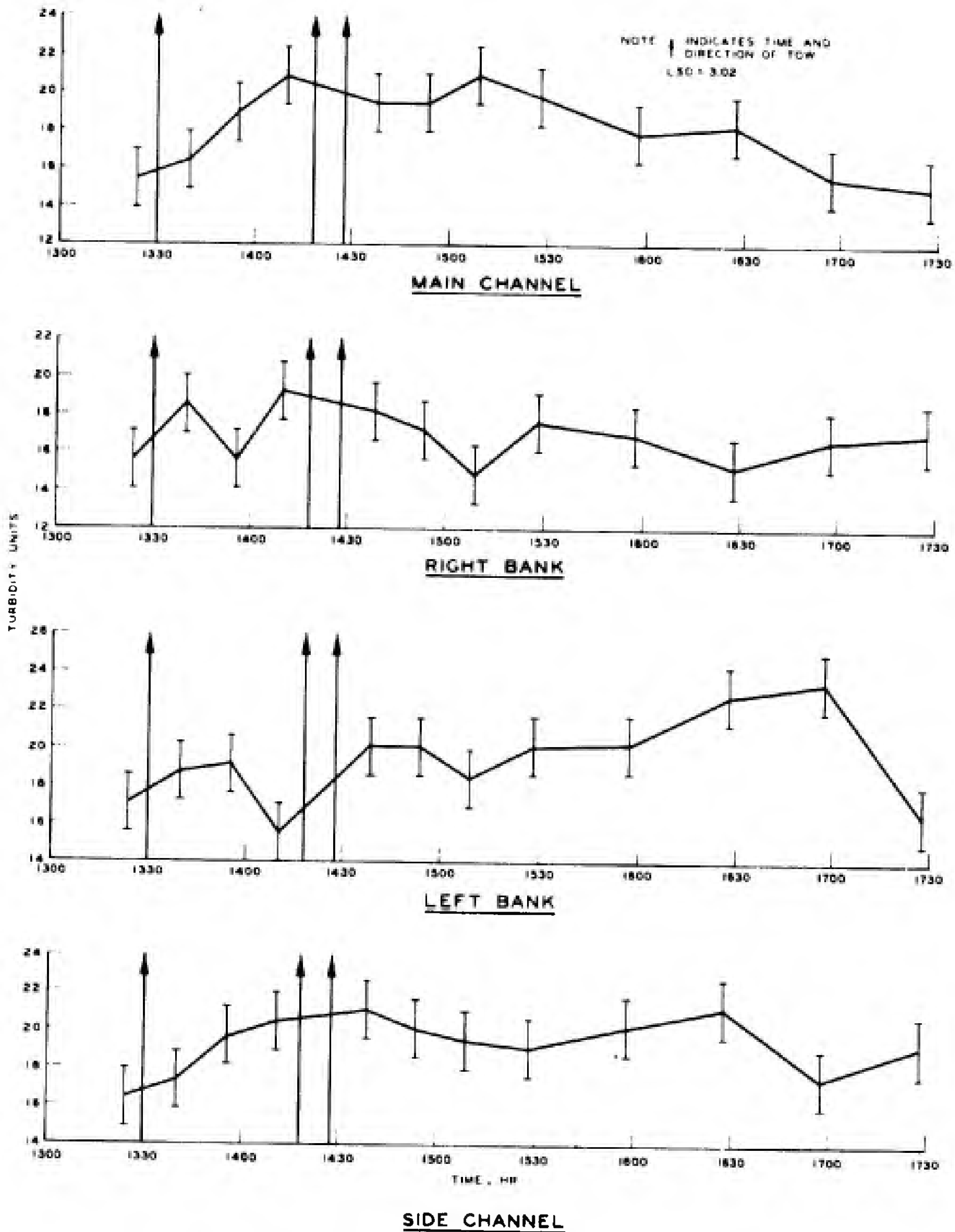


Figure 31. Effect of event 1 (multiple tow) on turbidity, Illinois River sampled at RM 215.8, 16 Oct 75

120. Dissolved oxygen. No apparent relationship was observed between maximum concentrations of sediments resuspended in the main channel and the dissolved oxygen concentrations measured at surface, mid-depth, and bottom strata (Figure 32). However, after the passage of tows 2 and 3, as suspended solids concentrations slowly declined, dissolved oxygen concentrations at all depths slightly increased. These increases amounted to only 0.5 mg/ℓ at the surface, 0.6 mg/ℓ at the bottom, and 0.7 mg/ℓ at mid-depth.

Event 2

121. Event 2 on the Illinois River at river mile 215.8 offered a unique opportunity to study the additive effects of several tows passing the study site because several samples were collected between the times that the tows passed. The event consisted of two upstream tows followed by one downstream tow and then by two more upstream tows. The initial 3 tows were pushing 3 or less loaded barges; the 2 later tows were pushing 15 and 6 loaded barges, respectively. Draft of the initial tow was 2.6 m; drafts for the remaining tows were 2.7. Differences in tow drafts and channel bottom ranged from 0.7 to 0.8 m.

122. Suspended solids. The passage of tow 1 caused suspended solids concentrations to increase significantly at all four stations with maximum change noted for the main channel station (Figure 33). At the main channel station 25 min after tow 1 passed, concentrations were increased 28 mg/ℓ over the ambient level. The second tow passed about 75 min later, and during this period concentrations in the main channel began to decline. Concentrations continued to decline at this station even after tow 2 passed but increased after tow 3 had passed. Similar responses were observed at all other stations. After tow 3 passed the four stations, maximum concentration increases were side channel, 70 mg/ℓ; left bank, 32 mg/ℓ; right bank, 22 mg/ℓ; and main channel, 12 mg/ℓ. For three of the stations (side channel, left bank, and right bank), these increased concentrations were considered to be additive in nature. The more pronounced response caused by the passage of tow 3 may have been related to the fact that this particular tow, although pushing as many barges as the previous tows, passed the study site with an

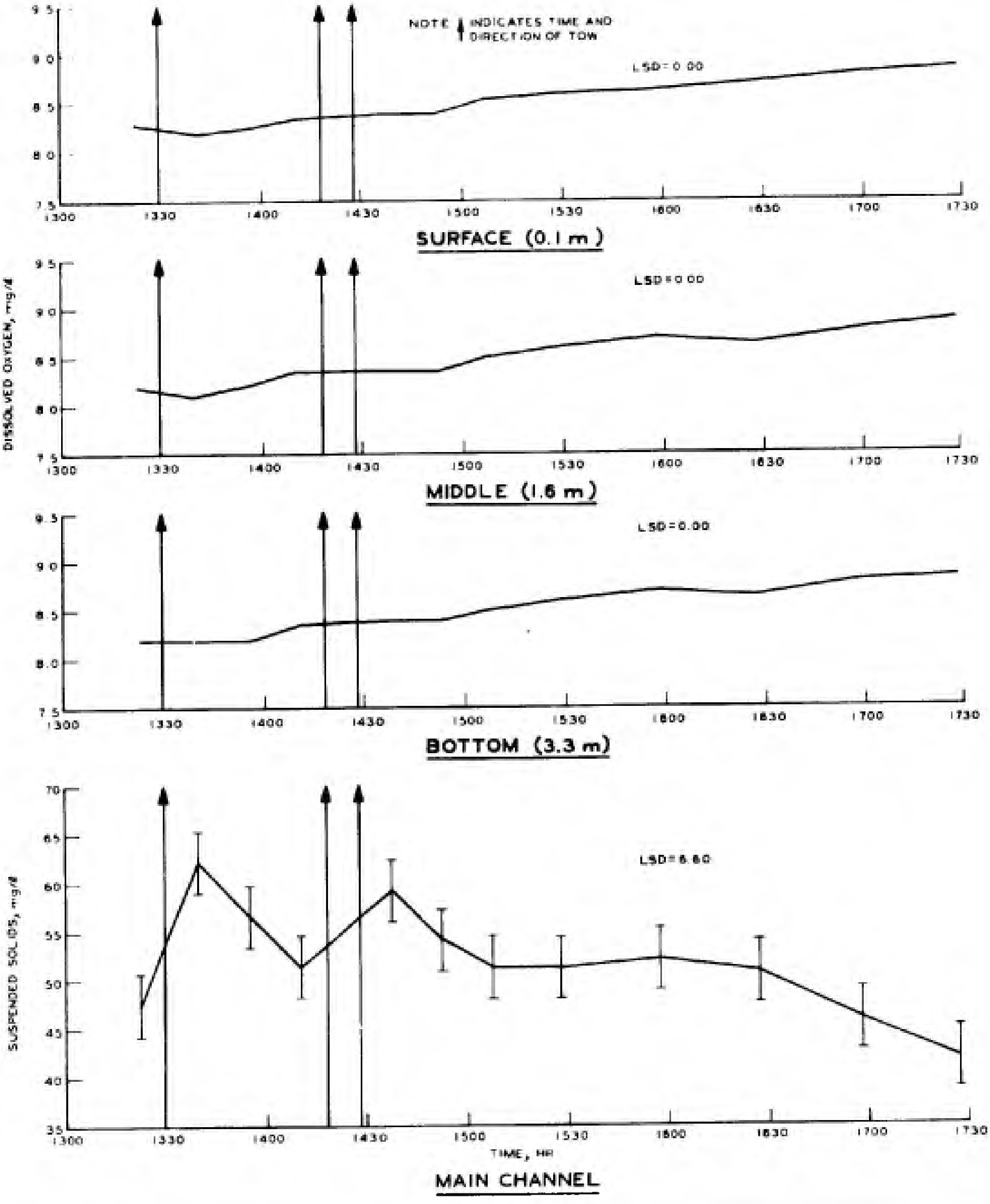


Figure 32. Effect of event 1 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Illinois River sampled at RM 215.8, 16 Oct 75 (Note: LSD value for DO too small to graph)

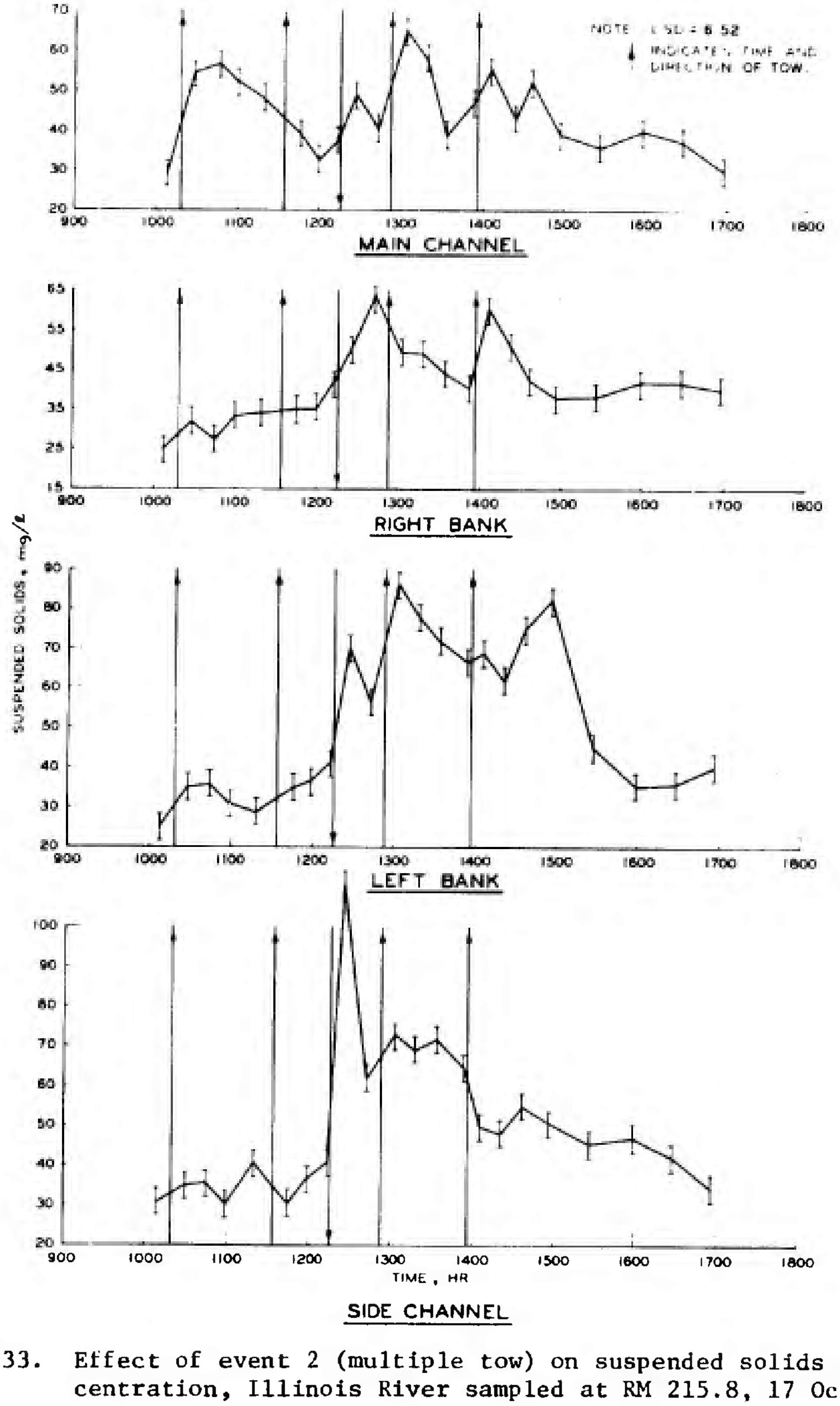


Figure 33. Effect of event 2 (multiple tow) on suspended solids concentration, Illinois River sampled at RM 215.8, 17 Oct 75

estimated velocity of 8 to 10 mph. Velocities of the other tows were less.

123. The passage of tow 4 pushing 15 loaded barges had an appreciable effect in elevating concentrations at main channel and left bank stations but not at right bank and side channel stations where suspended solids concentrations were already high. At all stations suspended solids concentrations were beginning to decrease prior to the arrival of the last tow. After tow 5 passed increasing concentrations were again observed at all stations except the side channel. During the passage of multiple tows at this site on the Illinois River, two recovery times were noted for both main channel and side channel stations. For the main channel station, these were 100 and 197 min; for the side channel station, the recovery times were 45 and 287 min. Concentrations at the right bank station remained above ambient level at the end of the sampling period. After the initial 60-min recovery period at the left bank station following the passage of tow 1, suspended solids concentrations never returned to ambient level for the duration of the sampling period.

124. Turbidity levels. Unlike the trend observed for suspended solids concentrations, the initial two tows had no effect on elevating turbidity levels at any of the stations (Figure 34). It was not until after tow 3 passed the study site that significant increases in turbidity were observed at all stations. As shown in Figure 34, the passage of tow 4 had an additive effect on previous levels of turbidity measured at the left bank station. The response at the right bank station following the passage of tow 5 was comparable to what was interpreted using the suspended solids data. Turbidity levels remained above ambient levels for 182 min at the main channel and left bank stations and for 152 min at the side channel station.

125. Dissolved oxygen. The only noteworthy response noted for dissolved oxygen concentrations was during the period following the passage of tow 3 (Figure 35). After its passage dissolved oxygen was reduced at all depths but recovered to ambient levels within a 30-min period. Although the reductions are quite evident in Figure 35, the

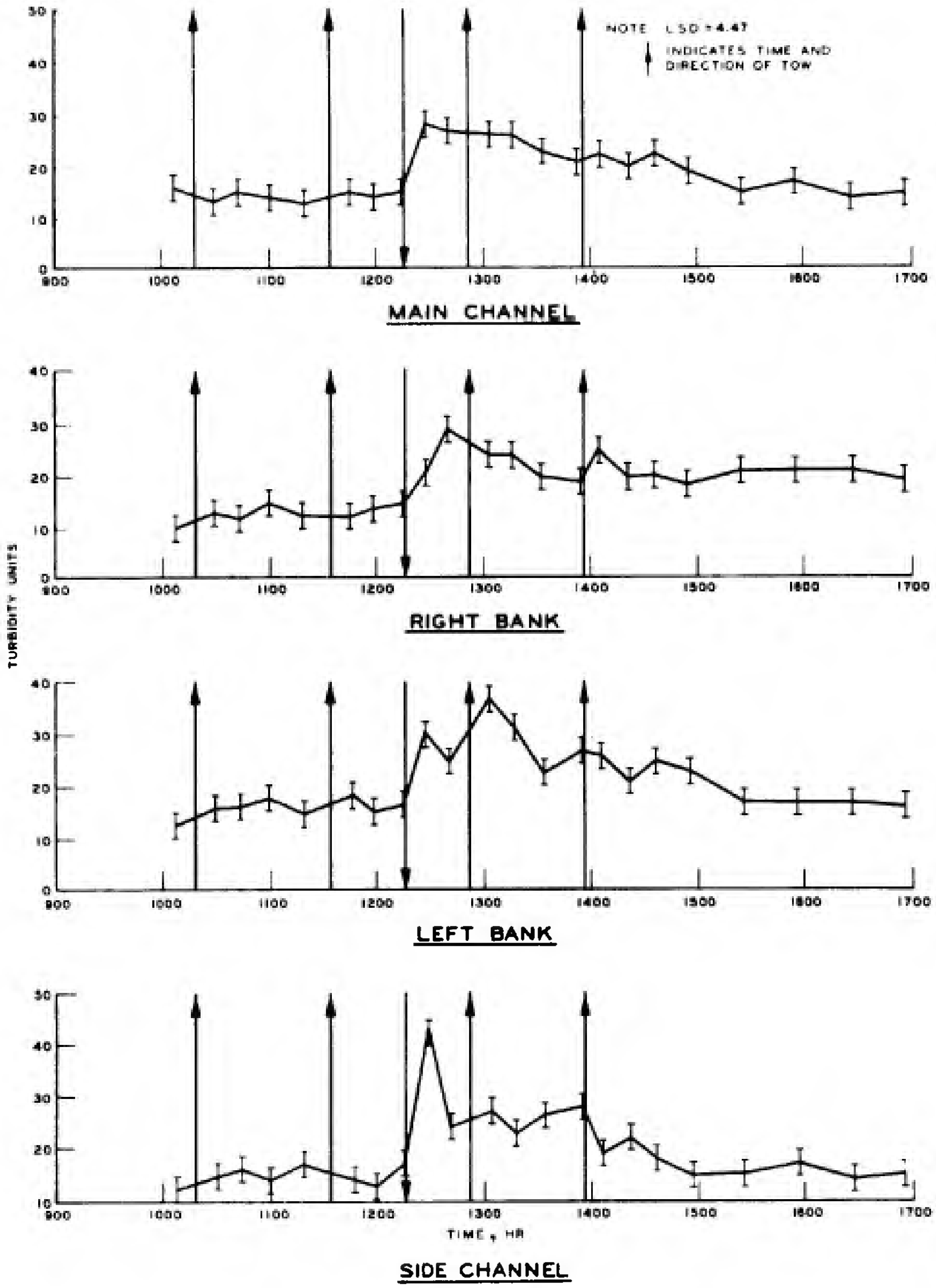


Figure 34. Effect of event 2 (multiple tow) on turbidity, Illinois River sampled at RM 215.8, 17 Oct 75

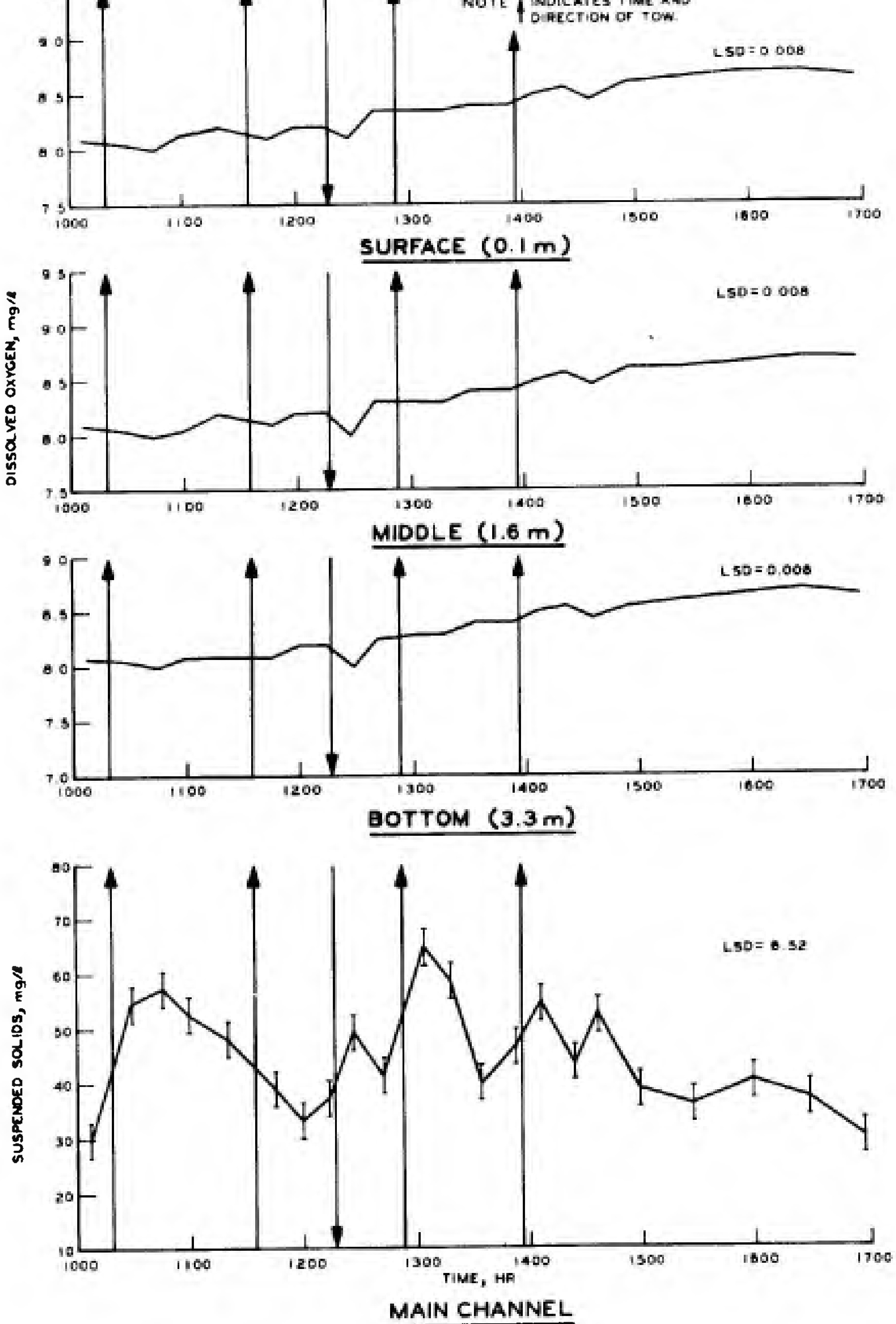


Figure 35. Effect of event 2 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Illinois River sampled at RM 215.8, 17 Oct 75 (Note: LSD value for DO too small to graph)

relative changes were small, amounting to no more than 0.2 mg/ℓ. Dissolved oxygen concentrations similarly showed the same steady rise throughout the sampling period as was observed for event 1. It may be that these increasing concentrations are related to increased turbulence in the area caused by the passing tows or to natural diel changes, which theoretically show a maximum increase in the late afternoon.

Discussion

126. Each of the two multiple tow traffic events that were monitored in the Illinois River at river mile 215.8 (site 1) showed that tow traffic significantly elevates concentrations of suspended solids and turbidity in this upper reach of the river. The data indicate that resuspended solids from the main channel areas do not exert a significant oxygen demand in the overlying water column. In fact, the response curves indicated that multiple tows moving through the area may slightly elevate dissolved oxygen concentrations because of the turbulence created by the tows.

127. Given the characteristic narrow widths in this reach of the Illinois River and relatively shallow depths of the main channel (the overall depth difference between tow drafts and channel bottom was 0.7 m), the passing of multiple tows during event 2 was observed to have an additive effect on suspended solids and turbidity concentrations.

128. Event 2 was probably the most demonstrative event monitored during the entire study to test for additive effects related to multiple tows. Not only did the intervals between tow arrivals allow time to collect several samples to assess more accurately the response, but multiple upstream tows are also considered to have more potential for an impact than downstream tows because more engine thrust is required for travel in an upstream direction against the current than a downstream direction where the natural currents aid the movement of the tow. Also, in situations where appreciable currents exist, upstream tows move more slowly past a given point and thus there exists more time for potential resuspension of bottom sediments.

129. Another effect associated with tow traffic in this reach of

the river was the effect on flow through the entrances of side channels. Sparks' observations relative to tows altering the rate of flow as they passed near side channels[4] were also confirmed during the two monitoring efforts at this location. For example, during event 1 the passage of a single upstream tow increased current velocities in the side channel at the surface from 0.25 m/sec before the tow passed to 0.41 m/sec after the tow passed. Currents measured at mid-depth in the side channel increased from 0.20 to 0.31 m/sec after the tow had passed.

130. Ranges of significant responses above ambient suspended solids concentrations for the four sampling stations were: side channel, 5.0 - 80.6 mg/ℓ; left bank, 11.0 - 61.3 mg/ℓ; main channel 14.7 - 39.0 mg/ℓ; and right bank, 12.6 - 38.0 mg/ℓ. A similar trend for significant responses was noted using turbidity data: side channel, 4.7 - 30.3 units; left bank, 6.3 - 23.4 units; main channel, 5.4 - 15.0 units; and right bank, 3.7 - 18.7 units. Evident from the foregoing is the fact that side channel and left bank stations consistently showed the greatest response to the passage of tows at this the uppermost site on the Illinois River.

131. Concentrations of suspended solids at the right bank station remained above ambient levels for the duration of both tow traffic events monitored. Generally, recovery times were longest for the side channel (45-287 min), next longest for the main channel (40-197 min), and shortest for the left bank (58-60 min) except on one occasion where suspended solids concentrations remained above ambient levels at the end of the sampling period. Recovery times based on the turbidity data essentially followed the suspended solids trends: longest for the side channel (152-200 min); next longest for the main channel (182-198 min); and shortest for the left bank (140-182 min). An exception to the trend was one occasion when no recovery occurred at the right bank. In those instances where concentrations did not return to ambient levels at stations located near the shoreline, the failure to return is probably related to the combined effects of initial tow passage and subsequent shoreline turbulence created by tow-generated waves.

132. Dissolved oxygen responses characteristically showed a steady rise throughout the sampling periods. Increased turbulence caused by

the tows or natural diel changes in oxygen concentrations could have accounted for the observed phenomenon.

133. For both of the events at river mile 215.8 on the Illinois River, significant linear relationships existed between suspended solids concentrations and turbidity units. The r values calculated for events 1 and 2 were +0.39 and +0.82, respectively, and were significant at the 5-percent level.

134. Ambient concentrations of suspended solids and turbidity in this reach of the river were relatively low compared to the middle reach of the river discussed later.

Description of study site 2 - river mile 113.5

135. The second site on the Illinois River was located at river mile 113.5 about 6 miles downstream from Havana, Illinois, and just above the town of Bath, Illinois. The study transect was positioned in a slight outside bend of the river (Figure B2). The side channel station was located in the entrance of Bath Chute, which is formed by Grand Island.

136. The width of the river across the three stations was approximately 240 m. The side channel station was located about 180 m downstream from the other stations in about 1.0 m of water. The main channel station was deepest (3.7 m), followed by the right bank station (2.9 m) and the left bank station (1.2 m). Highest measured current velocities were recorded for the main channel station (surface - 0.34 m/sec; bottom - 0.34 m/sec) and the side channel station (surface - 0.31 m/sec; bottom - 0.25 m/sec). Current velocities at the right bank station (surface - 0.30 m/sec; bottom - 0.17 m/sec) were slightly higher than those observed for the left bank station.

137. Two multiple tow traffic events were monitored on two different days at this study site. One event consisted of one upstream and one downstream tow; the other consisted of two upstream and two downstream tows. River stages were slowly decreasing prior to the monitoring efforts and dropped 0.2 ft between the two sampling dates. Based on the records, river stages were about 1.4 ft above normal pool conditions at the time samples were collected.

Event 3

138. The single downstream and single upstream tows monitored during this event were pushing four and two loaded barges, respectively. Both passed the study site traveling at about the same velocity; draft depths of the barges ranged from 2.6 to 2.7 m. Depth differences between tow drafts and channel bottom ranged from 1.0 to 1.1 m. The second tow passed the study site 98 min after the first tow had passed. This event provided an opportunity to study the effects of two relatively similar tows traveling in different directions.

139. Suspended solids. The passage of tow 1 increased concentrations of suspended solids only at main channel and left bank stations (Figure 36). The exclusion of the right bank from any observable effects appeared to be related to the fact that its position was oriented more on the inside of the slight bend noted for this area (Figure B2). An additional consideration is that ambient concentrations at the right bank station appeared to be already elevated relative to the other stations, thus masking any increases in concentrations caused by the tow. Suspended solids concentrations increased to a maximum of 80 mg/ℓ at the main channel following the passage of tow 1 and returned to ambient levels 90 min later. A quicker response was noted for the left bank station, where concentrations increased 67 mg/ℓ above ambient levels immediately following the passage of the tow with the station recovering in a shorter period of time (25 min). The second tow to pass the study site produced essentially an equivalent effect both in terms of affecting similar stations and also in elevating concentrations to about the same levels noted for the response of tow 1 except at the main channel station, where concentrations were incresased 113.0 mg/ℓ above ambient levels. However, recovery times were shorter at the main channel station (50 min) and longer at the left bank station (110 min) than was observed at these stations after tow 1 had passed them. Because the lag time between tows was apparently greater than the settling time of resuspended sediments, no additive effects were observed.

140. Turbidity levels. Interpretation of the response based on turbidity levels generally followed the trends observed for suspended

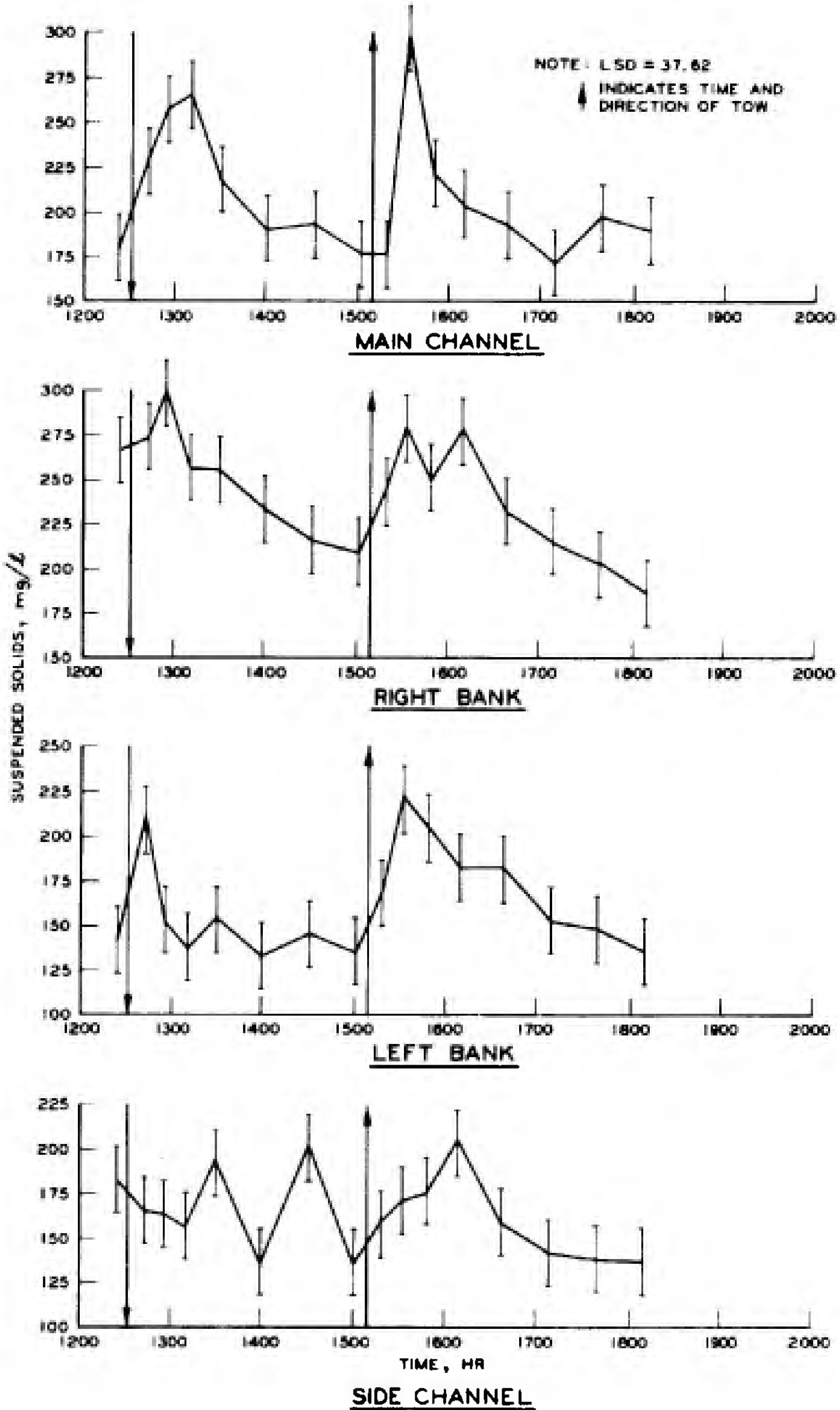


Figure 36. Effect of event 3 (multiple tow) on suspended solids concentration, Illinois River sampled at RM 113.5, 19 Oct 75

solids with some exceptions (Figure 37). Significant increases in turbidity levels were observed not only for main channel and left bank stations but the side channel station as well. Main channel and left bank station responses were very similar to those curves noted using suspended solids data (compare Figures 36 and 37). Recovery times following the passage of tow 1 for main channel and left bank stations were 120 min and 25 min, respectively. After tow 2 passed ambient levels were reached within 110 min at the main channel and within 120 min at the left bank station. The responses noted at the side channel station, particularly at 1431 hr and 1501 hr, could not be accounted for. At these times turbidity increased about 120 units from the previous measurement. Furthermore, the variation in the six observations used to calculate the means was small (Table E3). It is doubtful that such a response was related to the passage of tow 1 since concentrations began to decrease immediately after the passage of tow 2 and continued without showing any upward trend. Recovery time determined for the side channel station was 78 min.

141. Dissolved oxygen. There was no apparent relationship between dissolved oxygen concentrations and concentrations of suspended solids generated by either of the two tows in the main channel (Figure 38). The same upward drift of dissolved oxygen concentrations, which was observed at river mile 215.8 on the Illinois River, was similarly observed at this location. The maximum increase in concentration observed at all depths was 0.67 mg/ℓ.

Event 4

142. The initial two upstream tows and later two downstream tows that comprised this event passed the study site within a period of 134 min. Time intervals between tows were: tows 1 and 2, 63 min; tows 2 and 3, 52 min; and tows 3 and 4, 19 min. The first three tows were pushing 13, 14, and 12 loaded barges, respectively. Tow 4 was pushing 4 loaded barges. Tow draft depths ranged from 2.6 to 2.7 m. Mean clearance depth from the channel bottom was 1.0 m.

143. Suspended solids. Generally, significant increases in suspended solids concentrations were either produced by the passage of each

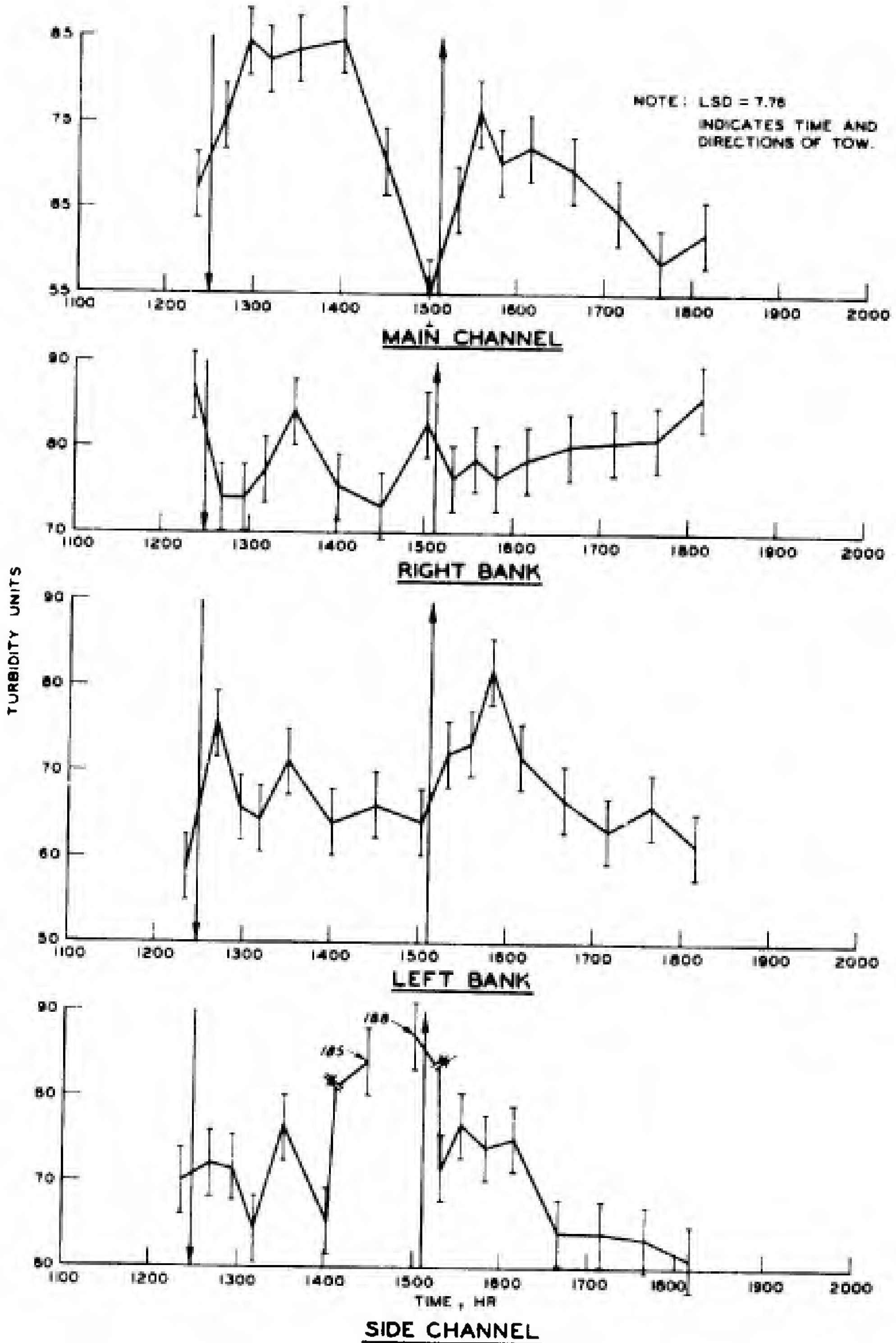


Figure 37. Effect of event 3 (multiple tow) on turbidity, Illinois River sampled at RM 113.5, 19 Oct 75

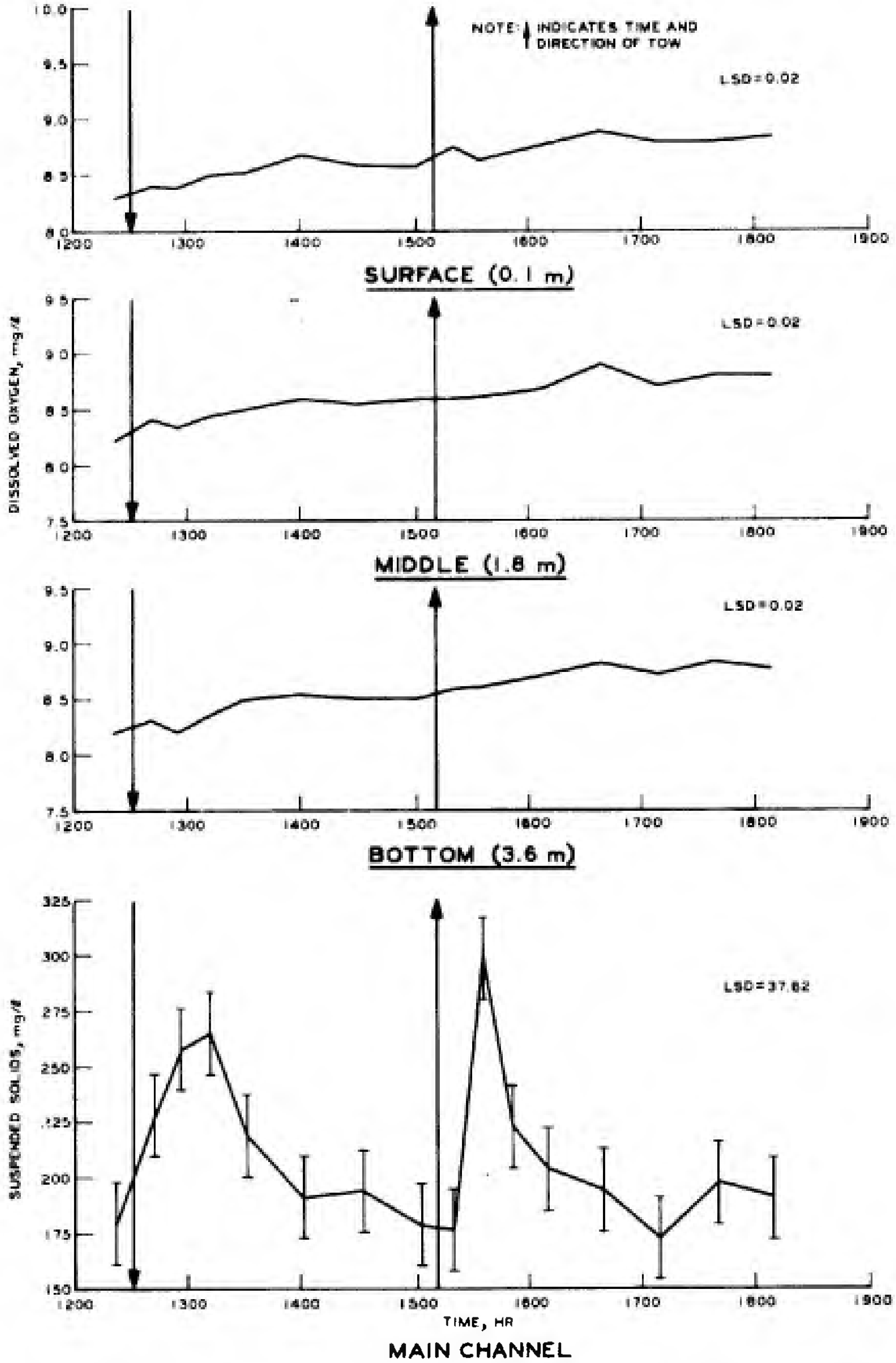


Figure 38. Effect of event 3 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Illinois River sampled at RM 113.5, 19 Oct 75 (Note: LSD value for DO too small to graph)

tow or were maintained above ambient levels (Figure 39). Additive effects were similarly noted at all stations sampled except the side channel station. After tow 1 passed, maximum increase in suspended solids concentration wa recorded in the main channel (149 mg/ℓ), followed next by the right bank station (124 mg/ℓ), then the side channel station (84 mg/ℓ), and last by the left bank station (75 mg/ℓ).

144. The passage of tow 2 maintained the already elevated concentrations at the main channel, left bank, and side channel stations. At the right bank station, concentrations started to decline.* Tow 3 had no immediate effect on concentrations at any of the stations; however, following the passage of tow 4, concentrations increased substantially at all stations except the side channel station. Concentrations increased 281 mg/ℓ above the concentration of the previous sample at the right bank station and 230 mg/ℓ at the main channel station. The left bank station also showed the same response but to a lesser extent. The passage of both tows 3 and 4 produced a pronounced additive effect on all stations except the side channel station. Recovery times noted for the main channel, left bank, and side channel stations were 284, 284, and 224 min, respectively. At the right bank station concentrations returned to ambient levels 125 min after tow 1 passed and 110 min after tow 4 had passed.

145. Turbidity levels. Those station responses discussed for suspended solids concentrations in paragraphs 143 and 144 above were essentially similar using the turbidity data (Figure 40). The passage of tows 3 and 4 produced the largest increases in turbidity levels. For example, at the right bank station, turbidity was increased 84 units above the level associated with 1511 hr. In the main channel, the increase at 1511 hr amounted to 72 units. Additive effects were noted

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* Link and Williamson[1] interpreted four computer photomaps produced from correlating aerial photographs and simultaneously collected ground truth suspended solids samples that were taken between the passages of tows 2 and 3. Essentially, the interpretations by Link and Williamson confirmed the responses observed during this study.

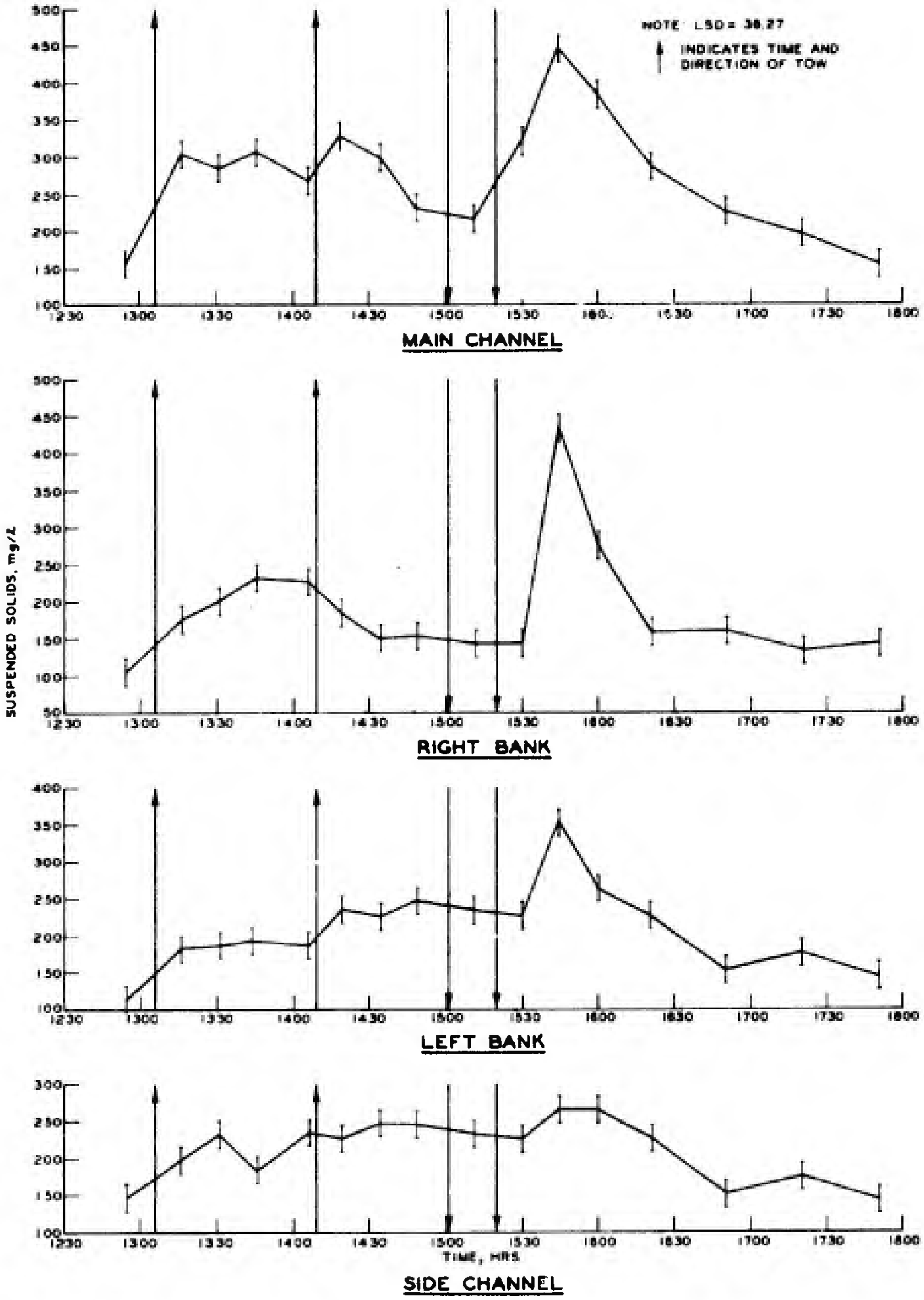

Figure 39. Effect of event 4 (multiple tow) on suspended solids concentration, Illinois River sampled at RM 113.5, 20 Oct 75

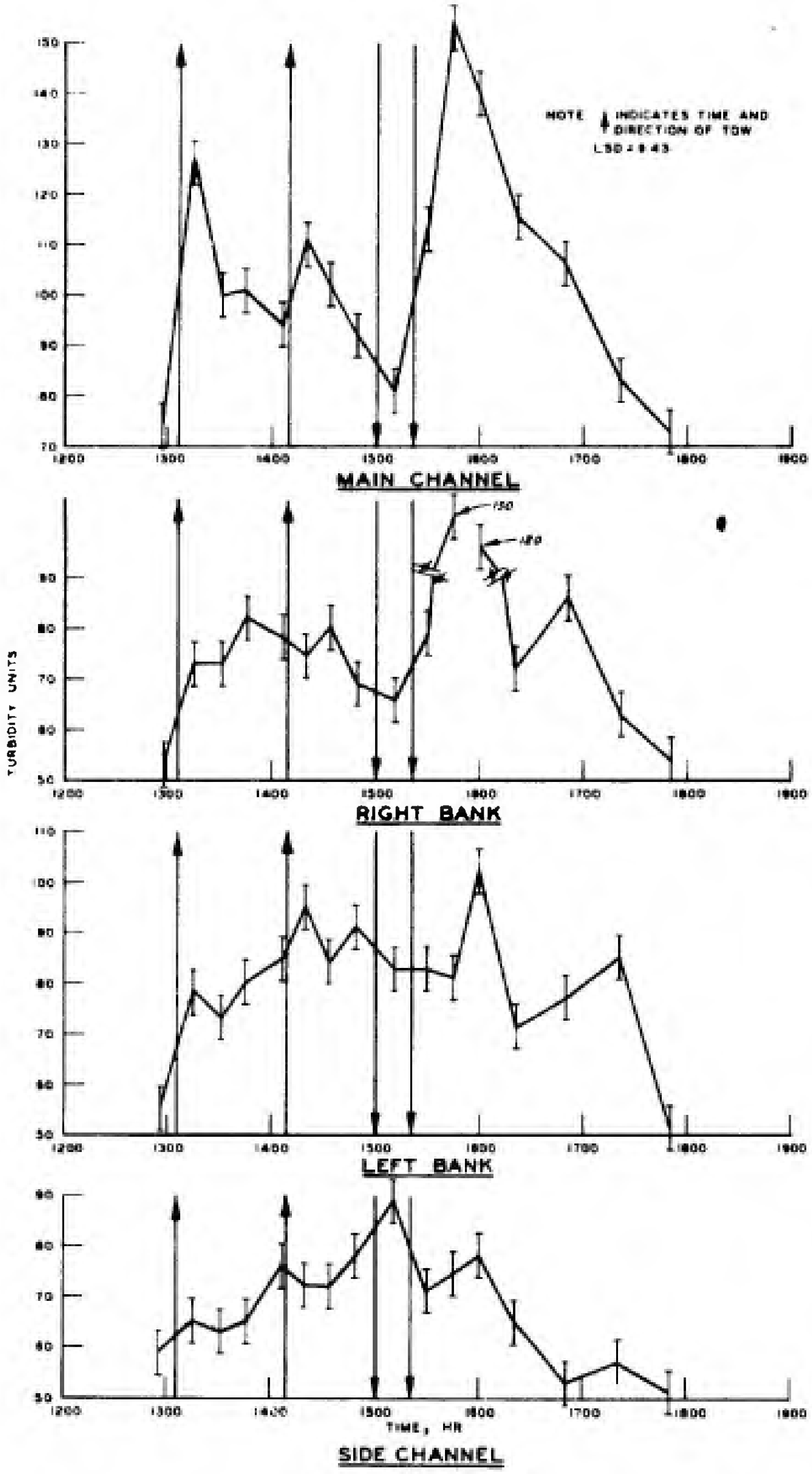

Figure 40. Effect of event 4 (multiple tow) on turbidity, Illinois River sampled at RM 113.5, 20 Oct 75

at the side channel station after tow 3 passed and at main channel and right bank stations after tow 4 passed the study site. Although significant effects were observed at the side channel station, on a comparative basis, the magnitudes were less in the side channel. Recovery times were 254 min for the right bank station, 254 min for the left bank station, and 169 min for the side channel station. During the sampling period, concentrations at the main channel returned to ambient levels twice. These recovery times were 125 and 129 min, respectively.

146. Dissolved oxygen. The dissolved oxygen curves (Figure 41) show very slight responses during the monitoring periods. Surface and mid-depth concentrations were reduced (0.2 and 0.04 mg/ℓ, respectively) after tow 1 passed. A similar response was noted after the passage of tow 2. Dissolved oxygen concentrations increased after tows 3 and 4 passed and continued to rise throughout the duration of the sampling period. Although the statistical analyses indicate that the means differed, the changes observed were of a small magnitude.

Discussion

147. Both tow traffic events monitored at river mile 113.5 (site 2) on the Illinois River produced highly statistically significant effects in terms of tow traffic elevating both mean turbidity and suspended solids concentrations above ambient concentrations. Although in some instances the dissolved oxygen curves showed a slight depression after tow passages, these changes were of a relatively small magnitude (usually less than 0.2 mg/ℓ). Possible explanations of the characteristically steady rise in dissolved oxygen concentrations include turbulence created by the tows themselves and natural diel changes in concentrations as previously discussed for events 1 and 2.

148. The initial event provided an opportunity to see if comparable tows, traveling in opposite directions, produced equivalent effects. Responses of turbidity and suspended solids concentrations were more similar for event 4, where the calculated r value (+0.80) was significant, than for event 3 where the r value (+0.13) was not significant. There were, however, some differences noted in recovery times for some

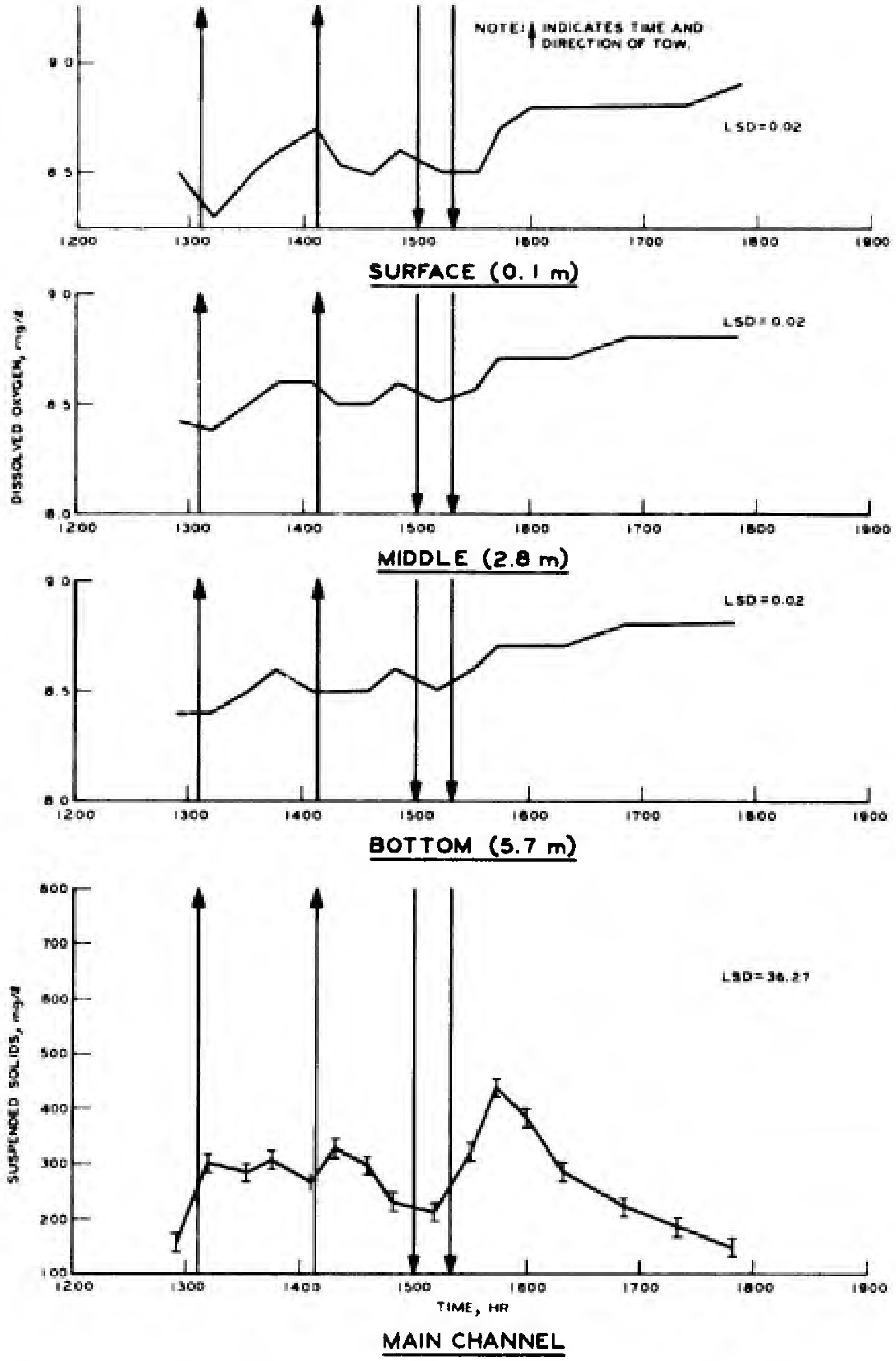

Figure 41. Effect of event 4 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Illinois River sampled at RM 113.5, 20 Oct 75 (Note: LSD value for DO too small to graph)

of the sampling stations. It was hypothesized that, because of the characteristic narrow widths and shallow depths in this area of the river, perhaps similar tows, although moving in different directions, elicit similar responses of the system.

149. The major difference between event 3, which consisted of two criss-crossing tows, and event 4, which consisted of two upstream tows followed by two downstream tows, was that the passage of the fewer number of tows (event 3) elicited the minimum response in terms of maximum increases in suspended solids and turbidity and shortest recovery times while passage of the larger number of tows (event 4) caused the maximum responses. For example, increases in suspended solids concentrations over ambient levels noted during event 3 were: main channel, 113.0 mg/ℓ; right bank, 32.6 mg/ℓ; left bank, 78.0 mg/ℓ; and side channel, 34.7 mg/ℓ. At these same stations during event 4, the increases were considerably greater: main channel, 293.0 mg/ℓ; right bank, 329.3 mg/ℓ; left bank, 238.3 mg/ℓ; and side channel, 123.3 mg/ℓ. The same trend was noted for turbidity with the exception of the reverse response at the side channel station. Recovery time ranges based on suspended solids concentrations for the sampling stations were as follows: main channel, 50 to 284 min; left bank, 25 to 284 min; side channel, 0 to 224 min; and right bank, 0 to 125 min. In each case, minimum recovery times were associated with event 3 while maximum recovery times were associated with event 4. This same trend was observed using the turbidity data.

150. Between passages of the four tows monitored during event 4, very definite additive effects were noted for all sampling stations except the side channel station. Based on the recovery times noted for event 3 and the responses observed during event 4, it was concluded that although suspended solids and turbidity concentrations did return to ambient levels within the duration of the sampling periods, multiple tows passing the site on the Illinois River not only maintained already-elevated concentrations but also further increased them.

151. It is considered noteworthy that even though ambient concentrations were considerably higher in this reach of the river than noted for the uppermost study site location (river mile 215.3), tow traffic

increased sediment concentrations above the naturally high ambient concentrations.

Description of study site 3 - river mile 31.0

152. The last study site on the Illinois River was located at river mile 31.0, approximately 1 mile downstream from Kampsville, Illinois. The study transect in this lower reach of the river was located on a slight outside bend just above Willow Island (Figure B3). The bank-to-bank width of the river was estimated to be about 425 m. The side channel station was positioned in 3.0 m of water and was approximately 335 m downstream from the other three sampling stations. Water depths recorded for left and right bank stations were 2.4 and 2.5 m, respectively. The depth of water at the main channel station was 3.3 m. Current velocities were essentially homogeneous at all stations and generally were all of a low magnitude. The range in current velocities at all stations was between 0.15 and 0.17 m/sec for surface strata and between 0.09 and 0.13 m/sec for bottom strata.

153. Two tow traffic events were monitored at this particular site: a multiple event consisting of three downstream tows and another multiple tow event including two upstream and two downstream tows. River stage data obtained from the Hardin gage (river mile 21.6) indicated that the river was at a normal pool condition and did not change during the monitoring period.

Event 5

154. Three downstream tows passing the study site within a 137-min interval were monitored first. The tows were pushing 12, 15, and 4 loaded barges, respectively. Differences in draft depths of the barges (2.7 to 2.8 m) and velocities (5.0 to 6.5 mph) of the tows were small. Mean clearance depth was 0.5 m.

155. Suspended solids. The initial tow passing the study site produced a significant effect within a 40-min period at both the main channel and side channel stations (Figure 42). Concentrations of suspended solids increased 30 mg/ℓ in the main channel and 23 mg/ℓ in the side channel over ambient levels. No effects were noted for right and left bank stations after tow 1 passed. Recovery times noted for main

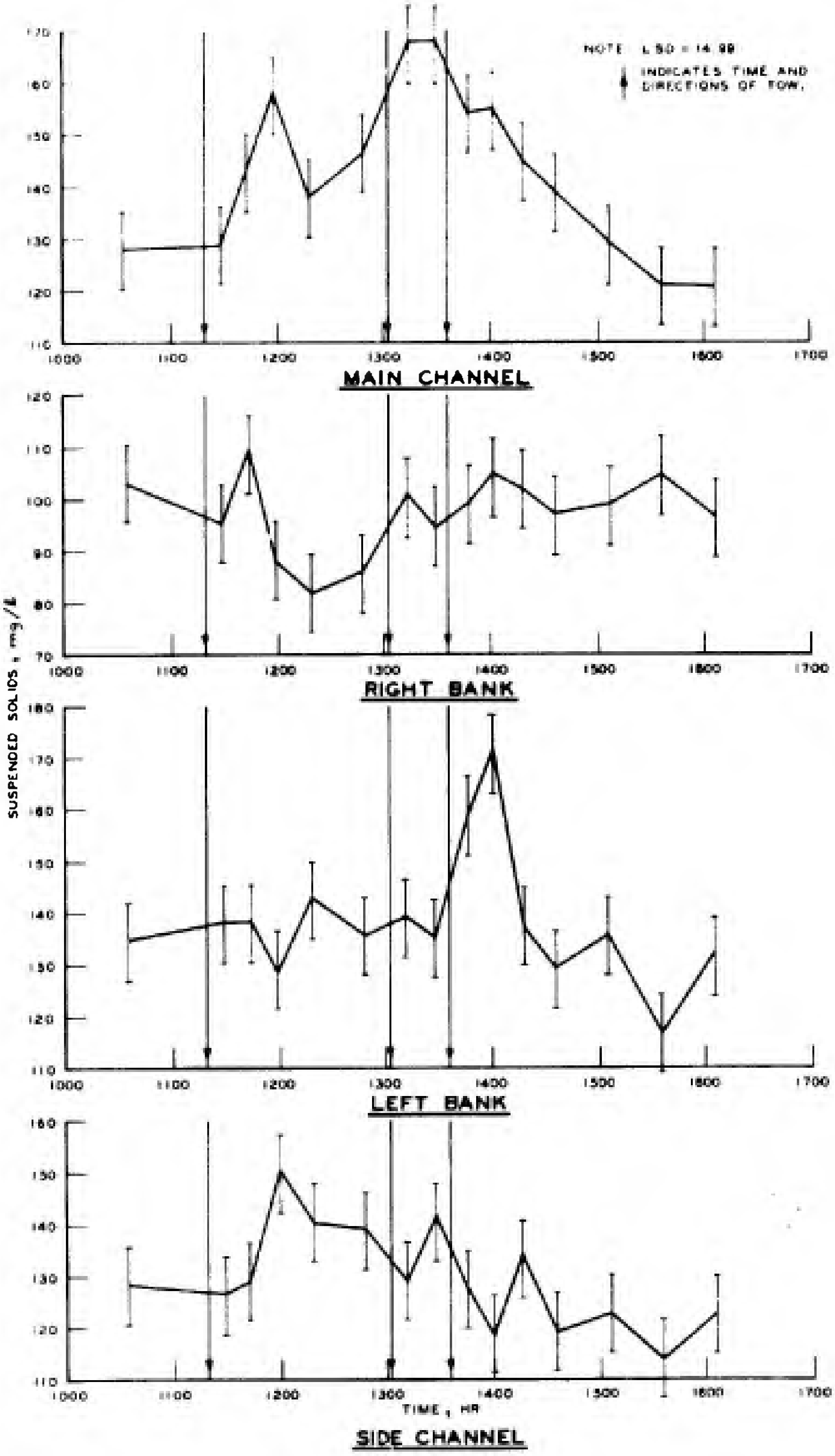

Figure 42. Effect of event 5 (multiple tow) on suspended solids concentration, Illinois River sampled at RM 31.0, 31 Oct 75

channel and side channel stations after tow 1 passed were 50 and 89 min, respectively. Two sets of samples were collected between the passages of tows 2 and 3. Significant increases in concentrations during this interval over those measured at 1249 hr were only noted for the main channel station, although slight increases were also observed for right and side channel stations. The passage of tow 3 increased suspended solids by 35 mg/ℓ above ambient levels at the left bank station but apparently had no significant effect on the other stations. No additive effects were noted. After tow 3 passed, concentrations at the left bank station remained above ambient levels for 25 min. A second recovery period, of a 143-min duration was observed at the main channel station.

156. Turbidity levels. As observed with several of the preceding tow traffic events, turbidity levels followed those trends noted using suspended solids data, especially for main channel, right bank, and side channel stations (compare Figures 42 and 43). Note that except for the 65-min lag in the response for the left bank station, significant increases in turbidity compared remarkably close to suspended solids increases according to time. No turbidity increases noted for any of the sampling stations exceeded 16 units over ambient levels. Recovery times for main channel, left bank, and side channel stations were 65, 60, and 35 min, respectively.

157. Dissolved oxygen. Responses in dissolved oxygen concentrations were similar for all three depths at which measurements were made (Figure 44). After tow 1 passed, dissolved oxygen concentrations uniformly increased about 0.3 mg/ℓ at all depths. No response was noted after the passage of tow 2. Following the maximum peak of suspended solids and the passage of tow 3, dissolved oxygen was reduced about 0.1 mg/ℓ at all depths. The changes noted during the sampling period were of a relatively small magnitude. The steady increase in dissolved oxygen concentrations noted during the sampling periods for events 1 through 4 on the Illinois River was not observed during this event.

Event 6

158. The last tow traffic event monitored in the Illinois River during the study consisted of four tows passing the study site within a

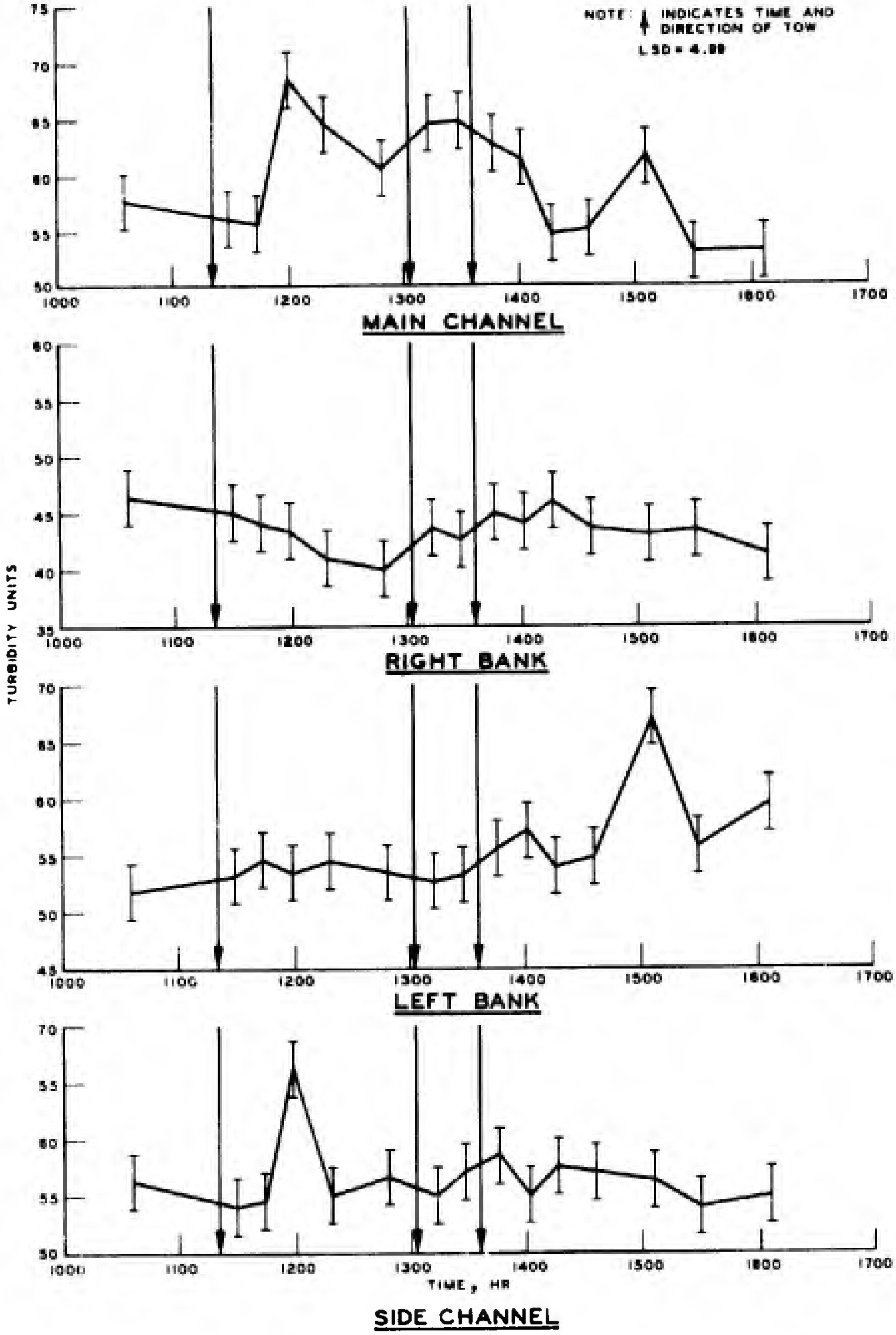

Figure 43. Effect of event 5 (multiple tow) on turbidity, Illinois River sampled at RM 31.0, 31 Oct 75

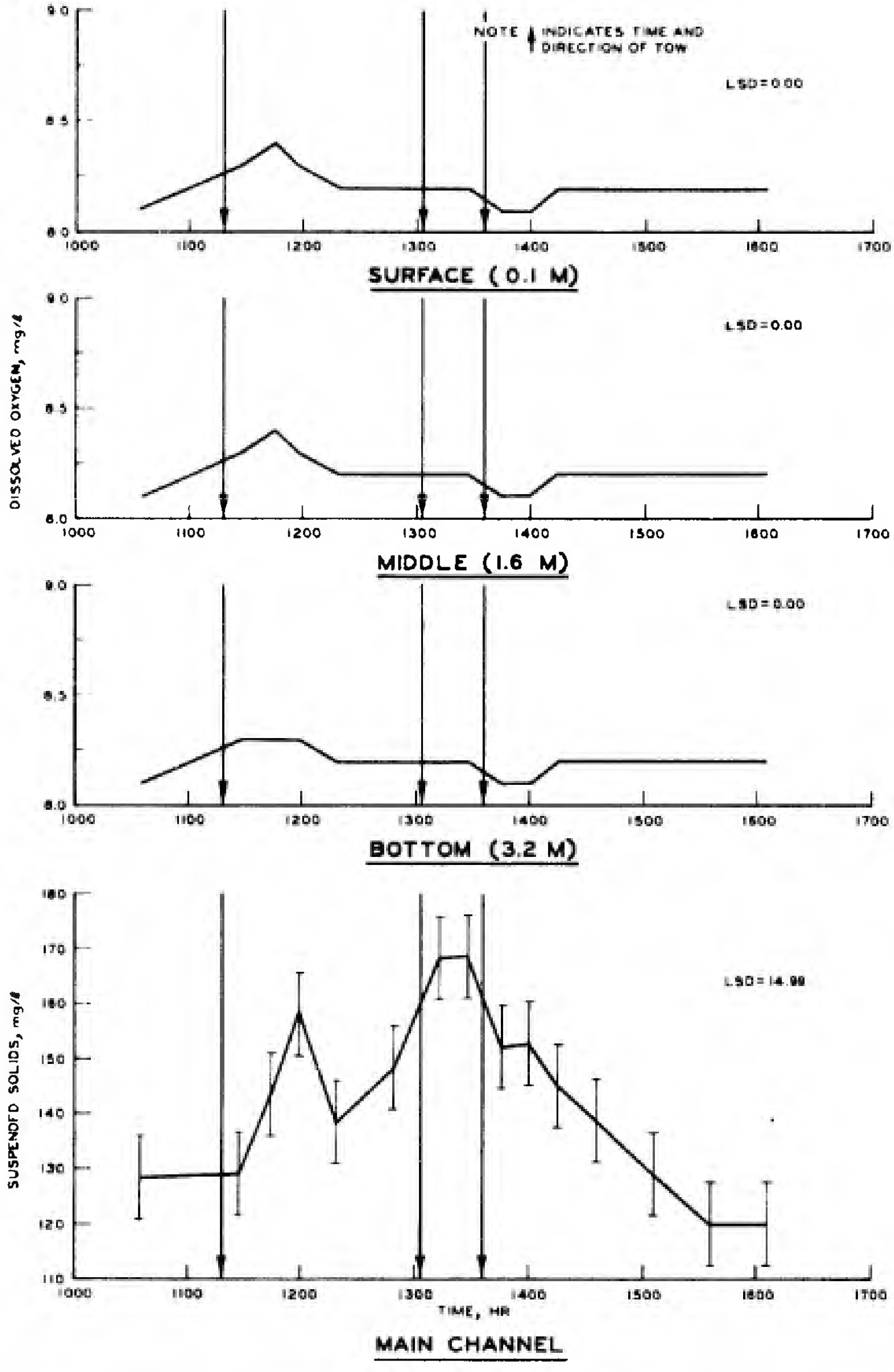

Figure 44. Effect of event 5 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Illinois River sampled at RM 31.0, 31 Oct 75 (Note: LSD value for DO too small to graph)

198-min time interval. Tows 1 and 2 were pushing 9 and 15 loaded barges, respectively; tows 3 and 4 were pushing 2 and 15 empty barges, respectively. Draft depths of the empty barges were 0.9 m, which was estimated to be 2.4 m from the bottom of the channel. Estimated draft depths of the loaded barges varied from 2.4 to 2.7 m and were estimated to be between 0.9 and 0.6 m from the bottom of the channel. Tow 1 passed the study area slowly traveling at 3.5 mph. The velocities of the other tows were greater and ranged between 5 and 7 mph.

159. Suspended solids. The slower moving initial tow did not resuspend any appreciable concentrations of sediments. Although slight increases were noted for main channel and side channel stations, the increases did not significantly differ from ambient levels measured at these stations (Figure 45).

160. The faster moving and more heavily loaded second tow did elevate suspended solids concentrations at main channel, left bank, and side channel stations. Thirty minutes were required following the passage of tow 2 for concentrations to return to ambient levels at the left bank station. The increase noted in the side channel lagged behind the responses observed at the other stations. Maximum increase in concentrations at the main channel station over the initial ambient level was about 39 mg/ℓ after tow 2 had passed.

161. The passage of tow 3, pushing two empty barges, did not appear to produce any immediate response at main channel and side channel stations. However, concentrations at both of these stations began to increase 40 min later. Concentrations measured at the main channel station returned to ambient levels in a 120-min period.

162. Following the passage of tow 4, which was pushing 15 empty barges, suspended solids concentrations increased at all four stations. The response in the main channel was quicker than those responses associated at other stations. The second recovery time noted for the main channel was of a 128-min duration. The observed increases at stations other than the main channel station could have represented the accumulated effects of two or more tows. The maximum increase over ambient levels was 75 mg/ℓ; this was observed at the side channel station 90 min

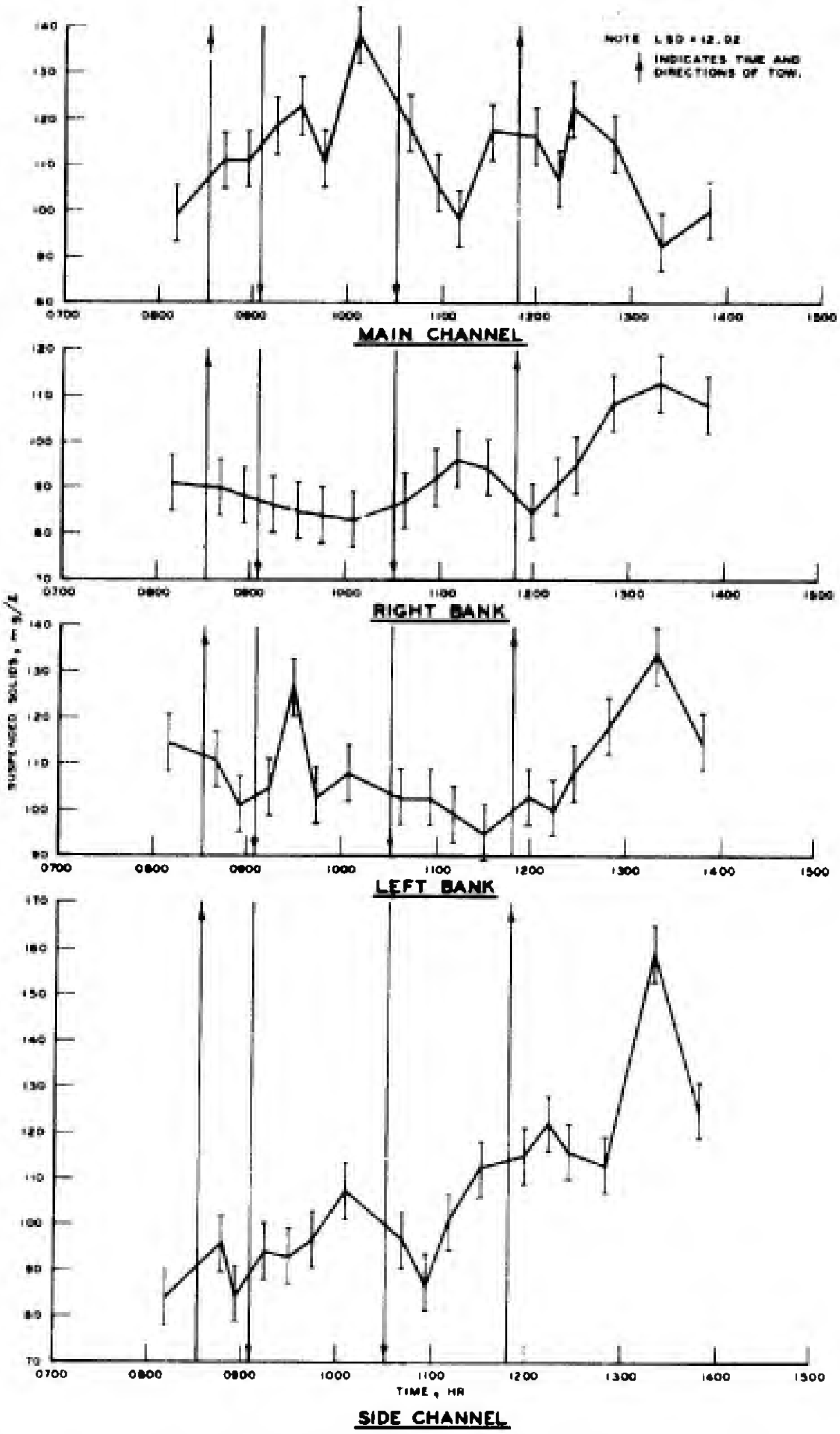

Figure 45. Effect of event 6 (multiple tow) on suspended solids concentration, Illinois River sampled at RM 31.0, 2 Nov 75

after the last tow had passed the study site. During the 120-min interval following the passage of tow 4, concentrations at right bank and side channel stations never returned to ambient levels during the sampling period. The data indicate that additive effects related to multiple tow traffic occurred at right bank and side channel stations.

163. Turbidity levels. Turbidity trends followed almost exactly those trends discussed previously for suspended solids concentrations (Figure 46). Exceptions to the observed trends include shorter recovery times for the main channel station (49 and 71 min versus 120 and 128 min for suspended solids) and the fact that turbidity levels at the side channel station did return to ambient levels at the end of the sampling period. No additive effects were observed.

164. Dissolved oxygen. The passage of two upstream and two downstream tows did not have any significant effect on reducing concentrations of dissolved oxygen at surface, mid-depth, and bottom strata (Figure 47). As noted in the figure, concentrations started to increase at 1131 hr. but changes after this point were considered small (less than 0.1 mg/ℓ).

Discussion

165. Multiple tow traffic monitored at river mile 31.0 in the lower reach of the Illinois River (site 3) produced significant increases in suspended solids and turbidity concentrations at all sampling stations. (The overall mean difference in depth of tow drafts and channel bottoms was 1.1 m.)

166. Ranges of maximum increases over ambient suspended solids concentrations noted for the combined events were: side channel 22.7 to 75.0 mg/ℓ; main channel, 39.4 to 40.7 mg/ℓ; left bank, 22.7 to 36.3 mg/ℓ; and right bank, 6.3 to 23.3 mg/ℓ. Similarily, rather small increases over ambient levels were also noted using the turbidity data: left bank, 5.3 to 16.0 units; main channel, 11.6 to 12.3 units; side channel, 6.3 to 12.3 units; and right bank, 0.7 to 3.3 units.

167. Concentrations of suspended solids at the right bank and side channel stations were still above ambient levels at the end of the sampling period during event 6. For main channel and left bank stations,

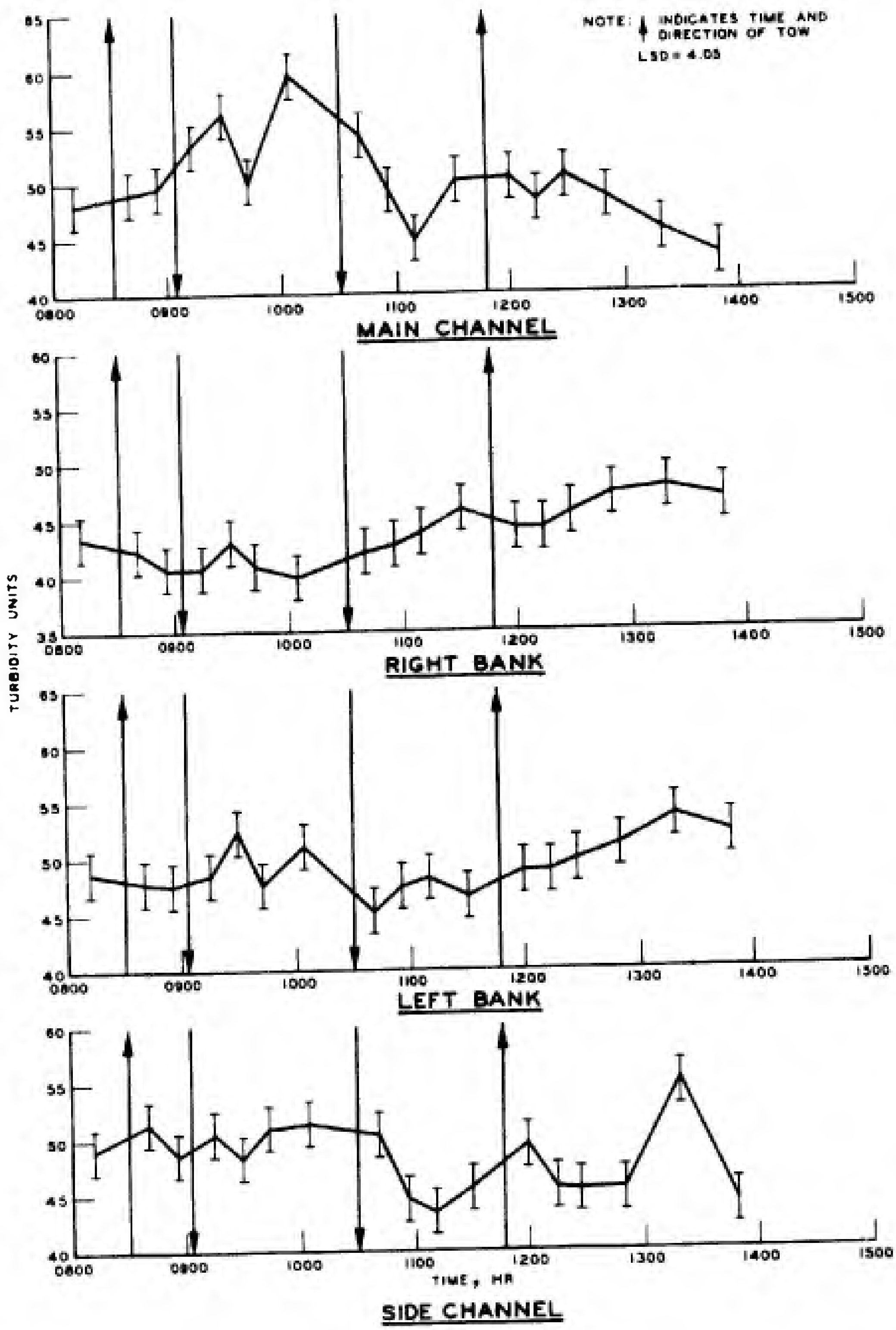

Figure 46. Effect of event 6 (multiple tow) on turbidity, Illinois River sampled at RM 31.0, 2 Nov 75

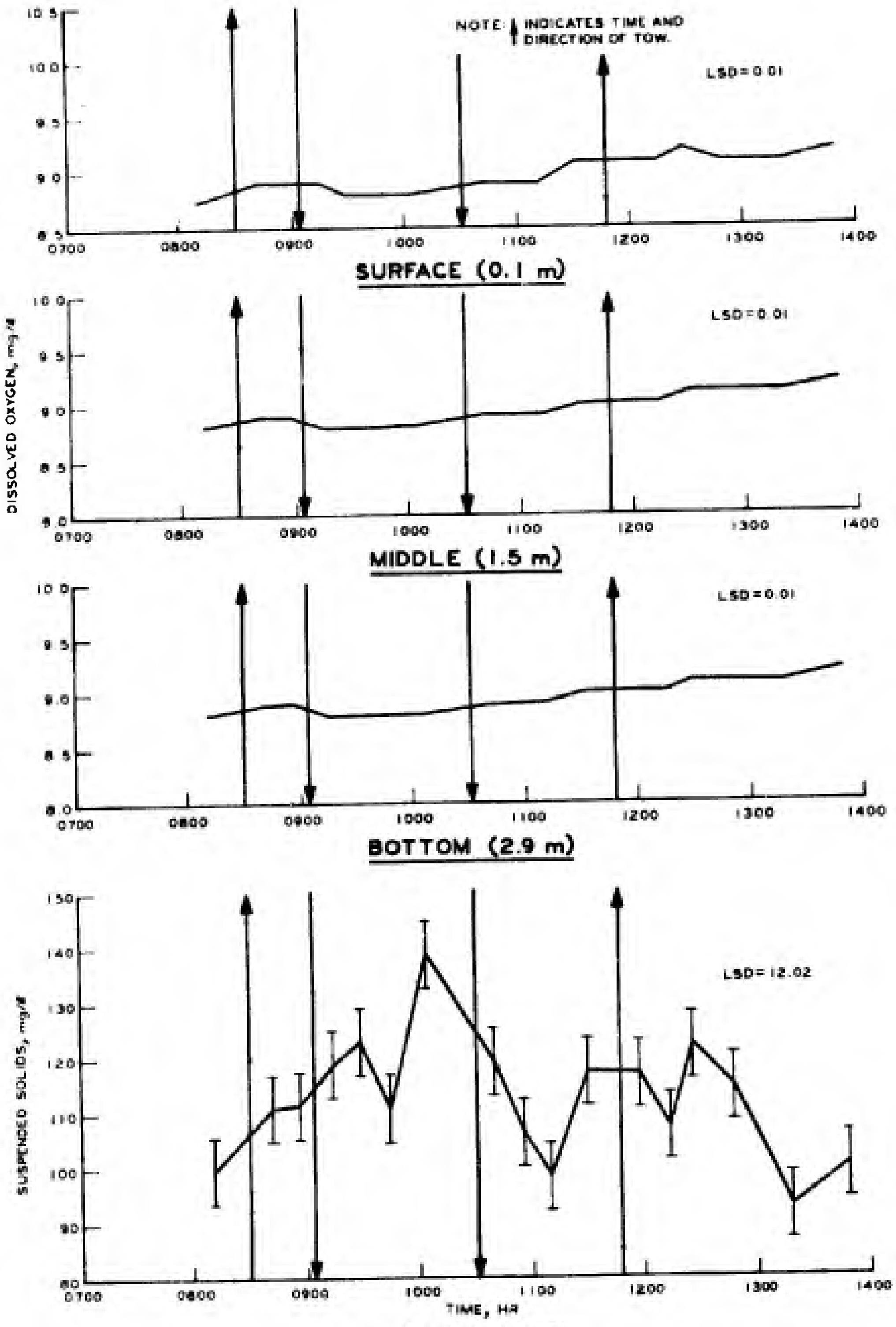

Figure 47. Effect of event 6 (multiple tow) on dissolved oxygen concentrations and related suspended solids concentrations in the water column, Illinois River sampled at RM 31.0, 2 Nov 75 (Note: LSD value for DO too small to graph)

recovery times during both events at this site ranged from 50 to 143 min and 25 to 30 min, respectively. Recovery times based on the turbidity data were greatest at right and left bank stations, which did not recover during the sampling period; less at the main channel, 49 to 71 min; and shortest at the side channel, 35 to 60 min.

168. The sampling station that showed the minimum response to increases in suspended solids and turbidity concentrations was the right bank station. This station was located on the inside of a bend in the river. Because the entrance of the side channel was aligned on the outside of the bend, it was vulnerable to receiving sediments resuspended by tow traffic. The side channel station showed the maximum response in increased concentrations of suspended solids over ambient levels (75.0 mg/ℓ).

169. Wave effects and subsequent changes in current velocities within the side channel were not as evident at this location as observed at river mile 215.8. The relatively greater width of the river at river mile 31.0 was thought to be the primary reason for the differences in effects. Greater river width and reduced currents may also account for the observed lower ambient concentrations of suspended solids and turbidity as compared to ambient concentrations at river mile 215.8.

170. During one traffic event at this study site, there was some evidence to indicate that slower moving tows had less effect on resuspending sediments from the main channel than faster moving tows. In past events the relationship of tow velocity and potential effects had not been as clear. It should also be pointed out that suspended solids and turbidity curves correlated very closely at this study site, both with respect to time and space responses.

171. Although appreciable quantities of suspended solids were measured in the water column, dissolved oxygen concentrations changed little during the sampling periods for both events. The characteristic steady increase in oxygen concentrations noted at the two other sites on the Illinois River was not as evident at this site. Apparently, at least for this location, tow traffic does not affect ambient levels of dissolved oxygen.

172. At this site on the Illinois River (river mile 31.0), the calculated r values for both events indicated a strong linear relationship between suspended solids and turbidity data. Correlation coefficients (r) for events 5 and 6 (+0.84 and +0.71, respectively) were significant at the 5-percent level.

PART IV: GENERAL DISCUSSION

Site Selection

173. During a 29-day period, nine tow traffic events on the Mississippi River and six tow traffic events on the Illinois River were monitored to determine if changes in concentrations of suspended solids, turbidity, and dissolved oxygen could be related to the passage of tows. This investigation included collecting data on 19 separate tows on the Mississippi River and 21 separate tows on the Illinois River. Three of the nine tow traffic events monitored on the Mississippi River consisted of multiple tows; the other six traffic events were the passage of single tows. All of the tow traffic events studied on the Illinois River were multiple in nature with no single tows.

174. Three study sites were chosen within both the Mississippi and Illinois Rivers for monitoring tow traffic events. Selection criteria of specific sampling sites was based, for the most part, on accessibility of the study area, main and side channel flow characteristics, and position of side channel habitats. The existence of side channels within the study area was considered a major criterion since several investigations have indicated that side channels are important features to the ecology of rivers.[11,12,13,14] Flow characteristics and position of side channel entrances with respect to river morphology were equally important considerations. Once these criteria were satisfied, it was reasoned that effects due to tow traffic on both rivers could be tested.

175. Since side channels exist under extremely variable conditions with respect to location (inside or outside of bends or in straight reaches), morphology, elevations, and flow regimes, it is important to point out that not all side channels are subject to the potential effects caused by tow traffic. Study site selections for this investigation were made so that the potentially most severe effects (changes in concentrations) of tow traffic on side channels could be tested. Among the six study sites selected, two were located where side channel entrances were aligned along the shoreline in straight river reaches and

four were located where the entrances were oriented on slight outside bends.

176. It became clearly evident after analyses of the data that responses associated with the various tow traffic events varied considerably both in terms of time and space. Because of the large number of tows monitored and due to the observed specificity in responses, it should be recognized that generalizations in this part of the report only reflect a synthesis of the responses. The unique responses observed at each of the study areas were presented earlier in Part III in the discussion section following each sampling site description.

Mississippi River

Suspended solids concentrations

177. Based on the results presented in Part III of this report, it was found that on several occasions tow traffic on the Upper Mississippi River did contribute to existing levels of suspended sediment measured both as suspended solids (a gravimetric measurement) and as turbidity (an optical measurement).

178. During the monitoring of the six multiple traffic events, statistically significant changes in suspended solids concentrations above ambient concentrations were observed more frequently at the four sampling stations (main channel, right bank, left bank, and side channel) than were nonsignificant changes. Of the 24 possibilities (four sampling stations monitored six times each) that were analyzed for effects, 15 were shown to be significant and 9 were not. The reverse trend was noted for the 3 single tow traffic events that were monitored: significant increases in suspended solids concentrations were noted for only 3 of the possible 12 occasions; for 9 possibilities, the changes were not significant. The apparent conclusion that single tows have less of an effect on elevating suspended solids concentrations than do multiple tows must be viewed with caution since two of the three single tows were monitored at river mile 258.0, where water depth in the main

channel was greater than at the other sampling sites.

179. For multiple and single tow traffic events combined, generally, significant increases in suspended solids concentrations were most commonly observed at the main channel sampling station, over which the river traffic passed. During only three of the nine traffic events monitored were concentrations of suspended solids not significantly increased above ambient levels in the main channel. Lateral movement of sediments resuspended and transported from the main channel to shoreward areas was also observed quite frequently during the study. During four of the nine traffic events, significant increases in concentrations were observed at side channel and left bank stations. Concentrations were increased during five of the traffic events at the right bank station.

180. Considering all three study sites on the Mississippi River and all nine tow traffic events that were monitored, the maximum increases in concentrations of suspended solids above ambient levels were relatively small compared to those observed for the Illinois River, which will be discussed later. Maximum mean increases in suspended solids concentrations over ambient concentrations for each sampling station were: main channel, 14.0 mg/ℓ; right bank, 22.6 mg/ℓ; left bank, 26.7 mg/ℓ; and side channel, 14.3 mg/ℓ. In some instances it was assumed that wave activity, produced by the tows or smaller craft, and subsequent shoreline erosion accounted for noted higher concentrations of suspended solids in shoreward areas.

181. Since the great majority of tow traffic events monitored consisted of multiple tows, there was ample opportunity to see if the passages of multiple tows had an additive effect on concentrations of suspended solids: that is, if the passage of additional tows past a given point in the river added signficantly to those concentrations generated by a previous tow. In every case where multiple tow traffic events were monitored on the Mississippi River (events 1, 2, 3, 4, 6, and 9), no additive effects were observed.

182. Recovery time (that time period during which concentrations contributed to by previous tow traffic returned to ambient levels)

varied considerably with each traffic event. At all sampling stations except the right bank station, concentrations of suspended solids elevated by tow traffic returned to ambient levels before or at the termination of the sampling periods. On four different occasions at the right bank station, concentrations remained elevated at the end of the sampling periods. For two of these occasions this response appeared to be related to shoreline turbulence caused by either wavewash due to the passage of small craft or the tows through the area. For the three study sites on the Mississippi River, recovery times were estimated for each of the sampling stations and varied accordingly: main channel, 15 to 155 min; right bank, 125 min to no recovery; left bank, 25 to 120 min; and side channel, 40 to 140 min.

Turbidity levels

183. Significant changes in turbidity levels above ambient levels due to the passages of tows through the study sites generally followed those responses observed using suspended solids data. For example, for the six multiple traffic events monitored, significant increases in turbidity rather than nonsignificant changes were noted most frequently at the four sampling stations. Of the 24 possibilities (four sampling stations monitored six times each) that were analyzed for effects, 16 resulted in significant changes and 8 did not. Also similar to those trends observed based on suspended solids data, the passage of 3 single tows significantly increased turbidity levels for only one of the 12 possibilities. In contrast to those trends observed using suspended solids data and considering all tow traffic events investigated on the Mississippi River, significant increases in turbidity levels above ambient levels were most commonly observed in the side channel stations. During six of the possible nine events, significant changes above ambient levels were noted for the main channel and left bank stations; increased turbidity levels were noted for only three events at the right bank station.

184. It should be stressed that the maximum increases above ambient turbidity levels were of an extremely low magnitude. Although in a strict statistical interpretation significant increases were

observed, these changes were considered extremely small. For each sampling station maximum mean responses were: main channel, 7.4 units; right bank, 5.7 units; left bank, 5.3 units; and side channel, 5.7 units.

185. Colbert et al. measured turbidity, in addition to several other physicochemical variables, at 13 transects in the Mississippi River between river miles 201.3 and 302.2 during average and flood stage conditions.[14] During an average flow period in September 1974, surface turbidity ranged from 25 to 45 Jackson turbidity units (JTU) and averaged 36.9 JTU at main channel stations and ranged from 20 to 140 JTU and averaged 61.3 JTU in side channel stations. During flood stage conditions in July 1974, Colbert et al. observed that turbidity increased considerably at these stations (main channel - range 155 to 500+ JTU, $\overline{X}$ = 282.3 JTU; side channel - range 45 to 500+ JTU $\overline{X}$ = 215.9 JTU). During the present study, the maximum mean ambient turbidity was 13.0 units measured at main channel stations and 13.6 at side channel stations. Although results from the two studies are not exactly comparable because different measurement methods were used,* these data are cited because they do serve to emphasize the fact that turbidity is normally high during flood conditions and considerably lower under other flow conditions. More importantly, however, they also indicate that turbidity levels elevated by tow traffic during normal pool conditions are extremely small compared with ambient levels during flood stage conditions.

186. Consistent with the observations made based on the suspended solids data, during all traffic events monitored on the Mississippi River the passages of multiple tows did not have an additive effect on elevating turbidity levels.

187. During all traffic events monitored and at every sampling station (except the left and right bank stations on one occasion), turbidity levels increased by the tows had returned to ambient levels at

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* Colbert et al. used the absorptometric method, and the nephelometric photoelectric method was used in this study.

the end of the sampling periods. The exceptions noted for left and right bank stations during event 9 were presumably related to shoreline erosion caused by wave action. Again considering all traffic events and sampling sites, the maximum recovery time was associated with the side channel station (208 min), followed by the main channel station (150 min). Maximum recovery times estimated for right and left bank stations were similar: 93 and 90 min, respectively.

Suspended solids/turbidity concentrations

188. Few studies in the Mississippi River (or in the Illinois River, for that matter) have measured suspended solids. The procedure involves a gravimetric analysis that provides units expressed as weight per volume concentration of particles in suspension. Most studies have emphasized the optical property of water containing suspended material expressed as turbidity. An important distinction between the usefulness of these two measurement units needs to be made for those studies that attempt to relate responses of the biota to suspended solids concentrations and turbidity units after they have once been quantified. While the measured optical property of water is considered important in studying plant responses, it seems unlikely that the light absorbing or light scattering properties of suspended particles are of equal importance in studying animal responses.

189. Based on the discussion in the preceding paragraphs and because water samples were analyzed for both suspended solids concentrations and turbidity, in some cases interpretation of the data differed according to which unit of measurement was used. Because suspended solids data (determined by gravimetric techniques) are for the most part less subject to variation and are more amenable to comparison, these data were emphasized in the interpretation of results. Also, since some sample sets were not kept refrigerated prior to turbidity analyses, the results based on final turbidity levels may reflect positive or negative changes from initial turbidity levels.

190. One of the greatest misunderstandings in turbidity measurements concerns the natural desire to relate the quantity (milligrams

per litre) of suspended solids with the measured turbidity of the sample.[15,16] Because the turbidity produced by particulate matter depends on such factors as particle size, shape, mineralogy, and color, there is no predictable correlation between the turbidity produced by equal weight per volume concentrations of different materials. This subject has been discussed in References 15 and 16, which basically conclude that about as far as one can go in relating turbidity to the quantity of suspended matter is to restrict comparisons to only those cases where turbidity measurements are made with the same type of turbidimeter on samples containing the same turbidity material. Even in this situation samples may not exhibit a linear relationship between the quantity of suspended matter and the measured turbidity. Kunkle and Comer showed that turbidity could be related to the quantity of suspended matter if all the particles were of a uniform nature and if instruments were calibrated against weighed samples.[16]

191. The potential linear relationships between suspended solids and turbidity, as measured during this study, were quantified using correlation analysis. For six traffic events monitored on the Mississippi River, the trends observed for suspended solids concentrations were similar to the trends observed using the turbidity data. However, for three events monitored, the responses of both measurements were poorly correlated.

Dissolved oxygen concentrations

192. Another objective of this study was to estimate the magnitude and duration of the oxygen demand exerted by riverbed sediments resuspended in the main channel by tow traffic. Dissolved oxygen concentrations were measured before and after tow traffic at surface, middle, and near-bottom depths. For the most part, concentrations were not reduced appreciably following the passage of tows on the Mississippi River. The maximum reduction in dissolved oxygen concentrations occurred during a multiple traffic event (event 4) at river mile 472.0 when concentrations at the surface were reduced by 1.0 mg/ℓ. With this one exception, surface concentrations were reduced no more than 0.5 mg/ℓ following the passage of tows for any of the nine events.

The maximum reduction at middle and near-bottom depths was 0.7 mg/ℓ for both. The great majority of changes for these strata amounted to 0.4 mg/ℓ or less. Sixty minutes were required for concentrations to return to ambient levels for two of the traffic events monitored. Generally, ambient concentrations were returned to in shorter periods of time (15 to 20 min).

Illinois River

193. Based on the relative changes in concentrations of suspended solids and turbidity following the passage of tow traffic at sites on both the Upper Mississippi and Illinois Rivers, the Illinois River appears to be more susceptible to tow traffic effects that the Mississippi River. That is, tow traffic on the Illinois River resuspended considerably greater quantities of riverbed sediments than did tow traffic on the Mississippi River.

Suspended solids concentration

194. Significant increases in suspended solids concentrations were observed more frequently following the passage of tows on the Illinois River than on the Mississippi River. Of all the sampling stations tested for effects during the six multiple traffic events on the Illinois River, nonsignificant increases were only noted on three occasions. Significant changes above ambient concentrations were consistently observed at main channel, left bank, and side channel sampling stations. During two traffic events (events 3 and 5), concentrations at the right bank station did not differ from ambient levels. This response appeared to be related to the position of the right bank station in those river reaches. At study sites for both events (river mile 113.5 and 31.0), the right bank station was positioned on the inside of bends in the river where current velocities are characteristically less than for other areas.

195. Ranges of maximum increased suspended solids concentrations over ambient concentrations for each sampling station and for all six traffic events were: main channel, 14.7 to 293.3 mg/ℓ; right bank,

12.6 to 329.3 mg/ℓ; left bank, 11.0 to 238.3 mg/ℓ; and side channel, 50.0 to 123.3 mg/ℓ. In every case the upper limits of the above ranges were observed for event 4 at river mile 113.5. The observed maximum responses at this particular study site and not at the other sites presumably were due to the larger number of loaded barges passing through the area. Forty-three loaded barges (and five empty barges) were transported through the transect of sampling stations. The mean difference between bottom of the channel and drafts of the barges was about 1 m.

196. In direct contrast to the lack of observed additive effects due to the passages of multiple tows on the Mississippi River, additive effects were observed during the monitoring of three traffic events on the Illinois River. Additive effects were noted for those multiple traffic events that consisted of four or more different tows (events 2, 4, and 6); additive effects were not observed for those traffic events consisting of three or fewer tows (events 1, 3, and 5). The most important difference between those events that produced additive effects and those that did not appeared not to be as much related to differences in numbers of tows but rather to differences in the number of barges being transported through the area. In every case the total number of barges, both loaded and unloaded, was greater for those traffic events where additive effects were noted and less where no additive effects were observed.

197. Generally, recovery times estimated using suspended solids data for tow traffic on the Illinois River were longer than those noted for the Mississippi River. For instance, on the Mississippi River concentrations remained above ambient levels at right bank stations only; for several occasions on the Illinois River, concentrations remained above ambient levels at the end of the sampling period for all sampling stations except the main channel station. Excluding those occasions where concentrations remained elevated at the end of the sampling periods, recovery times at each station varied as follows: main channel, 40 to 284 min; right bank, 110 to 125 min; left bank, 25 to 284 min; and side channel, 45 to 287 min. Maximum recovery times were associated with event 4 at river mile 113.5, which has been

previously discussed as eliciting the maximum responses in terms of increased suspended solids concentrations.

198. Differences between the minimum responses noted for the Mississippi River and the maximum responses noted for the Illinois River appeared to be related to the more numerous and larger tows (number of barges) and the characteristically narrower widths and finer bed material[3] of the Illinois River. While depth of water in the main channel could be another consideration in interpreting different responses measured during the normal pool conditions that existed for both rivers, main channel depths were similar in the upper reaches of both rivers.

Turbidity levels

199. The majority of responses relative to changes in turbidity levels following the passage of tows were significant increases in turbidity levels. Significant increases in turbidity levels were noted at every sampling station following all six events with the exception of the right bank station. On two occasions turbidity did not increase at the right bank stations for the same reasons previously discussed in the interpretation of suspended solids data.

200. Maximum mean responses above ambient levels for each sampling station were: main channel, 79.3 units; right bank, 96.3 units; left bank, 47.0 units; and side channel, 27.7 units. As in the suspended solids data, the maximum turbidity units were recorded at river mile 113.5 during event 4, which consisted of the largest total number of barges of all the traffic events. Sparks conducted a study during normal pool conditions in 1963 and reported that surface turbidity in the main channel at river mile 25.9 increased about 100 JTU after the passage of three tows.[4] He observed that about 150 min (2.5 hr) were required before turbidity levels returned to ambient levels. His data also indicated that the passage of multiple tows did not have an additive effect of elevating turbidity levels. As cited by Sparks,[4] Starrett observed that turbidity levels were increased 212 units after two tows passed river mile 65.1 on the Illinois River during November 1964.[17] The SLD monitored tow traffic events on three different

occasions in the Illinois River during March 1975 when river stages were slightly above or below flood stages.[2] On two occasions when river stages were 0.9 and 1.4 ft below recorded flood stage for river mile 73.8 and 76.3, respectively, they concluded that the passage of multiple tows had very little effect on elevating surface turbidity levels in the Illinois River. On the other occasion, at river mile 35.5 when river stages were 2.5 ft above flood stage, SLD data indicated that the initial tow increased turbidity levels by about 20 to 30 units above background levels at four of five sampling stations.

201. Just as the Mississippi River is described as being characteristically more turbid during flood conditions than during lower flow conditions, Colbert et al. made the same observation for the Illinois River.[14] Data in Reference 14 also incidated that ambient turbidity differences between flood stage and average flow conditions were less for the Illinois River than for the Mississippi River. This could mean that during average flow conditions, tow traffic on the Illinois River may elevate turbidity levels to those levels that occur naturally during flood stage conditions. If Colbert's data are considered to be representative of turbidity levels encountered during flood stage conditions, comparison of his data with data from this study indicates that during normal pool conditions, most tow traffic would not elevate turbidity levels above those that occur naturally during annual flood conditions. Mean surface turbidities of 144 JTU were reported by Colbert et al. for main channel stations in an 80-mile reach of the lower Illinois River during flood conditions; 144.0 and 150.0 JTU were reported for right and left bank stations, respectively, and 122.0 JTU for side channel stations.[14] During the present study (with one exception) turbidity levels affected by the passage of tows were not elevated above those levels that occur naturally during flood conditions. Only during event 4 on the Illinois River, which consisted of the largest number of barges, did turbidity levels exceed flood stage turbidities.

202. Additive effects based on turbidity data were similarily observed during the same events discussed for the suspended solids data

with one exception. During event 6, the passage of four tows pushing 20 empty and 24 loaded barges did not produce any additive effects such as were noted from interpreting the suspended solids data.

203. Recovery times estimated from turbidity responses essentially followed the same patterns discussed previously for suspended solids data even though some differences were noted. While concentrations of suspended solids remained above ambient levels for one occasion at the side channel station, in every instance turbidity levels measured in side channel stations had recovered by the end of the sampling periods. Excluding those instances where recovery did not occur (two for the right bank and one for the left bank), recovery times at each sampling station based on turbidity responses varied as follows: main channel, 49 to 198 min; right bank, 73 to 254 min; left bank, 25 to 254 min; and side channel, 35 to 200 min.

Suspended solids/turbidity concentrations

204. Concentrations of suspended solids were linearly related to or responded similarly to turbidity levels except for one traffic event. For the most part, the trends interpreted using both measurement units were similar.

Dissolved oxygen concentrations

205. During the six multiple traffic events monitored on the Illinois River, dissolved oxygen concentrations at all depths were reduced very little in the main channel following the passage of tows. Maximum concentration reductions at the surface for all events was 0.2 mg/ℓ; maximum reduction at mid- and near-bottom depths was 0.1 mg/ℓ. During three traffic events, no reductions were noted for surface and mid-depth measurements and near-bottom concentrations were reduced on only one occasion.

206. An interesting phenomenon observed during four of the six events monitored was a characteristically steady rise in dissolved oxygen concentrations throughout the sampling period. In fact, the positive changes in concentrations were, in every instance, greater than the negative changes or reductions. Maximum increases over ambient

concentrations usually occurred in the afternoon at the end of each sampling period. Considering every event monitored, the maximum increase at the three sampling depths in the main channel was 0.6 mg/ℓ at the surface, 0.7 mg/ℓ at mid-depth, and 0.6 mg/ℓ at the bottom. Possible explanations accounting for this phenomenon could be related to the turbulence and subsequent reaeration caused by tows moving through the area or to natural diel oxygen changes, which have been observed for other rivers.[18] Theoretically, maximum positive changes in dissolved oxygen concentrations occur in rivers in late afternoon periods after the maximum exposure of photosynthesizing plants (phytoplankton) to irradiant energy. Although the observed positive changes in dissolved oxygen concentrations are within the range of naturally occurring diel changes observed in other rivers,[18] the excessively turbid nature of the Illinois River presumably would limit phytoplankton productivity even during normal pool conditions. Turbidity has been suggested by other workers to be a major photosynthesis limiting factor in the Illinois River.[19,20,21]

207. During normal pool conditions, Sparks also measured oxygen responses following the passage of three tows on the Illinois River.[4] His results indicated that after the first tow passed, dissolved oxygen concentrations were reduced by 0.4 mg/ℓ at the bottom and less than 0.2 mg/ℓ at the surface. The mid-depth concentrations were increased slightly (<0.2 mg/ℓ). Approximately 120 min following the passage of the second and third tow, both surface and bottom concentrations were increased above the initial ambient concentrations. Although only a few measurements were reported by Sparks in Reference 4, the magnitude of the responses generally agreed with the results of this study.

208. Butts measured the in situ oxygen demand of sediments at several locations in the Illinois River between river mile 179.0 and 283.6.[22] He devised a unique bottom sampler that was designed to entrap and seal a quantity of water at the river bottom where changes in dissolved oxygen concentrations were measured with an attached probe. He concluded that the oxygen demand of sediment at several locations was sufficiently high to impose a considerable demand on the dissolved

oxygen concentrations of the overlying water. He further stated that "the resuspension of sediments by barge traffic may increase short-term localized oxygen demand loads by seven or eight fold." Although Butts' study was well designed and contributes to the understanding of sediment oxygen demand at locations in upper reaches of the Illinois River, one word of caution is in order. Because the oxygen changes noted by Butts were measured in an enclosed sampler and, therefore, excluded reaeration effects due to flowing water, his assumption that barge traffic may increase oxygen demand loads by seven or eightfold appears to be doubtful. In fact, the results of this field study indicate that, even with several tows passing the same location, dissolved oxygen concentrations are not drastically changed from ambient levels throughout the entire water column. Alonso et al. studied reaeration in uniform laboratory streams with and without suspended sediments and concluded that the reaeration rate decreases as the average suspended sediment concentration increases.[23] It may be that the resuspension of sediments due to tow traffic and subsequent dilution are great enough that drastic reductions in dissolved oxygen are not seen. Under low flow conditions and in those areas where the organic matter of the sediment is high, a drastic reduction in oxygen may occur.

Current velocity

209. One other effect associated with tow traffic in the Illinois River but not observed in the Mississippi River was the effect of increasing current velocity through the entrances of side channels. This appeared to be related to the characteristically smaller widths of the Illinois River as opposed to the greater widths of the Mississippi River.

Prediction of Effects of Tow Traffic

210. The magnitude of the resuspension of riverbed sediment caused by tow traffic, intuitively at least, is dependent upon several factors. Some of these factors include tow size, speed, draft, and direction of travel; operating horsepower of engine(s); depth of channel; particle

size of bed material; and single tow versus multiple tow passage. Although investigation of the characteristics of riverbed material was beyond the scope of this study, information related to those other factors mentioned above was collected during each traffic event to determine if any relationships existed. For the most part, because of the complexity of the problem and lack of control of the traffic monitored, no clear predictive pattern was evident from inspection of these data. There were occasions where, for instance, faster moving tows had a greater effect on resuspending sediments than slower moving tows. Also, as has been already pointed out, multiple tow traffic produced additive effects and maintained previously elevated concentrations caused by prior traffic. For one sampling site (river mile 113.5 on the Illinois River), one traffic event composed of many barges (event 4) appreciably increased concentrations of suspended solids and turbidity in addition to prolonging estimated recovery periods; whereas for the same sampling site, another traffic event (event 3) with fewer barges being transported did not appreciably increase concentrations or prolong recovery periods. Additionally, because of the greater channel depth measured at river mile 258.0 on the Mississippi River, tow traffic had little if any effect in this area.

211. One final important point needs to be emphasized. Throughout this report the word "significant" has been used in a statistical sense: that is, hypotheses were formulated and data were subjected to statistical analyses to determine whether or not the effects being tested differed at a specified probability level. Although this approach allowed consistent treatment of all the data and aided in separating opinion from fact, the reader should not associate the use of the words "statistical significance" with "environmental significance." While it certainly would be worthwhile to put into prespective the degree to which these changes in concentrations may effect the biota in terms of environmental impact, this was not within the scope of this investigation. Beyond the time constraints for this study, a considerable investment in time and money would necessarily have to be made in order to address this problem adequately.

PART V: CONCLUSIONS

212. Results of this study indicate statistically that tow traffic on the Upper Mississippi and Illinois Rivers during normal pool conditions contributes to existing levels of suspended sediment measured as both suspended solids (a gravimetric measurement) and as turbidity (an optical measurement). Furthermore, it was found that lateral movement of sediments resuspended by tows and transported from the main channel to shoreward areas, including potentially productive side channel areas, does occur during normal pool conditions.

213. Comparison of data collected during this study with data collected and published in recent studies, indicates that elevated turbidity levels caused by tow traffic during normal pool conditions are extremely small compared with ambient levels during flood stage conditions for the Upper Mississippi River. With the exception of one multiple tow event, which consisted of the largest number of loaded barges, turbidity levels affected by the passage of tows in the Illinois River were not elevated above those levels that occur naturally during flood stage conditions.

214. Based on the relative changes in concentrations of suspended solids and turbidity following the passage of tow traffic at sites on both the Upper Mississippi and Illinois Rivers, the Illinois River appears to be more susceptible to tow traffic effects than the Mississippi River: that is, tow traffic on the Illinois River resuspended considerably greater quantities of riverbed sediments than did tow traffic on the Mississippi River. Also, statistically significant increases in suspended solids and turbidity concentrations were more frequently observed following the passage of tows on the Illinois River than on the Mississippi River.

215. Since the great majority of tow traffic events monitored consisted of multiple tows, there was ample opportunity to see if the passage of multiple tows had an additive effect on suspended solids concentrations and turbidity levels: that is, if the passage of additionnal tows past a given point in the river added significantly to those

concentrations generated by a previous tow. In direct contrast to the lack of observed additive effects due to the passage of multiple tows on the Mississippi River, additive effects were observed during the monitoring of three of the six traffic events on the Illinois River. The most important difference between those events that produced additive effects and those that did not appeared not to be as much related to differences in numbers of tows but rather to differences in the number of barges being transported through the area. In every case the total number of both loaded and unloaded barges was greater for those traffic events where additive effects were noted and less where no additive effects were observed.

216. Recovery time (time during which concentrations contributed to by previous tow traffic returned to ambient levels) varied considerably with each traffic event for both rivers. Generally, recovery times estimated using both suspended solids and turbidity data for tow traffic on the Illinois River were longer than those noted for the Mississippi River. Concentrations elevated by tow traffic for the Mississippi River sampling stations (with few exceptions) returned to ambient levels before or at the termination of the sampling periods. In contrast, on several occasions for the Illinois River sampling stations, concentrations remained above ambient levels at the end of the sampling periods. In some cases, this response appeared to be related to shoreline wave activity produced by the tows or smaller craft and resulting shoreline erosion.

217. Differences between the minimum responses noted for the Mississippi River and the maximum responses noted for the Illinois River appeared to be related to the more numerous and larger tows (number of barges) and the characteristically narrower widths and finer bed material of the Illinois River. It was also found that in most cases tow traffic did not reduce dissolved oxygen concentrations in the main channel of either river. In some instances, dissolved oxygen concentrations were reduced after tow passages, but in almost every case these reductions were of a relatively low magnitude. An interesting phenomenon, observed during four of the six events monitored on the Illinois

River and not observed on the Mississippi River, was a characteristically steady rise in dissolved oxygen concentrations throughout afternoon sampling periods. Proposed explanations that could account for this phenomenon were turbulence and subsequent reaeration caused by the tows moving through the area or natural diel oxygen changes (which have been observed in other rivers).

218. One other effect associated with tow traffic in the Illinois River but not observed in the Mississippi River was the effect of increasing current velocity through the entrances of side channels. This appeared to be related to the characteristically smaller widths of the Illinois River as opposed to greater widths of the Mississippi River.

219. As other studies have pointed out, the magnitude of the resuspension of riverbed sediment caused by tow traffic may be dependent upon several factors including tow size, speed, draft, and direction of travel; operating horsepower of engine(s); depth of channel; particle size of bed material; and type of traffic (single tow versus multiple tow). Investigation of the characteristics of riverbed material was beyond the scope of this study, but most of the other information was collected during each traffic event to determine if any relationships existed. For the most part, because of the complexity of the problem and lack of control of the traffic monitored, no clear predictive pattern was evident from inspection of these data. There were occasions where, for instance, it appeared that faster moving tows had a greater effect on resuspending sediments than did slower moving tows. Also, as previously stated, multiple tow traffic produced additive effects and maintained previously elevated concentrations caused by prior traffic. For one sampling site on the Illinois River, a traffic event composed of many barges, appreciably increased concentrations of suspended solids and turbidity in addition to prolonging estimated recovery periods; another traffic event for the same sampling site where the number of barges being transported was less did not appreciably increase concentrations or recovery periods. Additionally, because of the greater channel depth measured at one site on the Mississippi River, tow traffic had little if any effect in this area.

220. As stated in paragraph 211 and repeated here for emphasis, one important point needs to be stressed. Throughout this report the word "significant" has been used in a statistical sense: that is, hypotheses were formulated and data were subjected to statistical analyses to determine whether or not the effects being tested differed at a specified probability level. Although this approach allowed consistent treatment of all the data and aided in separating opinion from fact, the reader should not associate the use of the words "statistical significance" with "environmental significance," determination of which was beyond the scope of this study.

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APPENDIX A: DETAILED MAPS OF STUDY AREAS IN THE UPPER MISSISSIPPI RIVER

APPENDIX A: DETAILED MAPS OF STUDY AREAS IN THE UPPER MISSISSIPPI RIVER

The sampling sites selected for the Mississippi River by river mile were 744.6, 472.0, and 258.0. Detailed maps of each site are shown in Figures A1, A2, and A3, respectively. Sampling sites in the river proper were positioned uniformly on a transect across the river and consisted of left bank, main channel, and right bank stations (left and right are oriented looking downriver). The fourth or side channel station was located just inside the upstream entrance of the side channel. On each map the stations are identified as RB, MC, LB, and SC for right bank, main channel, left bank, and side channel, respectively.

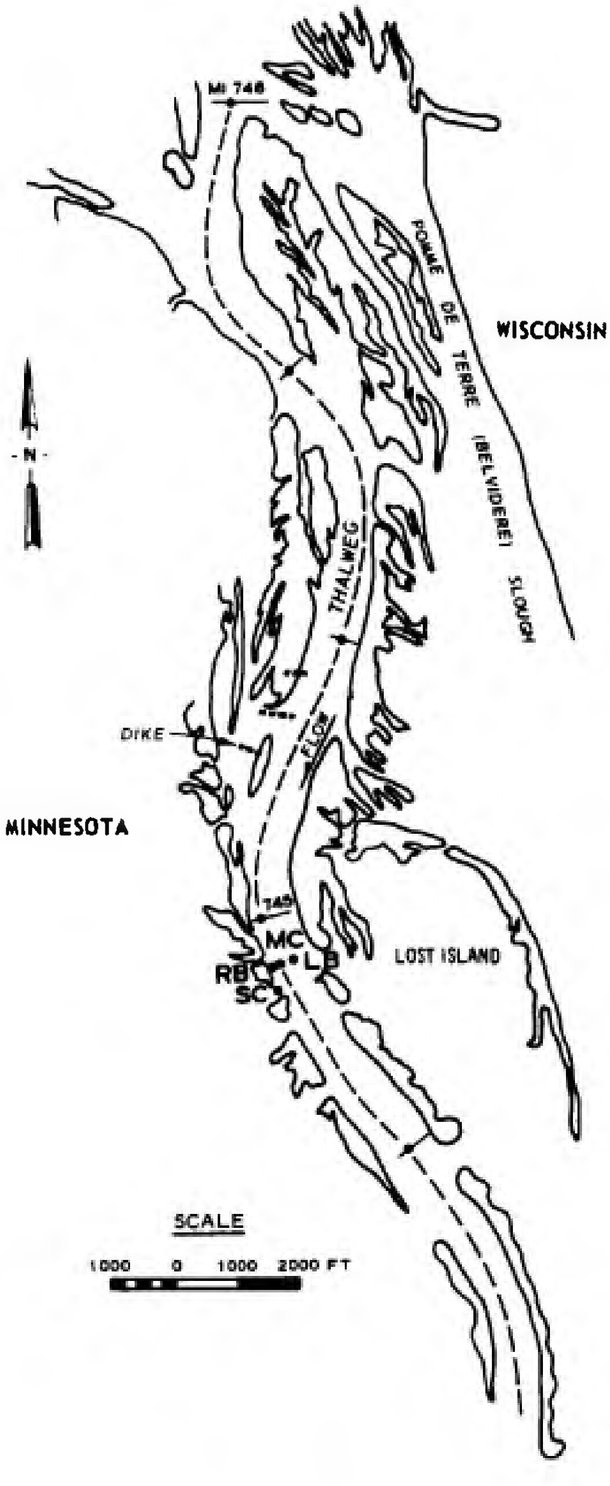

Figure A1. Mississippi River study site 1 located at RM 744.6

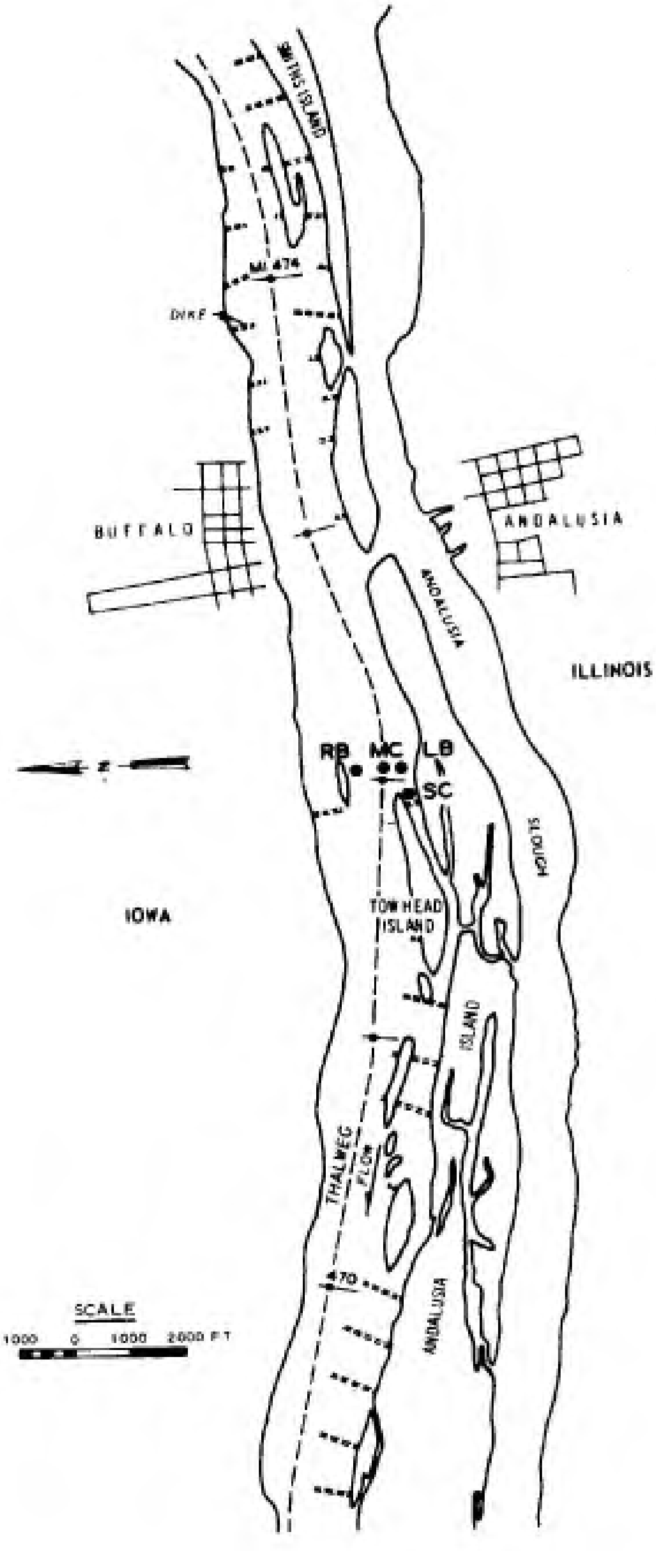

Figure A2. Mississippi River study site 2 located at RM 472.0

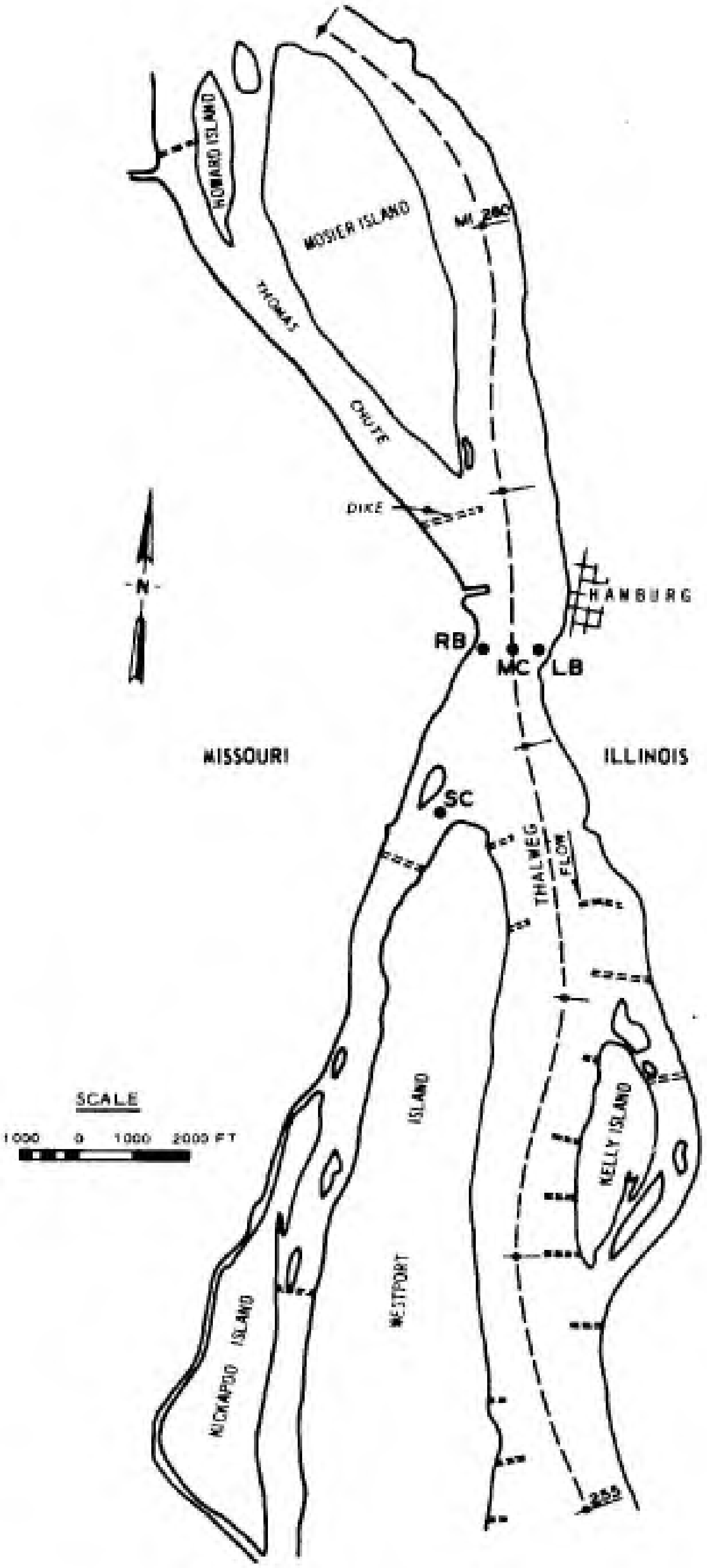

Figure A3. Mississippi River study site 3 located at RM 258.0

APPENDIX B: DETAILED MAPS OF STUDY AREAS IN THE ILLINOIS RIVER

APPENDIX B: DETAILED MAPS OF STUDY AREAS IN THE ILLINOIS RIVER

The sampling sites selected for the Illinois River by river mile were 215.8, 113.5, and 31.0. Detailed maps of each site are shown in Figures B1, B2, and B3, respectively. Sampling sites in the river proper were positioned uniformly on a transect across the river and consisted of left bank, main channel, and right bank stations (left and right are oriented looking downriver). The fourth or side channel station was located just inside the upstream entrance of the side channel. On each map the stations are identified as RB, MC, LB, and SC for right bank, main channel, left bank, and side channel, respectively.

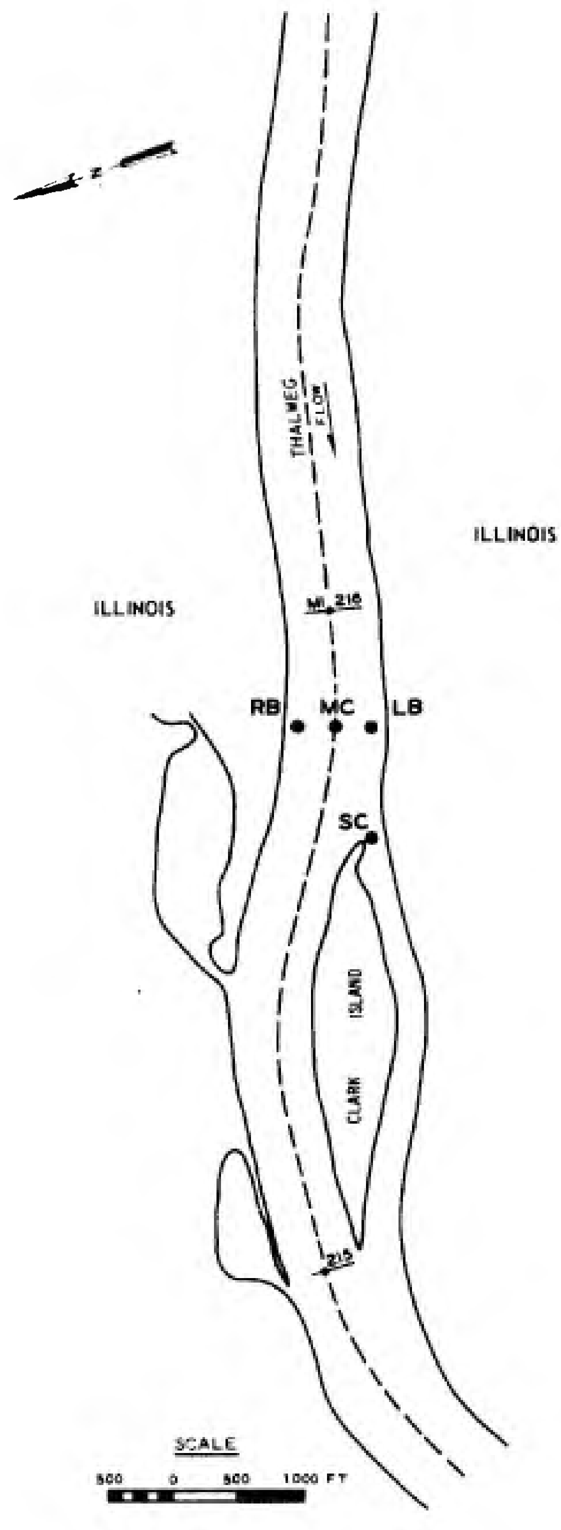

Figure B1. Illinois River study site 1 located at RM 215.8

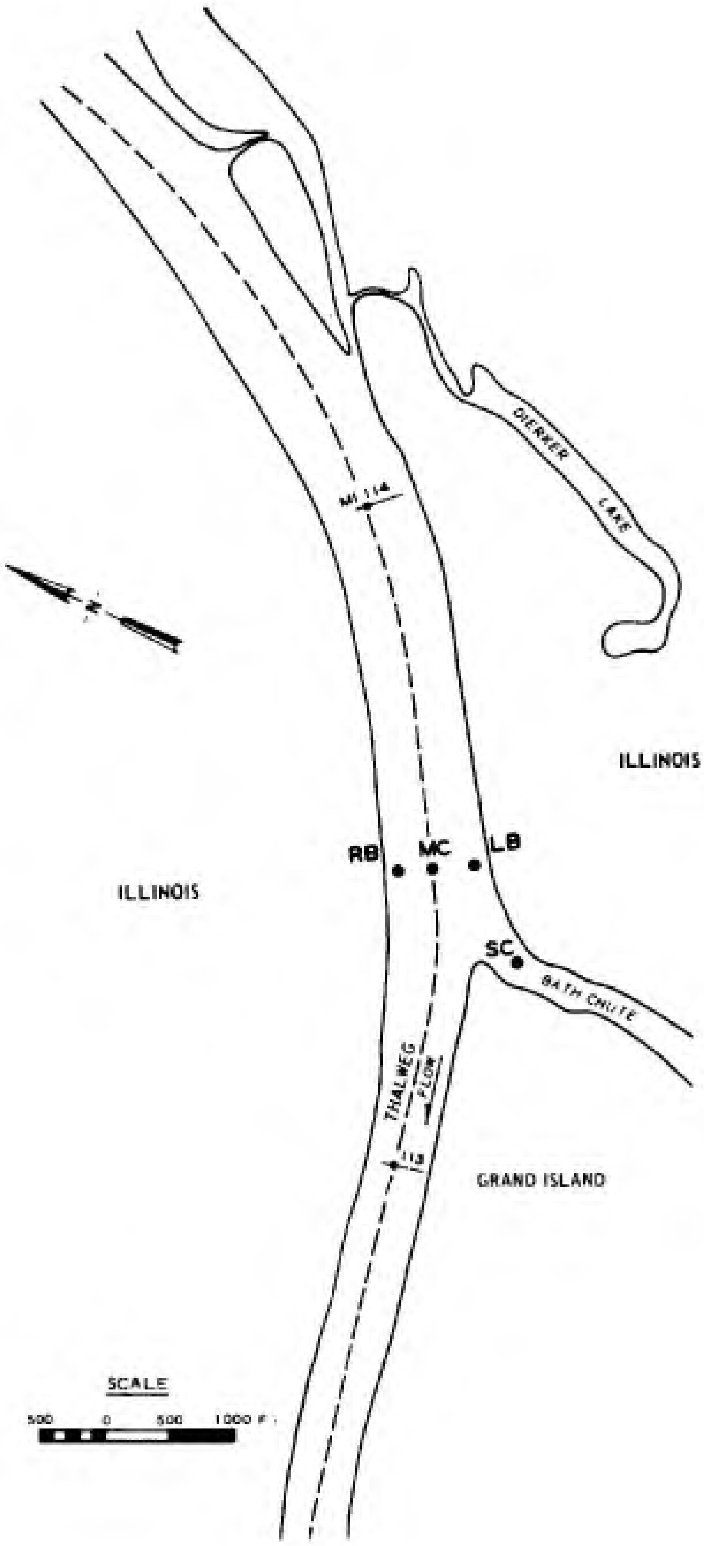

Figure B2. Illinois River study site 2 located at RM 113.5

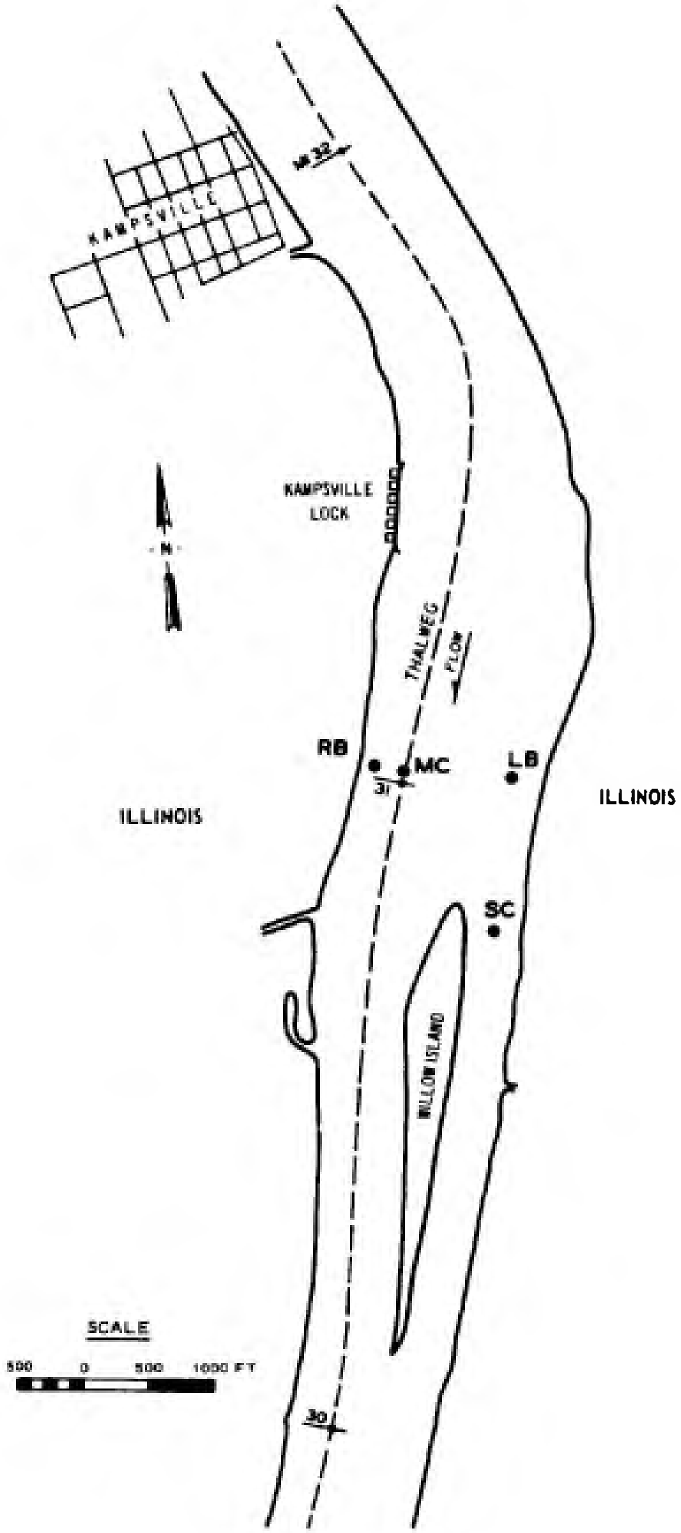

Figure B3. Illinois River study site 3 located at RM 31.0

APPENDIX C: SUSPENDED SOLIDS CONCENTRATIONS AND TURBIDITY DATA FOR THE MISSISSIPPI RIVER TOW TRAFFIC EVENTS

Table C1

Effect of Event 1* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 744.6 on 3 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x̄	SE+	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE
1720	19 19 21	19.6	0.66	7 8 7	7.3	0.33	14 15 19	16.0	1.00	8 6 8	7.3	0.67	20 17 17	18.0	1.00	[illegible] 7 7	7.3	0.33	21 19 24	22.0	2.08	[illegible]	[illegible]	[illegible]
1735*																								
1745	20 28 24	24.0	2.30	8 8 8	8.0	0.00	23 23 20	22.0	1.00	9 9 9	9.0	0.00	31 31 33	31.6	0.66	10 13 13	12.0	1.00	[illegible]	24.0	2.0[illegible]	[illegible]	[illegible]	[illegible]
1750	20 21 21	20.0	0.33	8 7 13	9.3	1.85	18 19 18	18.3	0.33	8 7 8	7.6	0.33	25 31 29	28.3	1.76	[illegible] 11 11	10.3	0.66	22 27 21	23.3	1.8[illegible]	7 8 [illegible]	7.3	0.33
1755*																								
1805	29 32 33	31.3	1.20	11 10 11	10.6	0.33	20 15 27	20.6	3.48	8 8 8	8.0	0.00	36 31 26	31.0	2.88	12 11 11	11.3	0.33	23 28 21	24.0	2.08	8 7 8	7.6	0.33
1820	24 27 25	25.3	0.88	10 10 9	9.6	0.33	20 34 25	26.3	4.09	10 10 9	9.6	0.33	23 25 27	25.0	1.15	10 11 10	10.3	0.33	27 24 28	26.3	1.20	[illegible]	9.0	[illegible]
1835	22 22 27	23.6	1.66	10 9 9	9.3	0.33	20 23 21	21.3	0.88	8 8 8	8.0	0.00	31 25 26	27.3	1.86	10 9 7	8.6	0.88	27 26 25	26.0	0.57	[illegible] [illegible] 10	10.0	0.00
1855	24 29 23	25.3	1.85	9 10 8	9.0	0.57	26 20 23	23.0	1.73	6 7 8	7.0	0.57	27 25 23	25.0	1.15	8 8 9	8.3	0.33	26 23 24	24.3	0.88	10 9 8	9.0	0.57
1925	24 28 31	27.6	2.02	9 8 10	9.0	0.57	24 18 29	23.6	3.17	7 8 8	7.6	0.33	35 16 20	23.6	5.78	8 7 7	7.3	0.33	20 25 30	25.0	2.88	[illegible] [illegible] 10	9.0	0.57
1955	27 19 26	24.0	2.51	8 8 9	8.3	0.33	17 19 18	18.0	0.57	8 8 7	7.6	0.33	24 22 26	24.0	1.15	8 7 6	7.0	0.57	25 22 19	22.0	1.73	8 [illegible] 8	8.0	0.00
2025	22 15 27	21.3	3.48	8 8 8	8.0	0.00	30 22 21	24.3	2.84	7 7 8	7.3	0.33	20 20 20	20.0	0.00	7 7 7	7.0	0.00	40 17 21	26.0	7.09	[illegible] [illegible] 10	10.3	[illegible]
2055	24 27 32	27.6	2.33	8 8 8	8.0	0.00	18 16 18	17.3	0.66	7 6 7	6.6	0.33	22 24 19	21.6	1.45	6 7 8	7.0	0.57	19 21 27	22.3	2.40	8 8 8	8.0	0.00

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 6.54; for turbidity = 1.77.
* Two tows moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
\+ SE is standard error of the mean.

Table C2

Effect of Event 2* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 744.6 on 8-9 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x̄	SE+	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE
2340	19 24 17	19.6	2.18	7 8 8	7.6	0.33	16 23 16	18.3	2.33	7 6 8	7.0	0.57	16 16 21	17.6	1.66	14 17 10	10.3	2.02	26 25 26	25.6	0.33	7 9 9	8.0	0.57
2350↓																								
2400↓																								
0015	22 23 14	19.6	2.84	8 8 8	8.0	0.00	16 16 22	18.0	2.00	7 8 7	7.3	0.33	5 21 26	17.3	6.33	7 7 9	7.6	0.66	17 29 15	20.3	4.37	13 8 11	10.6	1.45
0030	47 25 29	33.6	6.76	13 19 13	15.0	2.00	17 23 17	19.0	2.00	6 7 8	7.0	0.57	47 51 35	44.3	4.80	12 16 14	14.0	1.15	17 26 22	21.6	2.60	9 9 9	9.3	0.33
0045	33 27 19	26.3	4.05	8 8 8	8.0	0.00	25 24 22	23.6	0.88	9 9 8	9.6	0.33	26 32 24	27.3	2.40	10 12 10	10.6	0.66	29 39 24	30.6	4.40	8 12 8	9.3	1.33
0105	29 20 18	22.3	3.38	9 9 8	8.6	0.33	24 24 15	21.0	3.00	8 8 7	7.6	0.33	22 16 15	17.6	2.18	8 8 7	7.6	0.33	22 27 26	25.0	1.52	9 8 11	9.3	0.88
0125	22 19 19	20.0	1.00	8 7 8	7.6	0.33	20 18 22	20.0	1.15	8 7 8	7.6	0.33	22 20 14	18.6	2.40	7 7 7	7.0	0.00	21 15 21	19.0	2.00	10 9 7	8.3	0.88
0155	23 19 24	22.0	1.52	7 10 6	7.6	1.20	21 8 20	16.3	4.17	7 8 7	7.3	0.33	16 18 17	17.0	0.57	7 6 6	6.3	0.33	17 22 18	19.0	1.52	8 9 8	8.3	0.33
0205↓																								
0225	28 27 27	27.3	0.33	8 7 7	7.3	0.33	24 21 23	22.6	0.88	7 8 7	7.3	0.33	20 18 16	18.0	1.15	8 7 7	7.3	0.33	17 18 17	17.3	0.33	8 7 7	7.3	0.33
0255	23 18 17	19.3	1.85	8 7 7	7.3	0.33	25 23 19	22.3	1.76	7 7 7	7.0	0.00	17 20 19	18.6	0.88	8 8 7	7.6	0.33	16 17 17	16.6	0.33	8 7 8	7.6	0.33

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 7.80; for turbidity = 2.10.
* Three tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
+ SE is standard error of the mean.

Table C3

Effect of Event 3* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 744.6 on 9 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/l	Mean x̄	SE†	Units	Mean x̄	SE	mg/l	Mean x̄	SE	Units	Mean x̄	SE	mg/l	Mean x̄	SE	Units	Mean x̄	SE	mg/l	Mean x̄	SE	Units	Mean x̄	SE
0535	18 17 17	17.3	0.33	6 6 7	6.3	0.33	19 15 19	17.6	1.33	7 8 6	7.0	0.57	17 24 15	19.6	2.18	7 [illegible] 6	7.0	0.33	17 23 17	19.0	2.00	7 8 7	7.3	0.33
0550 ↑																								
0600	27 22 21	23.3	1.85	8 7 7	7.3	0.33	18 21 16	18.3	1.45	7 8 7	7.3	0.33	25 33 23	27.0	3.05	9 10 10	9.3	0.67	19 19 22	20.0	1.00	7 7 7	7.0	0.00
0620 ↓																								
0630	23 39 22	28.0	5.50	8 8 8	8.0	0.00	17 17 16	16.6	0.33	7 7 7	7.3	0.33	19 28 22	23.0	2.64	7 8 [illegible]	8.3	0.88	23 22 23	22.6	0.33	7 7 7	7.0	0.00
0645	24 27 19	23.3	2.33	8 8 8	8.0	0.00	24 20 21	21.6	1.20	8 8 8	8.3	0.33	23 38 23	28.0	5.00	8 8 9	8.3	0.33	19 13 22	18.0	2.64	9 8 8	8.0	0.00
0700	37 27 16	26.6	6.06	10 9 8	9.0	0.57	29 28 20	25.6	2.84	8 8 8	8.0	0.00	46 18 21	28.3	8.87	17 8 8	11.0	3.00	16 29 20	21.6	3.94	7 8 9	8.0	0.57
0720	24 22 26	24.0	1.15	8 7 9	8.0	0.57	19 14 17	16.6	1.45	8 8 8	8.0	0.00	19 19 19	19.0	0.00	9 7 6	7.3	0.88	26 14 16	18.6	3.71	8 9 8	8.3	0.33
0750	21 16 22	19.6	1.85	7 8 8	7.6	0.33	22 27 21	23.3	1.85	8 7 8	7.6	0.33	19 16 15	16.6	1.20	7 6 6	6.3	0.33	26 26 28	26.6	0.66	9 10 10	9.6	0.33
0820	21 22 17	20.0	1.52	7 6 7	6.6	0.33	34 22 29	28.3	3.48	8 8 8	8.0	0.00	23 10 20	17.6	3.93	8 7 6	7.0	0.57	20 22 24	22.0	1.15	8 8 8	8.0	0.00

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 8.56; for turbidity = 1.86.
* One tow moving upstream and one tow moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table C4

Effect of Event 4* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 472.0 on 12 October 1975

	Main Channel						Right Bank					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean $\bar{x}$	SE†	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
	32			14			33			12		
1115	32	32.3	0.33	14	13.0	1.00	29	31.3	1.20	11	11.6	0.33
	33			11			32			12		
1128↑												
	28			12			37			12		
1138	34	33.0	2.64	10	11.0	0.57	34	36.3	2.64	14	12.6	0.66
	37			11			38			12		
	30			12			33			11		
1153	29	29.6	0.33	8	10.0	1.15	25	29.6	2.40	12	11.0	0.57
	30			10			31			10		
1156↓												
	32			12			33			7		
1206	35	32.6	1.20	11	11.6	0.33	31	32.3	0.66	6	6.0	0.57
	31			12			33			5		
	29			8			30			10		
1221	35	31.6	1.76	10	8.6	0.66	28	28.0	1.15	10	10.0	0.00
	31			8			26			10		
	29			6			28			10		
1236	27	28.0	0.57	5	5.6	0.33	25	26.0	1.00	10	9.6	0.33
	28			6			25			9		
	32			5			27			10		
1256	36	31.6	2.60	5	5.0	0.00	25	25.3	0.66	11	10.3	0.33
	27			5			24			10		
1300↓												
	36			11			38			12		
1326	37	36.6	0.33	10	10.3	0.33	40	38.6	0.66	12	12.3	0.33
	37			10			38			13		
	32			9			40			10		
1356	32	33.3	1.33	9	9.3	0.33	40	42.3	2.33	11	10.3	0.33
	36			10			47			10		

	Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
	33			11			35			12		
1115	35	32.6	1.20	13	11.6	[illegible]	35	35.3	0.33	12	11.3	[illegible]
	32			11			[illegible]			[illegible]		
1128↑												
	33			12			30			11		
1138	38	34.6	1.66	11	12.0	1.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	33			13			[illegible]			11		
	35			12			33			12		
1153	32	34.0	1.00	12	11.6	0.33	31	[illegible]	[illegible]	12	[illegible]	[illegible]
	35			11			31			12		
1156↓												
	35			13			34			11		
1206	31	32.3	1.33	12	12.0	0.57	47	[illegible]	4.70	[illegible]	13.0	2.51
	31			11			32			[illegible]		
	35			14			32			12		
1221	38	36.0	1.00	15	14.0	0.57	34	37.0	4.04	12	13.0	1.00
	35			13			45			15		
	31			12			35			11		
1236	34	33.0	1.20	13	12.6	0.33	38	36.0	1.00	13	12.0	[illegible]
	35			13			35			12		
	31			12			35			12		
1256	29	30.3	0.66	12	12.3	0.33	46	44.0	[illegible]	11	11.6	0.33
	31			13			49			12		
1300↓												
	28			14			35			12		
1326	34	32.3	2.19	11	12.6	0.88	67	47.6	[illegible]	28	16.6	[illegible]
	35			13			41			10		
	34			12			36			11		
1356	29	30.6	1.66	12	11.3	0.66	38	37.6	0.88	12	11.0	0.57
	29			10			39			11		

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 7.00; for turbidity = 3.32.
* One tow moving upstream and two tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table C5

Effect of Event 5* (Single Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 472.0 on 13 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean $\bar{x}$	SE♠	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
	34			12			20			9			41			12			35			12		
1420	36	33.6	1.45	12	11.6	0.33	25	23.0	1.52	8	9.0	0.57	35	37.0	2.00	12	11.6	0.33	38	36.3	0.88	14	13.6	0.88
	31			11			24			10			35			11			36			15		
1433↓																								
	31			11			26			9			34			8			30			10		
1443	31	31.0	0.00	12	11.0	0.57	24	24.6	0.66	10	9.6	0.33	35	34.6	0.33	10	10.0	1.15	26	29.3	1.76	11	11.0	0.57
	31			10			24			10			35			12			32			12		
	39			12			28			9			31			12			45			10		
1458	37	38.0	0.57	12	12.3	0.33	28	27.6	0.33	9	9.0	0.00	33	31.3	0.88	11	11.6	0.33	44	42.3	2.19	12	10.3	0.88
	38			13			27			9			30			12			38			9		
	34			15			27			10			31			12			38			9		
1513	36	34.6	0.66	13	13.3	0.88	30	27.6	1.20	10	10.3	0.33	23	29.0	3.05	10	11.3	0.66	38	37.0	1.00	8	8.0	0.57
	34			12			26			11			33			12			35			7		
	32			12			28			8			28			10			47			9		
1533	34	23.0	0.57	12	12.6	0.66	33	31.3	1.66	9	9.0	0.57	33	30.0	1.52	10	9.6	0.33	35	38.0	4.58	10	11.3	2.40
	33			14			33			10			29			9			32			16		
	40			12			29			10			35			12			43			8		
1603	30	33.6	3.18	10	11.0	0.57	28	30.3	1.85	8	8.6	0.66	37	36.0	0.57	11	11.6	0.33	43	41.3	1.66	7	7.6	0.57
	31			11			34			8			36			12			38			6		
	33			10			27			10			38			12			38			12		
1633	35	35.6	1.76	10	11.3	1.33	31	30.3	1.76	9	9.6	0.33	41	39.0	1.00	12	11.6	0.33	48	43.6	2.96	10	11.3	0.66
	39			14			33			10			38			11			45			12		
	32			12			30			8			39			9			20			10		
1703	26	32.3	3.75	13	13.0	0.57	39	35.3	2.72	8	8.3	0.33	27	34.0	3.60	8	8.6	0.33	27	26.6	3.75	12	11.3	0.33
	39			14			37			9			36			9			33			12		
	36			11			35			10			44			12			20			12		
1733	37	36.6	0.33	12	11.0	0.57	40	36.6	0.66	10	10.0	0.00	30	36.0	4.16	12	11.6	0.33	18	19.3	0.66	10	11.0	0.57
	37			10			35			10			34			11			20			11		

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 5.86; for turbidity = 2.00.

* Single tow moving downstream at time indicated in table.

** Arrow indicates time and direction of tow past sampling station.

♠ SE is standing error of the mean.

Table C4

Effect of Event 4* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 472.0 on 12 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean $\bar{x}$	SE†	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
1115	32 32 33	32.3	0.33	14 14 11	13.0	1.00	33 29 32	31.3	1.20	12 11 12	11.6	0.33	31 35 32	32.6	1.20	11 13 11	[illegible]	[illegible]	[illegible]	[illegible]	0.33	12 12 [illegible]	[illegible]	[illegible]
1128↑																								
1138	28 34 37	33.0	2.64	12 10 11	11.0	0.57	37 34 38	36.3	2.64	12 14 12	12.6	0.66	33 38 33	34.6	1.66	12 11 13	12.0	1.70	30 [illegible] 38	[illegible]	[illegible]	11 15 11	[illegible]	[illegible]
1153	30 29 30	29.6	0.33	12 8 10	10.0	1.15	33 25 31	29.6	2.40	11 12 10	11.0	0.57	35 32 35	34.0	1.00	12 12 11	[illegible]	0.33	33 31 31	[illegible]	[illegible]	12 12 12	[illegible]	[illegible]
1156↓																								
1206	32 35 31	32.6	1.20	12 11 12	11.6	0.33	33 31 33	32.3	0.66	7 6 5	6.0	0.57	35 31 31	32.3	1.33	13 12 11	12.0	0.57	34 47 32	[illegible]	4.70	11 [illegible] 10	13.0	2.51
1221	29 35 31	31.6	1.76	8 10 8	8.6	0.66	30 28 26	28.0	1.15	10 10 10	10.0	0.00	35 38 35	36.0	1.00	14 15 13	14.0	0.57	32 34 45	37.0	4.04	12 12 15	13.0	1.00
1236	29 27 28	28.0	0.57	6 5 6	5.6	0.33	28 25 25	26.0	1.00	10 10 9	9.6	0.33	31 34 35	33.0	1.20	12 13 13	12.6	0.33	38 35 35	36.0	1.00	11 13 12	12.0	0.57
1256	32 36 27	31.6	2.60	5 5 5	5.0	0.00	27 25 24	25.3	0.66	10 11 10	10.3	0.33	31 29 31	30.3	0.66	12 12 13	12.3	0.33	38 46 48	44.0	3.05	12 11 12	11.6	0.33
1300↓																								
1326	36 37 37	36.6	0.33	11 10 10	10.3	0.33	38 40 38	38.6	0.66	12 12 13	12.3	0.33	28 34 35	32.3	2.18	14 11 13	[illegible]	0.88	35 67 41	47.6	[illegible]	12 28 10	16.6	[illegible]
1356	32 32 36	33.3	1.33	9 9 10	9.3	0.33	40 40 47	42.3	2.33	10 11 10	10.3	0.33	34 29 29	30.6	1.66	12 12 10	11.3	0.66	36 39 38	37.6	0.88	11 12 11	11.0	0.57

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 7.00; for turbidity = 3.32.

* One tow moving upstream and two tows moving downstream at times indicated in table.

** Arrow indicates time and direction of tow past sampling station.

† SE is standard error of the mean.

Table C6

Effect of Event 6* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 472.0 on 14 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean $\bar{x}$	SE†	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
1145	28 27 22	25.6	1.85	13 12 10	11.6	0.88	31 33 32	32.0	0.57	12 10 10	10.6	0.66	41 31 31	34.3	3.33	16 18 12	15.3	1.76	29 29 28	28.6	0.33	11 11 12	11.3	0.33
1154→																								
1204	27 30 30	29.0	1.00	12 12 11	11.6	0.33	35 32 31	32.6	1.20	13 15 14	14.0	0.57	38 38 33	36.3	1.6[illegible]	12 14 13	13.0	0.57	40 44 35	39.6	2.60	14 15 15	14.[illegible]	0.33
1219	31 35 37	34.3	1.76	11 12 12	11.6	0.33	29 28 30	29.0	0.57	14 15 12	13.6	0.88	29 35 31	31.6	1.76	10 12 15	12.3	1.45	3[illegible] 33 38	35.6	1.45	14 12 12	12.[illegible]	0.[illegible]
1234	39 30 37	35.3	2.72	10 12 12	11.3	0.66	29 32 31	30.6	0.88	8 8 12	9.3	1.33	33 32 37	34.0	0.52	11 12 15	12.[illegible]	1.20	30 30 30	32.3	2.33	15 13 15	14.3	0.[illegible]
1252→																								
1302	33 37 38	36.0	1.52	12 12 15	13.0	1.00	31 27 28	28.6	1.20	12 10 10	10.6	0.66	32 43 37	37.3	3.18	12 16 15	14.3	1.20	30 37 33	33.3	2.02	14 15 15	14.[illegible]	0.33
1309→																								
1319	33 35 37	35.0	1.15	14 13 12	13.0	0.57	26 32 31	29.6	1.85	10 14 11	11.6	1.20	34 32 33	33.0	0.57	14 13 15	14.0	0.57	38 35 37	36.[illegible]	0.58	15 1[illegible] 13	14.[illegible]	0.[illegible]
1334	33 34 36	34.3	0.88	12 12 12	12.0	0.00	31 31 29	30.3	0.66	10 10 13	11.0	1.00	35 35 34	34.6	0.33	16 12 11	13.0	1.52	28 31 30	29.6	0.88	10 14 15	13.[illegible]	1.[illegible]
1349	34 33 34	33.6	0.33	13 12 12	12.3	0.33	22 22 21	21.6	0.33	8 16 8	10.6	2.66	33 26 37	32.0	3.21	8 14 10	10.6	1.7[illegible]	27 29 32	29.3	1.45	15 14 1[illegible]	15.0	0.57
1409	31 29 30	30.0	0.57	12 11 12	11.6	0.33	20 27 27	24.6	2.33	10 8 10	9.3	0.66	26 23 27	25.3	1.20	9 10 13	10.6	1.20	37 36 29	34.0	2.51	15 15 15	15.0	0.00

(Continued)

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 5.05; for turbidity = 2.91.
* Three tows moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table C6 (Concluded)

Time	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
	30			10			27			9			21			11			23			15		
1439	37	31.6	2.72	12	11.3	0.66	27	25.6	1.33	10	9.0	0.57	23	24.6	2.72	12	12.3	0.88	34	29.0	3.21	11	[illegible]	1.33
	28			12			23			8			30			14			30			15		
	23			18			26			10			40			10			30			13		
1509	29	27.6	2.40	10	14.0	2.30	23	26.3	2.02	10	10.0	0.00	36	37.3	1.33	11	10.6	0.33	32	30.6	0.66	11	[illegible]	[illegible]
	31			14			30			10			36			11			30			[illegible]		
	28			11			31			9			33			9			35			15		
1539	28	29.0	1.00	13	12.0	0.57	28	29.6	0.88	10	9.6	0.33	34	32.0	1.52	12	11.0	1.00	37	33.3	2.72	18	17.0	1.00
	31			12			30			10			29			12			28			19		

Table C7

Effect of Event 7* (Single Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 258.0 on 22 October 1975

Time**	Main Channel						Right Bank					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity		
	mg/ℓ	Mean x	SE†	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
1320	22 19 23	21.3	1.20	5 5 7	5.6	0.66	75 64 73	70.6	3.38	28 25 24	25.6	1.20
1334 ↓												
1344	19 23 25	22.3	1.76	5 5 7	5.6	0.66	63 66 54	61.0	3.60	18 22 18	19.3	1.33
1359	23 25 22	23.3	0.88	5 5 5	5.0	0.00	48 62 62	57.3	4.66	17 18 18	17.6	0.33
1414	25 18 22	21.6	2.02	6 6 6	6.0	0.00	60 62 62	61.3	0.66	17 17 18	17.3	0.33
1434	23 15 15	17.6	2.66	5 6 7	6.0	0.57	39 56 56	50.3	5.66	15 18 18	17.0	1.00
1504	16 16 16	16.0	0.00	6 5 6	5.6	0.33	33 32 29	31.3	1.20	16 12 12	13.3	1.33
1534	16 16 16	16.0	0.00	5 5 5	5.0	0.00	32 31 30	31.0	0.57	12 12 12	12.0	0.00
1604	16 15 12	14.3	1.20	6 6 7	6.3	0.33	95 82 74	83.6	6.12	28 25 22	25.0	1.73

Time**	Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity		
	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
1320	26 25 22	24.3	1.20	7 7 8	7.3	0.33	23 23 22	22.6	0.33	7 6 6	6.3	0.33
1334 ↓												
1344	22 21 19	20.6	0.88	8 8 8	8.0	0.00	18 19 17	18.0	0.57	7 5 7	6.3	0.66
1359	19 20 22	20.3	0.88	8 7 8	7.6	0.33	21 13 19	17.6	2.40	6 6 6	6.0	0.00
1414	19 19 22	20.0	1.00	8 8 7	7.6	0.33	19 21 20	20.0	0.57	5 6 5	5.3	0.33
1434	22 21 20	21.0	0.57	7 7 6	6.6	0.33	19 19 18	18.6	0.33	6 5 5	5.3	0.33
1504	25 24 24	24.3	0.33	7 8 7	7.3	0.33	18 17 15	16.6	0.88	6 6 7	6.3	0.33
1534	25 19 20	21.3	1.85	8 8 8	8.0	0.00	14 12 14	13.3	0.67	7 6 6	6.3	0.33
1604	21 18 22	20.3	1.20	8 8 7	7.6	0.33	15 16 14	15.0	0.57	6 7 6	6.3	0.33

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 6.19; for turbidity = 1.76.
* Single tow moving downstream at time indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table C8

Effect of Event 8* (Single Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 258.0 on 29 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x	SE†	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
	30			12			22			10			29			13			25			8		
1507	27	27.7	1.20	11	11.6	0.33	21	23.3	1.86	11	10.6	0.33	25	27.3	1.20	14	13.3	0.33	28	29.3	2.96	10	9.0	0.57
	26			12			27			11			28			13			35			9		
1556*																								
	23			13			26			10			35			12			27			10		
1606	27	24.7	1.20	12	12.3	0.33	24	24.3	0.88	10	10.0	0.00	33	33.3	0.88	12	12.0	0.00	25	26.0	0.58	10	10.0	0.00
	24			12			23			10			32			12			26			10		
	28			11			25			10			29			12			27			12		
1621	25	27.3	1.20	12	11.6	0.33	27	24.3	1.76	10	10.3	0.33	26	26.7	1.20	10	10.6	0.66	28	27.0	0.58	12	12.0	0.00
	29			12			21			11			25			10			26			12		
	23			11			26			12			27			11			27			10		
1636	24	24.7	1.76	12	11.6	0.33	25	24.7	0.88	10	10.6	0.66	31	27.7	1.76	12	11.6	0.33	27	28.3	1.33	10	10.0	0.00
	27			12			23			10			25			12			31			10		
	28			9			25			10			24			9			27			10		
1656	27	27.7	0.33	10	9.0	0.57	27	26.0	0.58	12	11.0	0.57	28	26.7	1.33	9	9.0	0.00	27	25.0	2.00	10	9.3	0.66
	28			8			26			11			28			9			21			8		
	28			11			22			10			37			11			26			10		
1726	27	26.7	0.88	9	10.0	0.57	26	26.0	2.31	11	10.6	0.33	34	33.7	2.03	12	11.3	0.33	25	25.0	0.58	10	10.0	0.00
	25			10			30			11			30			11			24			10		
	22			10			22			10			32			12			19			9		
1756	24	22.7	0.67	10	10.0	0.00	21	21.3	0.33	11	10.3	0.33	34	30.7	2.40	11	11.3	0.33	23	22.0	1.53	9	9.0	0.00
	22			10			21			10			26			11			24			9		
	20			12			16			9			27			12			20			9		
1826	25	22.3	1.45	10	11.3	0.66	23	20.0	2.08	10	9.6	0.33	29	27.3	0.88	10	10.6	0.66	23	21.7	0.88	10	9.6	0.33
	22			12			21			10			26			10			22			9		

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 4.03; for turbidity = 1.13.
* Single tow moving upstream at time indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table C9

Effect of Event 9* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Mississippi River Sampled at River Mile 258.0 on 30 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x	SE†	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
0805	23 26 32	27.0	2.65	12 11 13	12.0	0.57	18 18 17	17.7	0.33	9 8 8	8.3	0.33	23 26 27	25.3	1.20	9 10 9	9.3	0.33	18 19 20	19.0	0.58	6 6 7	7.6	0.33
0816↑																								
0826	20 21 19	20.0	0.58	10 8 8	8.6	0.66	19 19 18	18.7	0.33	7 9 8	8.0	0.57	23 26 28	25.7	1.45	9 10 12	10.3	0.66	18 22 21	20.3	1.20	8 8 8	8.0	0.00
0647↓																								
0659↓																								
0909	20 26 24	23.3	1.76	10 10 9	9.6	0.33	29 25 24	26.0	1.53	12 12 12	12.0	0.00	25 24 30	26.3	1.86	12 12 13	12.3	0.33	18 22 18	19.3	1.33	8 8 8	8.0	0.00
0924	22 25 23	23.3	0.88	8 8 10	8.6	0.66	23 24 29	25.3	1.86	10 12 12	11.3	0.66	28 24 22	24.7	1.76	10 10 10	10.0	0.00	23 19 21	21.0	1.16	8 8 8	8.0	0.00
0939	27 27 28	27.3	0.33	10 9 8	9.0	0.57	31 31 35	32.3	1.33	9 10 11	10.0	0.57	21 22 22	21.7	0.33	10 12 12	11.3	0.66	18 18 17	17.7	0.33	8 8 7	7.6	0.33
0959	23 29 24	25.3	1.86	8 9 8	8.3	0.33	26 30 26	27.3	1.33	8 7 8	7.6	0.33	24 21 24	23.0	1.00	11 10 10	10.3	0.33	20 17 21	19.3	1.20	7 7 7	7.0	0.00
1029	31 26 24	27.0	2.08	10 8 8	8.6	0.66	22 23 24	23.0	0.58	8 8 8	8.0	0.00	22 21 18	20.3	1.20	16 14 14	14.6	0.66	21 21 18	20.0	1.00	7 7 8	7.3	0.33
1059	24 24 26	24.7	0.67	10 9 8	9.0	0.57	27 25 26	26.0	0.58	10 10 10	10.0	0.00	19 20 21	20.0	0.58	13 13 12	12.6	0.33	16 21 21	19.3	1.67	9 8 8	8.3	0.33
1129	23 23 25	23.7	0.67	9 10 9	9.3	0.33	22 23 23	22.7	0.33	9 10 9	9.3	0.33	21 18 19	19.3	0.88	13 12 12	12.3	0.33	20 16 18	18.0	1.16	9 8 8	8.3	0.33
1159	20 22 20	20.7	0.67	8 8 10	8.6	0.66	24 28 26	26.0	1.16	11 11 11	11.0	0.00	19 22 22	21.0	1.00	12 12 13	12.3	0.33	19 22 21	20.7	0.88	9 9 8	8.6	0.33

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 3.43; for turbidity = 1.23.
* One tow moving upstream and two tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

APPENDIX D: DISSOLVED OXYGEN CONCENTRATIONS DATA FOR THE MISSISSIPPI RIVER TOW TRAFFIC EVENTS

Table D1

Effect of Event 1* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat
Mississippi River Sampled at River Mile 744.6 on 8 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.8 m)			Bottom (Depth = 2.7 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1720	9.6			9.4			9.3		
	9.6	9.63	0.033	9.5	9.43	0.033	9.2	9.26	0.033
	9.7			9.4			9.3		
1735†									
1745	9.0			9.8			10.0		
	9.3	9.20	0.100	9.8	9.80	0.000	10.1	10.10	0.058
	9.3			9.8			10.2		
1750	9.2			9.8			10.1		
	9.3	9.23	0.033	9.8	9.80	0.000	10.1	10.13	0.033
	9.2			9.8			10.2		
1755†									
1805	9.8			9.8			9.9		
	9.6	9.66	0.067	9.8	9.80	0.000	10.0	9.96	0.033
	9.6			9.8			10.0		
1820	8.9			9.3			9.8		
	9.0	8.96	0.033	9.5	9.43	0.067	10.0	9.93	0.067
	9.0			9.5			10.0		
1835	9.5			9.8			10.0		
	9.5	9.53	0.033	9.8	9.80	0.000	10.1	10.03	0.033
	9.6			9.8			10.8		
1855	9.4			9.8			10.1		
	9.4	9.40	0.000	9.8	9.83	0.033	10.1	10.10	0.000
	9.4			9.9			10.1		
1925	9.3			9.8			10.0		
	9.3	9.33	0.033	9.8	9.76	0.033	10.0	10.00	0.000
	9.4			9.7			10.0		
1955	9.2			9.7			10.7		
	9.3	9.26	0.033	9.8	9.76	0.033	10.1	10.30	0.200
	9.3			9.8			10.1		
2025	10.0			10.2			10.5		
	10.1	10.03	0.033	10.4	10.33	0.067	10.5	10.50	0.000
	10.0			10.4			10.5		
2055	11.5			11.5			11.0		
	10.0	10.50	0.500	10.3	10.73	0.384	10.4	10.70	0.173
	10.0			10.4			10.7		

* Two tows moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.35.

Table D2

Effect of Event 2* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 744.6 on 8-9 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.8 m)			Bottom (Depth = 2.7 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
2340	10.5 10.3 10.5	10.43	0.067	10.7 10.8 10.7	10.73	0.033	10.7 10.8 10.7	10.73	0.033
2350↓									
2400↓									
0015	10.7 10.8 10.7	10.73	0.033	10.7 10.8 10.8	10.76	0.033	10.8 10.8 10.8	10.80	0.000
0030	10.7 10.8 10.8	10.76	0.033	10.8 10.7 10.8	10.76	0.033	10.7 10.9 10.8	10.80	0.058
0045	10.7 10.7 10.7	10.70	0.000	10.7 10.8 10.7	10.73	0.033	10.8 10.8 10.8	10.80	0.000
0105	10.7 10.8 10.8	10.76	0.033	10.7 10.7 10.7	10.70	0.000	10.7 10.8 10.8	10.76	0.033
0125	10.7 10.7 10.7	10.70	0.000	10.7 10.7 10.7	10.70	0.000	10.8 10.7 10.8	10.76	0.033
0155	10.7 10.7 10.7	10.70	0.000	10.7 10.7 10.7	10.70	0.000	10.7 10.7 10.7	10.70	0.000
0205↓									
0225	9.7 10.0 10.0	9.90	0.033	9.8 10.0 10.0	9.96	0.100	9.9 10.0 10.1	10.00	0.058
0255	10.3 10.4 10.4	10.36	0.033	10.4 10.4 10.4	10.40	0.000	10.5 10.5 10.5	10.50	0.000

* Three tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.11.

Table D3

Effect of Event 3* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 744.6 on 9 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.8 m)			Bottom (Depth = 2.7 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
0535	10.0			10.1			10.2		
	10.0	10.00	0.000	10.0	10.06	0.033	10.2	10.20	0.000
	10.0			10.1			10.2		
0550↑									
0600	10.1			10.2			10.2		
	10.0	10.10	0.058	10.1	10.20	0.058	10.2	10.23	0.033
	10.2			10.3			10.3		
0620↓									
0630	10.4			10.3			10.3		
	10.3	10.33	0.033	10.3	10.30	0.000	10.3	10.30	0.000
	10.3			10.3			10.3		
0645	10.2			10.3			10.3		
	10.3	10.26	0.033	10.2	10.26	0.033	10.3	10.30	0.000
	10.3			10.3			10.3		
0700	10.1			10.2			10.2		
	10.0	10.13	0.088	10.2	10.20	0.000	10.2	10.20	0.000
	10.3			10.2			10.2		
0720	10.2			10.3			10.2		
	10.3	10.26	0.033	10.2	10.26	0.033	10.3	10.23	0.033
	10.3			10.3			10.3		
0750	10.1			10.2			10.2		
	10.2	10.16	0.033	10.2	10.20	0.000	10.2	10.20	0.000
	10.2			10.2			10.2		
0820	10.2			10.3			10.3		
	10.3	10.26	0.033	10.3	10.30	0.000	10.3	10.30	0.000
	10.3			10.3			10.3		

* One tow moving upstream and one tow moving downstream at times indicated in table.

** Arrow indicates time and direction of tow past sampling station.

† Least Significant Difference (LSD) = 0.09.

Table D4

Effect of Event 4* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 472.0 on 12 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.8 m)			Bottom (Depth = 2.7 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1115	12.0			11.5			11.5		
	11.9	11.93	0.033	11.5	11.53	0.033	11.4	11.46	0.033
	11.9			11.6			11.5		
1128↑									
1138	11.1			11.2			11.4		
	11.2	11.16	0.033	11.3	11.26	0.033	11.4	11.40	0.000
	11.2			11.3			11.4		
1153	11.1			11.0			11.2		
	11.2	11.16	0.033	11.2	11.13	0.067	11.3	11.26	0.033
	11.2			11.2			11.3		
1156↓									
1206	10.8			11.2			11.3		
	11.0	10.93	0.067	11.2	11.23	0.033	11.4	11.36	0.033
	11.0			11.3			11.4		
1221	11.6			11.6			11.5		
	11.6	11.60	0.000	11.6	11.56	0.033	11.6	11.56	0.033
	11.6			11.5			11.6		
1236	11.8			11.7			11.7		
	11.7	11.73	0.033	11.7	11.73	0.033	11.8	11.76	0.033
	11.7			11.8			11.8		
1256	11.9			11.8			11.8		
	11.9	11.90	0.000	11.8	11.83	0.033	11.7	11.76	0.033
	11.9			11.9			11.8		
1300↓									
1326	11.1			11.4			11.5		
	11.2	11.16	0.033	11.5	11.46	0.033	11.4	11.46	0.033
	11.2			11.5			11.5		
1356	11.7			11.8			11.8		
	11.7	11.73	0.033	11.8	11.80	0.000	11.7	11.76	0.033
	11.8			11.8			11.8		

* One tow moving upstream and two tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.09.

Table D5

Effect of Event 5* (Single Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 472.0 on 13 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.6 m)			Bottom (Depth = 3.3 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1420	11.2 11.2 11.2	11.20	0.000	11.2 11.2 11.2	11.20	0.000	11.4 11.3 11.3	11.33	0.033
1433↓									
1443	11.0 11.0 11.0	11.00	0.000	11.0 11.0 11.1	11.06	0.017	11.1 11.1 11.1	11.10	0.000
1458	11.1 11.1 11.2	11.15	0.029	11.2 11.2 11.2	11.20	0.000	11.2 11.2 11.2	11.20	0.000
1513	11.2 11.2 11.2	11.20	0.000	11.2 11.2 11.2	11.20	0.000	11.2 11.2 11.2	11.20	0.000
1533	11.1 11.0 11.0	11.03	0.033	11.0 11.0 11.0	11.00	0.000	10.9 10.9 10.0	10.90	0.000
1603	10.8 10.8 10.8	10.80	0.000	11.0 11.0 11.0	11.00	0.000	11.0 11.0 11.0	11.00	0.000
1633	11.0 11.0 11.0	11.00	0.000	11.0 11.0 11.0	11.00	0.000	11.2 11.2 11.2	11.20	0.000
1703	11.0 11.0 11.0	11.00	0.000	11.0 11.0 11.0	11.00	0.000	11.0 11.0 11.0	11.00	0.000
1733	11.0 11.1 11.1	11.06	0.033	11.2 11.2 11.2	11.20	0.000	11.2 11.2 11.2	11.20	0.000

* Single tow moving downstream at time indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.37.

Table 106

Effect of Event [illegible]* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 472.0 on 14 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.8 m)			Bottom (Depth = 3.6 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1145	11.5 11.5 11.5	11.50	0.000	11.3 11.3 11.3	11.30	0.000	11.3 11.3 11.3	11.30	0.000
1154↑									
1204	11.1 11.1 11.1	11.10	0.000	11.1 11.1 11.1	11.10	0.000	11.1 11.1 11.1	11.10	0.000
1219	11.1 11.1 11.1	11.10	0.000	11.2 11.2 11.2	11.20	0.000	11.2 11.2 11.2	11.20	0.000
1234	11.3 11.3 11.3	11.30	0.000	11.4 11.4 11.4	11.40	0.000	11.4 11.4 11.4	11.40	0.000
1252↑									
1302	11.3 11.3 11.3	11.30	0.000	11.3 11.3 11.3	11.30	0.000	11.3 11.3 11.3	11.30	0.000
1309↑									
1319	11.3 11.3 11.3	11.30	0.000	11.2 11.2 11.2	11.20	0.000	11.2 11.2 11.2	11.20	0.000
1334	11.3 11.2 11.2	11.23	0.033	11.2 11.1 11.1	11.13	0.033	11.1 11.1 11.1	11.10	0.000
1349	11.2 11.2 11.2	11.20	0.000	11.1 11.1 11.1	11.10	0.000	11.1 11.1 11.1	11.10	0.000
1409	11.1 11.0 11.0	11.03	0.033	11.0 11.0 11.0	11.00	0.000	11.0 11.0 11.0	11.00	0.000
1439	11.2 11.2 11.2	11.20	0.000	11.3 11.2 11.2	11.23	0.033	11.2 11.2 11.2	11.20	0.000
1509	11.3 11.2 11.2	11.23	0.033	11.3 11.3 11.3	11.30	0.000	11.3 11.3 11.3	11.30	0.000
1539	11.4 11.4 11.4	11.40	0.000	11.4 11.4 11.4	11.40	0.000	11.4 11.4 11.4	11.40	0.000

* Three tows moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.03.

Table 47

Effect of Event 7* (Single Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 258.0 on 22 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 2.8 m)			Bottom (Depth = 5.7 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1320	9.6 9.6 9.7	9.63	0.033	9.7 9.6 9.7	9.66	0.033	9.7 9.7 9.7	9.70	0.000
1334↓									
1344	9.4 9.4 9.4	9.40	0.000	9.7 9.7 9.7	9.70	0.000	9.7 9.7 9.7	9.70	0.000
1359	9.6 9.6 9.6	9.60	0.000	9.7 9.7 9.7	9.70	0.000	9.7 9.7 9.7	9.70	0.000
1414	9.6 9.6 9.6	9.60	0.000	9.7 9.7 9.7	9.70	0.000	9.8 9.8 9.8	9.80	0.000
1434	9.9 9.9 9.9	9.90	0.000	10.0 10.0 9.9	9.96	0.033	9.9 9.9 9.9	9.90	0.000
1504	9.4 9.4 9.5	9.43	0.033	9.6 9.6 9.6	9.60	0.000	9.7 9.7 9.7	9.70	0.000
1534	9.7 9.7 9.8	9.73	0.033	9.9 9.9 9.9	9.90	0.000	10.0 10.0 10.0	10.00	0.000
1604	9.7 9.6 9.6	9.63	0.033	9.9 9.9 9.9	9.90	0.000	9.9 9.9 9.9	9.90	0.000

* Single tow moving downstream at time indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.001.

Table D8

Effect of Event 8* (Single Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 258.0 on 29 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 4.5 m)			Bottom (Depth = 9.1 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1507	9.6			9.6			9.5		
	9.6	9.60	0.000	9.6	9.60	0.000	9.5	9.50	0.000
	9.6			9.6			9.5		
1556↑									
1606	9.8			9.7			9.7		
	9.7	9.73	0.033	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
1621	9.7			9.6			9.6		
	9.6	9.63	0.033	9.6	9.60	0.000	9.6	9.60	0.000
	9.6			9.6			9.6		
1636	9.7			9.7			9.7		
	9.7	9.70	0.000	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
1656	9.7			9.7			9.7		
	9.7	9.70	0.000	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
1720	9.7			9.7			9.7		
	9.7	9.70	0.000	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
1756	9.7			9.7			9.7		
	9.7	9.70	0.000	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
1826	9.8			9.8			9.8		
	9.8	9.80	0.000	9.8	9.80	0.000	9.8	9.80	0.000
	9.8			9.8			9.8		

* Single tow moving downstream at time indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.02.

Table D9

Effect of Event 9* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Mississippi River Sampled at River Mile 258.0 on 30 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 4.5 m)			Bottom (Depth = 9.1 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
0805	9.8			9.8			9.8		
	9.8	9.80	0.000	9.8	9.80	0.000	9.8	9.80	0.000
	9.8			9.8			9.8		
0816↑									
0826	9.7			9.7			9.7		
	9.7	9.70	0.000	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
0847↓									
0859↓									
0909	9.7			9.7			9.7		
	9.7	9.70	0.000	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
0924	9.8			9.8			9.8		
	9.8	9.80	0.000	9.8	9.80	0.000	9.8	9.80	0.000
	9.8			9.8			9.8		
0939	9.8			9.8			9.8		
	9.8	9.80	0.000	9.8	9.80	0.000	9.8	9.80	0.000
	9.8			9.8			9.8		
0959	9.7			9.7			9.7		
	9.7	9.70	0.000	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
1029	9.7			9.6			9.6		
	9.7	9.66	0.033	9.6	9.60	0.000	9.6	9.60	0.000
	9.6			9.6			9.6		
1059	9.7			9.7			9.7		
	9.8	9.73	0.033	9.7	9.70	0.000	9.7	9.70	0.000
	9.7			9.7			9.7		
1129	9.5			9.5			9.5		
	9.5	9.50	0.000	9.5	9.50	0.000	9.5	9.50	0.000
	9.5			9.5			9.5		
1159	9.6			9.6			9.6		
	9.6	9.60	0.000	9.6	9.60	0.000	9.6	9.60	0.000
	9.6			9.6			9.6		

* One tow moving upstream and two tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.02.

APPENDIX E: SUSPENDED SOLIDS CONCENTRATIONS AND TURBIDITY DATA FOR THE ILLINOIS RIVER TOW TRAFFIC EVENTS

Table E1

Effect of Event 1* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Illinois River Sampled at River Mile 215.8 on 16 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x̄	SE+	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE
	46			18			24			17			32			20			44			18		
1323	47	47.6	1.20	17	15.6	1.85	28	27.0	1.52	14	15.6	0.88	34	35.6	2.72	15	17.0	1.52	44	44.6	0.33	16	17.3	0.88
	50			12			29			16			41			16			46			18		
1330+																								
	64			18			25			16			36			16			42			18		
1340	52	62.3	5.54	15	16.6	0.88	32	32.0	4.04	18	18.6	1.75	34	37.3	2.40	19	18.6	0.33	37	40.6	1.85	16	17.3	0.66
	71			17			39			22			42			19			43			18		
	58			23			32			16			37			20			48			18		
1355	56	56.6	0.66	16	19.0	2.08	32	31.3	0.66	16	15.6	0.33	32	35.3	1.66	19	19.0	0.57	41	42.0	3.21	20	19.6	0.88
	56			18			30			15			37			18			37			21		
	55			24			38			19			40			17			42			20		
1410	57	51.6	4.37	21	21.0	1.73	36	36.0	1.15	20	19.3	0.33	38	38.0	1.15	12	15.3	0.33	46	44.0	1.15	20	20.3	0.33
	43			18			34			19			36			17			44			21		
1418+																								
1428+																								
	51			20			35			19			35			19			47			22		
1438	60	59.3	4.63	21	19.6	0.88	33	35.3	1.45	17	18.3	0.66	42	40.3	2.72	21	20.0	0.57	47	47.0	0.00	20	21.0	0.57
	67			18			38			19			44			20			47			21		
	51			19			37			17			49			16			52			19		
1453	55	54.0	1.52	22	19.6	1.20	38	37.0	0.57	17	17.3	0.33	46	46.0	1.73	24	20.0	2.31	40	46.6	3.52	21	20.0	0.57
	56			18			36			18			43			20			48			20		
	53			23			39			15			33			18			48			19		
1508	50	51.3	0.88	20	21.0	1.00	38	36.0	2.51	15	15.0	0.00	40	36.6	2.02	17	18.3	0.88	47	49.6	2.18	22	19.6	1.33
	51			20			31			15			37			20			54			18		

(Continued)

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 6.60; for turbidity = 3.02.
* Three tows moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
\+ SE is standard error of the mean.

Table E1 (Concluded)

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
	42			19			42			17			41			20			44			19		
1528	55	51.3	4.70	21	20.0	0.57	33	39.6	3.38	17	17.6	0.66	42	42.0	0.57	20	20.0	0.00	45	45.0	0.57	20	19.0	0.66
	57			20			44			19			43			20			46			19		
	52			18			35			16			46			19			45			20		
1553	51	52.0	0.57	16	18.0	1.15	42	37.0	2.52	16	17.0	1.00	44	46.3	1.45	21	20.0	0.57	44	43.0	1.52	19	20.0	0.57
	53			20			34			19			49			20			40			21		
	51			19			39			15			44			20			44			21		
1628	48	50.6	1.45	17	18.3	0.66	36	34.6	2.96	16	15.3	0.33	51	46.6	2.19	27	22.6	2.18	42	43.3	0.66	20	21.0	0.57
	53			19			29			15			45			21			44			22		
	48			16			33			17			40			21			40			18		
1658	45	45.6	1.20	19	15.6	2.02	33	33.3	0.33	15	16.6	0.88	47	45.3	2.72	25	23.3	1.20	28	36.0	4.00	16	17.3	0.66
	44			12			34			18			49			24			40			18		
	41			16			38			17			42			17			36			21		
1728	40	41.6	1.20	14	15.0	0.57	37	37.3	0.33	19	17.0	1.15	36	40.0	2.00	16	16.3	0.33	35	37.0	1.52	18	19.0	1.00
	44			15			37			15			42			16			40			18		

Table E2

Effect of Event 2* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Illinois River Sampled at River Mile 215.8 on 17 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean $\bar{x}$	SE†	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
1007	27 30 30	29.0	1.00	18 15 15	16.0	1.00	23 27 26	25.0	1.52	9 11 11	10.3	0.66	24 26 26	25.3	0.66	14 13 14	13.6	0.33	32 32 29	31.0	1.00	13 12 12	12.3	0.33
1019↓																								
1029	52 52 59	54.3	2.33	15 13 13	13.6	0.66	30 31 36	32.3	1.85	14 13 12	13.0	0.57	33 36 36	35.0	1.00	17 16 15	16.0	0.57	35 36 34	35.0	0.57	16 15 15	15.3	0.33
1044	55 61 56	57.3	1.86	15 15 15	15.0	0.00	24 32 26	27.3	2.40	12 12 12	12.0	0.00	38 38 33	36.3	1.66	18 17 15	16.6	0.88	36 39 34	36.3	1.45	15 15 13	1[illegible].0	1.00
1059	53 54 49	52.0	1.52	13 14 15	14.0	0.57	34 31 35	33.3	1.20	15 16 14	15.0	0.57	30 34 30	31.6	1.20	15 24 15	18.0	3.00	31 33 31	31.6	0.66	14 14 16	14.6	0.33
1119	45 56 45	48.6	3.66	13 11 15	13.0	1.15	33 36 34	34.3	0.88	12 12 17	13.6	1.66	30 29 29	29.3	0.33	15 15 15	15.0	0.00	32 48 45	41.6	4.91	15 16 21	17.3	1.85
1134↓																								
1144	39 41 39	39.6	0.66	16 15 15	15.3	0.33	33 31 41	35.0	3.05	12 15 11	12.6	1.20	37 27 43	35.6	4.66	17 15 24	18.6	2.72	34 29 30	31.0	1.52	19 14 9	14.0	2.88
1159	30 32 27	33.0	2.08	13 14 15	14.0	0.57	37 34 34	35.0	1.00	15 15 12	14.0	1.00	32 27 40	33.0	3.78	15 15 17	15.6	0.66	39 34 38	37.0	3.78	12 14 15	13.6	0.88
1214	38 38 36	37.3	0.66	16 15 16	15.6	0.33	37 39 48	41.3	3.38	14 13 17	14.6	1.20	39 37 38	38.0	0.57	18 17 15	16.6	0.88	57 35 32	41.3	7.89	19 17 15	17.0	1.15
1216↑																								
1226	47 50 50	49.0	1.00	23 33 30	28.6	2.96	51 47 54	50.6	2.02	19 18 27	21.3	2.84	67 63 81	70.3	5.45	26 26 39	30.3	4.33	103 124 108	111.6	6.33	39 47 42	42.6	2.33
1241	44 38 41	41.0	1.73	32 24 25	27.0	2.51	69 63 57	63.0	3.46	32 28 27	29.0	1.52	62 55 54	57.0	2.51	28 23 24	25.0	1.52	60 60 66	62.0	2.00	22 25 27	24.6	1.45

(Continued)

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 6.52; for turbidity = 4.47.

* Four tows moving upstream and one tow moving downstream at times indicated in table.

** Arrow indicates time and direction of tow past sampling station.

† SE is standard error of the mean.

Table E2 (Concluded)

Time	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
1253*																								
	57			30			56			26			90			43			73			25		
1303	58	65.6	8.17	23	26.6	2.02	44	49.3	3.52	25	24.6	0.88	90	86.6	3.33	37	37.0	3.46	72	73.0	0.57	28	27.6	1.45
	82			27			48			23			80			31			74			30		
	54			27			47			24			75			32			74			25		
1318	63	58.0	2.64	26	26.0	0.57	51	49.0	1.15	24	24.0	0.00	83	78.3	2.40	32	32.0	0.00	68	69.6	2.18	24	23.6	0.88
	57			25			49			24			77			32			67			22		
	31			24			44			23			58			23			68			25		
1333	45	39.6	4.37	22	23.3	0.66	51	44.0	4.04	20	20.6	1.20	51	53.0	2.51	23	23.0	0.00	73	72.0	2.08	25	25.3	0.33
	43			24			37			19			50			23			75			26		
	42			22			42			18			69			27			77			35		
1353	48	47.0	2.64	23	21.6	0.88	39	40.3	0.88	20	19.0	0.57	68	67.3	1.20	30	27.0	1.73	61	65.6	5.69	26	28.3	3.38
	51			20			40			19			65			24			59			24		
1356*																								
	58			22			53			25			63			24			52			19		
1406	56	55.6	1.45	20	22.3	1.45	60	60.3	4.33	24	25.6	1.20	70	69.0	3.21	25	26.3	1.85	49	50.0	1.00	18	19.0	0.57
	53			25			68			28			74			30			49			20		
	44			21			58			23			71			20			50			21		
1421	43	43.6	0.33	18	20.3	1.20	51	50.0	4.93	20	20.0	1.73	61	62.6	4.40	24	21.3	1.33	44	48.6	2.40	21	22.0	1.00
	44			22			41			17			56			20			52			24		
	56			23			43			20			64			21			52			18		
1436	53	53.6	1.20	19	22.3	1.76	43	42.6	0.33	20	20.3	0.33	73	75.6	7.62	23	25.3	3.38	64	55.6	4.17	20	18.3	0.88
	52			25			42			21			90			32			51			17		
	41			19			39			20			48			18			46			19		
1456	40	39.6	0.88	18	19.0	0.57	43	39.0	2.30	18	18.6	0.66	53	82.6	32.19	18	23.3	5.33	45	51.0	5.50	16	15.3	2.33
	38			20			35			18			147			34			62			11		
	40			17			37			20			55			20			50			14		
1526	33	36.3	2.02	14	15.3	0.88	37	39.0	2.00	20	21.0	1.00	39	45.3	4.91	17	17.6	1.20	46	46.0	2.30	17	15.3	0.88
	36			15			43			23			42			16			42			15		
	41			15			43			21			34			12			44			15		
1556	40	40.3	0.33	19	17.0	1.15	40	42.6	1.45	22	21.0	0.57	39	36.0	1.52	22	17.0	2.88	46	47.3	2.40	17	17.3	1.45
	40			17			45			20			35			17			52			20		
	38			15			43			22			28			15			55			14		
1626	40	37.0	2.08	16	14.3	1.20	42	42.0	0.57	20	21.6	0.88	34	36.6	5.92	22	17.0	2.51	35	42.0	6.50	16	14.6	0.66
	33			12			41			23			48			14			36			14		
	27			14			40			19			35			17			35			15		
1656	34	30.6	2.02	15	14.6	0.33	37	40.0	1.73	20	19.6	0.33	30	31.3	1.85	17	16.3	0.66	35	34.6	0.33	15	15.3	0.33
	31			15			43			20			29			15			34			16		

Table E3

Effect of Event 3* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Illinois River Sampled at River Mile 113.5 on 19 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x̄	SE†	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE
1222	200 176 180	185.3	7.42	65 70 68	67.7	1.45	296 269 233	266.0	18.24	88 86 87	87.0	0.58	140 144 147	143.6	2.02	57 59 60	58.7	0.88	170 181 162	184.3	18.47	68 72 70	70.0	1.15
1231↓																								
1241	238 213 237	229.3	8.17	82 71 74	75.7	3.28	260 278 270	269.3	5.207	74 72 76	74.0	1.15	260 200 170	210.0	26.46	81 72 74	75.7	2.73	162 182 153	165.6	[illegible]	74 70 72	72.0	1.15
1256	306 245 220	257.0	25.54	80 91 82	84.3	3.38	243 314 339	298.6	28.76	74 72 76	74.0	1.15	158 175 130	154.3	13.12	69 64 64	65.7	1.7	172 166 154	164.0	5.30	76 69 70	71.7	2.13
1311	256 266 274	265.3	5.207	76 91 80	82.3	4.48	250 240 285	258.3	13.70	79 77 76	77.3	0.88	148 129 139	138.6	5.49	65 63 65	64.3	0.67	158 151 159	156.0	2.51	68 60 66	64.7	2.40
1331	240 211 208	219.6	10.203	86 81 84	83.7	1.45	268 243 256	255.6	7.21	82 84 86	84.0	1.15	170 154 136	153.3	9.90	71 70 73	71.3	0.88	163 250 168	193.6	28.203	76 81 72	76.3	2.60
1401	179 196 200	191.6	6.43	85 81 88	84.7	2.03	220 228 251	233.0	9.30	75 79 72	75.3	2.03	135 130 135	133.3	1.66	65 63 64	64.0	0.58	122 163 130	138.3	12.54	67 66 63	65.3	1.20
1431	202 184 196	194.0	5.30	89 64 58	70.3	9.49	208 225 215	216.0	5.00	72 76 71	73.0	1.53	156 144 140	146.6	4.80	69 66 63	66.0	1.73	145 280 178	201.0	41.00	184 185 186	185.0	0.58
1501	184 168 182	178.0	5.03	68 70 27	55.0	14.01	220 200 212	210.6	5.81	82 80 86	82.7	1.76	138 127 145	136.6	5.23	63 64 65	64.0	0.58	182 117 110	136.3	23.00	187 188 189	188.0	0.58
1509↑																								
1519	198 193 138	176.3	19.22	64 68 66	66.0	1.15	225 243 261	243.0	10.40	75 74 80	76.3	1.86	163 168 175	168.6	3.50	70 73 73	72.0	1.00	145 162 157	156.0	6.70	72 72 71	71.7	0.33
1534	313 350 232	298.3	34.90	78 74 76	76.0	1.15	283 278 273	278.0	2.90	79 77 80	78.7	0.88	221 219 225	221.6	1.76	75 76 72	74.3	1.20	155 170 190	171.6	10.14	74 71 85	76.7	4.26

(Continued)

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 37.62; for turbidity = 7.76.
* One tow moving downstream and one tow moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table E3 (Concluded)

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE	mg/ℓ	Mean $\bar{x}$	SE	Units	Mean $\bar{x}$	SE
	230			69			285			76			218			82			173			77		
1549	225	223.3	4.41	74	70.3	1.86	283	252.0	32.005	79	76.3	1.45	192	205.6	7.53	76	81.7	3.18	178	175.6	1.45	73	74.0	1.53
	215			68			188			74			207			87			176			72		
	195			71			290			81			177			71			194			74		
1609	203	204.3	5.81	72	72.3	0.88	268	277.0	6.70	79	78.7	1.45	181	183.6	4.90	73	71.7	0.67	211	204.3	5.23	79	75.0	2.08
	215			74			273			76			193			71			208			72		
	190			69			215			80			200			70			166			64		
1639	195	194.3	2.33	75	69.3	3.18	248	232.6	9.60	82	80.0	1.15	195	182.6	15.00	61	66.7	2.85	161	161.6	2.33	66	64.0	1.15
	198			64			235			78			153			69			158			62		
	175			66			198			80			144			65			150			68		
1709	173	172.6	1.45	62	64.7	1.33	215	215.3	10.105	84	80.7	1.76	138	154.0	13.11	60	63.0	1.53	140	142.6	3.71	62	64.0	2.00
	170			66			233			78			180			64			138			62		
	165			58			204			80			144			64			137			60		
1739	230	197.6	18.80	56	58.7	1.76	211	204.0	4.04	82	81.0	0.58	162	149.6	6.18	69	66.0	1.53	139	138.0	0.05	65	63.3	1.67
	198			62			197			81			143			65			138			65		
	198			66			214			84			126			62			132			63		
1809	178	190.3	6.22	58	62.0	2.31	175	187.6	13.17	88	86.0	1.15	131	131.3	3.18	61	61.3	0.33	140	137.3	2.66	59	61.7	1.33
	195			62			174			86			137			61			140			63		

Table E4

Effect of Event 4* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Illinois River Sampled at River Mile 113.5 on 20 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x	SE†	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
1255	180 140 145	155.0	12.58	79 71 72	74.0	2.52	102 105 114	107.0	3.61	56 51 54	53.7	1.45	115 112 118	115.0	1.73	57 55 53	55.0	1.15	119 168 151	146.0	14.36	55 59 64	59.3	2.60
1306↑																								
1316	345 323 245	304.3	30.34	140 120 120	126.7	6.67	160 176 200	178.7	11.62	66 70 85	73.7	5.78	182 185 185	184.0	1.00	79 83 73	78.3	2.91	194 202 200	198.7	2.40	65 62 68	65.0	1.73
1331	343 290 220	284.3	35.62	100 100 100	100.0	0.00	204 204 192	200.0	4.00	73 75 73	73.7	0.67	183 183 198	188.0	5.00	73 72 75	73.3	0.88	242 232 216	230.0	7.57	58 64 68	63.3	2.91
1346	290 309 328	309.0	10.97	93 110 100	101.0	4.93	225 238 232	231.7	42.33	78 90 80	82.7	3.71	178 192 200	190.0	6.43	76 81 85	80.7	2.60	186 200 174	186.7	7.51	65 64 66	65.7	1.20
1406	273 282 254	269.7	8.25	110 89 85	94.7	7.75	218 238 233	229.7	6.01	73 84 77	78.0	3.21	120 204 210	178.0	29.05	83 88 85	85.3	1.45	224 230 250	234.7	7.86	72 76 80	76.0	2.31
1409↑																								
1419	354 298 338	330.0	16.65	110 110 110	110.0	0.00	185 185 190	186.7	1.67	75 75 74	74.7	0.33	230 208 202	213.3	8.51	94 99 92	95.0	2.08	248 214 222	228.0	10.26	73 75 70	72.7	1.45
1434	279 286 337	300.7	18.28	91 97 120	102.7	8.84	165 115 173	151.0	18.15	82 78 82	80.7	1.33	214 231 212	219.0	6.03	83 83 88	84.7	1.67	264 256 228	249.3	10.91	66 72 76	72.0	2.31
1449	237 229 230	232.0	2.52	93 91 92	92.0	0.58	168 158 140	155.3	8.19	71 71 66	69.3	1.67	285 297 276	286.0	6.08	100 89 86	91.7	4.26	254 242 250	248.7	3.53	80 76 78	78.0	1.15
1501↓																								
1511	227 224 205	218.7	6.89	85 79 80	81.3	1.86	133 148 148	143.0	5.00	65 66 67	66.0	0.58	226 226 255	235.7	9.67	84 87 79	83.3	2.33	234 232 228	231.3	1.76	92 87 88	89.0	1.53
1520↓																								

(Continued)

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 36.27; for turbidity = 9.43.
* Two tows moving upstream and two tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table 24 (Concluded)

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time	mg/l	Mean x	SE	Units	Mean x	SE	mg/l	Mean x	SE	Units	Mean x	SE	mg/l	Mean x	SE	Units	Mean x	SE	mg/l	Mean x	SE	Units	Mean x	SE
	288			110			95			69			230			81			224			70		
1530	362	321.0	21.73	120	113.3	3.33	178	142.7	24.74	85	79.3	5.17	216	225.3	4.67	82	83.0	1.53	216	225.3	5.61	74	71.0	1.53
	313			110			155			84			230			86			236			69		
	490			116			460			160			356			79			256			78		
1545	445	448.3	23.15	160	153.3	6.67	432	436.3	12.60	140	150.0	5.77	344	353.3	4.81	81	81.0	1.15	294	269.3	12.35	74	74.7	1.76
	410			140			417			150			360			83			258			72		
	417			150			298			120			284			99			242			79		
1600	380	384.0	18.01	140	140.0	5.77	263	277.0	10.69	120	120.0	0.00	260	306.3	35.03	97	102.0	4.04	290	268.7	14.11	80	78.0	1.53
	355			130			270			120			375			110			274			75		
	280			120			158			75			182			70			238			65		
1620	312	286.3	13.37	115	115.0	2.89	160	159.3	0.67	71	72.3	1.33	230	2 0.3	14.33	70	71.0	1.00	212	228.0	8.08	68	65.7	1.20
	267			110			160			71			195			73			234			64		
	245			110			180			89			162			76			154			56		
1650	223	225.7	10.48	120	106.3	9.13	148	160.0	10.07	95	86.7	5.61	171	172.7	6.69	77	77.0	0.58	164	152.7	6.96	52	53.7	1.20
	209			89			152			76			185			78			140			53		
	186			89			125			66			156			84			208			58		
1720	198	194.7	4.37	80	83.0	3.00	148	132.7	7.67	60	63.7	1.86	137	149.7	6.33	84	85.3	1.33	160	176.0	16.00	62	57.7	2.60
	200			80			125			65			156			88			160			53		
	148			65			145			55			141			79			142			48		
1750	158	156.7	4.67	79	73.3	4.26	150	145.0	25.00	55	54.3	0.67	153	138.7	9.03	81	77.7	5.78	138	142.0	2.31	56	51.0	2.52
	164			76			140			53			122			73			146			49		

Table E5

Effect of Event 5* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Illinois River Sampled at River Mile 31.0 on 31 October 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x	SE†	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
1035	127 110 147	128.0	10.69	55 55 63	57.7	2.67	102 104 103	103.0	0.58	46 47 46	46.3	0.33	140 131 134	135.0	2.65	52 50 53	51.7	0.88	127 124 134	128.3	2.96	56 58 55	56.3	0.88
1119↓																								
1129	138 125 124	129.0	4.51	58 55 55	56.0	1.00	91 92 102	95.0	3.51	45 46 44	45.0	1.00	144 137 134	138.3	2.96	53 53 53	53.0	0.00	126 127 127	126.7	0.33	54 55 53	54.0	0.58
1144	180 117 132	143.0	19.00	57 55 55	55.7	0.67	138 94 96	109.3	14.35	45 44 43	44.0	0.58	141 142 132	138.3	3.18	56 55 53	54.7	0.88	171 135 129	126.3	4.06	54 54 56	54.7	0.67
1159	146 165 163	158.0	6.03	64 68 73	68.3	2.60	84 90 93	89.0	2.65	45 43 42	43.3	0.88	122 120 147	129.7	8.69	53 53 54	53.3	0.33	144 159 150	151.0	4.36	58 60 81	66.33	7.36
1219	142 140 132	138.0	3.06	63 66 64	64.3	0.88	77 93 76	82.0	5.51	40 42 41	41.0	0.58	131 150 140	140.3	5.46	54 54 55	54.3	0.33	165 129 128	140.7	12.17	58 54 53	55.0	1.53
1249	160 134 146	147.7	7.51	68 55 58	60.3	3.93	88 85 85	86.0	1.00	40 40 40	40.0	0.00	129 147 130	135.3	5.84	55 52 53	53.3	0.88	138 138 140	138.7	0.67	56 58 56	56.7	0.67
1303↓																								
1313	155 174 175	168.0	6.51	60 67 66	64.3	2.19	97 97 109	101.0	4.00	43 43 45	43.7	0.67	138 147 133	139.3	4.10	52 52 54	52.7	0.67	132 134 122	129.3	3.71	55 55 55	55.0	0.00
1328	175 168 163	168.7	3.48	65 66 63	64.7	0.88	100 82 103	95.0	6.56	43 42 43	42.7	0.33	131 137 143	137.0	3.46	54 53 52	53.0	0.58	144 140 137	140.3	2.03	59 57 55	57.0	1.15
1336↓																								
1346	162 147 148	152.3	4.84	66 62 60	62.7	1.76	99 102 95	98.7	2.03	43 44 48	45.0	1.53	149 165 163	159.0	5.03	54 57 55	55.3	0.88	125 130 128	127.7	1.45	57 58 61	58.7	1.20
1401	157 142 160	153.0	5.57	62 60 62	61.3	0.67	104 101 109	104.7	2.33	45 43 44	44.0	0.58	171 173 170	171.3	0.88	53 60 58	57.0	2.08	114 118 123	118.3	2.60	57 53 55	55.0	1.15

(Continued)

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 14.99; for turbidity = 4.99.
* Three tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table E5 (Concluded)

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
	145			55			100			43			137			55			128			[illegible]		
1416	146	145.0	0.58	57	54.7	1.45	106	102.0	2.00	46	45.7	1.45	137	137.3	0.33	53	53.7	0.67	134	134.0	3.46	[illegible]	[illegible]	[illegible]
	144			52			100			48			138			53			140			[illegible]		
	139			55			97			44			123			52			119			[illegible]		
1436	140	139.0	0.58	55	55.0	0.00	104	97.7	3.48	44	43.7	0.33	129	129.0	3.46	53	54.7	2.19	[illegible]	119.7	1.20	[illegible]	[illegible]	[illegible]
	138			55			92			43			135			59			118			[illegible]		
	132			65			101			43			139			80			[illegible]			[illegible]		
1506	126	129.0	1.73	62	61.7	2.03	95	98.3	1.76	43	43.0	0.00	139	136.3	2.67	63	67.7	6.33	119	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	129			58			99			43			131			60			[illegible]			[illegible]		
	116			53			108			44			124			57			117			[illegible]		
1536	119	120.3	2.96	53	53.0	0.00	106	105.3	1.76	43	43.3	0.33	113	117.7	3.28	54	55.7	[illegible]	121	114.0	[illegible]	[illegible]	[illegible]	[illegible]
	126			53			102			43			116			56			104			[illegible]		
	124			54			93			40			127			55			124			[illegible]		
1606	124	120.7	3.33	52	53.0	0.58	97	96.7	2.03	42	41.3	0.67	117	132.0	10.41	56	59.3	3.84	124	122.3	1.67	[illegible]	[illegible]	[illegible]
	114			53			100			42			152			67			119			[illegible]		

Table E6

Effect of Event 6* (Multiple Tow) on Suspended Solids Concentration and Turbidity

Illinois River Sampled at River Mile 31.0 on 2 November 1975

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time**	mg/ℓ	Mean x	SE†	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE	mg/ℓ	Mean x	SE	Units	Mean x	SE
0810	98 100 101	99.6	0.88	48 48 48	48.0	0.00	89 93 93	91.6	1.33	43 44 43	43.3	0.33	127 112 105	114.6	6.48	50 48 48	48.6	0.66	95 75 82	84.0	5.86	50 47 50	49.0	1.00
0831†																								
0841	115 100 118	111.0	5.57	51 48 48	49.0	1.00	84 89 97	90.0	3.79	43 42 42	42.3	0.33	110 116 108	111.3	2.40	48 50 45	47.6	1.45	97 99 92	96.0	2.08	52 52 50	51.3	0.66
0856	113 107 114	111.3	2.19	52 49 48	49.6	1.20	89 85 92	88.6	2.02	40 41 41	40.6	0.33	98 105 102	101.6	2.02	48 46 48	47.3	0.66	91 79 84	84.6	3.50	48 48 50	48.6	0.66
0905↓																								
0915	115 121 122	119.3	2.18	53 53 54	53.3	0.33	92 85 83	86.6	2.72	39 42 41	40.6	0.88	110 103 103	105.3	2.33	48 48 49	48.3	0.33	101 91 91	94.3	3.33	53 50 49	50.6	1.20
0930	113 115 141	123.0	9.01	53 52 63	56.0	3.51	80 88 88	85.3	2.66	40 44 45	43.0	1.52	113 143 126	127.3	8.69	[illegible] 54 54	52.3	1.66	95 100 85	93.3	4.40	50 48 48	48.6	0.66
0945	109 115 111	111.6	1.76	49 49 52	50.0	1.00	86 85 82	84.3	1.20	44 39 40	41.0	1.52	103 98 110	103.6	3.50	49 48 46	47.6	0.88	98 97 95	96.6	0.88	52 52 49	51.0	1.00
1006	115 144 158	139.0	12.67	48 66 65	59.6	5.84	84 84 82	83.3	0.66	40 38 42	40.0	1.15	95 116 115	108.6	6.84	49 53 51	51.0	1.15	112 108 103	107.6	2.60	50 53 51	51.3	0.88
1031↓																								
1041	122 126 110	119.3	4.80	63 52 48	54.3	4.48	84 91 88	87.6	2.02	43 40 43	42.0	1.00	102 102 105	103.0	1.00	44 46 45	45.0	0.57	101 92 97	96.6	2.60	53 49 49	50.3	1.33
1056	108 99 113	106.6	4.09	50 51 47	49.3	1.20	89 96 92	92.3	2.02	44 42 42	42.6	0.66	103 108 98	103.0	2.90	48 47 47	47.3	0.33	87 86 88	87.0	0.05	48 44 42	44.6	1.76
1111	103 103 90	98.6	4.33	47 44 44	45.0	1.00	102 93 93	96.0	3.00	47 45 42	44.6	1.45	97 102 98	99.0	1.53	48 48 48	48.0	0.00	101 101 99	100.3	0.66	45 43 42	43.3	0.88

(Continued)

Note: For all habitats, Least Significant Difference (LSD) for suspended solids = 12.02; for turbidity = 4.05.
* Two tows moving upstream and two tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† SE is standard error of the mean.

Table E6 (Concluded)

	Main Channel						Right Bank						Left Bank						Side Channel					
	Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity			Suspended Solids			Turbidity		
Time	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE	mg/ℓ	Mean x̄	SE	Units	Mean x̄	SE
1131	117 117 118	117.3	0.33	50 50 50	50.0	0.00	93 97 94	94.6	1.20	45 46 46	45.6	0.33	93 97 95	95.0	1.15	46 47 46	46.3	0.33	109 112 115	112.0	1.73	44 47 46	45.6	[illegible]
1149*																								
1159	100 123 126	116.3	8.21	48 50 53	50.3	1.45	86 87 83	85.3	1.20	44 44 44	44.0	0.00	103 103 105	103.6	0.66	48 49 49	48.6	0.33	119 113 114	115.3	1.85	47 49 50	48.6	0.33
1214	103 106 113	107.3	2.96	47 44 54	48.3	2.96	86 88 98	90.6	3.71	44 44 44	44.0	0.00	103 97 102	100.6	1.85	48 49 49	48.6	0.33	123 124 119	122.0	1.53	48 43 46	45.6	1.45
1226	146 118 104	122.6	12.34	57 48 47	50.6	3.17	95 95 95	95.0	0.00	43 48 45	45.3	1.45	105 112 108	108.3	2.02	50 51 48	49.6	0.88	117 118 113	116.0	1.53	45 45 46	45.3	0.33
1249	109 135 101	115.0	10.26	46 53 47	48.6	2.18	114 105 107	108.6	2.72	48 45 48	47.0	1.00	114 112 128	118.0	5.03	50 51 52	51.0	0.57	121 97 123	113.6	8.35	45 45 46	45.3	0.33
1319	104 87 88	93.0	5.50	45 45 46	45.3	0.33	118 114 108	113.3	2.90	50 46 47	47.6	1.20	137 133 132	134.0	1.53	54 54 53	53.6	0.33	154 168 155	159.0	4.50	53 58 54	55.0	1.57
1349	100 95 106	100.3	3.18	45 43 43	43.6	0.66	108 105 112	108.3	2.02	48 45 47	46.6	0.88	123 113 111	115.6	3.71	51 52 53	52.0	0.57	131 128 117	125.3	4.30	44 44 45	44.3	0.33

APPENDIX F: DISSOLVED OXYGEN CONCENTRATIONS DATA FOR THE ILLINOIS RIVER TOW TRAFFIC EVENTS

Table F1

Effect of Event 1* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Illinois River Sampled at River Mile 215.8 on 16 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.6 m)			Bottom (Depth = 3.3 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1323	8.3			8.2			8.2		
	8.3	8.30	0.000	8.2	8.20	0.000	8.2	8.20	0.000
	8.3			8.2			8.2		
1330↑									
1340	8.2			8.1			8.2		
	8.2	8.20	0.000	8.1	8.10	0.000	8.2	8.20	0.000
	8.2			8.1			8.2		
1355	8.2			8.2			8.2		
	8.2	8.20	0.000	8.2	8.20	0.000	8.2	8.20	0.000
	8.2			8.2			8.2		
1410	8.3			8.3			8.3		
	8.3	8.30	0.000	8.3	8.30	0.000	8.3	8.30	0.000
	8.3			8.3			8.3		
1418↑									
1428↑									
1438	8.4			8.3			8.4		
	8.4	8.40	0.000	8.3	8.30	0.000	8.4	8.40	0.000
	8.4			8.3			8.4		
1453	8.4			8.3			8.4		
	8.4	8.40	0.000	8.3	8.30	0.000	8.4	8.40	0.000
	8.4			8.3			8.4		
1508	8.5			8.5			8.5		
	8.5	8.50	0.000	8.5	8.50	0.000	8.5	8.50	0.000
	8.5			8.5			8.5		
1528	8.6			8.6			8.6		
	8.6	8.60	0.000	8.6	8.60	0.000	8.6	8.60	0.000
	8.6			8.6			8.6		
1558	8.6			8.7			8.7		
	8.6	8.60	0.000	8.7	8.70	0.000	8.7	8.70	0.000
	8.6			8.7			8.7		
1628	8.7			8.6			8.6		
	8.7	8.71	0.000	8.6	8.60	0.000	8.6	8.60	0.000
	8.7			8.6			8.6		
1658	8.8			8.8			8.8		
	8.8	8.80	0.000	8.8	8.80	0.000	8.8	8.80	0.000
	8.8			8.8			8.8		
1728	8.8			8.9			8.8		
	8.8	8.80	0.000	8.9	8.90	0.000	8.8	8.80	0.000
	8.8			8.9			8.8		

* Three tows moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.00.

Table F2

Effect of Event 2* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Illinois River Sampled at River Mile 215.8 on 17 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.6 m)			Bottom (Depth = 3.3 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1007	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000
1019↑									
1029	8.0 8.0 8.0	8.00	0.000	8.0 8.0 8.0	8.00	0.000	8.1 8.1 8.1	8.10	0.000
1044	8.0 8.0 8.0	8.00	0.000	8.0 8.0 8.0	8.00	0.000	8.0 8.0 8.0	8.00	0.000
1059	8.1 8.1 8.1	8.11	0.000	8.1 8.1 8.0	8.06	0.033	8.1 8.1 8.1	8.10	0.000
1119	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.1 8.1 8.1	8.10	0.000
1134↑									
1144	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000
1159	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1214	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1216↓									
1226	8.1 8.1 8.1	8.10	0.000	8.0 8.0 8.0	8.00	0.000	8.0 8.0 8.0	8.00	0.000
1241	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000	8.2 8.2 8.2	8.20	0.000
1253↑									
1303	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000
1318	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000
1333	8.4 8.4 8.4	8.40	0.000	8.4 8.4 8.4	8.40	0.000	8.4 8.4 8.4	8.40	0.000
1353	8.4 8.4 8.4	8.40	0.000	8.4 8.4 8.4	8.40	0.000	8.4 8.4 8.4	8.40	0.000
1356↑									
1406	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000
1421	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000

(Continued)

* Four tows moving upstream and 1 tow moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.008.

Table F2 (Concluded)

	Dissolved Oxygen Content, mg/ℓ+								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.6 m)			Bottom (Depth = 3.3 m)		
Time	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1436	8.4 8.4 8.4	8.40	0.000	8.4 8.4 8.4	8.40	0.000	8.4 8.4 8.4	8.40	0.000
1456	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000	8.5 8.5 8.5	8.50	0.000
1526	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000
1556	8.7 8.7 8.7	8.70	0.000	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000
1626	8.7 8.7 8.7	8.70	0.000	8.7 8.7 8.7	8.70	0.000	8.7 8.7 8.7	8.70	0.000
1656	8.6 8.6 8.6	8.60	0.000	8.7 8.7 8.6	8.68	0.016	8.6 8.6 8.6	8.60	0.000

Table F3

Effect of Event 3* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Illinois River Sampled at River Mile 113.5 on 19 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.8 m)			Bottom (Depth = 3.6 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1222	8.3			8.2			8.2		
	8.3	8.30	0.000	8.2	8.23	0.017	8.2	8.20	0.000
	8.3			8.2			8.2		
1231↓									
1241	8.4			8.4			8.3		
	8.4	8.40	0.000	8.4	8.40	0.000	8.3	8.33	0.017
	8.4			8.4			8.3		
1256	8.4			8.3			8.2		
	8.4	8.40	0.000	8.3	8.35	0.000	8.2	8.20	0.000
	8.4			8.3			8.2		
1311	8.6			8.4			8.3		
	8.5	8.51	0.017	8.4	8.45	0.000	8.3	8.35	0.000
	8.5			8.4			8.3		
1331	8.5			8.5			8.5		
	8.5	8.53	0.017	8.5	8.50	0.000	8.5	8.50	0.000
	8.5			8.5			8.5		
1401	8.7			8.6			8.5		
	8.7	8.70	0.000	8.6	8.60	0.000	8.5	8.55	0.000
	8.7			8.6			8.5		
1431	8.6			8.5			8.5		
	8.6	8.60	0.000	8.5	8.55	0.000	8.5	8.50	0.000
	8.6			8.5			8.5		
1501	8.6			8.6			8.5		
	8.6	8.60	0.000	8.6	8.60	0.000	8.5	8.50	0.000
	8.6			8.6			8.5		
1509↑									
1519	8.8			8.6			8.6		
	8.8	8.78	0.017	8.6	8.60	0.000	8.6	8.60	0.000
	8.7			8.6			8.6		
1534	8.6			8.6			8.6		
	8.6	8.65	0.000	8.6	8.61	0.167	8.6	8.60	0.000
	8.6			8.6			8.6		
1549	8.7			8.6			8.6		
	8.7	8.70	0.000	8.6	8.65	0.000	8.6	8.65	0.000
	8.7			8.6			8.6		
1609	8.8			8.7			8.7		
	8.8	8.80	0.000	8.7	8.70	0.000	8.7	8.70	0.000
	8.8			8.7			8.7		
1639	8.9			8.9			8.8		
	8.9	8.90	0.000	8.9	8.90	0.000	8.8	8.80	0.000
	8.9			8.9			8.8		
1709	8.8			8.7			8.7		
	8.8	8.80	0.000	8.7	8.70	0.000	8.7	8.70	0.000
	8.8			8.7			8.7		
1739	8.8			8.8			8.8		
	8.8	8.80	0.000	8.8	8.80	0.000	8.8	8.80	0.000
	8.8			8.8			8.8		
1809	8.9			8.8			8.7		
	8.9	8.86	0.033	8.8	8.80	0.000	8.7	8.75	0.000
	8.8			8.8			8.7		

* One tow moving downstream and one tow moving upstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.02.

Table F4

Effect of Event 4* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Illinois River Sampled at River Mile 113.5 on 20 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.8 m)			Bottom (Depth = 3.6 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1255	8.5 8.5 8.5	8.50	0.000	8.5 8.4 8.4	8.43	0.033	8.4 8.4 8.4	8.40	0.000
1306↑									
1316	8.3 8.3 8.3	8.30	0.000	8.4 8.4 8.3	8.39	0.006	8.4 8.4 8.4	8.40	0.000
1331	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000
1346	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000
1406	8.7 8.7 8.7	8.70	0.000	8.6 8.6 8.6	8.60	0.000	8.5 8.5 8.5	8.50	0.000
1409↑									
1419	8.6 8.5 8.5	8.53	0.033	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000
1434	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000
1449	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000	8.6 8.6 8.6	8.60	0.000
1501↓									
1511	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000	8.5 8.5 8.5	8.50	0.000
1520↓									
1530	8.5 8.5 8.5	8.50	0.000	8.5 8.6 8.6	8.56	0.033	8.6 8.6 8.6	8.60	0.000
1545	8.7 8.7 8.7	8.70	0.000	8.7 8.7 8.7	8.70	0.000	8.7 8.7 8.7	8.70	0.000
1600	8.8 8.8 8.8	8.80	0.000	8.7 8.7 8.7	8.70	0.000	8.7 8.7 8.7	8.70	0.000
1620	8.8 8.8 8.8	8.80	0.000	8.7 8.7 8.7	8.70	0.000	8.7 8.7 8.7	8.70	0.000
1650	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000
1720	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000
1750	8.9 8.9 8.9	8.90	0.000	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000

* Two tows moving upstream and two tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.023.

Table F5

Effect of Event 5* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Illinois River Sampled at River Mile 31.0 on 31 October 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.6 m)			Bottom (Depth = 3.2 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
1035	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000
1119↓									
1129	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000
1144	8.4 8.4 8.4	8.40	0.000	8.4 8.4 8.4	8.40	0.000	8.3 8.3 8.3	8.30	0.000
1159	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000	8.3 8.3 8.3	8.30	0.000
1219	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1249	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1303↓									
1313	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1328	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1336↓									
1346	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000
1401	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000	8.1 8.1 8.1	8.10	0.000
1416	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1436	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1506	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1536	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000
1606	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000	8.2 8.2 8.2	8.20	0.000

* Three tows moving downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.00.

Table F6

Effect of Event 6* (Multiple Tow) on Dissolved Oxygen Content in Main Channel Habitat

Illinois River Sampled at River Mile 31.0 on 2 November 1975

	Dissolved Oxygen Content, mg/ℓ†								
	Surface (Depth = 0.1 m)			Middle (Depth = 1.5 m)			Bottom (Depth = 2.9 m)		
Time**	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean	Measurement	Mean, $\bar{x}$	Std Error of Mean
0810	8.7 8.7 8.8	8.733	0.033	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000
0831↑									
0841	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000
0856	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000
0905↓									
0915	8.9 8.9 8.9	8.90	0.000	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000
0930	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000
0945	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000
1005	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000	8.8 8.8 8.8	8.80	0.000
1031↓									
1041	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000
1056	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000
1111	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000	8.9 8.9 8.9	8.90	0.000
1131	9.1 9.1 9.1	9.10	0.000	9.0 9.0 9.0	9.00	0.000	9.0 9.0 9.0	9.00	0.000
1149↑									
1159	9.1 9.1 9.1	9.10	0.000	9.0 9.0 9.0	9.00	0.000	9.0 9.0 9.0	9.00	0.000
1214	9.1 9.1 9.1	9.10	0.000	9.0 9.0 9.0	9.00	0.000	9.0 9.0 9.0	9.00	0.000
1229	9.2 9.2 9.2	9.20	0.000	9.1 9.1 9.1	9.10	0.000	9.1 9.1 9.1	9.10	0.000
1249	9.1 9.1 9.1	9.10	0.000	9.1 9.1 9.1	9.10	0.000	9.1 9.1 9.1	9.10	0.000
1319	9.1 9.1 9.1	9.10	0.000	9.1 9.1 9.1	9.10	0.000	9.1 9.1 9.1	9.10	0.000
1349	9.2 9.2 9.2	9.20	0.000	9.2 9.2 9.2	9.20	0.000	9.2 9.2 9.2	9.20	0.000

* Two tows upstream and two tows downstream at times indicated in table.
** Arrow indicates time and direction of tow past sampling station.
† Least Significant Difference (LSD) = 0.01.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Johnson, Jeffrey H

Effects of tow traffic on the resuspension of sediments and on dissolved oxygen concentrations in the Illinois and Upper Mississippi Rivers under normal pool conditions, by Jeffrey H. Johnson. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.

1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report Y-76-1)

Prepared for U. S. Army Engineer District, St. Louis, St. Louis, Missouri.

Includes bibliography.

1. Dissolved oxygen. 2. Illinois River. 3. Mississippi River. 4. Sediment transport. 5. Suspended sediments. 6. Towing. I. U. S. Army Engineer District, St. Louis. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report Y-76-1)

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