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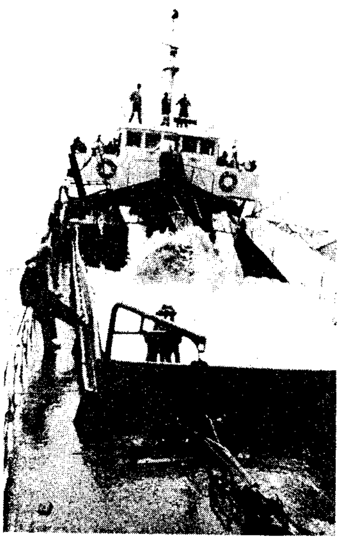
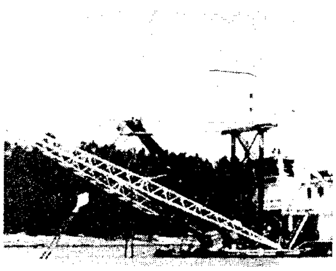
MISCELLANEOUS PAPER EL-88-1

# DEMONSTRATIONS OF INNOVATIVE AND CONVENTIONAL DREDGING EQUIPMENT AT CALUMET HARBOR, ILLINOIS





by

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As part of a larger effort to evaluate dredging and disposal options of contaminated material at Indiana Harbor, Indiana, field demonstrations were conducted at Calumet Harbor, Illinois, to evaluate the water quality impacts of different dredging and disposal equipment. This report documents the Calumet Harbor field study and presents the results. The dredging equipment evaluations were conducted to evaluate the sediment resuspension characteristics of a cutterhead suction dredge, clamshell dredge, and Dutch-designed matchbox suction head dredge. The Calumet Harbor demonstration represents the first use of the matchbox suction head in this country. The disposal equipment demonstration included the use of a submerged diffuser designed to place material close to the bottom and reduce the exit velocities.

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The Calumet Harbor demonstration indicated that the clamshell dredge generated the largest suspended sediment plume affecting the entire water column. The cutterhead and matchbox dredges were successful in limiting sediment resuspension to the lower portion of the water column with the cutterhead slightly outperforming the matchbox. Improved instrumentation and increased operator experience with the matchbox suction head dredge may help in further reducing sediment resuspension. The submerged diffuser proved to be successful in limiting sediment resuspension to the lower portion of the water column and significantly reducing discharge velocities.

CONTENTS

# DEMONSTRATIONS OF INNOVATIVE AND CONVENTIONAL DREDGING EQUIPMENT AT CALUMET HARBOR, ILLINOIS

## PART I: INTRODUCTION

### Background

1. Indiana Harbor, located in East Chicago, Ind., has been scheduled for maintenance dredging. However, two reaches, with dredging requirements totaling 200,000 cu yd* of sediment, have been identified as having elevated levels of polychlorinated biphenyls (PCBs) and other contaminants. Because of these elevated levels, studies were proposed to identify alternative dredging and dredged material disposal techniques for this material. The US Army Engineer Waterways Experiment Station (WES) in cooperation with the US Army Engineer District, Chicago (CD), has evaluated several alternatives for the dredging and disposal of this material. The results of these evaluations are given in "Disposal Alternatives for PCB-Contaminated Sediments from Indiana Harbor, Indiana" (Environmental Laboratory 1986). This report describes field studies designed to evaluate selected dredging and dredged material disposal equipment and techniques. The results of these studies were used to augment and support evaluations and recommendations in the report.

2. In an investigation of PCB-laden sediments, Fulk, Gruber, and Wullschleger (1975) found that almost all of the contaminant transfer from the sediment into the water column resulted from the resuspension of solids. When contaminated sediments are disturbed, as in dredging operations, contaminants may be released into the water column either by dispersal of interstitial water or desorption from the resuspended solids. The contaminant release can, therefore, be reduced by reducing sediment resuspension during the dredging and disposal operations.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

## Purpose of Field Studies

3. Selection of the proper dredging equipment for any project includes analysis of the characteristics and quantity of material, distance to and type of disposal, dredging depth, level of contamination, and several other factors. Several different alternative types of dredges may be suitable for removing the contaminated Indiana Harbor sediments; these dredges fall into three broad categories: hydraulic, mechanical, and special purpose dredges. As part of the larger effort to evaluate dredging and disposal options of contaminated material at Indiana Harbor, field demonstrations were conducted at Calumet Harbor, Illinois. The purposes of these field studies were to evaluate the sediment resuspension potential of conventional dredges and special equipment that may feasibly be used in the Indiana Harbor dredging project. These evaluations provided data for use in selecting appropriate dredging equipment and related operational controls. Limited data were also collected on contaminant release during dredging, which will be analyzed and presented in a later document. The dredge plants monitored during the Calumet Harbor field studies included a clamshell bucket, a cutterhead suction dredge, and a matchbox suction head dredge. The matchbox suction head was designed by Volker Stevin Dredging Company of Rotterdam and Bean Dredging Company of New Orleans. The field studies also provided an opportunity to evaluate the performance of a submerged diffuser for subaqueous placement of fine-grained dredged material. Data from the submerged diffuser demonstration were used in the evaluation of the contained aquatic disposal (CAD) alternative for the Indiana Harbor sediments.

## Application of Results

4. The demonstrations were carried out in Calumet Harbor, which is north of Indiana Harbor on Lake Michigan (Figure 1). Sediment samples and current measurements collected at both locations suggest that the physical parameters of both sediments and the hydrodynamic conditions at both sites were similar. Therefore the results obtained from these field evaluations should be directly applicable to Indiana Harbor. The dredging equipment evaluations herein are based on total suspended solids (TSS) concentration data collected during the demonstrations. All TSS measurements were carried out in accordance with

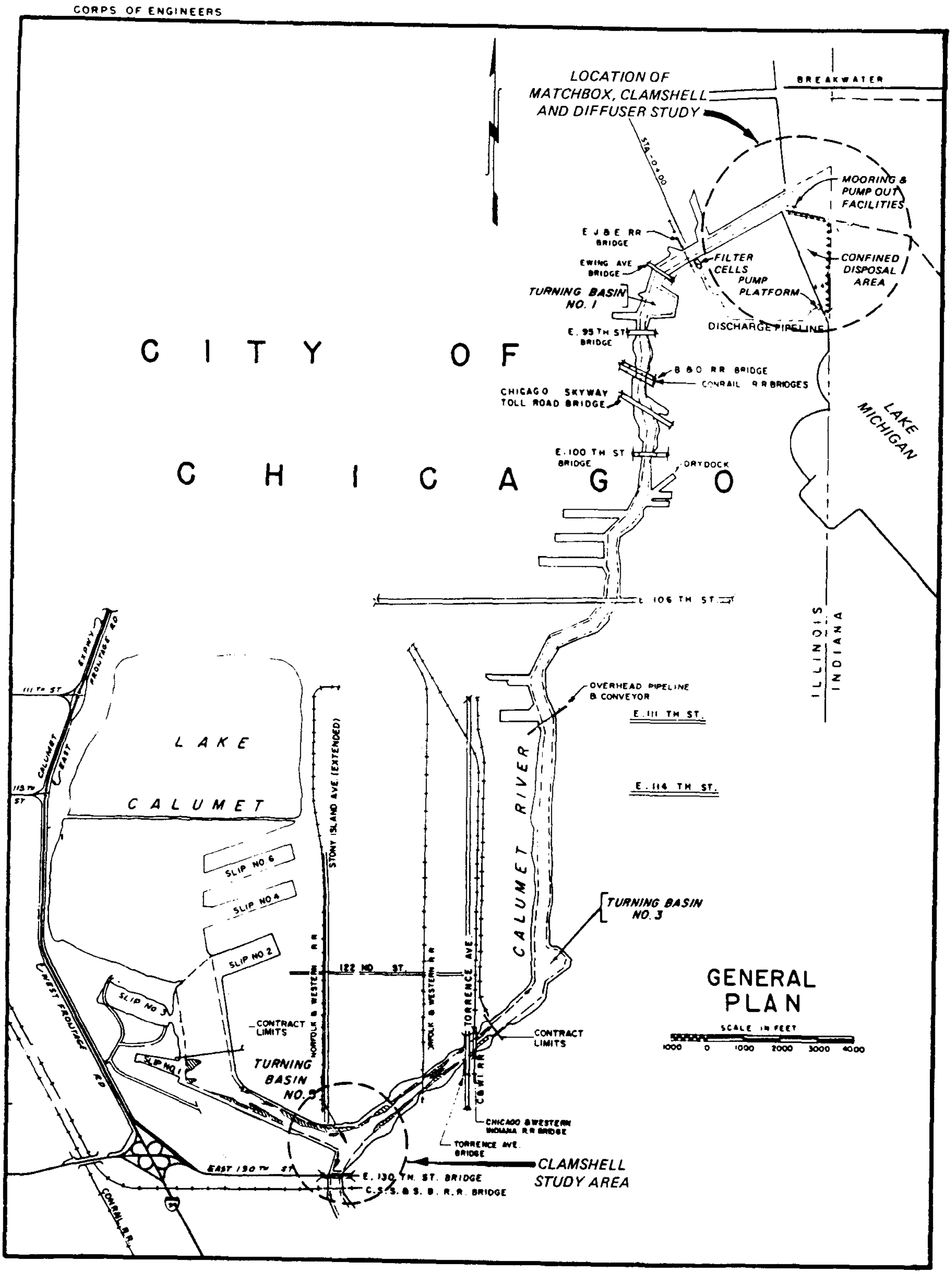



Figure 1. Location for Calumet field demonstration

APHA-AWWA-WPCF, Standard Methods for Examination of Water and Wastewater, 15th ed., (American Public Health Association (APHA) 1976).

## Relationship of Turbidity to Suspended Solids Concentration

5. Turbidity is a term describing the cloudy appearance of water and is normally measured by percent light transmission or percent light scattered. The term "suspended solids," however, describes the concentration, by weight, of material suspended in a given volume of water. The confusion and misuse of terminology associated with the relationship of turbidity to suspended solids concentration is an old problem. Attempts have been made to formulate a consistent relationship between the two terms for all conditions, but the characteristics of the suspended sediment particles (e.g., particle-size distribution, particle shape, etc.) that cause variation in the light transmission (i.e., turbidity) are mostly site specific, and some even change with time. Since the amount of suspended sediment in the vicinity of the dredging operations is of interest here, the term "turbidity" will be used only as a qualitative description. It may, however, be used to describe a cloud of suspended sediment or its behavior as a continuous body.

## PART II: HYDRAULIC SUCTION DREDGE COMPARISONS

### Background

6. The cutterhead suction dredge has been in use in the United States for several decades, whereas the newly developed matchbox suction dredge is just being introduced. The Calumet Harbor demonstration represents the first use of the matchbox suction head in this country. For a better understanding of the matchbox and its operation relative to a cutterhead dredge, a brief description of each is given in the following paragraphs.

#### Cutterhead dredges

7. Description. The hydraulic pipeline, cutterhead suction dredge is the most commonly used dredging plant and is generally the most efficient and versatile (Figure 2). It performs the major portion of the dredging work load in the United States. Because it is equipped with a rotating cutter apparatus surrounding the intake end of the suction pipe, it can efficiently dig and pump all types of alluvial materials and compacted deposits, such as clay and hardpan. By combining the mechanical cutting action with hydraulic suction, this dredge has the capability of efficient excavation and removal by pumping dredged material long distances to upland disposal areas. Although the cutterhead dredge was developed to loosen densely packed deposits and cut through soft rock, it can excavate a wide range of materials including clay, silt, sand, and gravel. The cutterhead dredge is suitable for maintaining harbors, canals, and outlet channels where wave heights are not excessive. Cutterhead

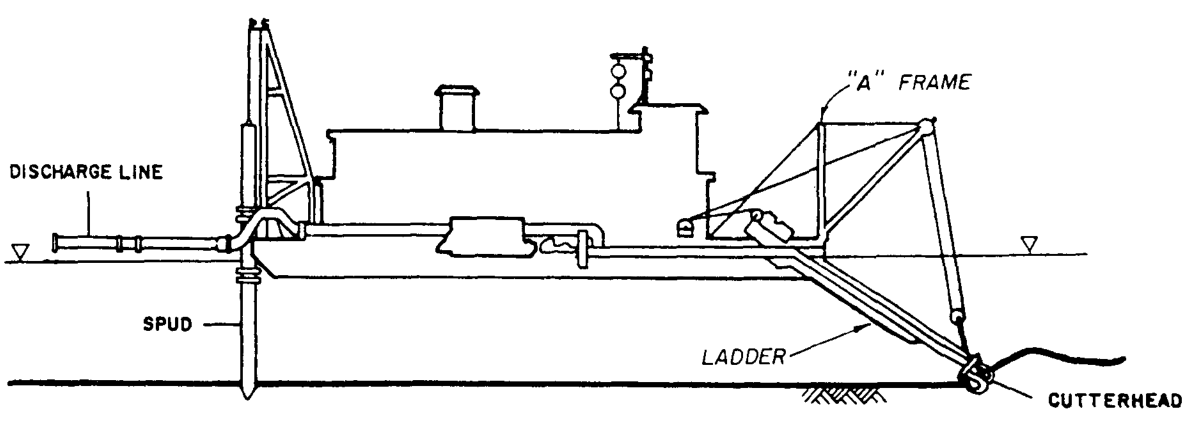



Figure 2. Hydraulic pipeline cutterhead dredge

dredges are normally limited to operating in protected waterways and wave heights less than 3 ft. However, some specifically designed to work offshore can work in waves up to 6 ft.

8. The cutterhead dredge is generally equipped with two stern spuds used to hold the dredge in working position and to advance the dredge into the cut or excavating area. During operation, the cutterhead dredge swings from side to side alternately using the port and starboard spuds as a pivot, as shown in Figure 3. Cables attached to anchors on each side of the dredge control lateral movement. Forward movement is achieved by lowering the starboard spud after the port swing is made and then raising the port spud; the dredge is then swung back to the starboard side of the cut center line. The port spud is then lowered, and the starboard spud is lifted to advance the dredge. A concept developed several years ago consists of a spud carriage, where the working spud is attached to a traveling carriage, activated by a hydraulic cylinder. The material removal efficiency is theoretically increased from 50 percent for the spud system to 75 percent for the spud carriage system.

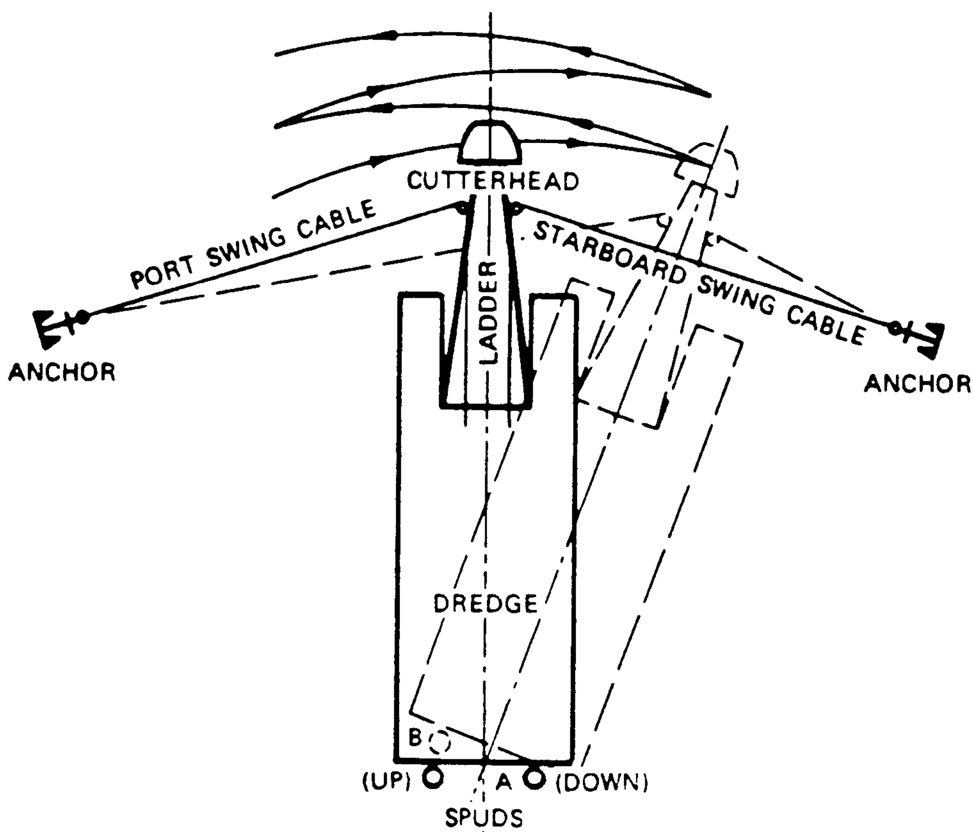



Figure 3. Operation of a cutterhead dredge (viewed from above)

9. Sediment resuspension sources. Concentration of suspended sediments from a cutterhead dredging operation ranges from 10 to 300 mg/ℓ near the cutterhead to a few milligrams per litre 1,000 to 2,000 ft from the dredge (Barnard 1978; Raymond 1984; Hayes, Raymond, and McLellan 1984; and others). The suspended solids plume is usually contained in the lower portion of the water column. Resuspension of sediments during cutterhead excavation is dependent on the operating techniques used and on equipment setup. Aside from careful operation of equipment peripheral to the cutterhead (e.g., spuds and anchors), a proper balance between the mechanical action of the cutter and the pickup ability of the pump must be achieved to reduce sediment resuspension. Indeed, the cutterhead may be the most sensitive of any dredge type to changes in operating techniques. The rate of sediment resuspension by a cutterhead dredge is dependent on thickness of cut, rate of swing, and cutter rotation rate (Barnard 1978). Proper balance of these operational parameters leads to greater efficiency and possibly higher production because almost all of the disturbed sediment is picked up by the hydraulic suction (Hayes, Raymond, and McLellan 1984).

Matchbox suction head dredge

10. Description. To dredge highly contaminated sediments in the Rotterdam Harbor, Volker Stevin Dredging developed the matchbox suction head dredge (Figure 4) (d'Angremond, de Jong, and de Waard 1984). The suction head was designed to dredge silt at as close to in situ density as possible, keep resuspension to a minimum while dredging layers of varying thickness, and

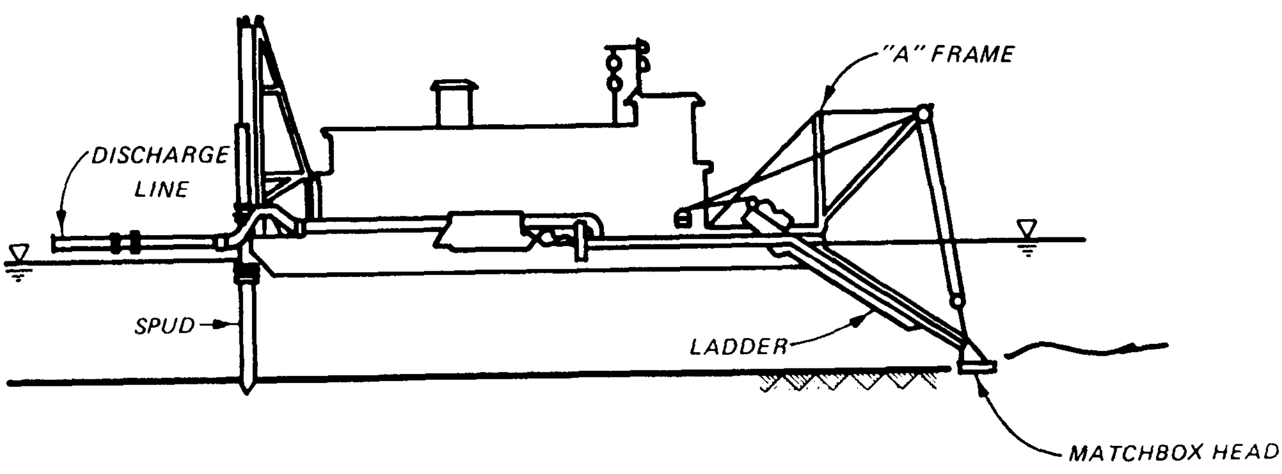



Figure 4. Matchbox suction head dredge

operate with restricted maneuverability. To keep resuspension to a minimum, cutter and water-jet devices commonly found on dredgeheads were not used.

11. Several innovative design features were incorporated into the matchbox dredgehead construction. These design features include the following:

a. A plate covered the top of the suction head to contain escaping gas bubbles and avoid the influx of water.

b. An adjustable angle was constructed between the suction head and ladder to maintain the optimum dredging position regardless of dredging depth.

c. Openings on both sides of the dredge were installed so that the leeward opening could be closed by a valve to avoid water influx.

d. The dredge plant dimensions were carefully chosen to account for the average flow rate and swing speed of the dredge.

12. In addition to the above design features, the matchbox suction head dredge used instrumentation allowing the operator to position the dredgehead intake at the optimum depth below the bottom. This kept the dredgehead from being buried (causing material to pile up on the dredgehead and increasing resuspension) or from being too shallow (reducing the efficiency of the dredge). A computer, in conjunction with a density meter, was also installed to monitor the density of the dredged slurry. The computer, using the slurry density as criteria, in turn controlled the swing speed and pump speed of the dredge to maintain optimal dredge efficiency.

13. The matchbox suction head dredge can be incorporated into a conventional cutterhead operation by removing the cutterhead and replacing it with the matchbox. The matchbox does not require all of the instrumentation listed above, but the efficiency of the dredge increases with its inclusion. Operation of the matchbox dredge is identical to that of a cutterhead dredge with the exception of the rotating cutterhead.

14. Sediment resuspension sources. Sediment resuspension sources are similar to the cutterhead dredge except that mechanical mixing is reduced because of the design features described previously and the absence of a rotating cutterhead.

## Field Setting

### Sequence of events

15. A direct comparison between a matchbox suction head and a conventional cutterhead was made. Both dredgeheads were fitted onto the cutter suction dredge DUBUQUE, owned by the US Army Corps of Engineers (CE) (see Figure 5). The field demonstration of the matchbox suction head was conducted in Calumet Harbor during October 1985. In conjunction with this demonstration, water quality samples were collected within 10 ft of the point of dredging (near field) and along a grid pattern beginning near the dredge and extending outward, while the dredge operated in the exit channel from

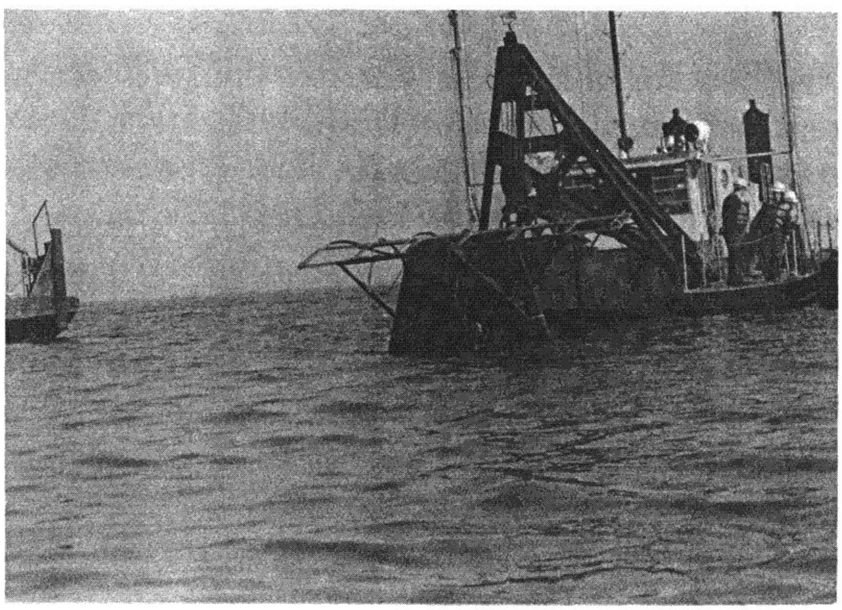


Figure 5. The DUBUQUE with the matchbox suction head attached

Calumet Harbor. After the matchbox demonstration, the dredge was refitted with the cutterhead, and a similar sampling effort was undertaken to gather water quality data to compare with the matchbox performance.

### Dredging area

16. Calumet Harbor is located south of Chicago along the western bank of Lake Michigan. The harbor is at the mouth of the Calumet River on Lake Michigan and is protected from the northeast by a breakwater extending from the shore. The Chicago Area Confined Disposal Facility (CDF) is located at the

mouth of the Calumet River, and its north dike extends outward along the south edge of the channel. The area dredged during the equipment demonstrations was in the Calumet River channel along this north dike (Figure 6). The dredged sediment was pumped into the CDF.

Background conditions

17. Water quality and bulk sediment samples were taken prior to the demonstrations at several locations throughout the dredging area to determine the properties of the sediment to be dredged (see Figure 6). Current velocity measurements were taken at Stations 30, 31, 32, 34, 36, 37, 38, 39, 40, 41, and 43. Additional water quality samples and current measurements were collected from these stations between the matchbox head and cutterhead demonstrations on October 23. The bulk sediment samples from Stations 33, 34, 35, and 36 were combined, classified, and analyzed for grain-size distribution, natural moisture content, Atterberg limits, and specific gravity. The results of these tests are given in Figure 7. The sediment is classified as a silty loam, ML, with a specific gravity of 2.71 and 80 percent by weight of the material passing the No. 200 sieve. The background suspended solids values are tabulated in Table C1; based on these results, the average suspended solids concentration under background conditions is 4 mg/ℓ. The measured background velocity profiles for a representative station are shown in Figure 8.

Dredging equipment

18. The dredge DUBUQUE is a 12-in. (inside diameter (ID) of discharge pipe) cutterhead suction dredge owned by the CE (Figure 9). The DUBUQUE's centrifugal pump is powered by a 485-hp (at 1,800 rpm) diesel engine and has a 14-in. (ID) suction pipe. It uses a 6-blade (with serrated edges) cutterhead that is 3 ft in diameter at its largest point and 2.5 ft long. The cutterhead is powered by a 125-hp hydraulic motor with a maximum speed of 27 rpm. The DUBUQUE is capable of dredging to a depth of 32 ft and widths of cut between 60 (minimum) and 120 (maximum) ft. The physical dimensions of the dredge plant are shown in Figure 10.

19. The matchbox suction head was specifically designed to be fitted onto the DUBUQUE (see Figure 5). The dredge was equipped with the design features described previously with some exceptions. These exceptions were (a) the instrumentation to indicate the dredgehead's position relative to the bottom was not installed and (b) the horizontal positioning of the dredgehead

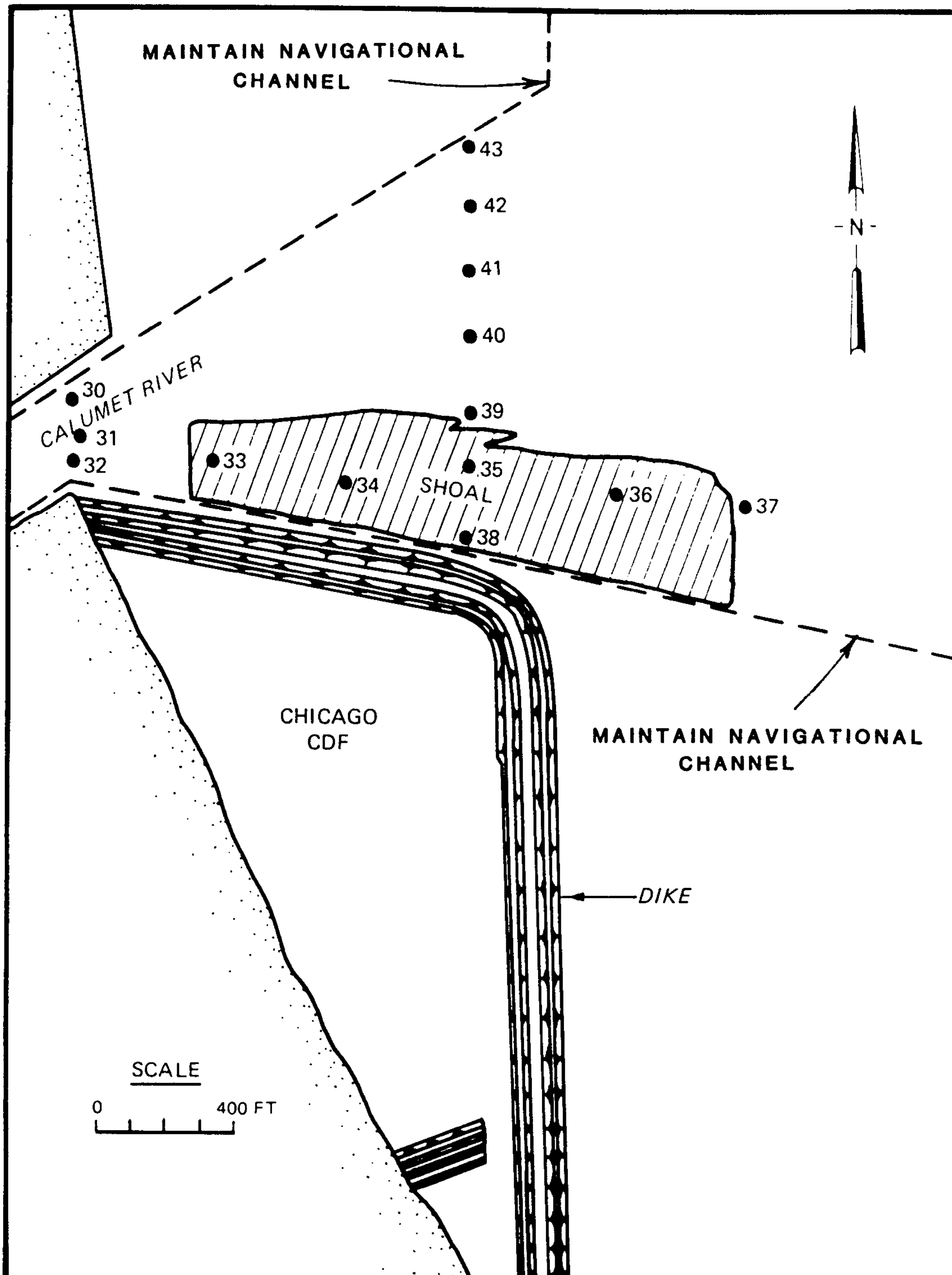
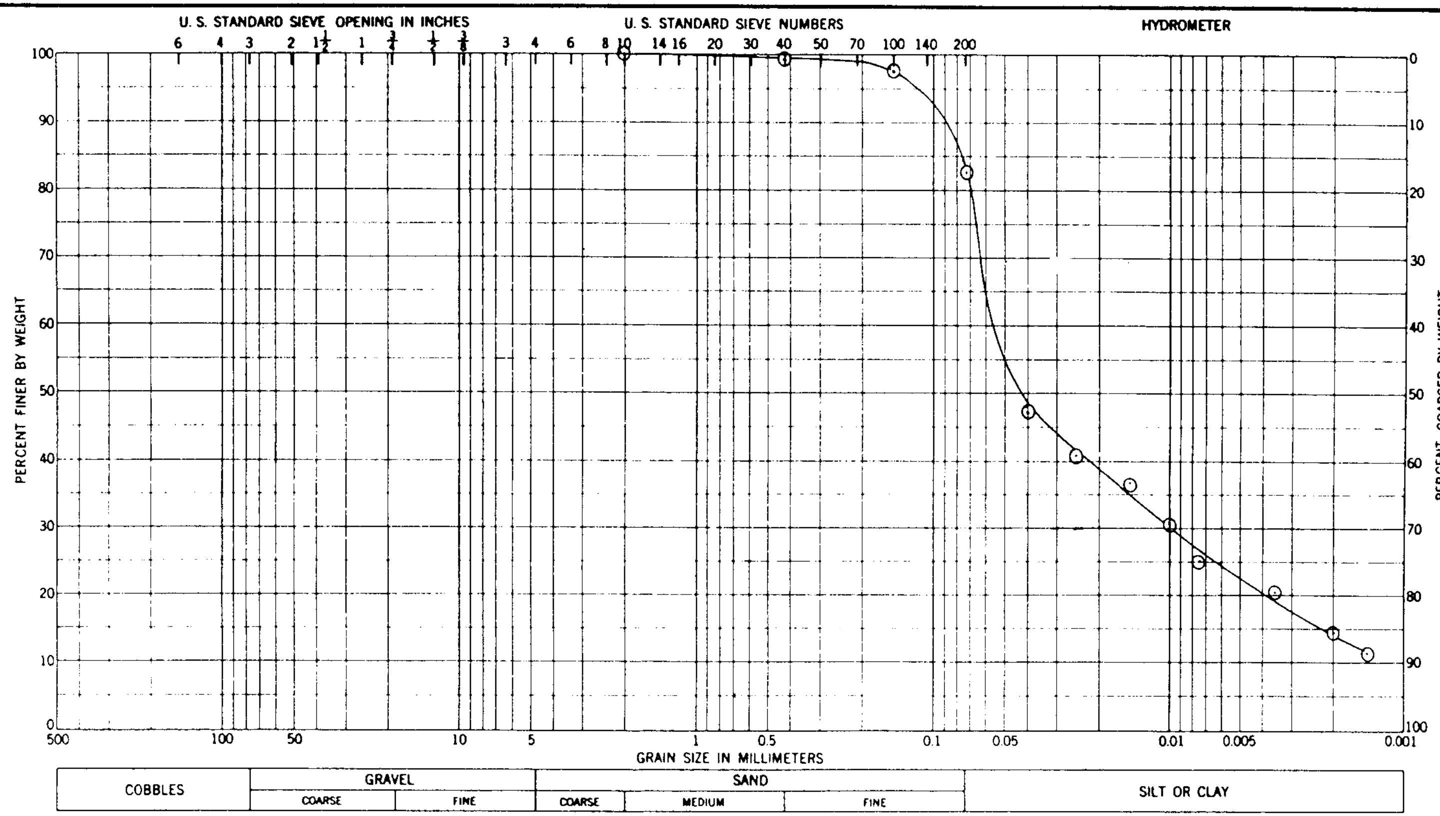



Figure 6. Dredging area and background sampling grid




| Sample No. | Elev or Depth | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| 2 | | Silty Loam<br>Specific Gravity · 2.71 | 71.1 | 25.4 | 25.0 | 0.4 |

Project: Calumet Harbor Matchbox/ Cutterhead Demonstration

Area: Station 33, 34, 35, and 36

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Date: October 9, 1985

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Figure 7. Grain-size distribution of composited bulk sediment samples

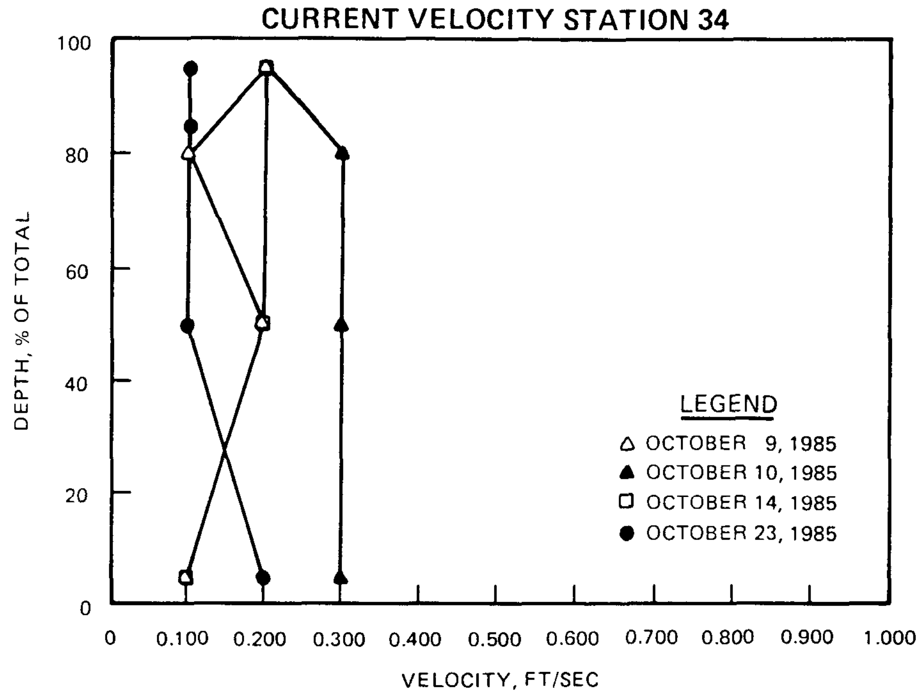


Figure 8. Velocity profiles at background sampling stations

was adjustable only by supporting the dredgehead with a crane, removing a pin, readjusting the dredgehead, and replacing the pin. For all practical purposes, this last procedure fixed the horizontal position of the dredgehead. Since the dredging reach was a uniform depth, 27 ft, this was not a great disadvantage. Also the dredge's swing speed and pump speed were manually controlled. Even with the absence of this instrumentation, the matchbox head performed well and limited resuspension during the dredging operation.

Instrumentation

20. The DUBUQUE has the standard array of gages found on most conventional cutter suction dredges: vacuum pressure, discharge pressure, depth, motor rpm, etc. A Texas Nuclear Integrated Flow and Density Meter was installed just prior to this testing. This meter continuously displays the almost instantaneous velocity and solids concentration in the discharge pipe as well as the total sediment removed, discharge flow rate, and operating time. As the study progressed and the dredge operator became familiar with the density meter, he began using it almost exclusively as an indicator of the dredge's performance.

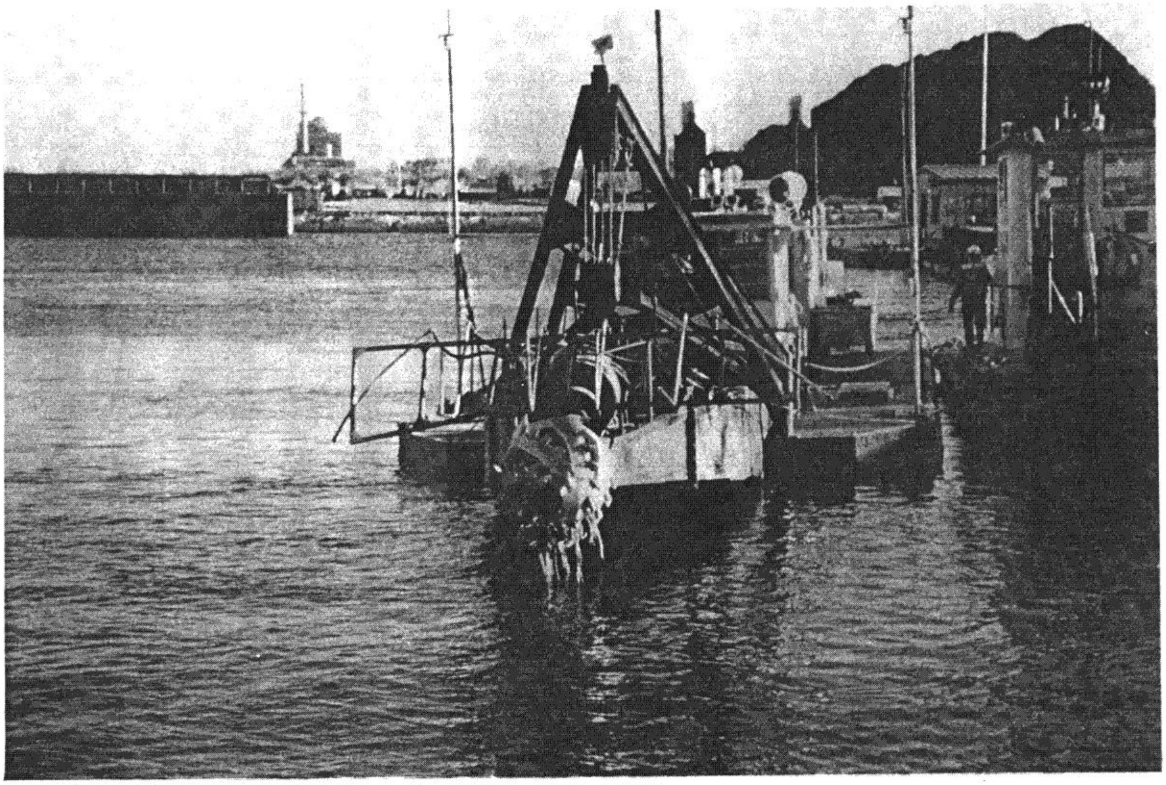

Figure 9. The DUBUQUE with cutterhead attached

## Cutterhead Field Tests

### Dredge operation during cutterhead tests

21. The DUBUQUE used normal operating procedures during the cutterhead testing periods except for the swing speed and cutter rotation speed. The cutterhead rotational speed and swing cable retrieval speed were equipped with variable power controls. The swing cable was also marked at every foot so that the retrieval speed of the cable could be timed. The swing speed of the dredge could then be calculated using the relative positions of the swing cable to the spud and the cutterhead to the spud. The swing cable was mounted 48 ft 4 in. from the spud (Figure 10), while the distance from the spud to the cutterhead depended on dredging depth. The cutterhead rotational speeds were calibrated by setting the cutterhead rotational speed controls at specific increments and counting the rotations of the cutterhead while it was out of water. These speeds were assumed constant for each control increment during the dredging operation. A constant swing speed of either 0.7 or 1.1 ft/sec

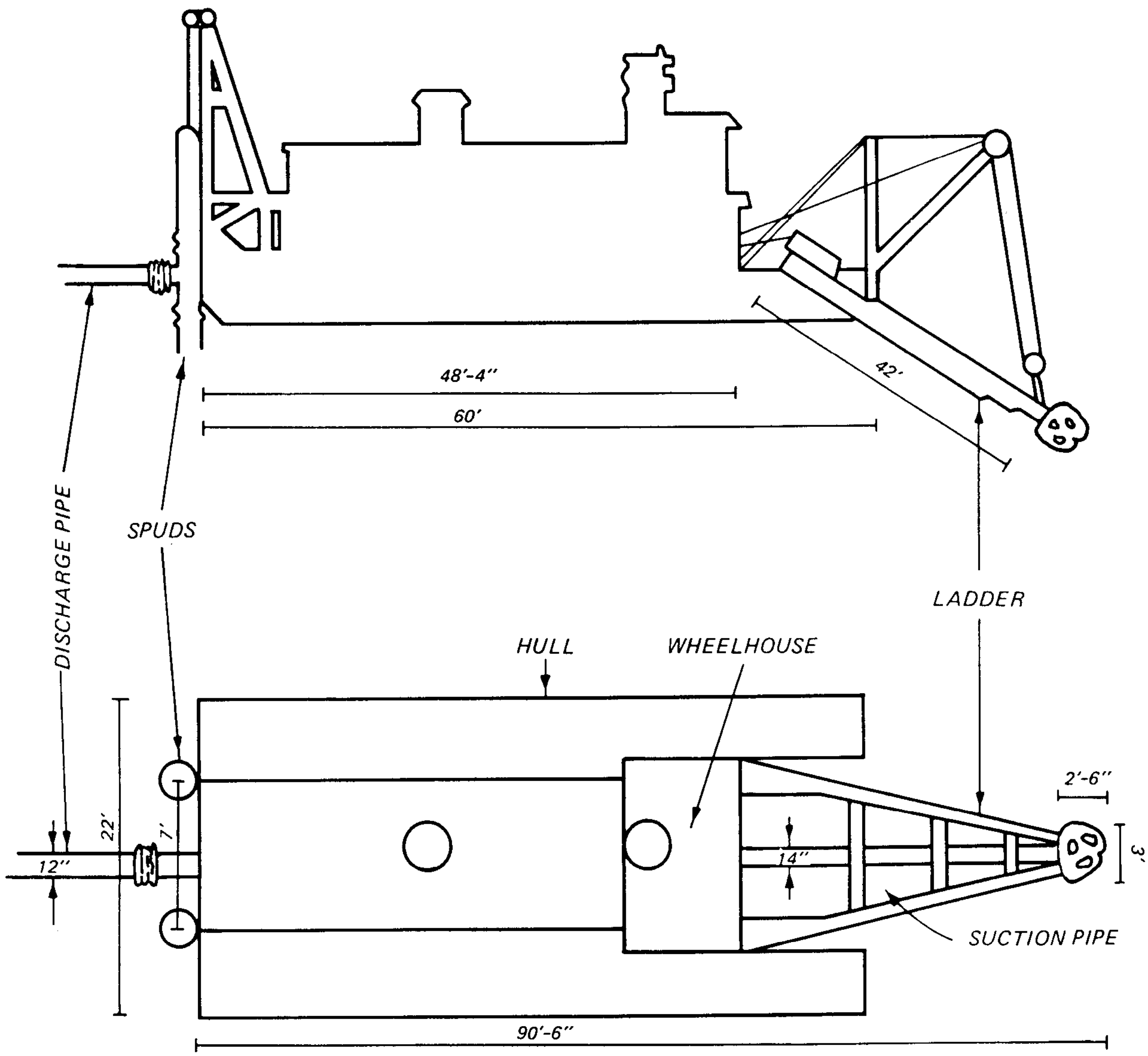


Figure 10. Physical dimensions of the DUBUQUE

(velocity at cutterhead tip) was used with cutter rotation speeds of either 27, 20, or 15 rpm for each of the six test periods, which lasted approximately 4 hr each. Table 1 summarizes the test periods and the operational parameters used along with the average measured flow rate for each test period. Individual flow rate measurements and operational parameter values are contained in Appendix A. A constant 100-ft-wide cutting path was used during the test periods. A normal full cut was used in all tests with approximately 3 ft of sediment removed from the initial bottom depth of approximately 27 ft.

Table 1

Operational Parameters for the Cutterhead Test Periods

| Date | Test Period | Beginning Time | Ending Time | Swing Speed ft/sec | Cutter Speed rpm | Flow Rate gpm |
|---|---|---|---|---|---|---|
| 10/24/85 | 1 | 0830 | 1200 | 0.7 | 27 | 4,200 |
| | 2 | 1200 | 1530 | 0.7 | 20 | 3,200 |
| 10/25/85 | 3 | 0800 | 1130 | 0.7 | 15 | 4,300 |
| | 4 | 1130 | 1500 | 1.1 | 15 | 4,200 |
| 10/26/85 | 5 | 0800 | 1130 | 1.1 | 20 | 5,300 |
| | 6 | 1130 | 1500 | 1.1 | 27 | 4,600 |

Collection of near field water quality samples

22. Samples were taken from each of six sampling points within a few feet of the cutterhead at regular intervals (approximately every 30 min) during each testing period. These sampling points were formed by attaching 3/4-in. galvanized steel pipes to a steel frame mounted on the dredge ladder near the cutterhead (see Figure 11). These samples were defined as being from the "near field" for the purposes of this report. The open ends of the six pipes were placed as shown in Figure 12 to gather data at various locations with respect to the cutterhead and suction inlet. Rubber hoses were attached to the steel pipes, and water samples were drawn using a 1/2-hp centrifugal pump located on the deck of the dredge.

23. The sampling intervals were varied, so the direction of swing for each time was different from the previous time. After purging the tubes, samples were obtained from each of the six tubes at each sampling interval. The near field water quality samples were taken in the order in which the tubes are shown in Figure 12, but in the opposite direction of the swing (e.g., for a port-starboard swing, samples were taken from tubes 1-6). Each water quality sample taken from the tubes was analyzed for suspended solids concentration. Additional samples were taken from each tube during each test period and analyzed for particle-size distribution using a Microtrak laser particle analyzer. The results of this analyses are given in Appendix A.

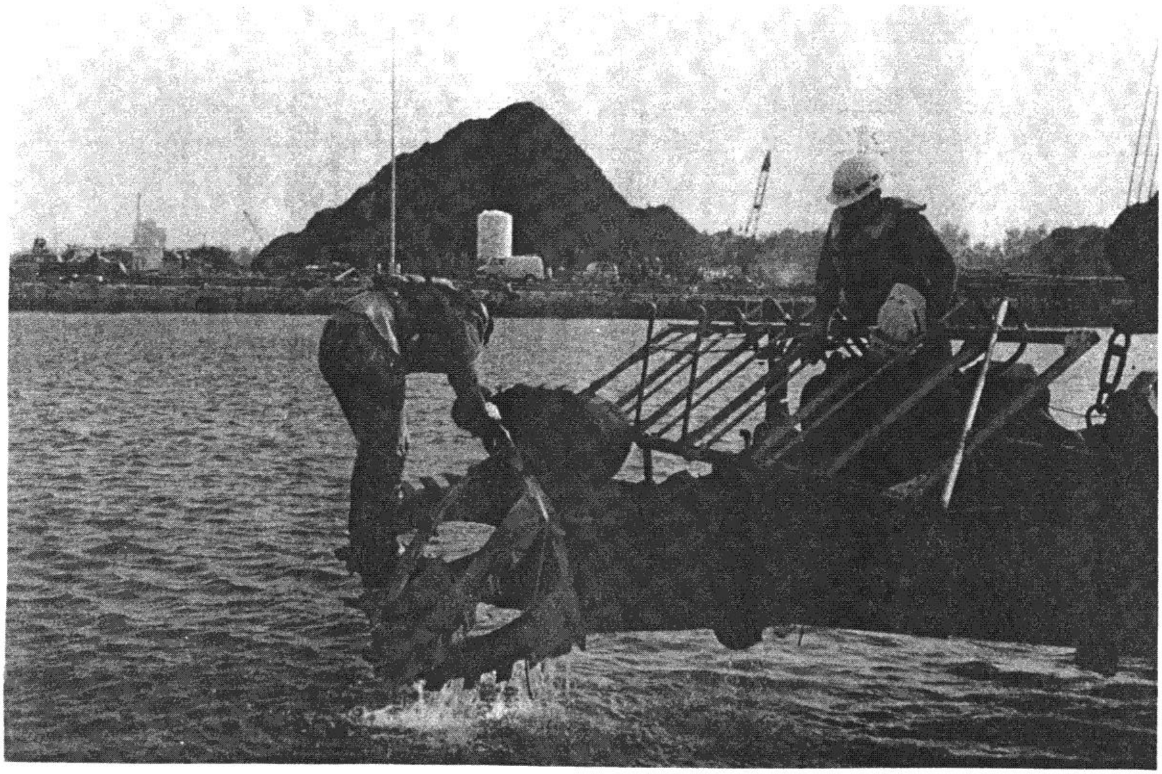

Figure 11. Near field sampling array for cutterhead tests

Near field data analysis

24. The near field data collected during the cutterhead testing periods have been divided into two major sections. The first section is the data collected during port-to-starboard swings, and the second is the data collected during starboard-to-port swings. Multiplying these 2 sections by the 6 sets of operational parameters yields a total of 12 distinctly different data sets for evaluating the characteristics of the sediment resuspension in the vicinity of the cutterhead. In general, the average concentrations observed in each tube or the average of all tubes were used to analyze the results. In this section, these average suspended solids concentrations are used to describe the sediment resuspension characteristics near the cutterhead. All suspended solids concentrations given in this section have been adjusted for the background level (see previous section) and represent the resuspension above background.

25. Concentration distributions near the cutterhead. The suspended solids concentrations varied around the cutterhead with both the lateral and

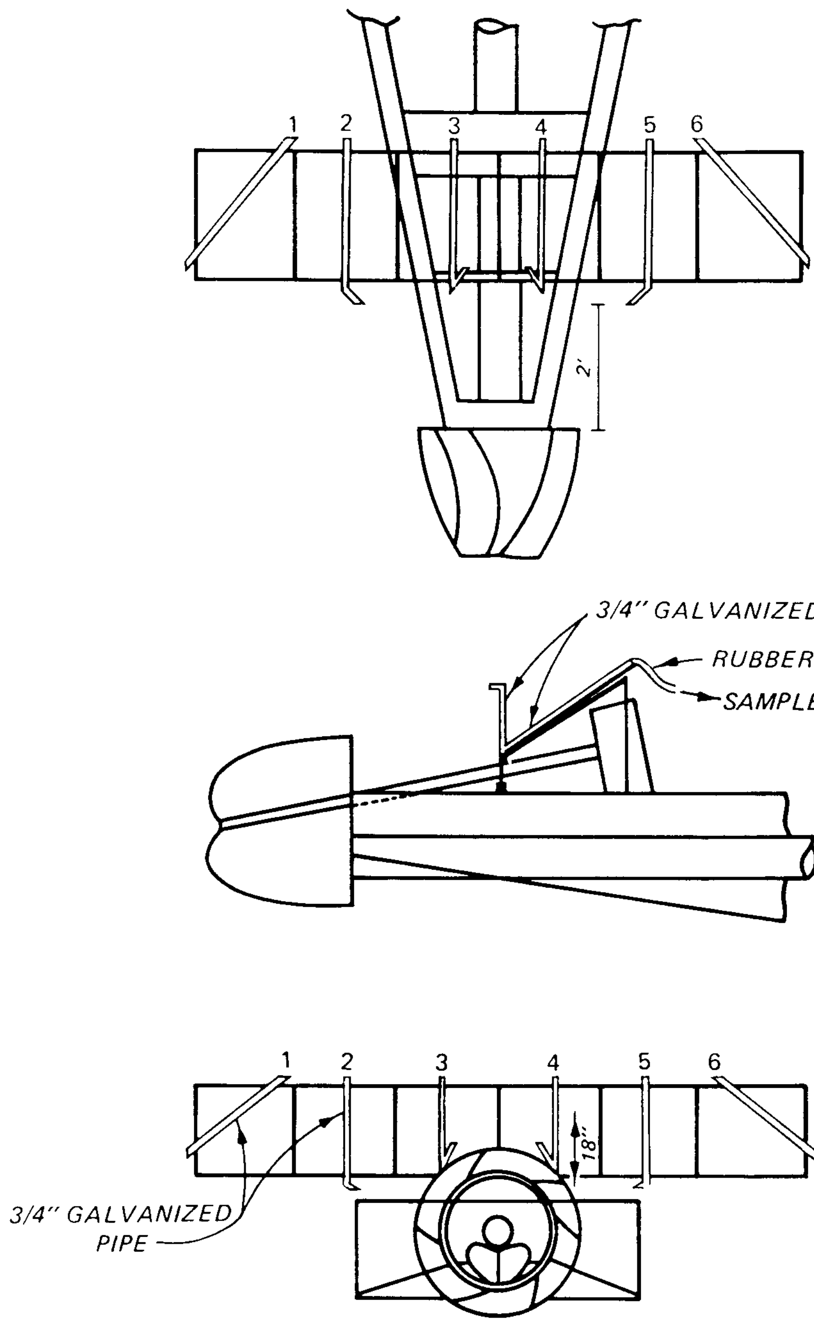


Figure 12. Locations of sample tubes for cutterhead tests

vertical distance from the cutter. The samples were collected on two sides of the cutter at three different lateral distances from the cutter and at two vertical distances to determine the variation. The lateral and vertical locations for each tube from the outer edge of the cutter are given in Table 2. Negative lateral values indicate positions on the starboard side of the cutter. The variation near the cutter can be seen in Figure 13. The effect of depth is apparent when the results from tubes 3 and 4 are compared with those from tubes 1, 2, 5, and 6. This shows that the resuspended solids are distributed from the bottom of the cut path (approximately -3 ft) to at least 3 ft above the original bottom elevation. The other factor that is quite apparent from Figure 13 is the effect of the swing direction. The observed suspended sediment concentrations are consistently higher for the

Table 2

Positioning of Near Field Sampling Tubes for Cutterhead Tests

| Tube Number | Lateral Position | Vertical Position, ft* |
|---|---|---|
| 1 | - 4 | 1 |
| 2 | - 1.5 | 1 |
| 3 | - 0** | 2.5 |
| 4 | 0** | 2.5 |
| 5 | 1.5 | 1 |
| 6 | 4 | 1 |

* Relative to the predredged bottom elevation.
** Tubes 3 and 4 were positioned laterally along the edge of the cutter, but were approximately 2.5 ft above the cutter.

starboard-to-port swings. This effect has been reported in earlier studies (Koba and Shiba 1984) and is due to the rotational direction of the cutterhead relative to swing direction. When the cutterhead undercuts the material during port-to-starboard swings, it places the material closer to the suction intake than the overcut, starboard-to-port swings, thus reducing the amount of material resuspended.

26. Grain-size analyses of resuspended sediment. The results of the grain-size analyses conducted on cutterhead near field samples are listed in Appendix A. The resuspended sediment particles were all smaller than 176 μ (slightly larger than a No. 100 sieve) for every sample with approximately 80 percent of the particles in the silt-size range (75 to 2 μ). Only a small fraction of the sediment particles (less than 3 percent) were in the clay

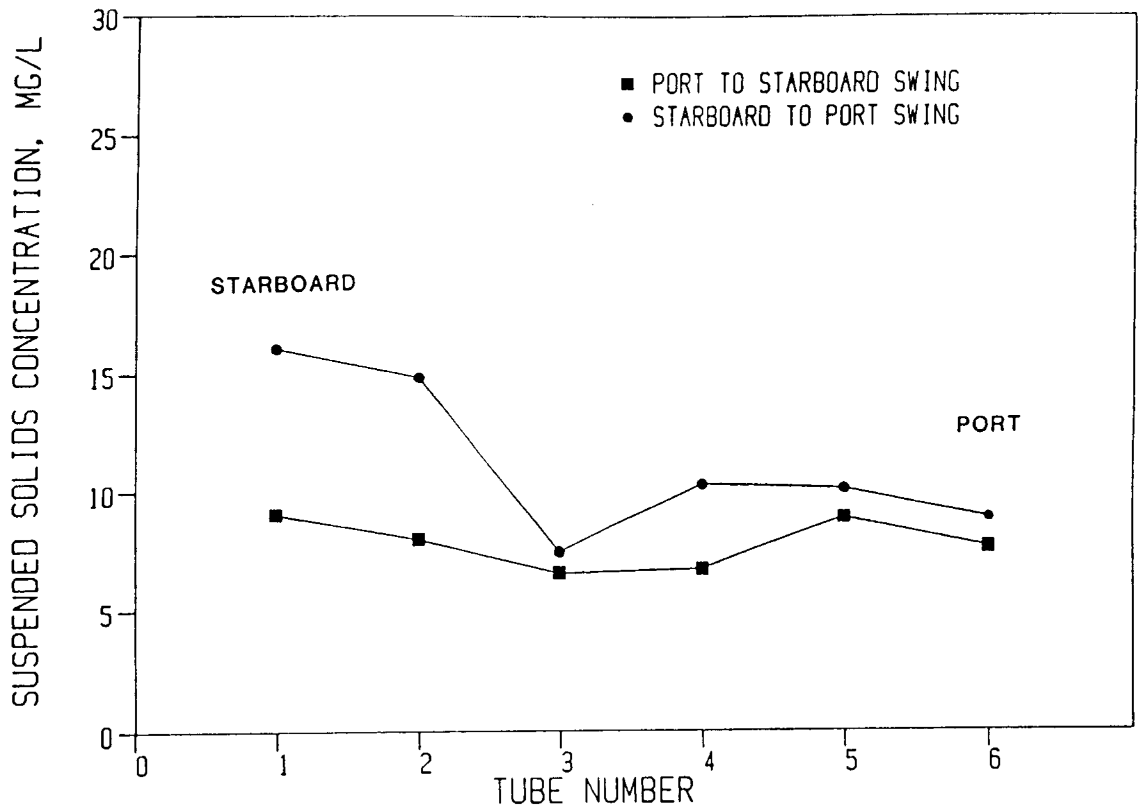


Figure 13. Suspended sediment distribution near the cutter

range. In comparison, the bed sediment contained approximately 14-percent clay-size particles with slightly less than 70-percent silt-size particles.

Collection of far field water quality samples

27. Samples were collected at four depths at each of 10 sampling stations arranged (Figure 14) around the dredging operation. Grid stations were located using a Ranging, Inc., Model 600 hand-held range finder. The samples were collected from two small 18 to 20-ft aluminum boats equipped with Simer Model UB85, 12-V portable pumps. The pumps were attached to weighted, reinforced nylon hoses marked every foot for depth indication. When the sample station was reached, the nylon hose was placed in the water, and the pump was turned on. After the hose had been lowered to the appropriate sample depth, it was allowed 45 sec to clear before a 200-ml water sample was collected. Water samples were collected at 5, 50, 80, and 95 percent of the depth at each station. The sample grid was completed two times for each set of dredge operating characteristics.

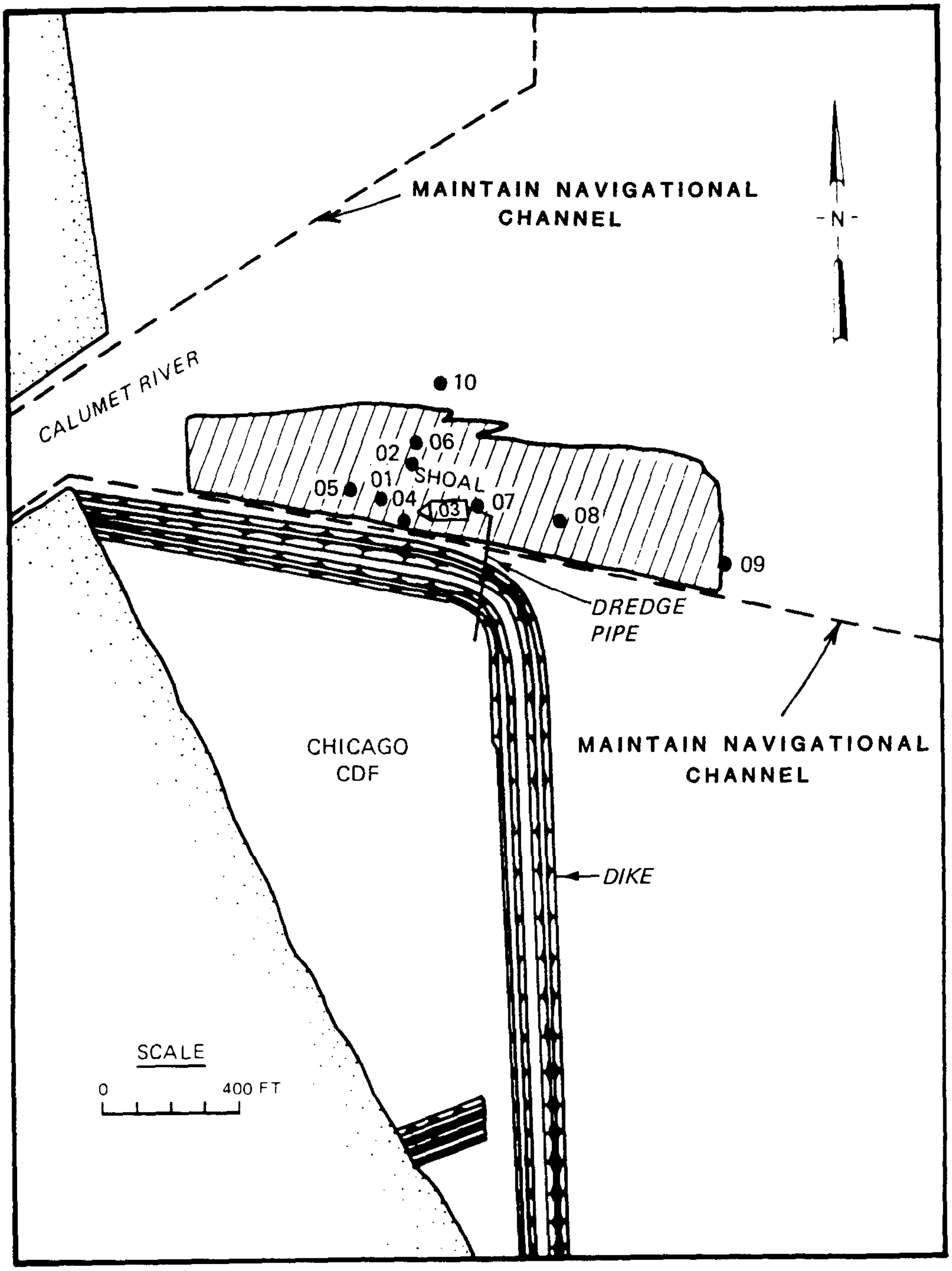


Figure 14. Far field sampling grid for cutterhead tests

28. Current measurements were obtained using a Marsh/McBirney Model 201-D Portable Water Current Meter. The current meter was mounted to a 15-lb weight on a Stevins Sounding Reel. Since the currents were small, the

sample grid was slightly skewed in the direction of the current with a majority of samples collected within 200 ft of the dredging operation.

Far field data analysis

29. The results of the far field sampling show that elevated suspended solids concentrations were confined to the immediate vicinity of the dredging operation. Most of the far field observations were at or near the background level, especially in the upper water column. Figures 15 through 18 show the concentration profiles surrounding the dredge at each depth. Some small amount of skew is evident in the lower water column due to the currents.

## Matchbox Field Tests

### Dredge operation during matchbox tests

30. During the matchbox testing periods, the DUBUQUE used similar operating procedures as were used with the cutterhead. The swing speed was held constant over each testing period; swing speeds of 0.46, 0.56, and 1.25 ft/sec (velocity at matchbox) were used to test the operation of the matchbox. Although these swing speeds are close to the cutterhead swing speeds, it was not possible to match them exactly because of differing drag relationships between the matchbox head and cutterhead. Table 3 summarizes

Table 3

Operational Parameters for the Matchbox Test Periods

| Date | Test Period | Beginning Time | Ending Time | Swing Speed ft/sec | Flow Rate gpm |
|---|---|---|---|---|---|
| 10/21/85 | 1 | 1025 | 1410 | 0.6 | 4,200 |
| 10/22/85 | 2 | 0935 | 1140 | 1.3 | 4,300 |
| 10/22/85 | 3 | 1210 | 1515 | 0.5 | 4,200 |

the test periods and the swing speeds used along with the average measured flow rate for each test period. Graphs of the individual flow rate measurements and operational parameter values are contained in Appendix A. A constant 100-ft-wide cutting path was used during the test periods. A normal

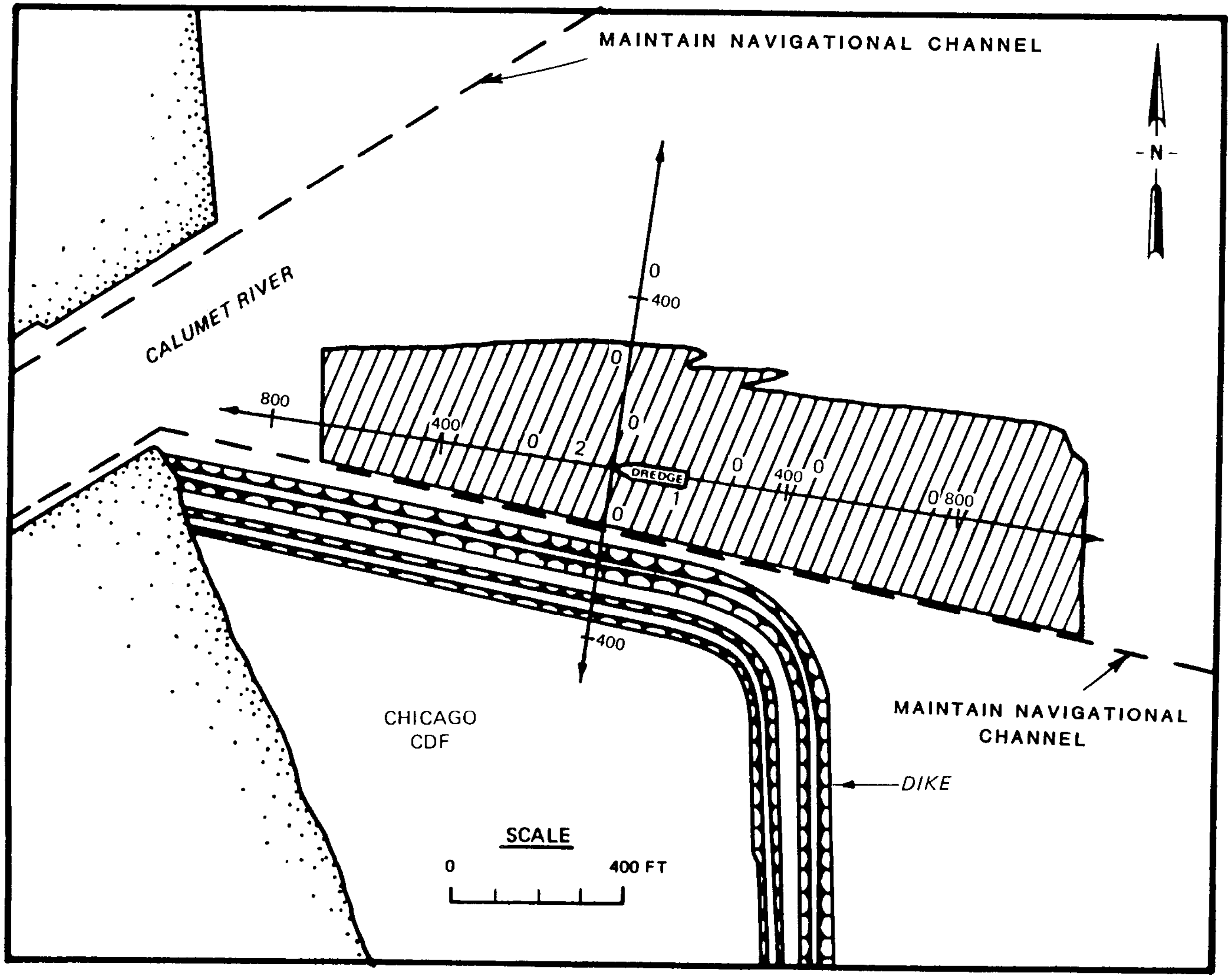


Figure 15. Observed suspended sediment concentrations for cutterhead tests (depth = 5 percent of total)

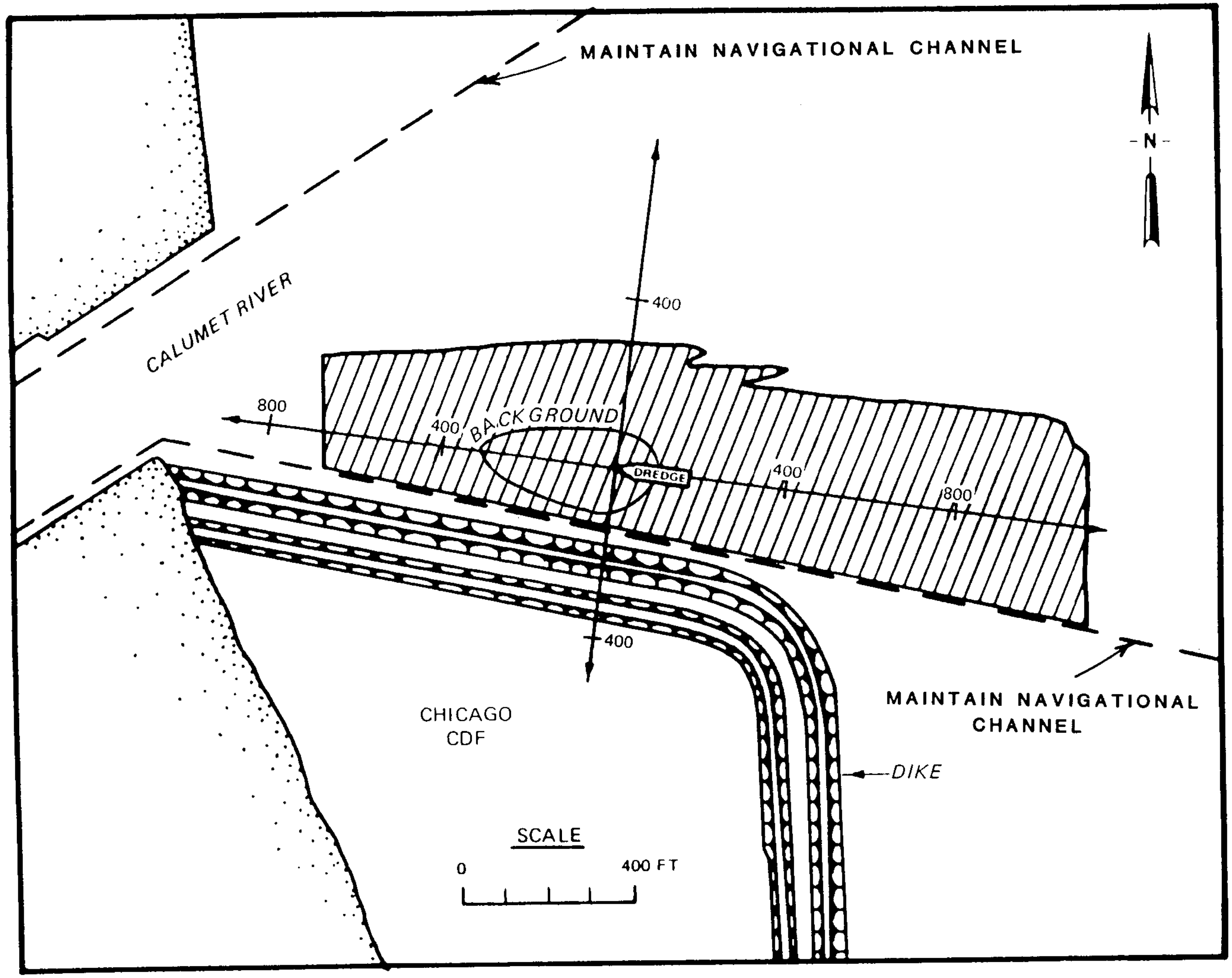


Figure 16. Background isoconcentration line for cutterhead tests (depth = 50 percent of total)

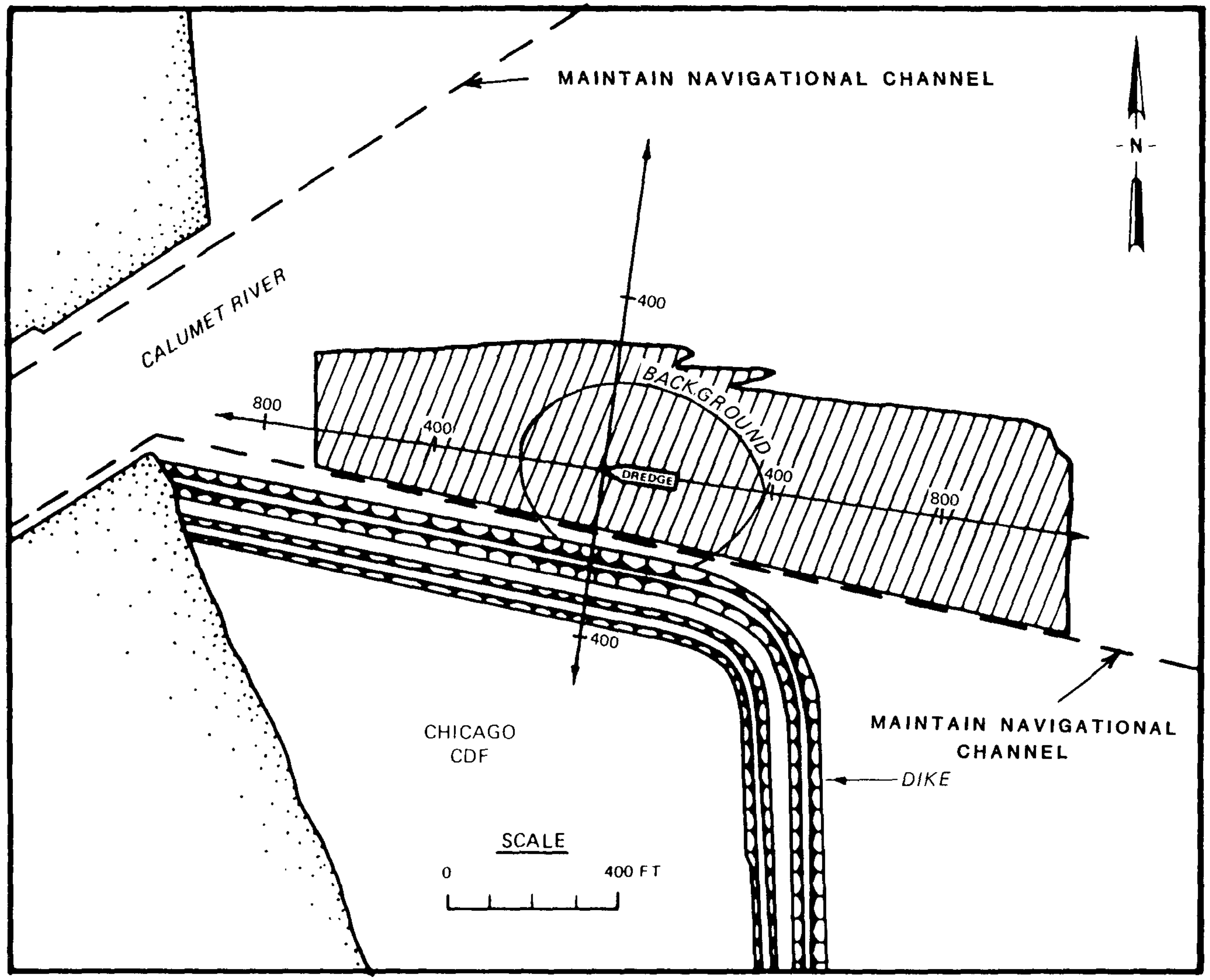


Figure 17. Background isoconcentration line for cutterhead tests (depth = 80 percent of total)

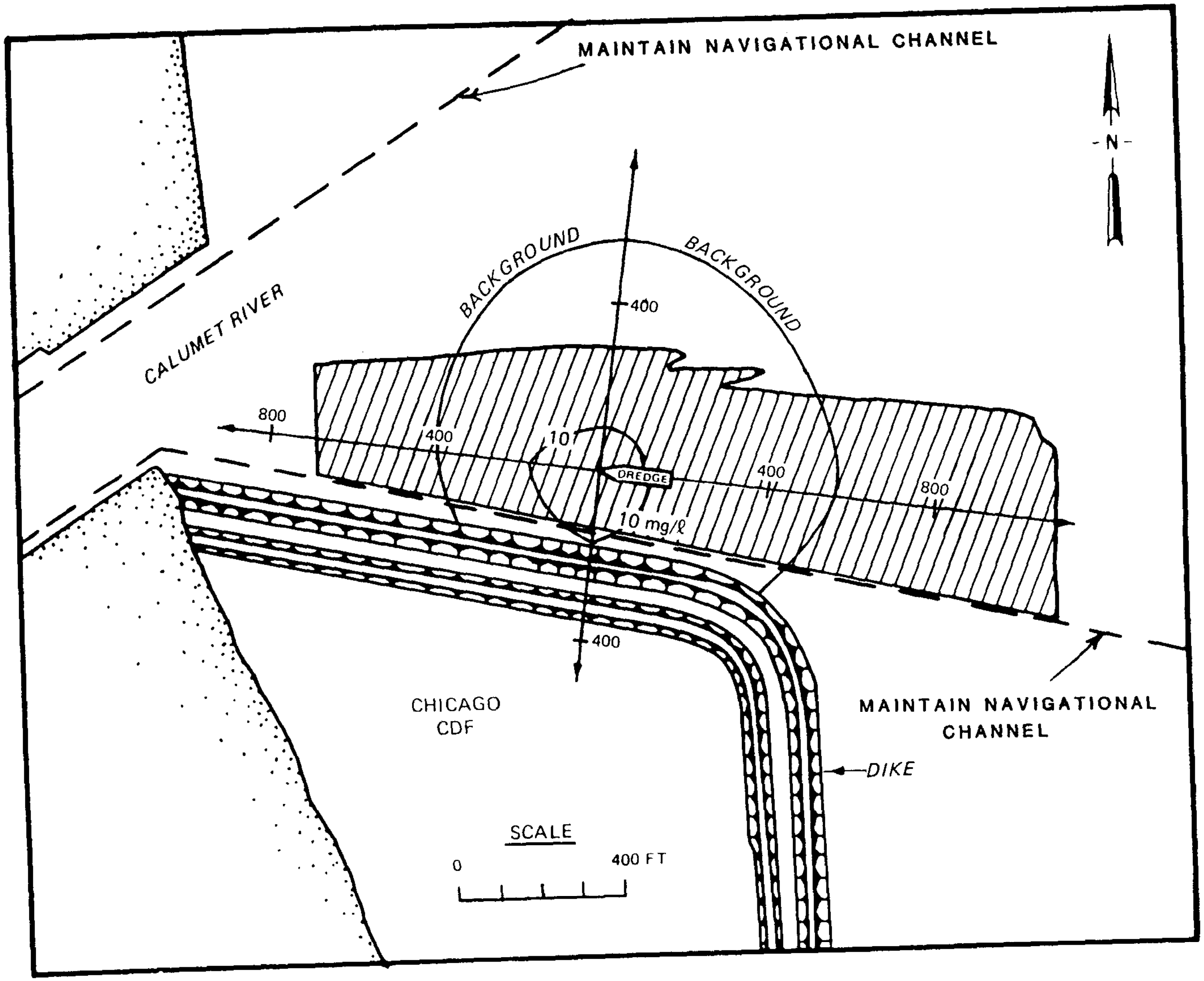


Figure 18. Isoconcentration lines for cutterhead tests (depth = 95 percent of total)

full cut was used in all tests, and approximately 1.5 ft of sediment was removed from the initial bottom depth of approximately 27 ft.

31. Since the dredge operator had no prior experience with a matchbox suction head, the techniques he used were developed as he gained experience. This is obviously not the best situation to obtain experimental data on the performance of the equipment, but the operator learned quickly, and performance was not significantly affected because of his inexperience. In fact, the matchbox operation proved to be very similar to cutterhead operation with only a few minor modifications.

32. One problem that persisted throughout the testing of the matchbox and affected the quality of the near field samples was the lack of instrumentation to accurately position the matchbox. Proper positioning for the matchbox head includes vertical and horizontal controls. The vertical positioning can be controlled by including instrumentation to indicate the depth of the top of the head in relation to the bottom. The precision of the head placement has a direct impact on both dredging efficiency and sediment resuspension. Horizontal controls ensure that the matchbox remains parallel to the bottom. A hydraulic piston located on the matchbox can be used for this purpose. Without this instrumentation, the operator had a difficult time positioning the matchbox. Sometimes material piled up on the side of the matchbox and clogged the water sample tubes located on the dredgehead.

33. Another persistent problem with the matchbox was the clogging of the suction intake. The lodged debris rendered the valve designed to regulate water intake inoperable and resulted in reduced dredging efficiency. A new grid system for the matchbox may be designed to help control this problem. Evaluation of the matchbox performance should take into account the lack of instrumentation and control in this particular demonstration.

Collection of near field water quality samples

34. Samples were taken from each of six sampling points within a few feet of the matchbox at regular intervals (approximately every 30 min) during each testing period. These sampling points were formed by attaching 3/4-in. galvanized steel pipes to a steel frame mounted on the framework that was part of the matchbox (see Figure 19). The steel sampling frame was specially designed for the matchbox head and was operated similar to the cutterhead sampling effort except as noted. The open ends of the six pipes were placed as shown in Figure 20 to gather data at various locations with respect to the

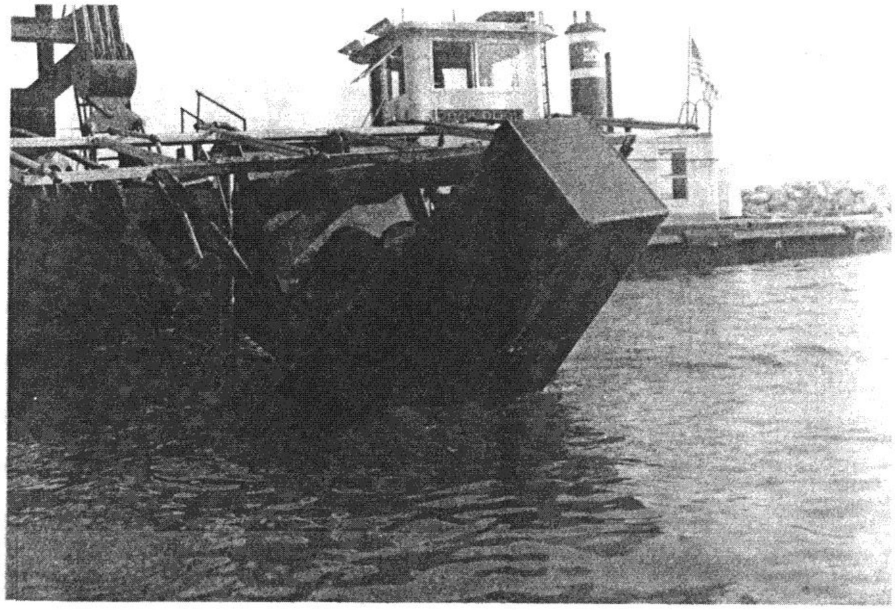

Figure 19. Near field sampling array for matchbox tests

matchbox. Each water quality sample collected from tubes was analyzed for suspended solids concentration. Additional samples were taken from each tube during each test period and analyzed for particle-size distribution using a Microtrak laser particle analyzer. The results of these analyses are given in Appendix A.

Near field data analysis

35. The near field data collected during the three matchbox testing periods were not divided according to the direction of the swing. Unlike the cutterhead, the matchbox should perform similarly in both directions. The near field water quality samples were taken in the order the tubes are shown in Figure 20, but in the opposite direction of the swing (e.g., for a port-to-starboard swing, samples were taken from tubes 1-6). Because of the matchbox positioning problem described previously, much of the near field data does not represent optimum performance of the matchbox. For this reason, data obtained during periods of questionable performance were not included in the analyses of matchbox performance. Average suspended solids concentrations are used to describe the sediment resuspension characteristics near the matchbox. All suspended solids concentrations have been adjusted for the background level and represent the resuspension above background.

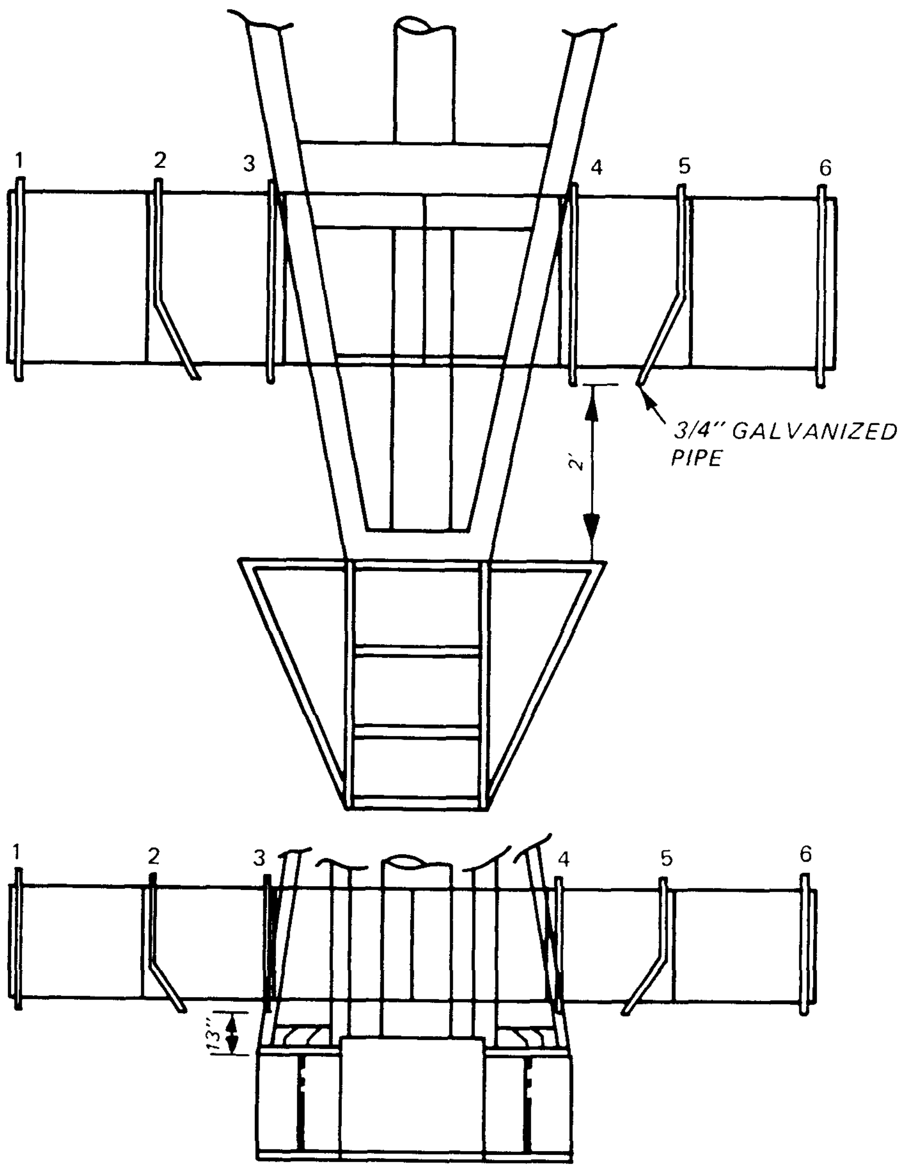


Figure 20. Locations of sample tubes for matchbox test

36. Concentration distributions near the matchbox. Samples were taken at three different lateral distances (on both sides of the matchbox) from the matchbox to determine the lateral variation. The lateral and vertical locations for each tube from the outer edge of the matchbox are given in Table 4. Because of the differences between the cutterhead and matchbox, the sample frame was not designed to obtain samples as close to the intake as for the cutterhead. Therefore, the lateral and vertical positions are somewhat greater for the matchbox than for the cutterhead. Negative lateral values

Table 4

Positioning of Near Field Sampling Tubes for Matchbox Tests

| Tube Number | Lateral Position, ft | Vertical Position, ft* |
|---|---|---|
| 1 | - 4 | 2 |
| 2 | - 1.5** | 2 |
| 3 | - 1.5** | 2 |
| 4 | 1.5** | 2 |
| 5 | 1.5** | 2 |
| 6 | 4 | 2 |

* Relative to the predredged bottom elevation.

** Tubes 2, 3, 4, and 5 were positioned laterally along the edge of the matchbox, but were approximately 2.5 ft above the matchbox.

indicate positions on the starboard side of the matchbox. Using the data collected and analyzed as described above, Figure 21 indicates variation in suspended sediment concentration near the matchbox.

37. Grain-size analyses of resuspended sediment. The results of the grain-size analyses conducted on matchbox near field samples are listed in Appendix A and indicate that the characteristics of the resuspended sediment are almost identical to those of a cutterhead sample. The resuspended sediment particles were all smaller than 176 μ (slightly larger than a No. 100 sieve) for every sample with approximately 80 percent of the particles in the silt-size range (75 to 2 μ). Only a small fraction of the sediment particles (less than 3 percent) were in the clay range. In comparison, the bed sediment contained approximately 14-percent clay-size particles with slightly less than 70-percent silt-size particles.

Collection of far field water quality samples

38. Samples were collected at four depths at each of 10 sampling stations arranged as shown in Figure 22 around the dredging operation. As for the cutterhead demonstration, the sampling grid was designed both to skew the sampling effort in the direction of current and to measure the suspended sediment dispersion in every direction since the currents were so small. A sample for suspended solids analysis was taken at 5, 50, 80, and 95 percent of total depth at each station during each sampling period. Two sampling periods were completed during each period of constant dredge operating characteristics.

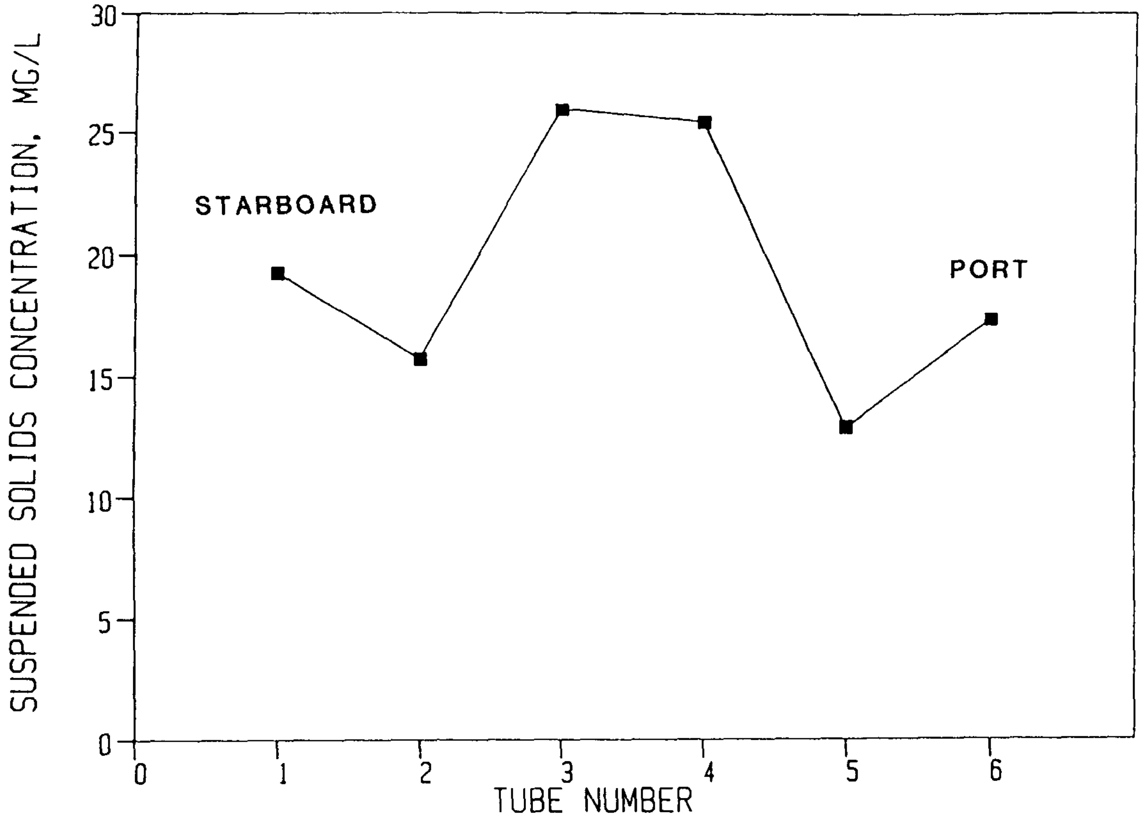


Figure 21. Suspended sediment distribution near the matchbox

Far field data analysis

39. Similar to the cutterhead tests, the results of the far field sampling effort show that very little suspended sediment was observed other than in the immediate vicinity of the dredging operation. In fact, most of the observations were at or near the background level, especially in the upper water column. Figures 23 through 26 show the concentration profiles surrounding the dredge at each depth. Some small amount of skew is evident in the lower water column due to the currents observed in the area.

## Summary

40. The hydraulic pipeline field study at Calumet Harbor allowed for a direct comparison of the resuspension characteristics of a cutterhead suction dredge and a matchbox suction head dredge. Both dredges operated under identical hydraulic and sediment conditions and at the time of the demonstration were attached to the same dredge, the Corps-owned DUBUQUE. This demonstration

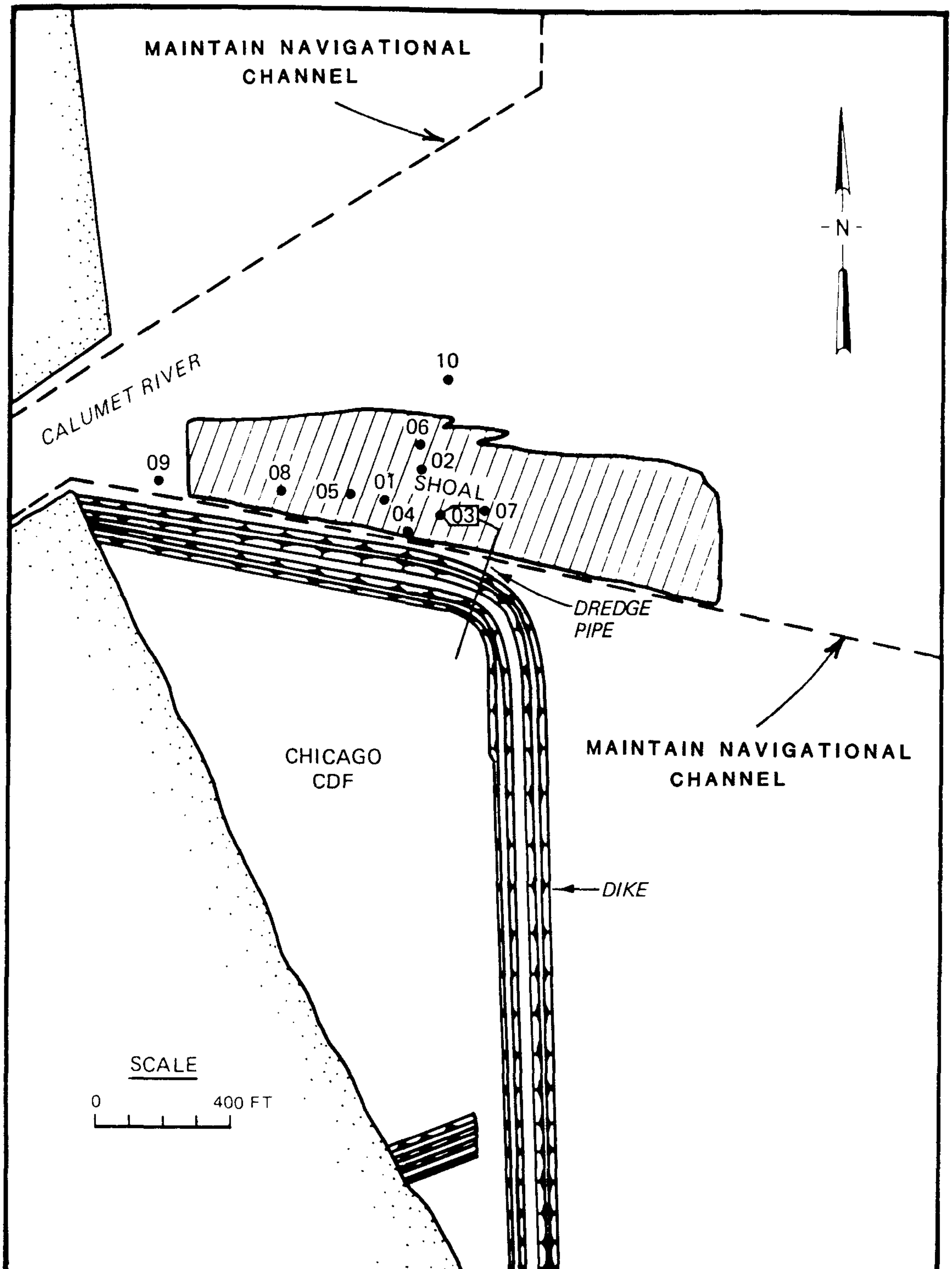


Figure 22. Far field sampling grid for matchbox tests

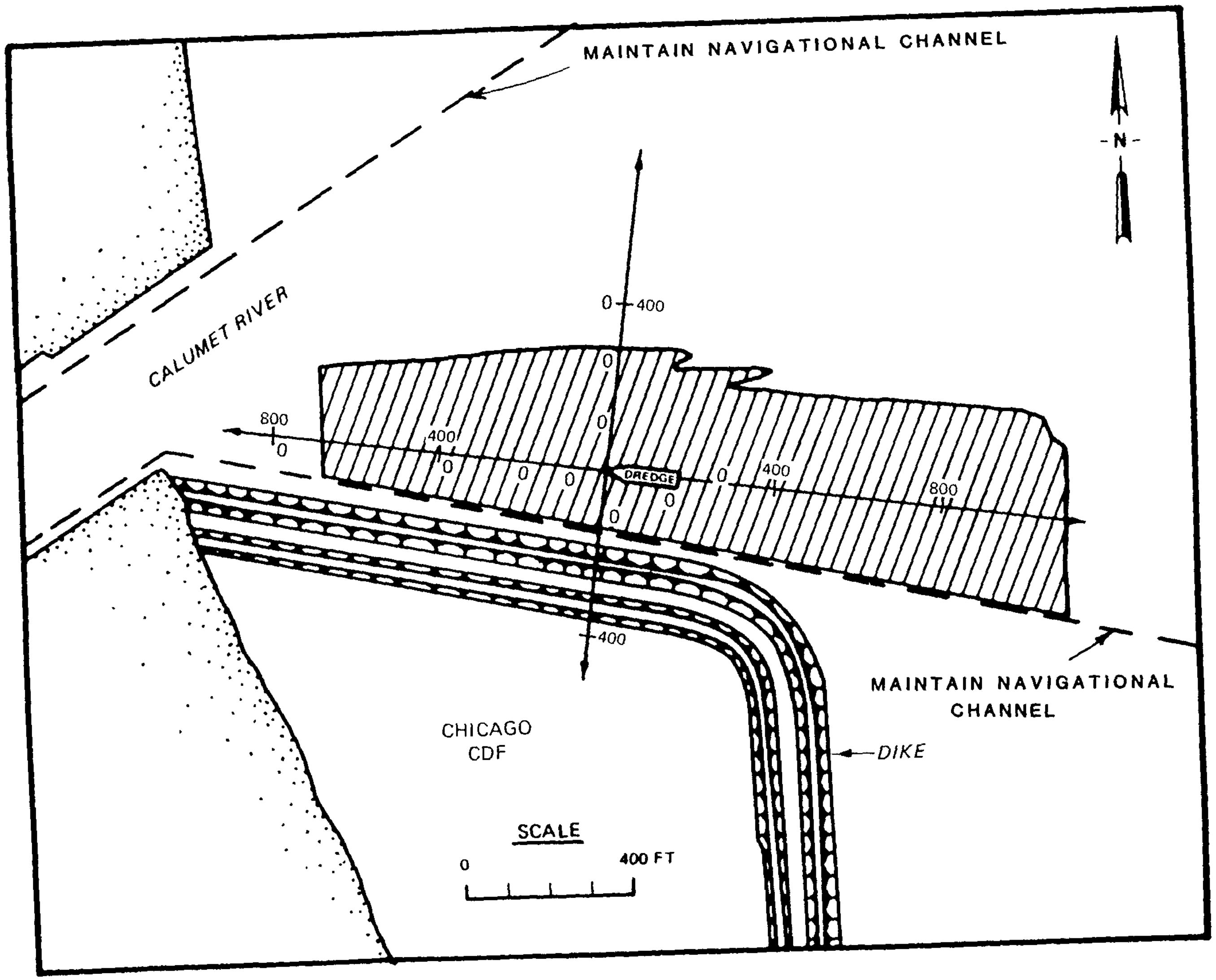


Figure 23. Observed suspended sediment concentrations for matchbox tests (depth = 5 percent of total)

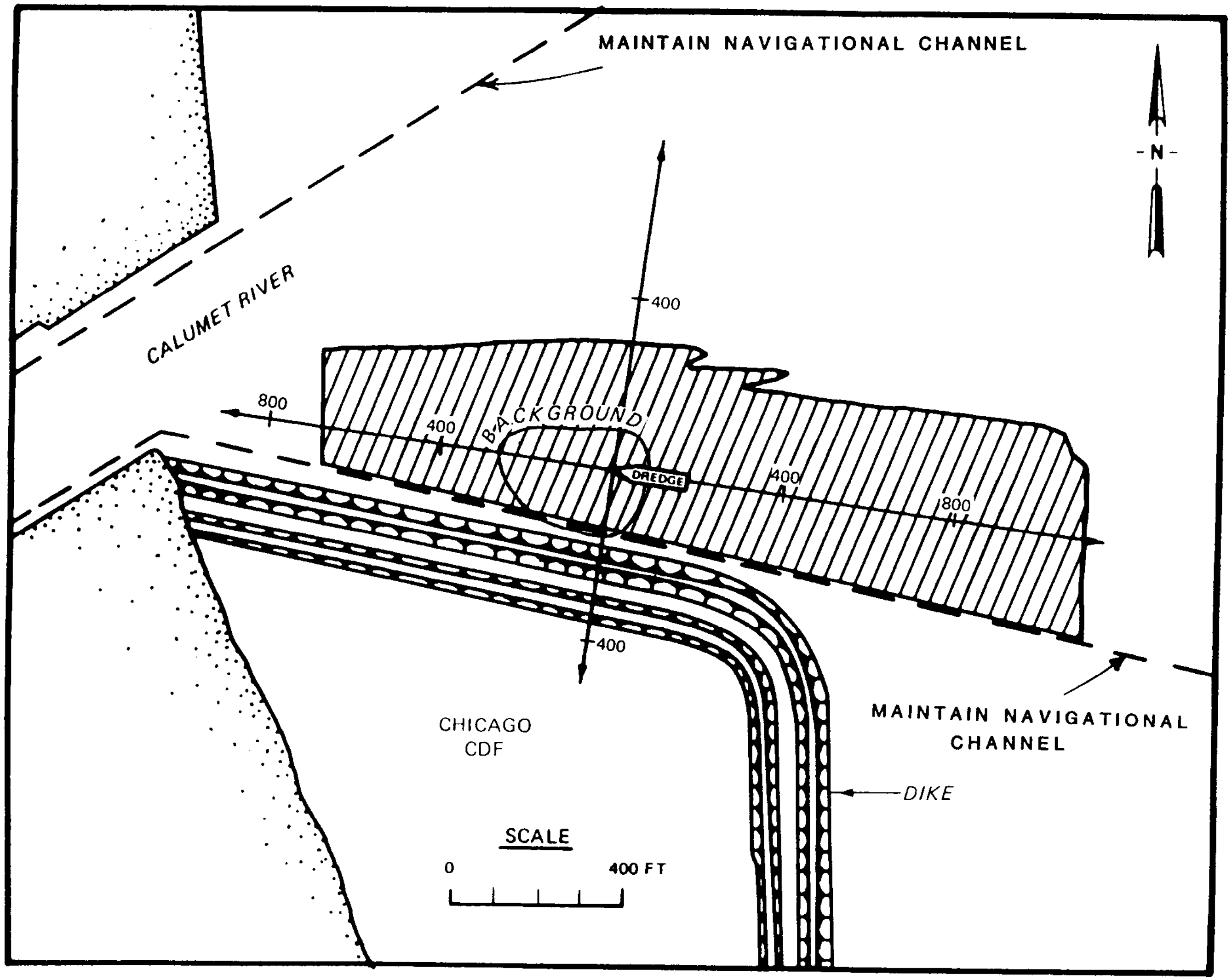


Figure 24. Background isoconcentration line for matchbox tests (depth = 50 percent of total)

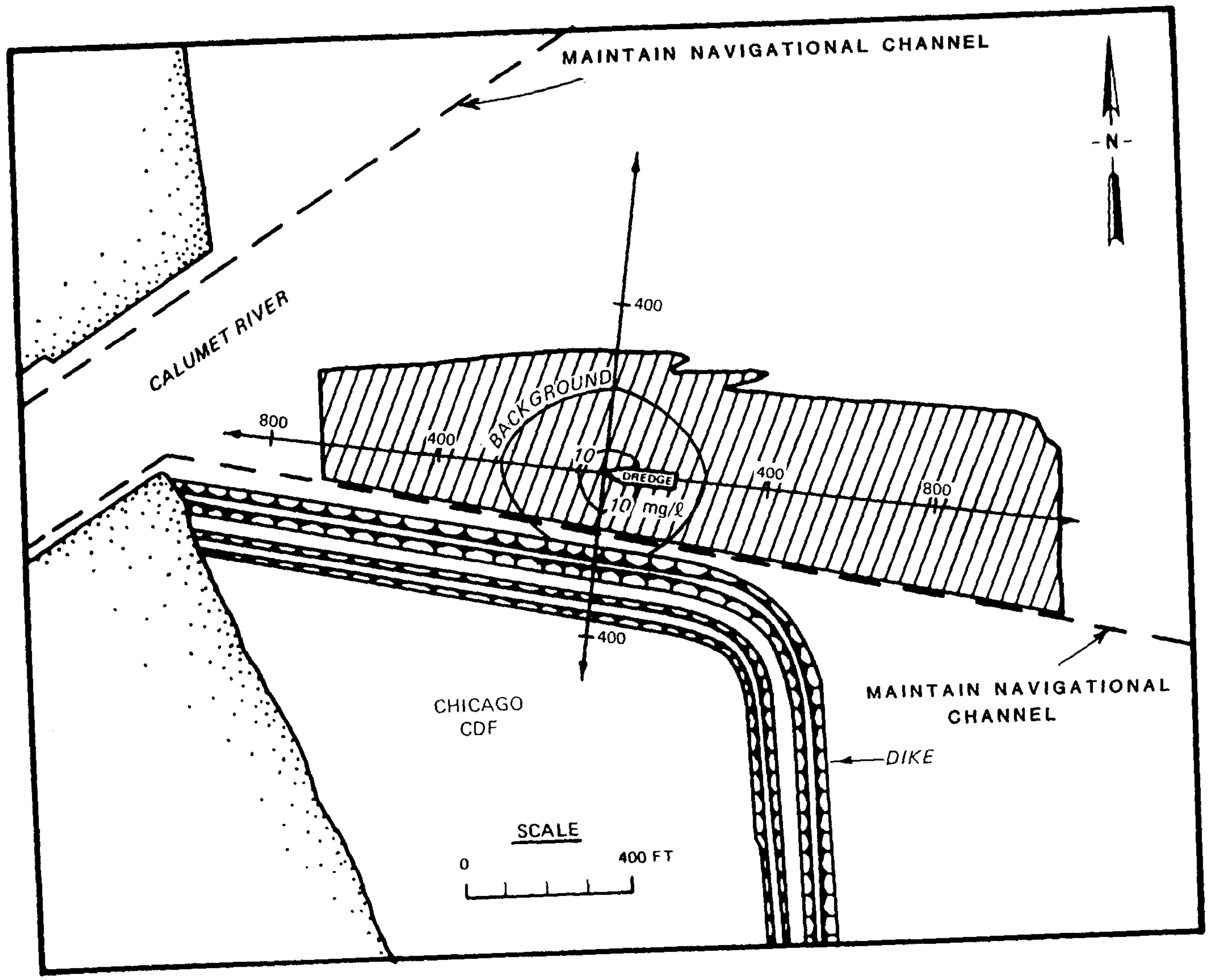


Figure 25. Isoconcentration lines for matchbox tests (depth = 80 percent of total)

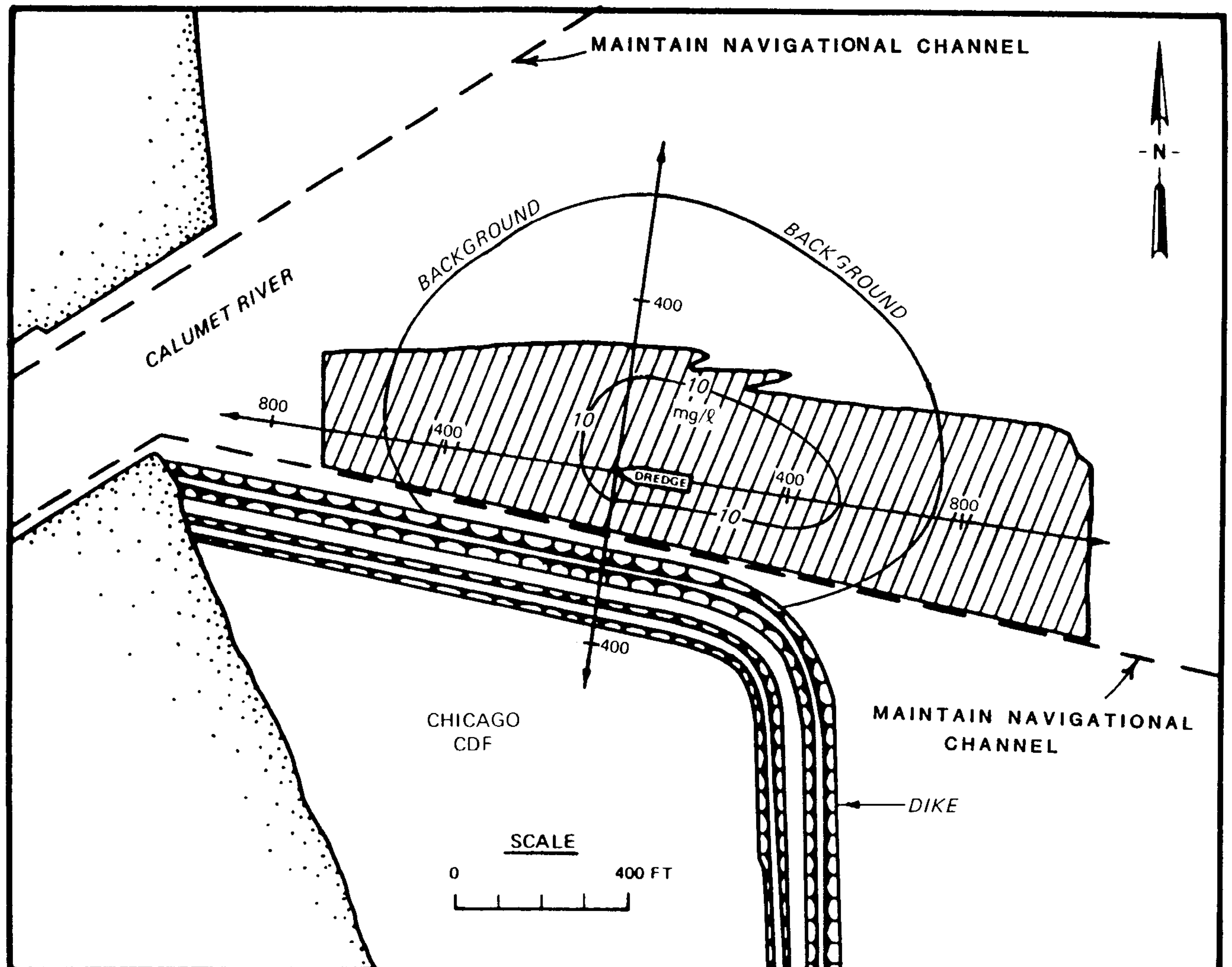


Figure 26. Isoconcentration lines for matchbox tests (depth = 95 percent of total)

represents the first use of the Dutch-designed matchbox dredge in this country and was part of a larger effort to evaluate dredging and dredged material disposal options for dredging contaminated sediments at Indiana Harbor. Data collection to analyze the resuspension characteristics of each dredge included near and far field water quality samples, background water quality and sediment samples, current measurements, and dredge operational measurements.

41. The cutterhead dredge was operated with varying swing speed and cutter rotation speeds during the Calumet Harbor field study. Samples collected near the dredgehead indicated suspended sediment concentrations of 7 to 17 mg/ℓ above background. The Calumet Harbor data also indicate that the overcut, starboard-to-port swing suspends more material than the undercut, port-to-starboard swing. The far field data indicate that the suspended sediment plume generated by the cutterhead remains close to the bottom and rapidly decreases upward through the water column. At the 95-percent depth interval, the cutterhead generated a 1.2-acre plume of at least 10-mg/ℓ concentration. Although the plume was evident up through the 50-percent depth interval, no concentration of at least 10 mg/ℓ was encountered above 95-percent depth.

42. The matchbox suction head dredge was operated identically to the cutterhead dredge and used similar swing speeds. Although the dredge lacked some instrumentation used for the matchbox, the dredgehead still performed well. Samples collected using the dredgehead sample frame indicate suspended sediment concentrations of 12 to 27 mg/ℓ. These levels fluctuated greatly, indicating that material may have been piling up on the matchbox. The matchbox generated a far field 10-mg/ℓ plume of 2.9 acres at 95-percent depth and 0.4 acres at 80-percent depth. No 10-mg/ℓ concentration levels were recorded above this level. The TSS concentration levels near the dredgehead and plume size should both decrease with increased instrumentation, automation, and operator experience of the matchbox suction head dredge.

43. The amount of sediment resuspended by both the matchbox and cutterhead was quite low. The operation of the dredge with the matchbox suction head attached proved that the matchbox is a workable piece of equipment and is capable of removing unconsolidated bottom sediments. Some operational difficulties were encountered with the matchbox, but most were due to the lack of required instrumentation for proper operation in this particular demonstration. Depth position instrumentation is important for optimum performance of

the matchbox. The cutterhead performance was not as sensitive to precise depth control as was the matchbox performance. Both dredges operated well during this field study, and one could not be recommended over the other for removal of unconsolidated contaminated material. Further tests using a matchbox head with all the suggested instrumentation and controls may help in making a more educated decision on which is the best dredge to use.

# PART III: CLAMSHELL DREDGE

## Background

44. The bucket type of dredge is a mechanical device that uses a bucket to excavate the material to be dredged (Figure 27). Different types of buckets can fulfill various types of dredging requirements. Bucket dredges include the clamshell, orangepeel, and dragline types and can be quickly interchanged to suit the task requirements. The vessel can be positioned and moved within a limited area using only anchors; however, in most cases anchors and spuds are used to position and move bucket dredges. The bucket dredge is effective while working near bridges, docks, wharves, pipelines, piers, or breakwater structures because it does not require much area to maneuver; there is little danger of damaging the structures because the dredging process can be controlled accurately. The material excavated is placed in scows or hopper barges that are towed to the disposal area. Bucket dredges normally range in capacity from 1 to 25 cu yd. The crane is mounted on a flat-bottomed barge, on fixed-shore installations, or on a crawler mount. A typical production rate is 20 to 50 cycles/hr, but large variations exist because of the variability in depths and materials being excavated. The effective working depth is limited to about 100 ft.

45. Previous studies (Barnard 1978; Bohlen, Lundy, and Tramentano 1979; Hayes, Raymond, and McLellan 1984) have determined that the majority of sediment resuspension during clamshell dredging operations results from the impact, penetration, and withdrawal of the bucket from bottom sediments.

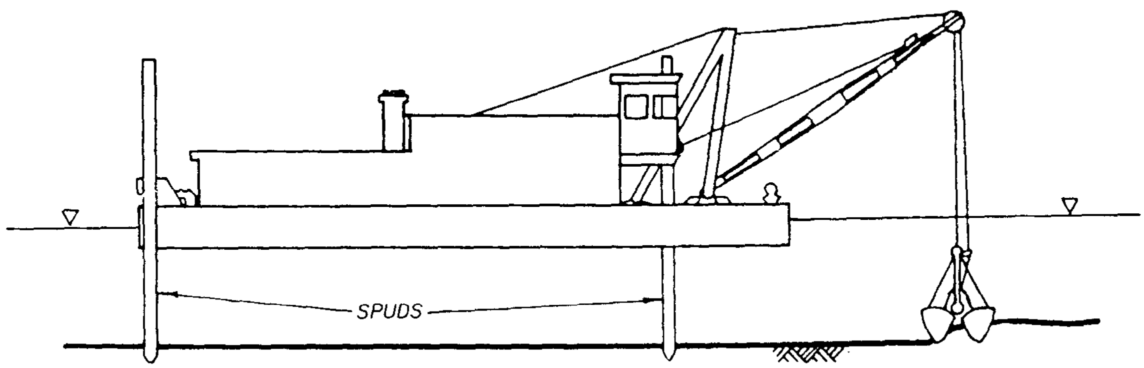


Figure 27. Clamshell bucket dredge

Additional loss of material occurs as the bucket is pulled through the water column, from spillage of turbid water from the bucket as it breaks the water surface, and from spillage or overflow while dumping. The amount of material resuspended during these processes is also influenced by the fit and condition of the bucket, the hoisting speed, and the properties of the sediment. Substantial losses of fine-grained material can occur during a clamshell operation even under ideal conditions. Summarizing previous research, Barnard (1978) stated that the resuspended plume from a clamshell operation may extend 1,500 ft near the bottom and have concentrations reaching 500 mg/ℓ.

46. The clamshell dredge field demonstration occurred in August 1985 in the upper portion of the Calumet River (Figure 1). The field study was incorporated into an ongoing dredging operation designed to remove approximately 215,000 cu yd of shoaled material from within 2 miles of the navigational channel and approach to Lake Calumet in order to maintain a 27-low-water-depth project depth. During the time of the field study, the dredge was operating near the northern bank of Turning Basin No. 5.

47. A 10-cu yd clamshell bucket was used to remove the soft, organic clay/silt mixture (OL). The dredging plant worked with three scows that were continually rotated when filled. When a scow became full it would be transported to the disposal facility located 6 miles upstream in Lake Michigan at the mouth of the Calumet River. The operating procedure for the dredge was to obtain a load of sediment, raise the bucket out of the water above the height of the scow, and then swing the bucket over the scow and release the material. The cycle time to complete this procedure and return to the bottom for another bucket of material was between 55 and 65 sec. After 15 to 18 cycles, the dredge would have cleared a cut of approximately 100-ft width. The bucket would then be lowered to the bottom and dragged across the freshly cut surface several times to smooth it out. The dredge operator would either readjust the crane or move the dredge to begin a new cut. The dredge was relocated several times during the study but remained in the general area of Turning Basin No. 5. The operation of the dredge was continuous from 0700 to 1600 hr except periods when the scows were replaced. Approximately 10 min was required to replace a scow.

## Data Collection

48. To determine the amount of sediment resuspended by the clamshell dredge, discrete water samples were collected at various depths and locations near the dredge. Background samples were also collected to establish ambient suspended sediment levels. Background levels were sampled 20 August 1985, and plume sampling was completed on 22 and 23 August.

49. Seven background stations, located throughout the dredging reach, were established, and discrete water samples were collected at the surface, middepth, and near bottom (Figure 28). The background current regime was established using three channel transects with three stations on each transect, dividing the channel into thirds (Figure 29). The sample boat was positioned using an electronic distance meter (EDM). Once in position, the sample boat would anchor and obtain measurements of the current and/or collect discrete water samples at the surface, middepth and near bottom.

50. A sample grid was established around the dredge for collection of suspended sediment samples during the dredging operation. The grid consisted of three transects, two perpendicular to ambient current direction and the third parallel to the current direction. The plume was assumed to be symmetric around the downstream transect so that the perpendicular transect was established only on one side of the dredge. In all, 13 stations were incorporated into the sampling effort (Figure 30). On August 22, Stations 3, 4, 6, 11, 12, and 13 were sampled for TSS. Discrete water samples were collected at each station at the surface (5 ft below surface), middepth (15 ft), and near bottom (27 ft) for later TSS analysis. Because of the low current regime (all measurements being below 0.2 fps for 20, 22, and 23 August), the size of the sample grid was reduced to obtain better definition of the plume. The transect perpendicular to the flow was moved up 400 ft to be aligned with the dredging operation, and the parallel transect was shortened from 800 to 600 ft downstream. Two stations were also added upstream of the dredge. From Figure 28, stations sampled on 23 August were 1, 2, 3, 4, 5, 6, 8, 9, and 10. Current measurements during the field study were collected at Stations 7, 11, 12, and 13 for 22 August and Stations 1, 2, 6, and 10 for August 23.

51. Weather conditions during the sample period were good. Winds were less than 8 mph during the entire study, and the temperature ranged from 60°

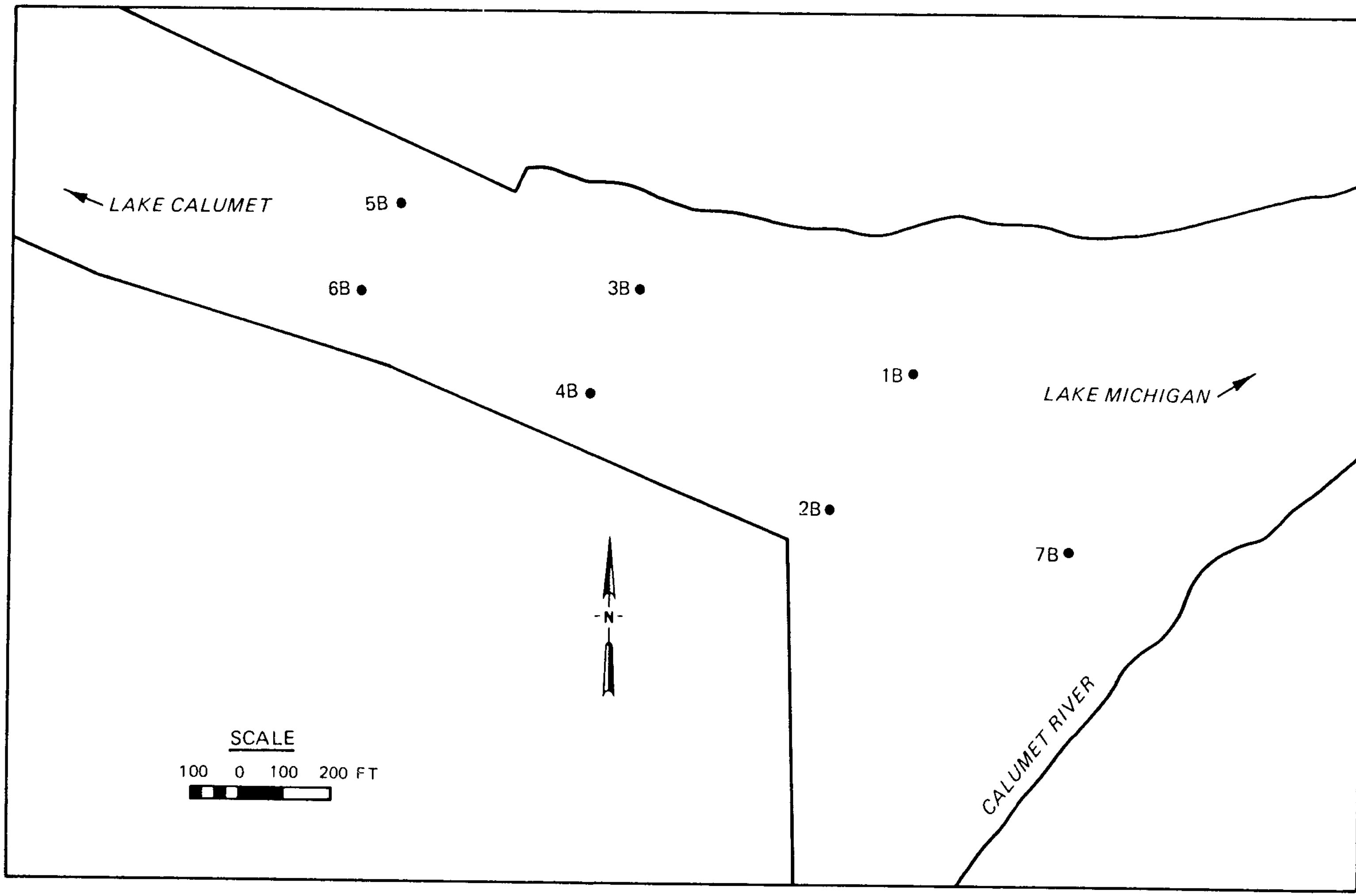


Figure 28. Background TSS station locations, 20 August 1985

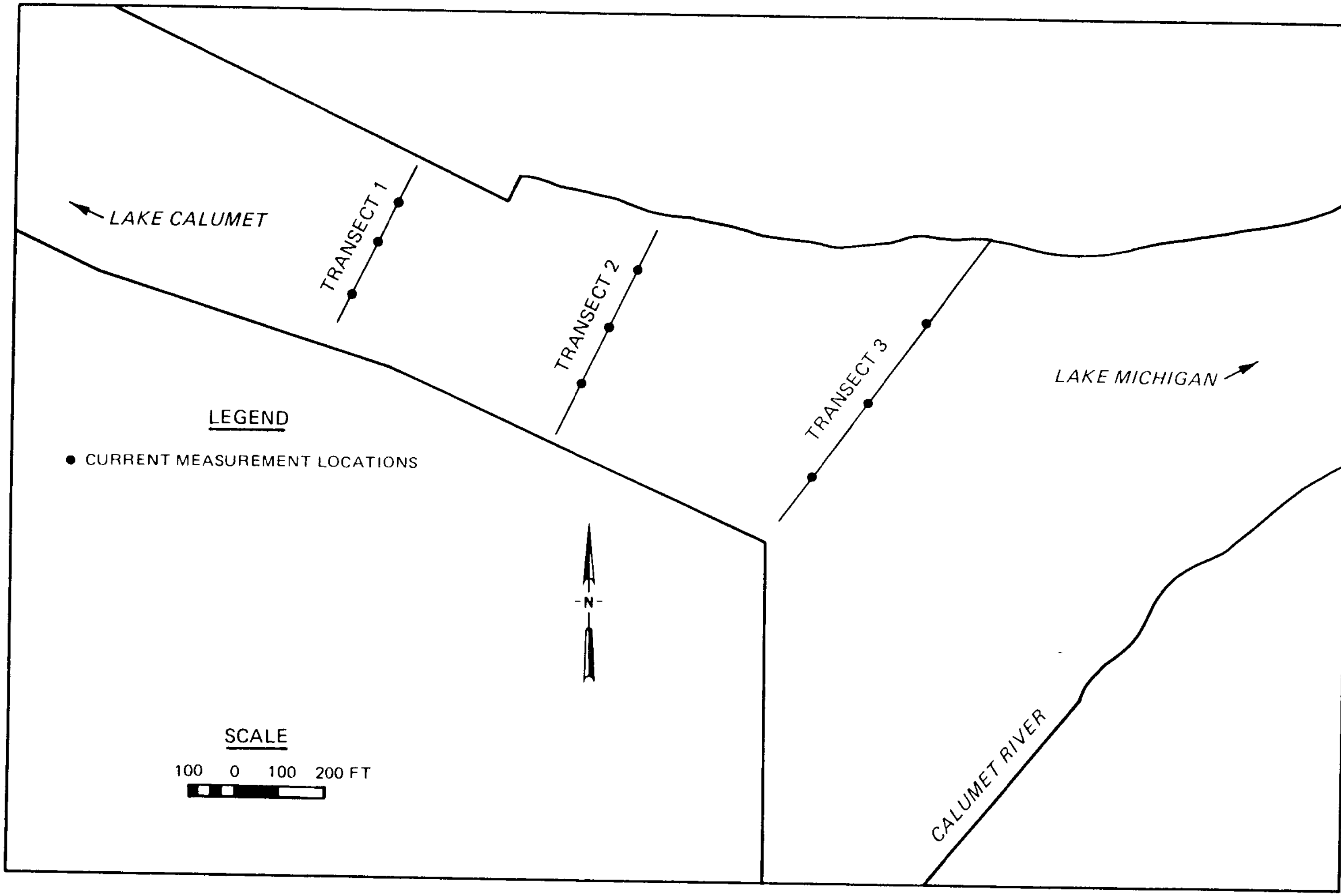


Figure 29. Background current transects, 20 August 1985

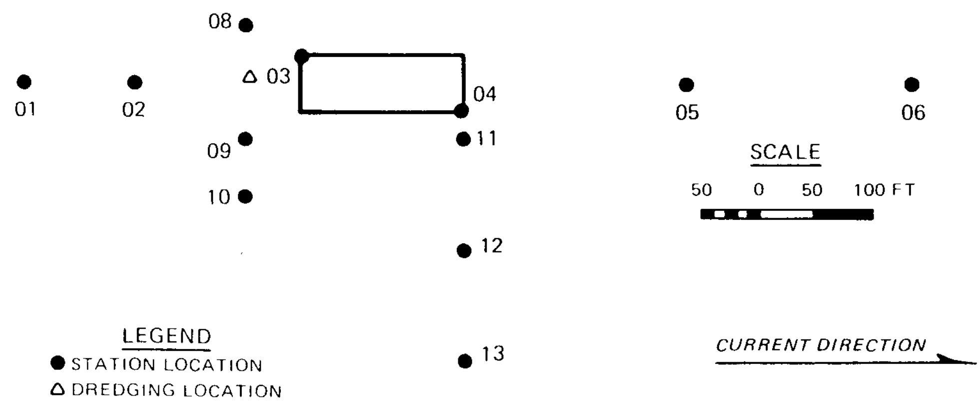


Figure 30. Clamshell dredge sample grid

to 85° F. Sampling coincided with the operation of the dredge with the exception of a 1-hr lag time after dredging began each day.

## Equipment

52. All water column samples and current measurements were collected from two small (15 to 20-ft) aluminum sample boats or directly from the dredge barge. All water column samples from Stations 3 and 4 were collected from the barge.

53. All background and plume water column samples were collected by using a 1- or 5-ℓ PVC Juday type sampler (Figure 31). The Juday sampler was allowed 30 sec to fill and then raised to the surface, where a 250-ml sample was collected.

54. The distance from the dredge to the stations was established using a Topcon DMS-2 EDM. The EDM was located on shore, and a john boat with reflectors was used to establish distances relative to the dredge barge. When a station was located, a marker buoy was placed overboard and used as a reference point for positioning the sample boat. This method worked very well for relocating and sampling at the same position in relation to the dredge.

55. A Marsh McBirney Model 201D electrostatic water current meter was used to measure the current velocity in the Calumet River. The current meter was attached to a Stevins Sounding Reel for raising and lowering the current meter. The line on the sounding reel was marked in 0.1-ft increments for accurate depth placement.

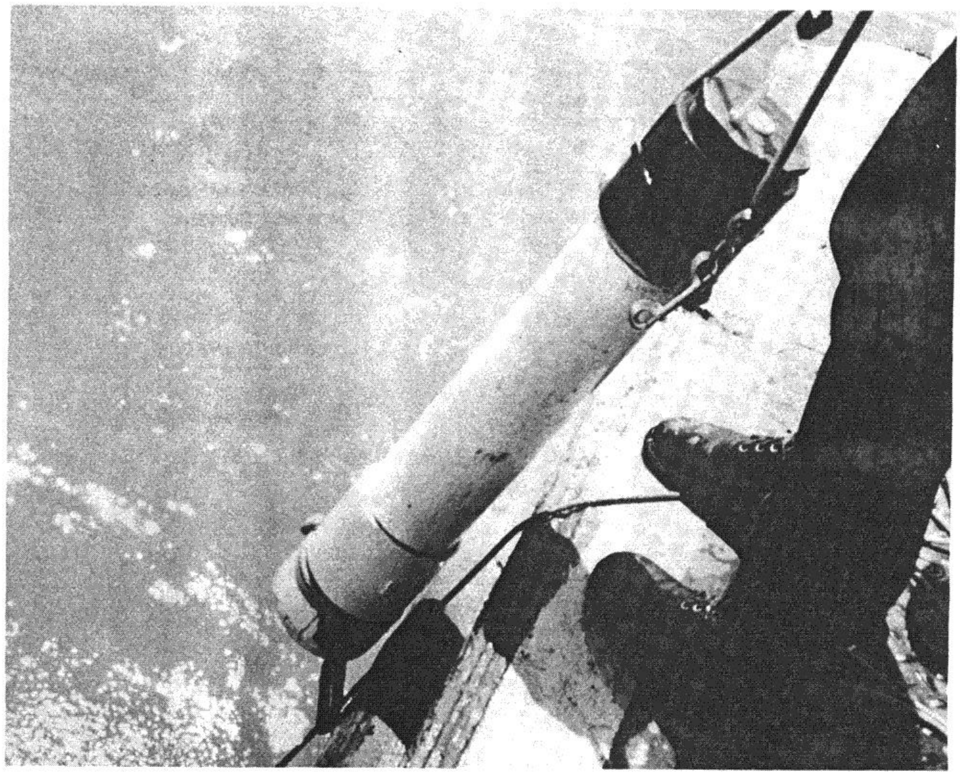

Figure 31. Juday water sampler

## Results

56. The gravimetric analyses were performed on the water samples to measure the TSS of each sample. A complete list of the TSS data is given in Appendix B with the location of the samples corresponding to the location numbers shown in Figure 32.

57. During the 3 days of sampling, the current velocity remained low. The velocity measurements on August 20 for Transects 1, 2, and 3 yielded the values in Table 5. Velocity measurements collected August 22 near the dredge yielded the values in Table 6. Stations 01, 02, 06, and 10 sampled on August 23 were very similar; therefore, no subsequent current measurements were obtained.

58. The background suspended sediment levels ranged between 9 and 12 mg/ℓ with the only exceptions being the surface measurement on Station 5B and the bottom measurement on Station 1B (Table 7). The 18-mg/ℓ reading at Station 5B is possibly due to the loading of crushed limestone occurring at

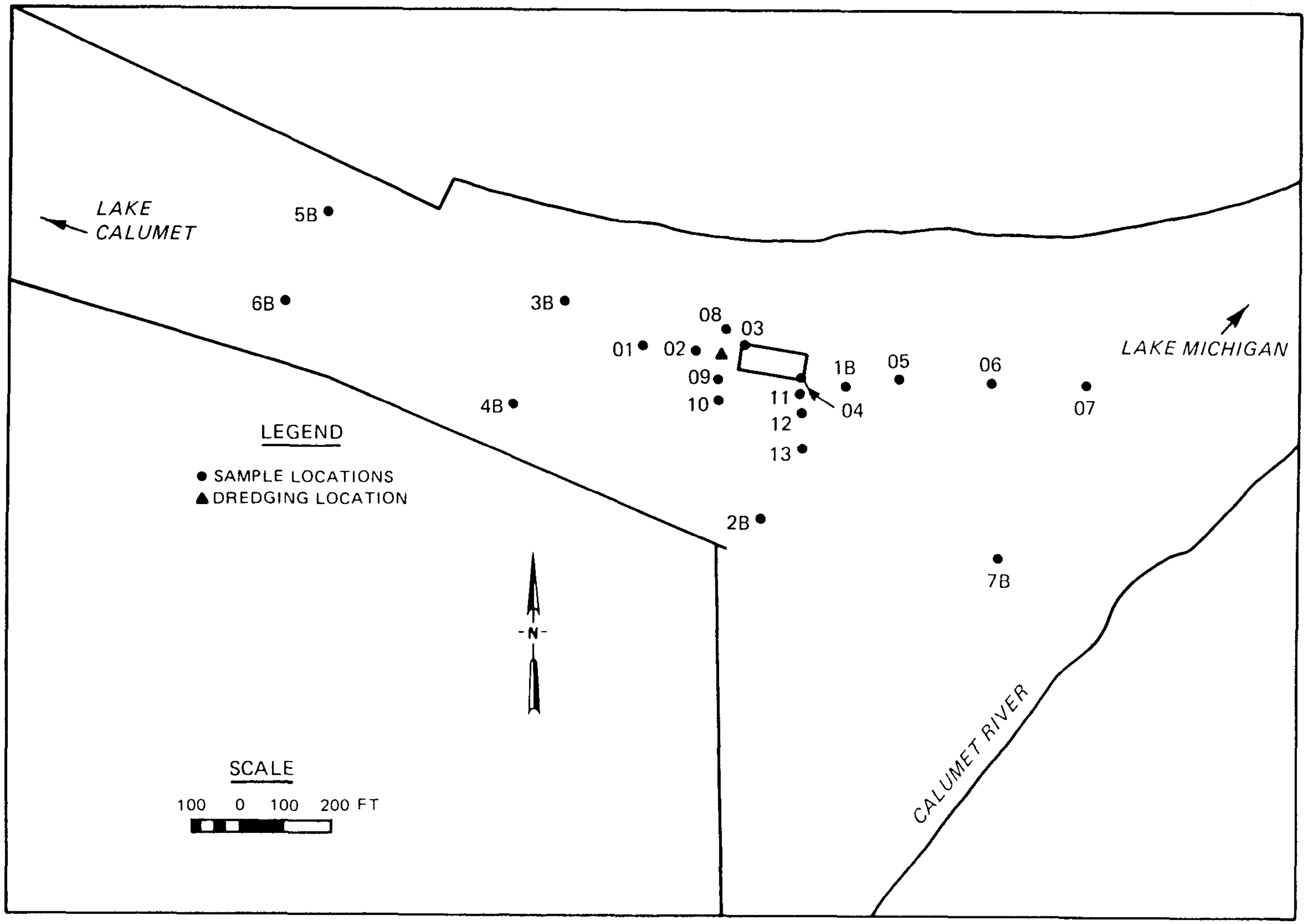


Figure 32. Sample locations for 20, 22, and 23 August 1985

Table 5

Background Current Velocity for 20 August 1985

| Transect No. | Average Velocity, fps | Velocity Range, fps |
|---|---|---|
| 1 | 0.06 | 0 to 0.18 |
| 2 | 0.06 | 0 to 0.09 |
| 3 | 0.11 | 0 to 0.18 |

Table 6

Current Velocity for 22 August 1985

| Station No. | Average Velocity, fps | Velocity Range, fps |
|---|---|---|
| 07 | 0 | 0 to 0.09 |
| 11 | 0 | 0 to 0.06 |
| 12 | 0 | 0 to 0.05 |
| 13 | 0 | 0 to 0.04 |

Table 7

Background Suspended Sediment Levels, 20 August 1985

| | Station | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth | 1B | 2B | 3B | 4B | 5B | 6B | 7B |
| Surface | 11 | 10 | 10 | 10 | 18 | 10 | 9 |
| Middepth | 12 | 12 | 10 | 12 | 12 | 11 | 10 |
| Bottom | 18 | 11 | 12 | 10 | 13 | 11 | 10 |

the dock located on the north bank of the river. The loading facility was located on the water, and a plume of fine limestone dust was visible on the water surface. This operation was occurring only on the day of background sampling, so it would not affect TSS levels during the dredging operation. The 18-mg/ℓ reading on Station 1B may be from the sampling device impacting the bottom and agitating the sediments before the sample was obtained. The potential for this problem was alleviated during the plume sampling by using a sounding reel located in the front of the sample boat to establish the depth of the site. The water sample was collected from the back of the boat, and the sampler was not allowed to touch bottom.

59. As earlier stated, TSS samples were collected at the surface, mid-depth, and near bottom during the dredging operation. Concentrations of the samples collected during the dredging operation varied widely, depending on the depth and distance from the dredge. For example, bottom concentrations of samples collected within 50 ft of the dredge ranged from 540 to 49 mg/ℓ. Farther from the dredge and higher in the water column, readings fluctuated less and ranged 2 to 4 mg/ℓ above background for samples collected 600 ft from the dredge.

60. At each station, all TSS values collected at that station were averaged by depth. This resulted in a single value for TSS at the surface, mid-depth, and bottom for each station. The TSS averages were arranged by depth, and smooth contour lines were drawn to represent the suspended solids plume. The surface, middepth, and bottom plumes are shown in Figures 33, 34, and 35 respectively. The plumes are adjusted for background levels and indicate the average concentration of suspended solids over the sample period. The 10-mg/ℓ contour represents approximately twice the ambient suspended solids level, and the maximum length ranges from 725 ft for the bottom contour to 500 ft for the surface plume. The maximum width ranges from 300 ft for the bottom plume to 200 ft for the surface plume. At each level, the plume is skewed in the direction of the current.

61. Table 8 indicates the area impacted by the 10-, 40-, and 90-mg/ℓ contours. The table implies that the greatest reduction in size and concentration of the suspended solids plume occurs between the bottom and middepth portion of the water column. Between these two levels there is a 48-percent reduction of impacted area for the 10-mg/ℓ contour, 82-percent reduction of the 40-mg/ℓ contour, and 100-percent reduction of the 90-mg/ℓ contour. In contrast, the reduction of impacted area from middepth to surface indicates almost no reduction for the 10-mg/ℓ contour and a 70-percent reduction for the 40-mg/ℓ contour. The majority of the suspended sediment remains near the bottom with secondary resuspension occurring from leakage from the bucket as it is pulled through the water column. These data tend to confirm that the impact, penetration, and withdrawal of the bucket from the sediment generates the majority of the sediment resuspension.

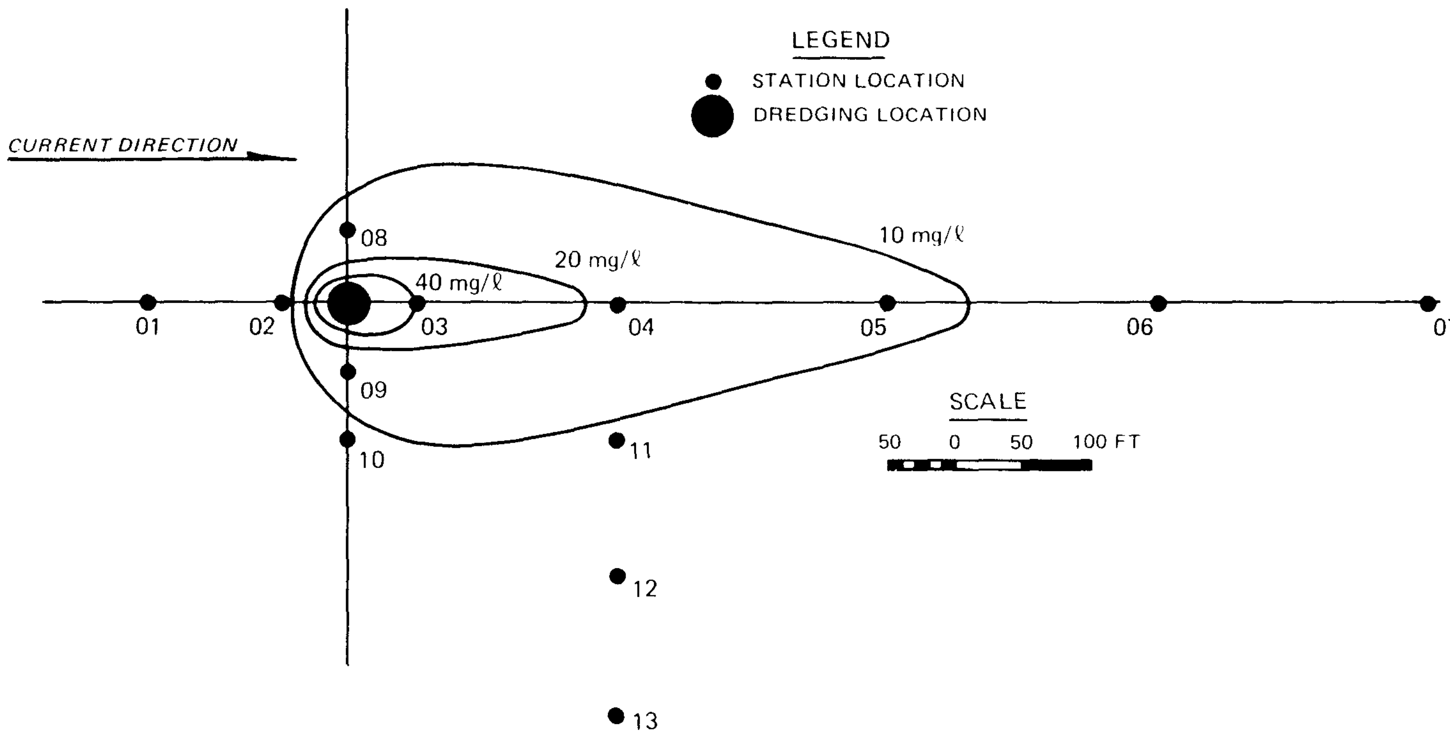


Figure 33. Surface TSS contours

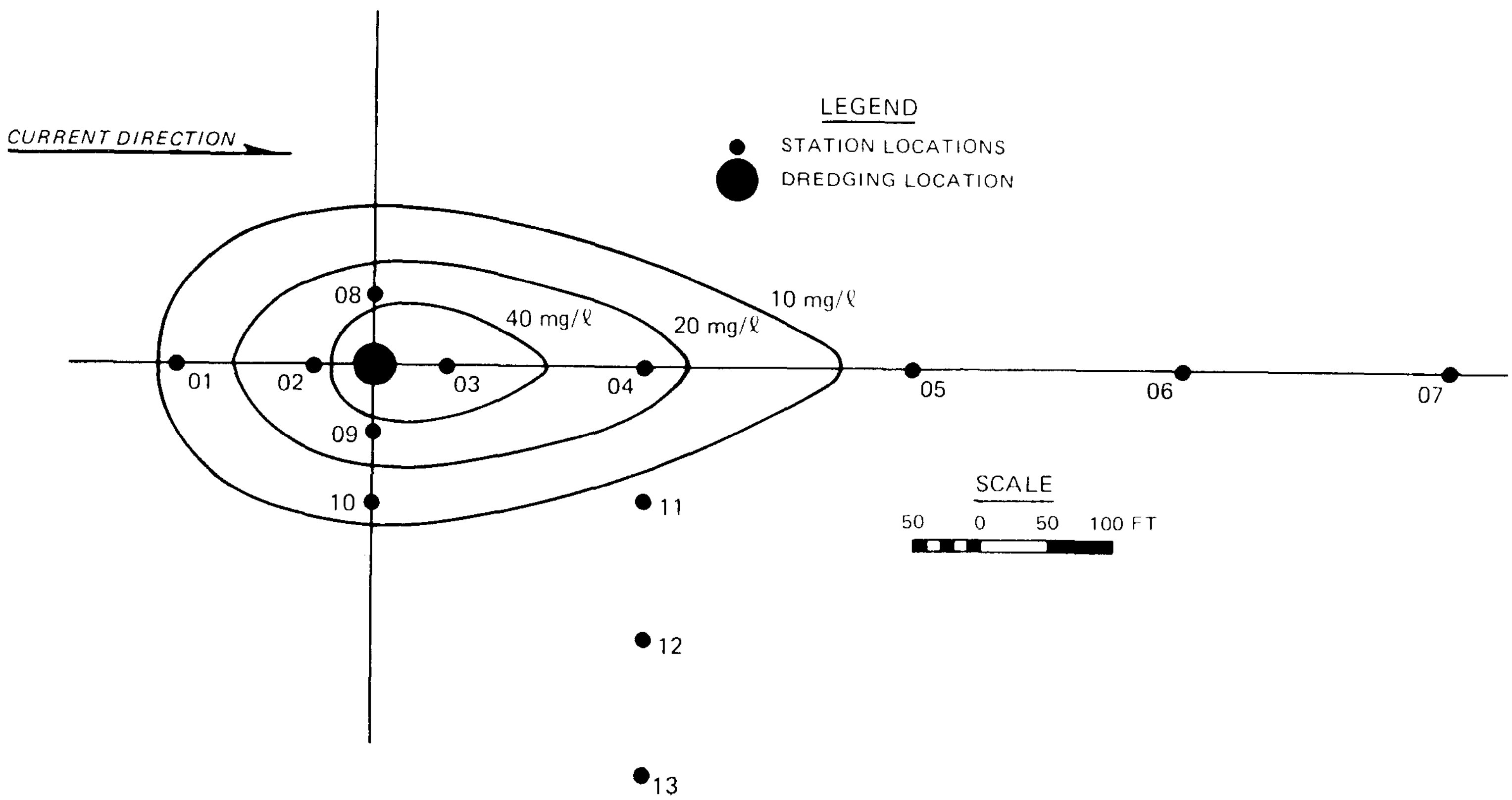


Figure 34. Middepth TSS contours

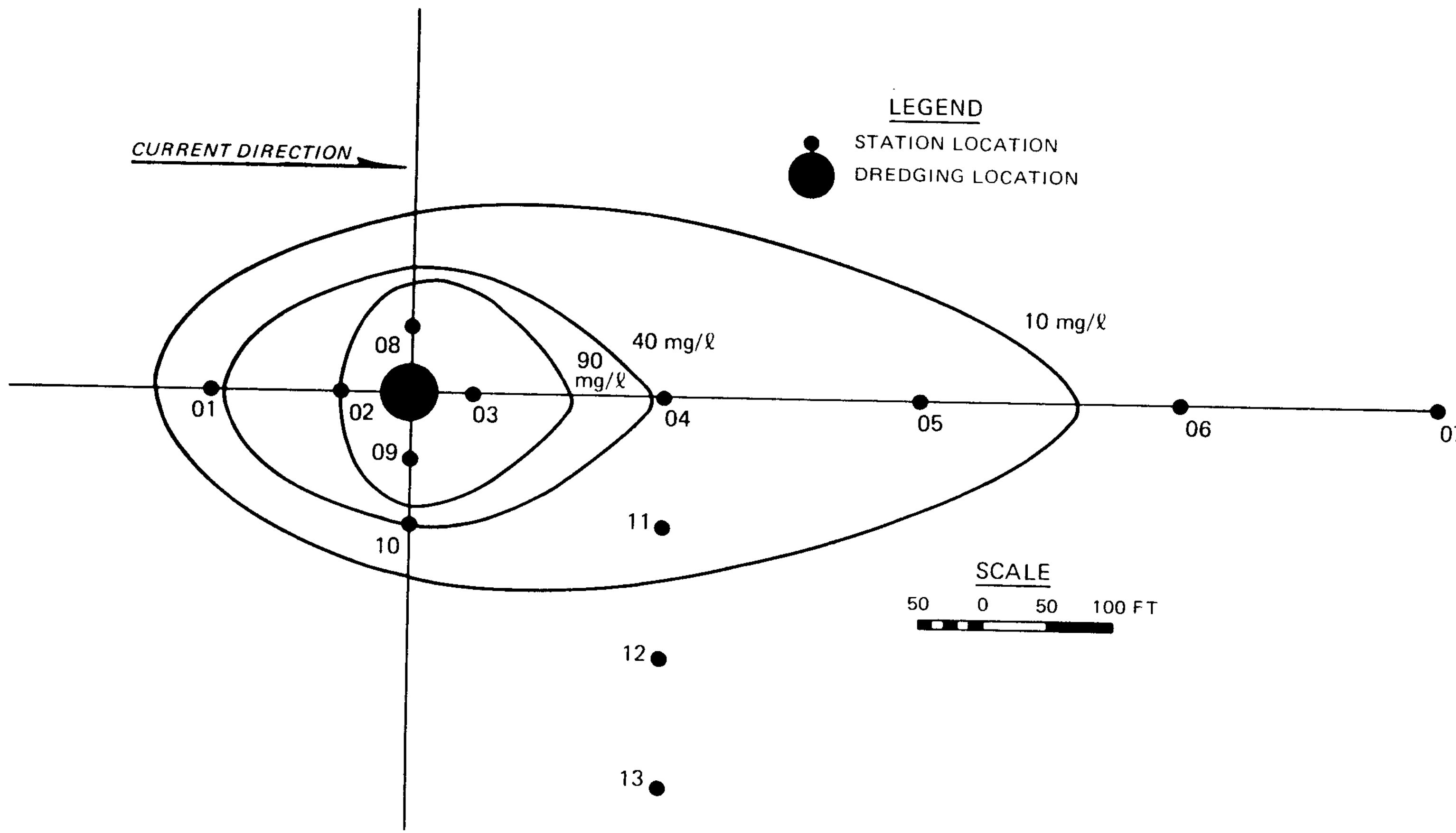


Figure 35. Bottom TSS contours

Table 8

Impacted Area in Acres from Calumet Clamshell Demonstration

| | Contour (mg/ℓ) | | |
|---|---|---|---|
| Depth | 10 | 40 | 90 |
| Surface | 1.7 | 0.1 | --* |
| Middepth | 1.8 | 0.2 | --* |
| Bottom | 3.5 | 1.1 | 0.5 |

* No 90-mg/ℓ contour encountered at that depth.

## Summary

62. The Calumet River field study allowed for the measurement of a suspended sediment plume generated near a clamshell dredge. This study was part of a larger effort to evaluate dredging and dredged material disposal options for the removal of contaminated material at Indiana Harbor. The dredge was a 10-cu yd clamshell operating to remove 215,000 cu yd of material from the Calumet River during normal maintenance operations. Data collection to analyze the resuspension characteristic of the clamshell dredge included water quality samples, current measurement, sediment samples, and background water quality samples and current measurements.

63. The TSS plume generated during the clamshell operation affected the entire water column with increasing concentrations from the surface to the bottom. The TSS plume was delineated using isoconcentration plots of 10, 40, and 90 mg/ℓ. The 10-mg/ℓ contour represents approximately twice the ambient suspended solids level and ranged in area from 1.7 acres near the surface to 3.5 acres near the bottom. The highest concentrations also occurred near the bottom, indicating that the impact penetration and withdrawal of the bucket from the sediment generates the majority of the sediment resuspension.

# PART IV: DIFFUSER STUDY

## Background

64. The controlled, accurate, subaqueous placement of dredged material at an open water disposal site can offer a number of benefits over conventional surface release. Previous investigations (Bokuniewicz et al. 1978, Gordon 1974, Morton 1980, Sumeri 1984, Truitt 1986) have demonstrated that dredged material released from the surface, both by instantaneous discharge from barges or hopper dredges and by continuous hydraulic pipeline discharge, tends to descend rapidly to the bottom as a dense jet with minimal short-term losses to the overlying water column. However, environmental impacts may still result from the spread of the material over the bottom and from chemical releases to the water column if the disposed sediment is contaminated. Therefore, situations may occur in which greater control is necessary over the chemical and/or physical behavior of the disposed material.

65. One basic control technology involves submerging the point of discharge some distance below the water's surface and moving the dredged material through the water column to that point by the use of a closed conduit. A 90-deg "elbow" turning a pipeline discharge beneath the surface is an example of simple conduit technology. To the extent that such a conduit passes through the water column physically isolating the material, its use minimizes mixing and chemical releases to the surrounding water; significantly reduces entrainment of site water, thereby reducing disposal volumes; negates the effects of currents and stratifications; and eliminates the increase of suspended solids in the upper water column. If the conduit is used together with a diffusive head to place the material near the bottom with reduced discharge velocities, direct and indirect benthic impacts can also be reduced by controlling the area over which sediment initially spreads and by reducing the suspended solids concentrations in the lower water column.

66. Developmental work on a submerged diffuser was performed as part of the Dredged Material Research Program (DMRP) and reported by JBF Scientific Corporation (Neal, Henry, and Green 1978). During 1981 through 1983, a Dutch-built diffuser based on the recommended DMRP design was used to accurately place contaminated sediment in excavated disposal areas within Rotterdam Harbor for subsequent capping (d'Angremond, de Jong, and de Waard 1984). Similar

types of diffusers have been used to a limited extent in the United States to reduce the turbidity associated with disposal of tailings from sand and gravel operations. The Calumet Harbor demonstration is the first attempt in this country to comprehensively monitor the field performance of a diffuser during an otherwise conventional dredging operation.

## Study Area

67. The diffuser was tested as part of the overall equipment demonstration in the same general area of the Calumet River south of Chicago, Ill. The specific location was chosen so that the monitoring could take place in a sheltered environment with minimal background hydrodynamic interferences. A point inside the Chicago Area CDF at the mouth of the river provided such a location (Figure 36).

68. The triangular CDF is approximately 43 acres in size with one side adjoining the bulkhead of the Port Authority property and the other two sides consisting of earth dikes armored with rock revetments. Water depths in the disposal area at the time of the demonstration averaged 10 to 15 ft. However, a recent bathymetric survey inside the CDF provided by the Chicago District identified a small area with substantially greater depths. This area was roughly 80 to 100 ft in diameter with maximum water depths to 27 ft and average depths approaching 20 ft. The location was sufficiently deep that the diffuser discharge would not be affected by surface currents and appeared wide enough that side slopes would not reflect discharged material during the relatively short test period.

## Description of Equipment

69. The diffuser tested is shown schematically in Figure 37 and photographically in Figure 38. The overall height of the processor was 42 in. with a diameter at the exit point of 66 in. The nominal diameter at the entrance was 12 in. corresponding to the size of the dredge discharge pipeline. Construction consisted of 1/2-in. sheet steel welded into three conical sections and connected to form the required shape. The diffuser was originally designed and built for the sand and gravel industry. For durability considerations, some streamline features from the DMRP design were sacrificed (these

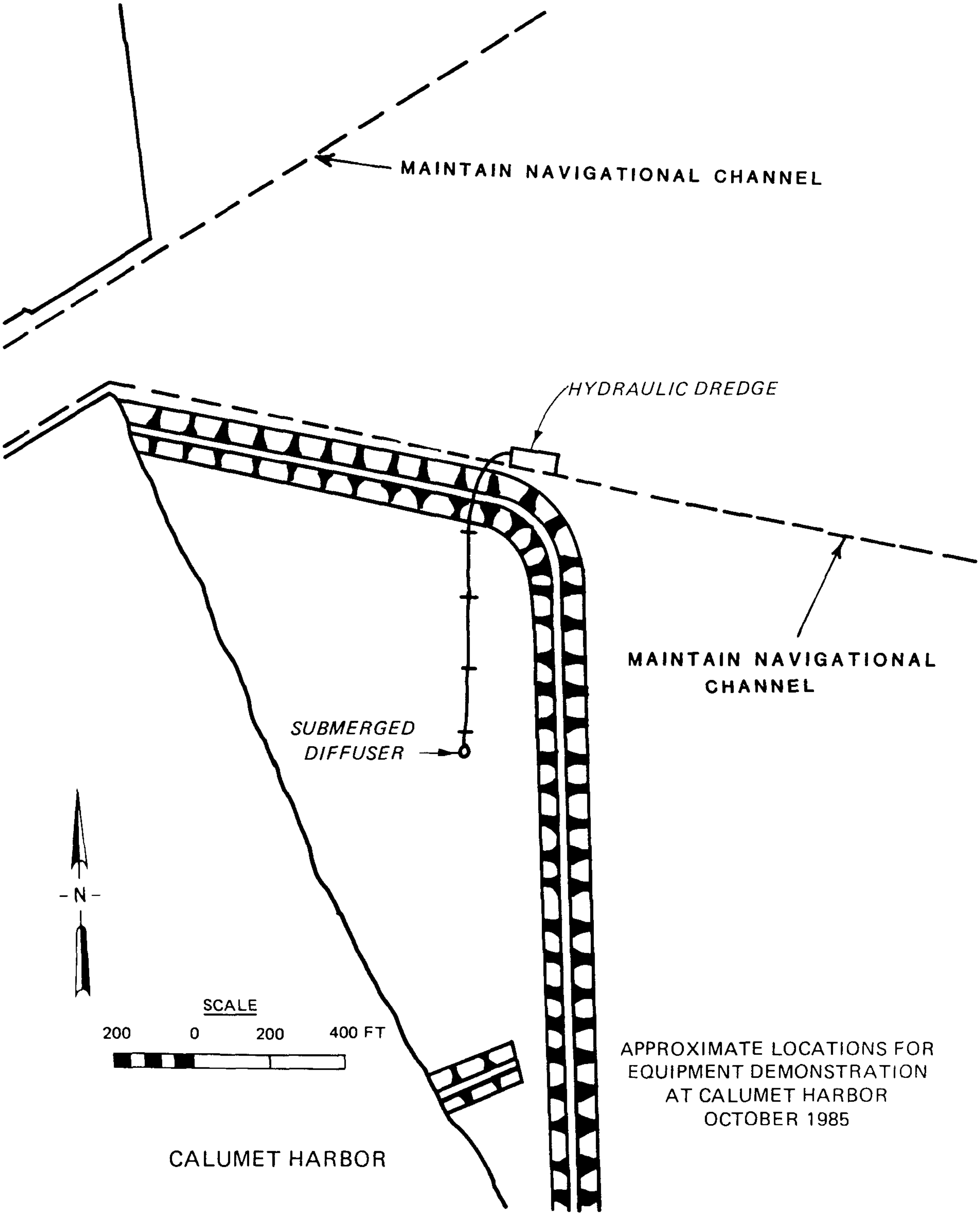


Figure 36. Location of diffuser study inside Chicago Area CDF

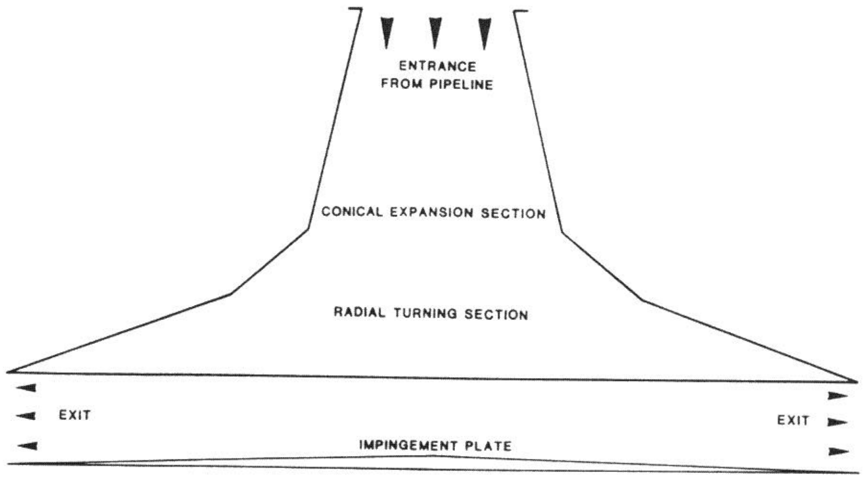


Figure 37. Schematic of diffuser tested

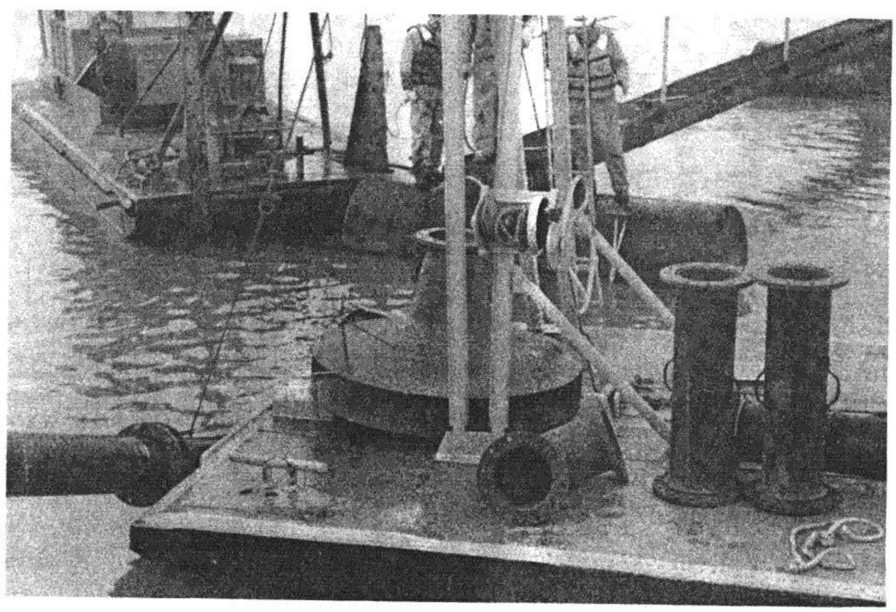

Figure 38. Diffuser as tested

are discussed later). However, the diffuser worked well in reducing the dredged material velocity and limiting sediment resuspension to the lower portion of the water column.

70. For purposes of the demonstration, the diffuser was suspended from a work barge by a fixed length of pipeline and secured by a wireline from an A-frame on the barge. (In actual operations, provisions would have to be made to vary the length of connecting pipe and to provide for adjusting the depth of the discharge point.) The diffuser was positioned to discharge at a point just over 20 ft below the water's surface and approximately 3.5 ft off the bottom.

71. Velocity measurements of the fluid at the exit point of the diffuser were made by field mounting the metering head of a Teledyne-Gurley Model 622 current meter directly on the edge (Daily and Associates 1986). Velocity measurements for background values and at the station 15 ft from the exit were accomplished with a Marsh/McBirney Model 201-D Current Meter. Water samples for analysis of suspended solids were collected using portable pumps with reinforced nylon intake hoses. All depths were accurately measured with marked sounding lines.

## Theoretical Considerations

72. In their original development of a design for the DMRP, Neal, Henry, and Greene (1978) referred to a general class of such devices as mechanical flow processors to emphasize that a number of different approaches are possible. The function of a processor is to reduce the velocity of the discharge while still maintaining isolation from the water column and minimizing entrainment. The design they recommended accomplished the required velocity reduction by passing the flow through a diffuser section having a gradually increasing cross-sectional area.

73. An explanation of the effect of such a diffuser on the discharging dredged material can be found in the basic statement of continuity for steady-state, incompressible flow: the volumetric flow rate exiting a section must be equal to the volumetric flow rate entering the section, or

$$Q(in) = Q(out) \tag{1}$$

where

Q(in) = volumetric flow rate at entrance

Q(out) = volumetric flow rate at exit

Since the volumetric flow rate is defined as the product of the average velocity of the flow, V , and its cross-sectional area, A , (e.g., Q = VA) Equation 1 can be written after substitution and rearrangement as:

$$\frac{V(in)}{V(out)} = \frac{A(out)}{A(in)} \tag{2}$$

74. This well-known result states simply that the reduction in velocity is a function of the change in cross-sectional area through the diffuser section. A very important assumption in the above statement is that the flow completely fills the area through which it passes. When the characteristics of the flow itself dominate over the frictional influence of adjacent boundaries (e.g., the pipe walls) flow separation may occur, zones of turbulence develop, and the assumption of full-section flow may not be valid. Neal, Henry, and Greene (1978) calculate that a 15-deg angle is the largest expansion that flow can negotiate before separation occurs and the discharge jets through the section. Figure 39 shows the schematic of the diffuser tested, but with a superimposed theoretical 15-deg maximum expansion section. Zones of likely flow separation are shown. The effects of such zones would be to produce a velocity reduction through the section somewhat less than the

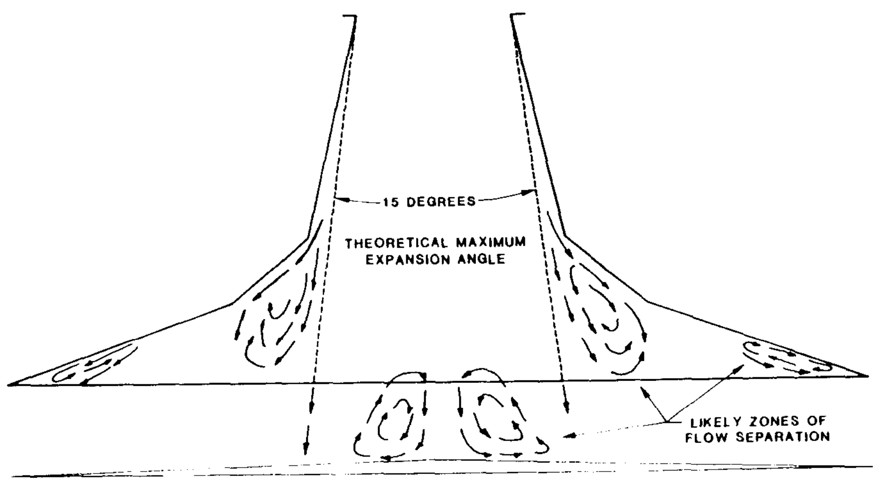


Figure 39. Schematic of diffuser tested showing theoretical behavior

maximum predicted by the ratio of the areas and to increase the level of turbulence and mixing in the discharge.

75. In addition to the conical diffuser section, the design includes a lower, turning section to change the direction of the discharge from vertical to horizontal (e.g., radially outward since the diffuser is three dimensional). However, the turning section also increases the area available for flow expansion and acts as a second diffuser to further reduce the velocity. Control over separation in the lower section could be achieved by adjusting the distance between the lower plate and the upper section to "tune" the cross-sectional area at the circumference to that of the discharging flow, and by providing a properly shaped conical impingement point on the lower plate. The minimum spacing between the upper section and the lower plate must be based on the diameter of expected debris passing through the pipeline.

76. For the diffuser tested in the demonstration, the entrance area at the pipeline connection was approximately 110 sq in., and the area at the exit circumference was approximately 1,470 sq in. Applying Equation 2, the theoretical velocity reduction through the diffuser should be:

$$\text{Theoretical velocity reduction} = \frac{110}{1470} = 0.0749 \qquad (3)$$

In other words, the flow exiting the diffuser should have a velocity equal to approximately 0.0749 times the average pipeline velocity. The momentum of the flow would be reduced by the same factor.

## Background Conditions

### Hydrodynamic conditions

77. During the diffuser demonstration, the dredge operated adjacent to the north side of the CDF in the mouth of the entrance channel (Figure 36). Currents in the channel typically result from a combination of wind stress, entering waves, and the operation of downstream flood-control structures. Normal currents are less than 0.2 fps and are variable in direction. Exceptions to normal conditions can occur during the transit of large, full draft

vessels. Measured current velocities in the vicinity of the dredge during the diffuser study remained below 0.3 fps.

78. Within the CDF, circulation patterns and velocities are predominated by wind stresses on the surface. Background current values were established at the point of the diffuser test by measurements taken on 2 successive days. Measurements were taken with an electromagnetic induction current meter at four depths at each of four stations. A typical background velocity profile at the test site (e.g., Figure 40) shows a velocity of 0.2 fps at the surface, 0.1 fps extending to a depth of 10 to 12 ft, and velocities below the instrument threshold from 16 ft to the bottom.

<u>Background suspended solids</u>

79. Background TSS concentrations in the area of the diffuser were estimated by collecting discrete water samples with depth at several stations and subsequently analyzing for TSS by gravimetric techniques. Background concentrations were consistent between and within two sampling events on successive

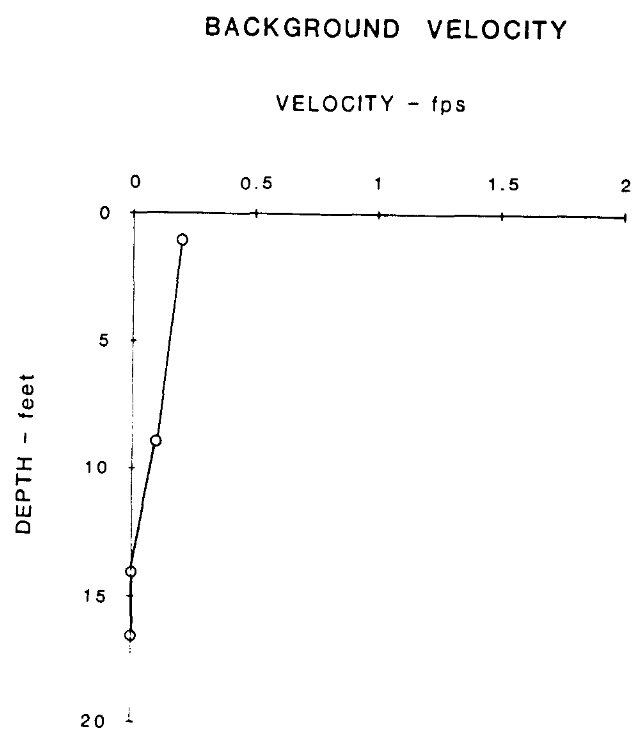


Figure 40. Typical background velocity profile prior to diffuser test

days. Values ranged from 2 to 10 mg/ℓ with an average of approximately 4 mg/ℓ. No trends with depth were apparent.

Preliminary pumping test

80. Prior to dredging, a preliminary test was conducted to further define background influences. Clear water was pumped from the dredge, through the pipeline, and out the diffuser in its expected demonstration position. This allowed an evaluation of the effect the exiting stream might have on resuspension of sediment existing in the depression in the CDF. The preliminary test also enabled the pipeline to be flushed and proposed test procedures verified.

81. Clear water was pumped for 30 min, during which velocity measurements and suspended solids water samples were collected at a point immediately above the diffuser and in vertical sets at stations approximately 7.5 and 12.5 ft from the edge of the diffuser. A schematic of the sampling array for the background (and actual test) is shown in Figure 41.

82. The resulting background values of TSS and exit velocity at the edge of the diffuser during the pumping test are shown in Figure 42. Similar data from stations 10 and 15 ft, respectively, from the diffuser are shown in Figure 43. The discharge stream did not alter the background TSS concentrations measured prior to pumping. The data resulting from the actual diffuser demonstration test reported in subsequent sections have been adjusted for these background concentrations.

## Results

Measurement procedures

83. Following the 30-min preliminary pumping test, discharge was halted, and the area around the diffuser was allowed to readjust to background conditions for approximately 45 min. At that time, actual dredging began, and the discharge of slurry was monitored for 60 min. The matchbox suction head was used during the test, and several operational parameters including pipeline velocity were recorded on the dredge each minute of pumping. The average pipeline velocity varied somewhat, as expected, but was typically in the range of 14.5 to 16 fps.

84. As with the preliminary pumping test, monitoring at the diffuser consisted of two sets of velocity measurements and two sets of water samples

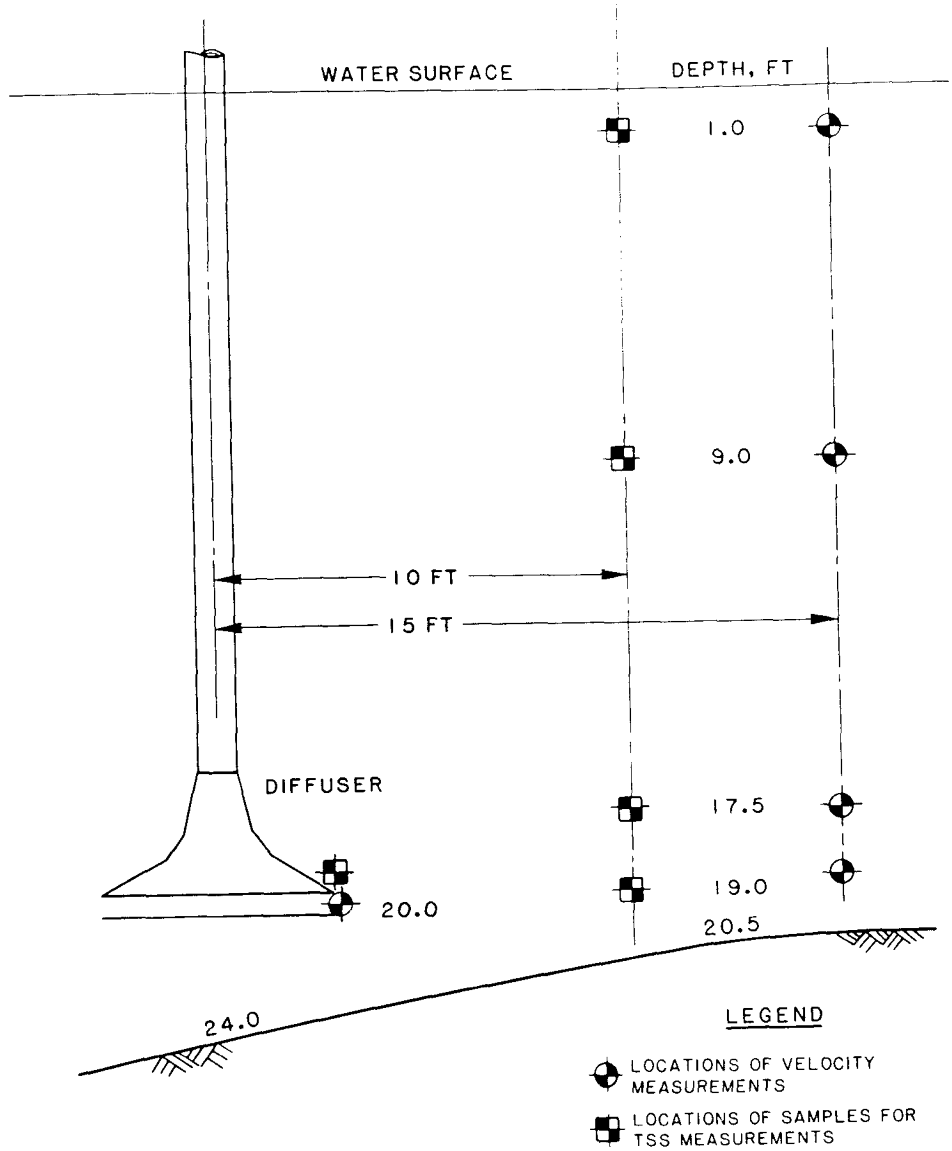


Figure 41. Schematic of sampling stations and depths

for TSS analysis. Velocity measurements were made directly in the exit stream of the diffuser and in a vertical series at a point 15 ft from the center of the diffuser (Figure 41). As indicated, at the station 15 ft from the diffuser, velocity readings were taken at 5, 50, 80, and 95 percent of the total water depth. These velocities and those at the single point on the diffuser circumference were recorded approximately every minute during the first half of the test and every 2 min during the second half.

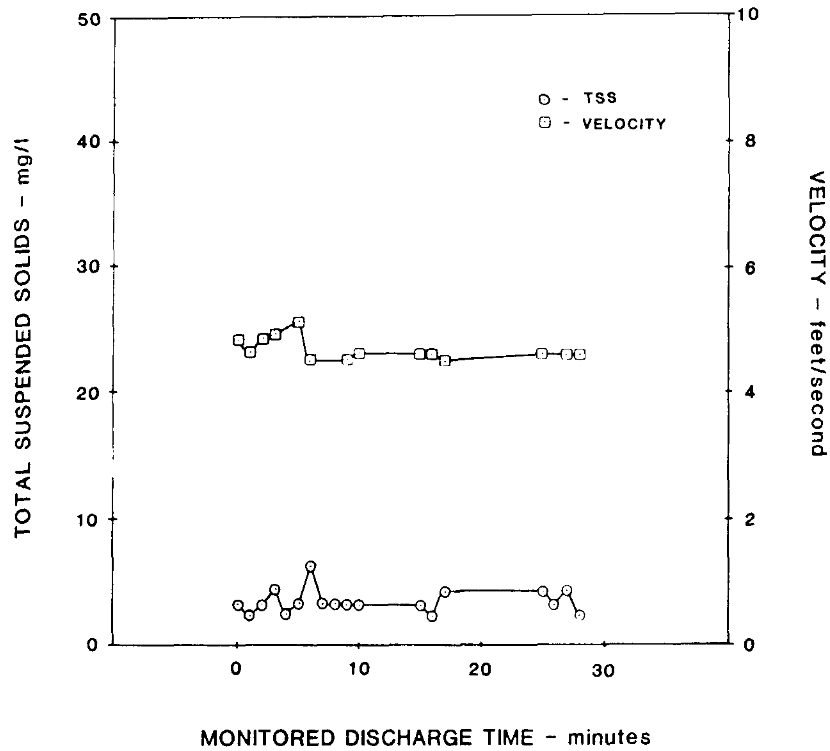


Figure 42. Background TSS and exit velocity measured at diffuser during preliminary pumping test

85. Water samples for TSS analysis were collected in a similar procedure at a point on the diffuser just above the exit stream and in a vertical series at a station 10 ft from the diffuser. The depths and sampling intervals for the TSS were similar to those for velocity.

Measured velocities

86. The velocities measured in the area of the diffuser are summarized on Figure 44. The velocity of the slurry as it exited the diffuser varied slightly but remained between 3 and 4 fps during most of the test. Because the velocity measured at the exit represents the reduction effect due to the diffuser itself, this value can be compared with the theoretical reduction discussed in previous sections. The results of applying Equation 2 indicated that the theoretical ratio of initial to final velocity within the section should be 0.0749. The predicted exit velocity, V(out) , should therefore be 0.0749 times the entering velocity, V(in) , or, using a typical measured pipeline velocity of 15 fps, the predicted exit velocity should be:

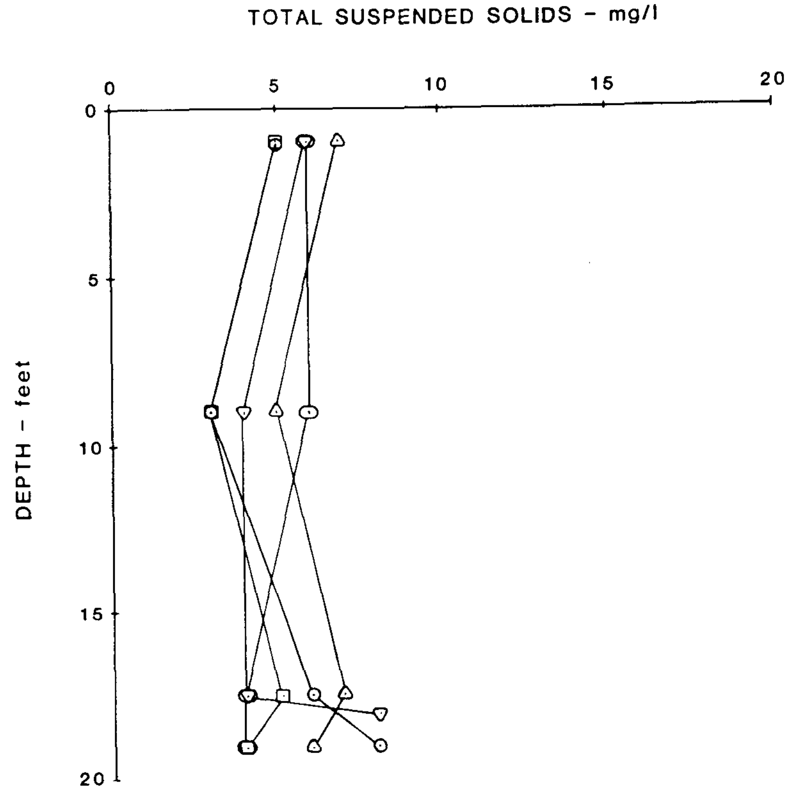


Figure 43. Background suspended solid concentrations measured 10 ft from diffuser during preliminary pumping test

$$V(out) = 0.0749\ (15)\ \text{fps} = 1.1\ \text{fps} \quad (4)$$

87. The observed exit velocities were typically three times the predicted. The difference is due to the too large expansion angle within the diffuser tested and the resulting flow separation and jetting (Figure 39). Even though the reduction observed was not as great as theory would predict, it should be noted that the diffuser did produce a significant reduction in discharge velocity of 75 to 80 percent and no decrease in the net flow rate. Figure 45 depicts the decrease in velocity through the diffuser and over distance from the point of discharge.

Measured suspended solids

88. The water samples collected just above the diffuser exit and at the station 10 ft away (see Figure 41) were subsequently analyzed for TSS to

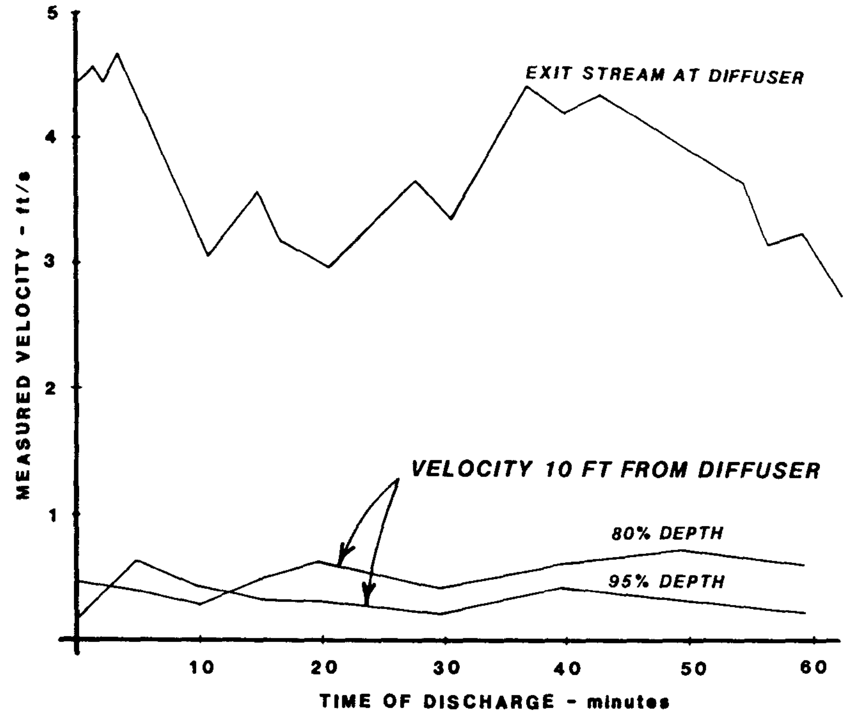


Figure 44. Velocity measured during actual test

establish the effect of the diffuser on turbidity levels during discharge. As discussed previously, background values of TSS did not vary significantly from the discharge point to the more distant station or during the preliminary pumping test. Background values in the range of 3 to 7 mg/ℓ were typical and will be used for the following comparisons.

89. The results of the sampling at the diffuser exit indicated that TSS remained in the range of background levels for the majority of the 60 min of monitored discharge. Samples representing a single 2- to 3-min period of discharge showed TSS concentrations of 105 and 165 mg/ℓ above background level. Three other samples had concentrations of 10 to 30 mg/ℓ above background. The remainder were at background levels.

90. At the station 10 ft from the diffuser, the TSS concentrations measured were much greater since the actual discharged slurry was being sampled. However, a trend in the concentration with depth was evident at this station. Although TSS values typically in the thousands of milligrams per litre were measured in the samples taken from 80 and 95 percent of the water depth, those measured in the upper 75 percent of the water column remained at, or just slightly above, background. Table 9 shows two profiles of measured TSS at

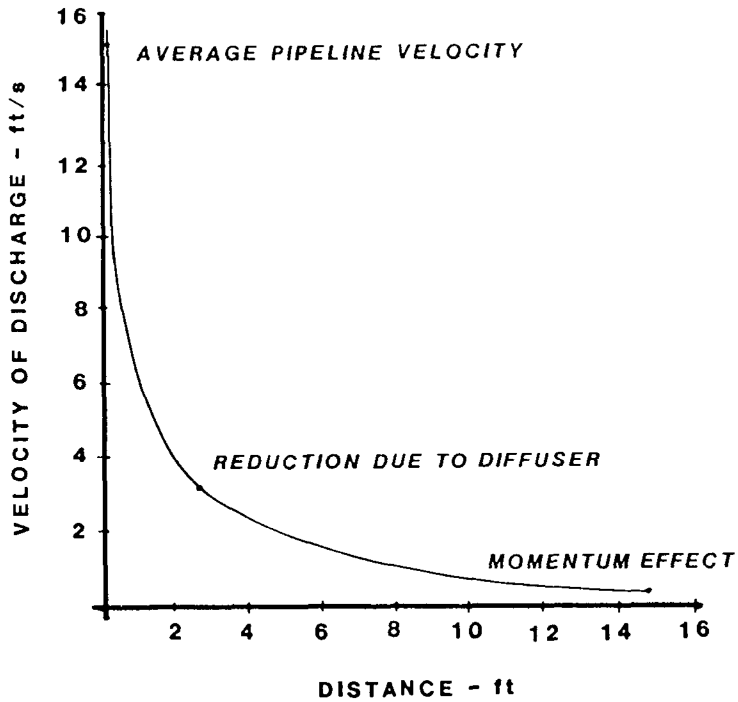


Figure 45. Decrease rate of flow velocity

10 ft from the diffuser. The variation in concentration over time from one sampling series to the next fluctuated with the normal variation in concentration (specific gravity of the slurry) in the pipeline as measured at the dredge.

Table 9

Representative TSS Profiles, 10 ft from Diffuser

| Depth, ft | Percent of Total Depth | Diffuser Discharge, TSS, mg/ℓ | |
|---|---|---|---|
| | | Profile 1 | Profile 2 |
| 1 | 5 | 3 | 5 |
| 9 | 50 | 4 | 3 |
| 17.5 | 80 | 589 | 1,835 |
| 19 | 95 | 7,100 | 19,700 |

91. Both the velocity and TSS results support the conclusion that the exit stream was well defined and moved parallel to the bottom. Shear between the discharging slurry and the receiving water was sufficiently low that stripping of solids from the flow into the water column was minimized. At a distance of 10 ft from the diffuser, the velocity had been reduced to approximately 25 percent of the average pipeline velocity, and the discharge was confined to the lower 20 to 30 percent of the water column with little influence above that point.

## PART V: SUMMARY

92. Equipment demonstrations were conducted in the NCC for a clamshell dredge, a hydraulic dredge using both the conventional cutterhead and the Dutch-designed matchbox suction head, and a submerged diffuser. The dredging plant demonstrations included monitoring of the dredging operations and provided data for a direct comparison of the three types of equipment working under similar conditions. Monitoring included the collection of samples prior to, and during, the dredging/disposal operations. Data were collected on current velocities and suspended sediment levels; sediment samples were collected to determine the in situ properties of the sediment. The monitoring programs used sample grids established in the vicinity of the dredging/ disposal operations to collect current velocity and suspended sediment measurements. Comparing suspended sediment levels before and during each dredging/disposal operation allowed the effect of that operation on the TSS levels to be evaluated.

93. The hydraulic dredge field studies were conducted at the mouth of the Calumet River along the western shore of Lake Michigan. Two days of background sampling preceded the two days of matchbox testing, which was followed by another day of background sampling and three days of cutterhead testing. A suspended sediment plume with a concentration of at least 10 mg/ℓ above ambient was identified for the matchbox operation over an area of 2.94 acres at 95 percent of the total depth and 0.4 acres at 80 percent of the total depth. The plume did not reach this concentration above 80-percent depth and was not discernible above the 50-percent depth level. Similarly, a suspended sediment plume with a concentration at least 10 mg/ℓ above ambient of 1.2 acres was identified for the cutterhead operation at nearly 95 percent of the total depth. The plume did not reach this concentration above the 95-percent depth level and was not discernible above the 50-percent depth level. The concentrations of suspended sediment in both plumes at distances of 100 ft or greater were all less than 20 mg/ℓ except for a few observations.

94. The near field data for the matchbox operation reflected positioning problems. The operator could not determine when the top of the matchbox was at the same level as the sediment. This is important for optimum operation of the matchbox. Additional studies are needed to evaluate matchbox performance where better control of the matchbox position relative to the bottom is

provided. Such equipment improvement would likely improve the matchbox's performance. The near field data did, however, indicate very low levels of resuspension near the matchbox. The near field data for the cutterhead operation also showed very low levels of resuspension near the cutterhead. Additional analysis of the near field cutterhead data may provide insight into the impact of operational parameters on the resuspension process.

95. Based on the results of these tests, the matchbox is quite capable of removing sediment with very little resuspension. However, the cutterhead tests showed that it also can remove sediment with very little resuspension when operated properly.

96. The clamshell dredge field study incorporated 1 day of background sampling with 2 days of plume monitoring in the interior Calumet River. The field study identified a suspended sediment plume with a suspended sediment concentration at least 10 mg/ℓ above ambient of 3.5 acres near the bottom, 1.8 acres at middepth, and 1.7 acres near the surface. This 10-mg/ℓ level also corresponded to approximately twice the concentration of the ambient suspended sediment concentration. The rapid reduction in area of the plume from bottom to middepth indicates that the plume is generated primarily by the impact, penetration, and withdrawal of the bucket from the sediment. The highest concentrations and greatest variability of the plume were found near the bottom, where samples collected within 50 ft of the dredge ranged from 540 to 49 mg/ℓ.

97. Table 10 shows the area of the 10-mg/ℓ contours for each of the dredging operations. The table indicates that the clamshell resuspends the largest amount of material followed by the matchbox and then the cutterhead. It is also evident that the clamshell affects the entire water column, whereas the cutterhead and matchbox affect only the lower portion of the water column. From the standpoint of resuspension alone, it is obvious that the cutterhead and matchbox outperform the clamshell dredge.

98. The submerged diffuser demonstration was designed to measure the field performance of the diffuser operating with a conventional dredging operation. The diffuser was placed in an existing depression in the Chicago Area CDF where the hydrodynamic effects of open water would be reduced. The diffuser demonstration included pumping clear water through the pipe as well as dredged material. Pumping of clear water was carried out to measure the effect of the diffuser operation on the ambient conditions in the CDF as well

Table 10

Plume Area for 10-mg/ℓ Contour for the Cutterhead, Clamshell, and Matchbox Dredges

| Depth percent | Cutterhead acres | Clamshell acres | Matchbox acres |
|---|---|---|---|
| 5 | 0 | 1.7 | 0 |
| 50 | 0 | 1.8 | 0 |
| 80 | 0 | -- | 0.4 |
| 95 | 1.2 | 3.5 | 2.95 |

as to test the diffuser itself. After pumping clear water for 30 min, the diffuser effluent did not elevate TSS above background and was able to reduce the pipeline exit velocity by 75 to 80 percent. However, the exit velocities were 3 to 4 times greater than the theoretical predictions. Additional investigations may be needed to evaluate these variations. The dredging portion of the demonstration clearly showed the diffuser's ability to limit sediment resuspension to the lower portion of the water column. At a station 10 ft from the diffuser exit in 20 ft of water, water column samples were collected at the 5-, 50-, 80-, and 95-percent total depth increments, every 5 min throughout the dredging period. With ambient TSS concentrations ranging between 2 and 10 mg/ℓ, the average TSS level for the 5- and 50-percent samples was 9.6 mg/ℓ, while the average of the lower two was 3,266 mg/ℓ. The diffuser was able to significantly reduce the slurry velocity, confine the discharged material to the lower 20 to 30 percent of the water column, and reduce suspended sediment effects in the upper portion of the water.

99. The outcome of these field demonstrations for the clamshell dredge, cutterhead dredge, and Dutch matchbox suction head dredge will aid in the selection of a dredge that produces the least sediment resuspension while maintaining acceptable production levels. The demonstration of the submerged diffuser operation included monitoring that verified the design of the system and its ability to place sediment on the channel bottom with a minimum amount of resuspension.

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# APPENDIX A: HYDRAULIC DREDGE OPERATIONAL DATA

Table A1

Calumet Harbor Matchbox Dredge Data

| Date | Time | Flow gal/min | Production cu yd/hr | Depth ft | Swing Speed ft/sec |
|---|---|---|---|---|---|
| OCT 21 | 1025 | 6130 | 28 | 31 | 0.6 |
| OCT 21 | 1040 | 5575 | 74 | 31 | 0.6 |
| OCT 21 | 1055 | 3800 | 83 | 31 | 0.6 |
| OCT 21 | 1110 | 5400 | 70 | 31 | 0.6 |
| OCT 21 | 1125 | 5400 | 65 | 31 | 0.6 |
| OCT 21 | 1140 | 6400 | 45 | 31 | 0.6 |
| OCT 21 | 1155 | 3900 | 66 | 31 | 0.6 |
| OCT 21 | 1210 | 4000 | 67 | 31 | 0.6 |
| OCT 21 | 1225 | 4850 | 62 | 31 | 0.6 |
| OCT 21 | 1240 | 4000 | 74 | 31 | 0.6 |
| OCT 21 | 1255 | 5650 | 48 | 31 | 0.6 |
| OCT 21 | 1310 | 6140 | 50 | 31 | 0.6 |
| OCT 21 | 1325 | 4160 | 57 | 31 | 0.6 |
| OCT 21 | 1340 | 3400 | 59 | 31 | 0.6 |
| OCT 21 | 1355 | 4800 | 64 | 31 | 0.6 |
| OCT 21 | 1410 | 6460 | 30 | 31 | 0.6 |
| OCT 22 | 940 | 5900 | 27.5 | 31 | 1.6 |
| OCT 22 | 955 | 4300 | 32.5 | 31 | 1.6 |
| OCT 22 | 1010 | 6200 | 31.2 | 31 | 1.6 |
| OCT 22 | 1025 | 6150 | 34.7 | 31 | 1.6 |
| OCT 22 | 1040 | 6660 | 34.3 | 31 | 1.6 |
| OCT 22 | 1055 | 3500 | 59.5 | 31 | 1.6 |
| OCT 22 | 1110 | 4190 | 68.6 | 31 | 1.6 |
| OCT 22 | 1125 | 5650 | 46.1 | 31 | 1.6 |
| OCT 22 | 1140 | 5950 | 46 | 31 | 1.6 |
| OCT 22 | 1155 | 3750 | 67 | 31 | 0.5 |
| OCT 22 | 1210 | 5600 | 35 | 31 | 0.5 |
| OCT 22 | 1335 | 5600 | 49.2 | 31 | 0.5 |
| OCT 22 | 1350 | 2700 | 63 | 31 | 0.5 |
| OCT 22 | 1405 | 5600 | 38.2 | 31 | 0.5 |
| OCT 22 | 1420 | 4100 | 60 | 31 | 0.5 |
| OCT 22 | 1435 | 5900 | 41 | 31 | 0.5 |
| OCT 22 | 1450 | 5450 | 51 | 31 | 0.5 |
| OCT 22 | 1505 | 5400 | 48.5 | 31 | 0.5 |
| OCT 22 | 1520 | 5700 | 53 | 31 | 0.5 |

Table A2

Calumet Harbor Cutterhead Dredge Data

| Date | Time | Flow gal/min | Production cu yd/hr | Depth ft | Swing Speed ft/sec | Cutter Speed ft/sec |
|---|---|---|---|---|---|---|
| OCT 24 | 917 | 5460 | 30.1 | 32 | 0.7 | 27 |
| OCT 24 | 930 | 3400 | 43.5 | 32 | 0.7 | 27 |
| OCT 24 | 945 | 5400 | 41.5 | 32 | 0.7 | 27 |
| OCT 24 | 1004 | 3800 | 56.5 | 32 | 0.7 | 27 |
| OCT 24 | 1015 | 4000 | 52.5 | 32 | 0.7 | 27 |
| OCT 24 | 1030 | 5300 | 52.1 | 32 | 0.7 | 27 |
| OCT 24 | 1048 | 3450 | 54.5 | 32 | 0.7 | 27 |
| OCT 24 | 1100 | 5225 | 41.1 | 32 | 0.7 | 27 |
| OCT 24 | 1115 | 2345 | 47.8 | 32 | 0.7 | 27 |
| OCT 24 | 1133 | 2340 | 60.1 | 32 | 0.7 | 27 |
| OCT 24 | 1146 | 4300 | 54.0 | 32 | 0.7 | 27 |
| OCT 24 | 1155 | 5600 | 38.6 | 32 | 0.7 | 27 |
| OCT 24 | 1225 | 5650 | 19.3 | 32 | 0.7 | 20 |
| OCT 24 | 1240 | 2600 | 68.0 | 32 | 0.7 | 20 |
| OCT 24 | 1255 | 3160 | 50.3 | 32 | 0.7 | 20 |
| OCT 24 | 1310 | 3080 | 52.5 | 32 | 0.7 | 20 |
| OCT 24 | 1320 | 2600 | 50.8 | 32 | 0.7 | 20 |
| OCT 24 | 1335 | 1700 | 54.0 | 32 | 0.7 | 20 |
| OCT 24 | 1350 | 2300 | 40.5 | 32 | 0.7 | 20 |
| OCT 24 | 1408 | 5150 | 39.5 | 32 | 0.7 | 20 |
| OCT 24 | 1422 | 3800 | 37.6 | 32 | 0.7 | 20 |
| OCT 24 | 1440 | 4300 | 40.6 | 32 | 0.7 | 20 |
| OCT 24 | 1455 | 2440 | 26.6 | 32 | 0.7 | 20 |
| OCT 24 | 1510 | 1075 | 41.2 | 32 | 0.7 | 20 |
| OCT 24 | 1515 | 4550 | 38.3 | 32 | 0.7 | 20 |
| OCT 24 | 1525 | 1770 | 37.5 | 32 | 0.7 | 20 |
| OCT 25 | 855 | 6030 | 19.3 | 31 | 0.7 | 15 |
| OCT 25 | 900 | 4000 | 80.1 | 31 | 0.7 | 15 |
| OCT 25 | 917 | 3980 | 71.2 | 31 | 0.7 | 15 |
| OCT 25 | 930 | 5175 | 61.8 | 31 | 0.7 | 15 |
| OCT 25 | 945 | 4100 | 80.1 | 31 | 0.7 | 15 |
| OCT 25 | 1000 | 3900 | 88.7 | 31 | 0.7 | 15 |
| OCT 25 | 1015 | 5160 | 57.3 | 31 | 0.7 | 15 |
| OCT 25 | 1030 | 2940 | 89.8 | 31 | 0.7 | 15 |
| OCT 25 | 1100 | 4015 | 73.1 | 31 | 0.7 | 15 |
| OCT 25 | 1115 | 3350 | 97.1 | 31 | 0.7 | 15 |
| OCT 25 | 1130 | 4130 | 82.5 | 31 | 0.7 | 15 |
| OCT 25 | 1208 | 3080 | 76.1 | 31 | 1.1 | 15 |
| OCT 25 | 1220 | 5740 | 37.3 | 31 | 1.1 | 15 |
| OCT 25 | 1235 | 2430 | 96.1 | 31 | 1.1 | 15 |
| OCT 25 | 1250 | 4680 | 58.8 | 31 | 1.1 | 15 |
| OCT 25 | 1312 | 5195 | 57.9 | 31 | 1.1 | 15 |

(Continued)

Table A2 (Concluded)

| Date | Time | Flow gal/min | Production cu yd/hr | Depth ft | Swing Speed ft/sec | Cutter Speed ft/sec |
|---|---|---|---|---|---|---|
| OCT 25 | 1327 | 6115 | 34.7 | 31 | 1.1 | 15 |
| OCT 25 | 1340 | 6150 | 35.4 | 31 | 1.1 | 15 |
| OCT 25 | 1355 | 3500 | 89.0 | 31 | 1.1 | 15 |
| OCT 25 | 1410 | 4700 | 60.2 | 31 | 1.1 | 15 |
| OCT 25 | 1435 | 2800 | 101.0 | 31 | 1.1 | 15 |
| OCT 25 | 1445 | 2700 | 81.6 | 31 | 1.1 | 15 |
| OCT 25 | 1500 | 2600 | 90.0 | 31 | 1.1 | 15 |
| OCT 26 | 842 | 2125 | 89.5 | 29 | 1.1 | 27 |
| OCT 26 | 900 | 5600 | 50.5 | 29 | 1.1 | 27 |
| OCT 26 | 915 | 5560 | 65.4 | 29 | 1.1 | 27 |
| OCT 26 | 930 | 5350 | 85.0 | 29 | 1.1 | 27 |
| OCT 26 | 943 | 5900 | 39.0 | 29 | 1.1 | 27 |
| OCT 26 | 1000 | 5600 | 74.0 | 29 | 1.1 | 27 |
| OCT 26 | 1013 | 5975 | 37.0 | 29 | 1.1 | 27 |
| OCT 26 | 1028 | 5250 | 109.0 | 29 | 1.1 | 27 |
| OCT 26 | 1045 | 5970 | 35.0 | 29 | 1.1 | 27 |
| OCT 26 | 1100 | 5850 | 40.8 | 29 | 1.1 | 27 |
| OCT 26 | 1115 | 5350 | 113.0 | 29 | 1.1 | 27 |
| OCT 26 | 1211 | 3080 | 71.5 | 29 | 1.1 | 20 |
| OCT 26 | 1230 | 4590 | 82.3 | 29 | 1.1 | 20 |
| OCT 26 | 1245 | 5550 | 48.3 | 29 | 1.1 | 20 |
| OCT 26 | 1305 | 5300 | 55.0 | 29 | 1.1 | 20 |
| OCT 26 | 1315 | 5030 | 20.5 | 29 | 1.1 | 20 |
| OCT 26 | 1330 | 5600 | 17.0 | 29 | 1.1 | 20 |
| OCT 26 | 1345 | 3700 | 90.0 | 29 | 1.1 | 20 |
| OCT 26 | 1400 | 2685 | 103.0 | 29 | 1.1 | 20 |
| OCT 26 | 1415 | 5190 | 50.0 | 29 | 1.1 | 20 |
| OCT 26 | 1430 | 3860 | 74.0 | 29 | 1.1 | 20 |
| OCT 26 | 1445 | 5670 | 38.0 | 29 | 1.1 | 20 |

Table A3

Results of Grain-Size Analyses on Near Field Samples

| Sample Number | Percent of Sediment Particles (by Weight) Smaller Size (μ) Grain Size (μ) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 176 | 125 | 88 | 62 | 44 | 31 | 22 | 16 | 11 | 7.8 | 5.5 | 3.9 | 2.8 |
| Samples Taken During Starboard-to-Port Swings | | | | | | | | | | | | | |
| 24-1435-11 | 100 | 97.1 | 93.0 | 81.3 | 71.4 | 61.3 | 47.7 | 38.0 | 26.5 | 17.9 | 13.6 | 7.9 | 3.4 |
| 12 | 100 | 95.5 | 86.3 | 73.7 | 62.9 | 51.0 | 39.4 | 29.6 | 21.2 | 13.9 | 8.7 | 5.0 | 2.6 |
| 15 | 100 | 96.4 | 87.8 | 74.7 | 60.1 | 44.5 | 30.4 | 22.0 | 14.1 | 9.3 | 6.0 | 3.1 | 1.7 |
| 16 | 100 | 91.4 | 75.8 | 58.5 | 50.9 | 35.1 | 23.1 | 19.4 | 13.3 | 5.9 | 4.8 | 2.6 | 0.6 |
| 25-1410-11 | 100 | 97.6 | 91.7 | 78.7 | 65.9 | 54.5 | 42.5 | 31.1 | 22.2 | 14.7 | 10.2 | 5.8 | 2.3 |
| 12 | 100 | 98.0 | 93.6 | 85.7 | 77.0 | 64.8 | 51.0 | 40.0 | 28.9 | 20.6 | 14.7 | 8.6 | 4.2 |
| 15 | 100 | 95.3 | 94.8 | 79.4 | 70.0 | 58.4 | 41.4 | 32.7 | 25.5 | 15.2 | 10.9 | 7.3 | 3.0 |
| 16 | 100 | 83.4 | 72.5 | 67.9 | 61.8 | 50.8 | 41.2 | 32.0 | 21.9 | 16.8 | 11.8 | 7.0 | 3.2 |
| 25-1047-11 | 100 | 96.3 | 89.7 | 82.9 | 76.7 | 65.4 | 54.9 | 45.6 | 33.5 | 23.9 | 16.6 | 10.0 | 5.4 |
| 12 | 100 | 92.6 | 83.4 | 66.8 | 57.0 | 44.6 | 33.4 | 26.2 | 18.1 | 12.0 | 9.8 | 5.9 | 1.7 |
| 15 | 100 | 98.2 | 96.0 | 88.2 | 79.6 | 70.1 | 60.7 | 47.3 | 36.8 | 27.7 | 20.4 | 12.6 | 5.9 |
| 16 | 100 | 94.5 | 84.2 | 70.8 | 60.2 | 46.5 | 36.2 | 27.8 | 18.9 | 13.7 | 8.9 | 5.2 | 2.8 |
| 26-1005-11 | 100 | 85.1 | 70.2 | 57.5 | 44.8 | 35.4 | 26.0 | 19.3 | 14.3 | 8.8 | 4.0 | 2.7 | 2.1 |
| 12 | 100 | 97.9 | 91.6 | 83.4 | 72.9 | 57.5 | 46.4 | 34.4 | 23.5 | 17.4 | 11.3 | 6.1 | 2.9 |
| 15 | 100 | 88.9 | 74.5 | 61.9 | 44.6 | 31.5 | 23.5 | 17.0 | 12.6 | 8.9 | 3.0 | 2.0 | 1.4 |
| 16 | 100 | 92.3 | 88.2 | 68.6 | 57.0 | 41.9 | 30.3 | 25.6 | 16.6 | 9.9 | 5.2 | 2.6 | 1.6 |
| 26-1340-11 | 100 | 93.0 | 81.8 | 70.8 | 63.3 | 50.2 | 37.7 | 28.5 | 20.5 | 13.8 | 8.8 | 4.8 | 2.7 |
| 12 | 100 | 96.8 | 83.9 | 69.6 | 58.6 | 45.8 | 35.7 | 26.7 | 28.9 | 12.6 | 8.4 | 4.9 | 1.8 |
| 15 | 100 | 93.2 | 88.3 | 76.4 | 62.5 | 51.4 | 39.1 | 29.1 | 20.2 | 12.2 | 9.5 | 5.0 | 1.8 |
| 16 | 100 | 93.0 | 83.8 | 62.4 | 53.6 | 42.2 | 32.8 | 23.8 | 17.5 | 10.6 | 6.8 | 4.5 | 1.9 |
| Samples Taken During Port-to-Starboard Swings | | | | | | | | | | | | | |
| 24-1105-11 | 100 | 94.8 | 83.2 | 65.0 | 50.6 | 38.7 | 28.0 | 19.3 | 11.4 | 7.8 | 4.6 | 2.3 | 1.7 |
| 12 | 100 | 94.9 | 86.8 | 79.3 | 64.4 | 51.6 | 40.7 | 29.6 | 21.2 | 14.2 | 8.5 | 5.5 | 3.2 |
| 15 | 100 | 91.6 | 78.5 | 61.6 | 45.4 | 32.4 | 23.0 | 15.4 | 7.9 | 5.1 | 4.1 | 2.0 | 1.0 |
| 16 | 100 | 100.0 | 95.9 | 86.1 | 77.1 | 63.8 | 52.9 | 40.8 | 29.9 | 21.7 | 14.9 | 8.4 | 3.6 |

Table A4

Calumet Harbor Cutterhead TSS Data

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 1 | 24 | 1015 | 1.7 | 4 |
| 1 | 24 | 1015 | 16.5 | 3 |
| 1 | 24 | 1015 | 28 | 7 |
| 1 | 24 | 1015 | 31.4 | 8 |
| 1 | 24 | 1130 | 1.7 | 2 |
| 1 | 24 | 1130 | 16.5 | 3 |
| 1 | 24 | 1130 | 28.1 | 6 |
| 1 | 24 | 1130 | 31.4 | 98 |
| 1 | 24 | 1345 | 1.7 | 3 |
| 1 | 24 | 1345 | 16.5 | 41 |
| 1 | 24 | 1345 | 28.1 | 17 |
| 1 | 24 | 1345 | 31.4 | 10 |
| 1 | 24 | 1450 | 1.7 | 45 |
| 1 | 24 | 1450 | 16.5 | 21 |
| 1 | 24 | 1450 | 28.1 | 4 |
| 1 | 24 | 1450 | 31.4 | 4 |
| 2 | 24 | 1028 | 2 | 3 |
| 2 | 24 | 1028 | 15.5 | 3 |
| 2 | 24 | 1028 | 26.5 | 6 |
| 2 | 24 | 1028 | 29.5 | 6 |
| 2 | 24 | 1139 | 2 | 2 |
| 2 | 24 | 1139 | 15 | 2 |
| 2 | 24 | 1139 | 25.5 | 4 |
| 2 | 24 | 1139 | 28.5 | 2 |
| 2 | 24 | 1355 | 2 | 3 |
| 2 | 24 | 1355 | 15 | 2 |
| 2 | 24 | 1355 | 25.5 | 4 |
| 2 | 24 | 1355 | 28.5 | 12 |
| 2 | 24 | 1459 | 2 | 4 |
| 2 | 24 | 1459 | 15 | 5 |
| 2 | 24 | 1459 | 25.5 | 11 |
| 2 | 24 | 1459 | 28.5 | 14 |
| 3 | 24 | 1023 | 2 | 4 |
| 3 | 24 | 1023 | 17 | 4 |
| 3 | 24 | 1023 | 28.5 | 10 |
| 3 | 24 | 1023 | 32 | 13 |
| 3 | 24 | 1133 | 2 | 5 |
| 3 | 24 | 1133 | 27 | 8 |
| 3 | 24 | 1133 | 30.5 | 14 |
| 3 | 24 | 1350 | 2 | 3 |
| 3 | 24 | 1350 | 16 | 4 |
| 3 | 24 | 1350 | 27 | 9 |
| 3 | 24 | 1350 | 30.5 | 10 |

(Continued)

(Sheet 1 of 11)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 3 | 24 | 1505 | 2 | 5 |
| 3 | 24 | 1505 | 16 | 4 |
| 3 | 24 | 1505 | 27 | 5 |
| 3 | 24 | 1505 | 30.5 | 9 |
| 4 | 24 | 1017 | 2 | 4 |
| 4 | 24 | 1017 | 16 | 5 |
| 4 | 24 | 1017 | 27 | 8 |
| 4 | 24 | 1017 | 30.5 | 101 |
| 4 | 24 | 1126 | 2 | 3 |
| 4 | 24 | 1126 | 16 | 2 |
| 4 | 24 | 1126 | 27 | 6 |
| 4 | 24 | 1126 | 30.5 | 7 |
| 4 | 24 | 1344 | 2 | 4 |
| 4 | 24 | 1344 | 14 | 5 |
| 4 | 24 | 1344 | 24 | 3 |
| 4 | 24 | 1344 | 26.5 | 6 |
| 4 | 24 | 1450 | 2 | 4 |
| 4 | 24 | 1450 | 14.5 | 4 |
| 4 | 24 | 1450 | 25 | 6 |
| 4 | 24 | 1450 | 27.5 | 4 |
| 5 | 24 | 1024 | 1.7 | 5 |
| 5 | 24 | 1024 | 17 | 4 |
| 5 | 24 | 1024 | 28.9 | 3 |
| 5 | 24 | 1024 | 32.3 | 11 |
| 5 | 24 | 1137 | 1.7 | 2 |
| 5 | 24 | 1137 | 17 | 3 |
| 5 | 24 | 1137 | 28.9 | 4 |
| 5 | 24 | 1137 | 32.3 | 4 |
| 5 | 24 | 1345 | 1.6 | 4 |
| 5 | 24 | 1345 | 15.5 | 2 |
| 5 | 24 | 1345 | 26.4 | 9 |
| 5 | 24 | 1345 | 29.5 | 8 |
| 5 | 24 | 1452 | 1.5 | 5 |
| 5 | 24 | 1452 | 15 | 3 |
| 5 | 24 | 1452 | 25.5 | 3 |
| 5 | 24 | 1452 | 28.5 | 7 |
| 6 | 24 | 1034 | 2 | 4 |
| 6 | 24 | 1034 | 17 | 6 |
| 6 | 24 | 1034 | 28.5 | 4 |
| 6 | 24 | 1034 | 32 | 10 |
| 6 | 24 | 1144 | 2 | 2 |
| 6 | 24 | 1144 | 17.5 | 4 |
| 6 | 24 | 1144 | 30 | 3 |
| 6 | 24 | 1144 | 33.5 | 3 |
| 6 | 24 | 1400 | 2 | 4 |

(Continued)

(Sheet 2 of 11)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 6 | 24 | 1400 | 17.5 | 5 |
| 6 | 24 | 1400 | 29.5 | 8 |
| 6 | 24 | 1400 | 33 | 10 |
| 6 | 24 | 1514 | 2 | 4 |
| 6 | 24 | 1514 | 17 | 6 |
| 6 | 24 | 1514 | 29 | 5 |
| 6 | 24 | 1514 | 32 | 7 |
| 7 | 24 | 1041 | 2 | 4 |
| 7 | 24 | 1041 | 16.5 | 6 |
| 7 | 24 | 1041 | 28 | 11 |
| 7 | 24 | 1041 | 32 | 15 |
| 7 | 24 | 1150 | 2 | 4 |
| 7 | 24 | 1150 | 16.5 | 4 |
| 7 | 24 | 1150 | 28 | 7 |
| 7 | 24 | 1150 | 31.5 | 11 |
| 7 | 24 | 1405 | 2 | 4 |
| 7 | 24 | 1405 | 16 | 5 |
| 7 | 24 | 1405 | 27 | 13 |
| 7 | 24 | 1405 | 30.5 | 18 |
| 7 | 24 | 1509 | 2 | 4 |
| 7 | 24 | 1509 | 15.5 | 4 |
| 7 | 24 | 1509 | 26 | 8 |
| 7 | 24 | 1509 | 29 | 12 |
| 8 | 24 | 1043 | 1.4 | 2 |
| 8 | 24 | 1043 | 13.5 | 3 |
| 8 | 24 | 1043 | 23 | 4 |
| 8 | 24 | 1043 | 25 | 3 |
| 8 | 24 | 1140 | 1.7 | 2 |
| 8 | 24 | 1140 | 16.5 | 2 |
| 8 | 24 | 1140 | 28.1 | 2 |
| 8 | 24 | 1140 | 31.4 | 4 |
| 8 | 24 | 1355 | 1.5 | 4 |
| 8 | 24 | 1355 | 15 | 3 |
| 8 | 24 | 1355 | 25.5 | 7 |
| 8 | 24 | 1355 | 28.5 | 7 |
| 8 | 24 | 1500 | 1.7 | 2 |
| 8 | 24 | 1500 | 17 | 2 |
| 8 | 24 | 1500 | 28.9 | 7 |
| 8 | 24 | 1500 | 32.3 | 7 |
| 9 | 24 | 1053 | 1.7 | 2 |
| 9 | 24 | 1053 | 17 | 3 |
| 9 | 24 | 1053 | 28.9 | 8 |
| 9 | 24 | 1053 | 32.3 | 14 |
| 9 | 24 | 1155 | 1.7 | 2 |
| 9 | 24 | 1155 | 17 | 2 |

(Continued)

(Sheet 3 of 11)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 9 | 24 | 1155 | 28.9 | 6 |
| 9 | 24 | 1155 | 32.3 | 6 |
| 9 | 24 | 1406 | 1.4 | 4 |
| 9 | 24 | 1406 | 14 | 3 |
| 9 | 24 | 1406 | 23.8 | 6 |
| 9 | 24 | 1406 | 26.6 | 4 |
| 9 | 24 | 1510 | 1.6 | 3 |
| 9 | 24 | 1510 | 6 | 4 |
| 9 | 24 | 1510 | 27.2 | 6 |
| 9 | 24 | 1510 | 30.4 | 6 |
| 10 | 24 | 1046 | 2 | 3 |
| 10 | 24 | 1046 | 20 | 4 |
| 10 | 24 | 1046 | 32 | 2 |
| 10 | 24 | 1046 | 38 | 4 |
| 10 | 24 | 1155 | 2 | 3 |
| 10 | 24 | 1155 | 19.5 | 4 |
| 10 | 24 | 1155 | 33 | 3 |
| 10 | 24 | 1155 | 37 | 5 |
| 10 | 24 | 1412 | 2 | 4 |
| 10 | 24 | 1412 | 19.5 | 5 |
| 10 | 24 | 1412 | 33 | 6 |
| 10 | 24 | 1412 | 38 | 9 |
| 10 | 24 | 1521 | 2 | 4 |
| 10 | 24 | 1521 | 19.5 | 5 |
| 10 | 24 | 1521 | 33 | 9 |
| 10 | 24 | 1521 | 36.5 | 9 |
| 1 | 25 | 1004 | 1.5 | 5 |
| 1 | 25 | 1004 | 15 | 11 |
| 1 | 25 | 1004 | 25.5 | 11 |
| 1 | 25 | 1004 | 28.5 | 8 |
| 1 | 25 | 1111 | 1.7 | 2 |
| 1 | 25 | 1111 | 16.5 | 4 |
| 1 | 25 | 1111 | 28.1 | 11 |
| 1 | 25 | 1111 | 31.4 | 27 |
| 1 | 25 | 1321 | 1.6 | 4 |
| 1 | 25 | 1321 | 15.5 | 9 |
| 1 | 25 | 1321 | 26.4 | 15 |
| 1 | 25 | 1321 | 29.5 | 2 |
| 1 | 25 | 1430 | 1.6 | 3 |
| 1 | 25 | 1430 | 16 | 2 |
| 1 | 25 | 1430 | 27.2 | 7 |
| 1 | 25 | 1430 | 30.4 | 170 |
| 2 | 25 | 1015 | 2 | 2 |
| 2 | 25 | 1015 | 15 | 4 |
| 2 | 25 | 1015 | 25.5 | 6 |

(Continued)

(Sheet 4 of 11)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 2 | 25 | 1015 | 28.5 | 5 |
| 2 | 25 | 1122 | 2 | 2 |
| 2 | 25 | 1122 | 15 | 3 |
| 2 | 25 | 1122 | 25.5 | 3 |
| 2 | 25 | 1122 | 28.5 | 4 |
| 2 | 25 | 1334 | 2 | 3 |
| 2 | 25 | 1334 | 15 | 4 |
| 2 | 25 | 1334 | 25.5 | 4 |
| 2 | 25 | 1334 | 28.5 | 5 |
| 2 | 25 | 1445 | 2 | 2 |
| 2 | 25 | 1445 | 15 | 4 |
| 2 | 25 | 1445 | 25.5 | 3 |
| 2 | 25 | 1445 | 28.5 | 4 |
| 3 | 25 | 1010 | 2 | 4 |
| 3 | 25 | 1010 | 15.5 | 3 |
| 3 | 25 | 1010 | 26.5 | 5 |
| 3 | 25 | 1010 | 29.5 | 6 |
| 3 | 25 | 1118 | 2 | 5 |
| 3 | 25 | 1118 | 16 | 5 |
| 3 | 25 | 1118 | 27 | 3 |
| 3 | 25 | 1118 | 30.5 | 8 |
| 3 | 25 | 1329 | 2 | 2 |
| 3 | 25 | 1329 | 13.5 | 2 |
| 3 | 25 | 1329 | 23 | 2 |
| 3 | 25 | 1329 | 26 | 5 |
| 3 | 25 | 1439 | 2 | 5 |
| 3 | 25 | 1439 | 13.5 | 5 |
| 3 | 25 | 1439 | 23 | 3 |
| 3 | 25 | 1439 | 25.5 | 4 |
| 4 | 25 | 1004 | 2 | 4 |
| 4 | 25 | 1004 | 15.5 | 6 |
| 4 | 25 | 1004 | 26.5 | 4 |
| 4 | 25 | 1004 | 29.5 | 6 |
| 4 | 25 | 1113 | 2 | 3 |
| 4 | 25 | 1113 | 16.5 | 4 |
| 4 | 25 | 1113 | 28 | 3 |
| 4 | 25 | 1113 | 30.5 | 9 |
| 4 | 25 | 1325 | 2 | 2 |
| 4 | 25 | 1325 | 16 | 2 |
| 4 | 25 | 1325 | 27 | 2 |
| 4 | 25 | 1325 | 30.5 | 5 |
| 4 | 25 | 1433 | 2 | 2 |
| 4 | 25 | 1433 | 16 | 6 |
| 4 | 25 | 1433 | 27 | 5 |
| 4 | 25 | 1433 | 30.5 | 35 |

(Continued)

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Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 5 | 25 | 1002 | 1.5 | 4 |
| 5 | 25 | 1002 | 15 | 4 |
| 5 | 25 | 1002 | 25.5 | 4 |
| 5 | 25 | 1002 | 28.5 | 6 |
| 5 | 25 | 1113 | 1.5 | 3 |
| 5 | 25 | 1113 | 15 | 3 |
| 5 | 25 | 1113 | 25.5 | 3 |
| 5 | 25 | 1113 | 28.5 | 6 |
| 5 | 25 | 1324 | 1.6 | 2 |
| 5 | 25 | 1324 | 15.5 | 2 |
| 5 | 25 | 1324 | 26.4 | 2 |
| 5 | 25 | 1324 | 29.5 | 26 |
| 5 | 25 | 1432 | 1.8 | 6 |
| 5 | 25 | 1432 | 16.3 | 36 |
| 5 | 25 | 1432 | 27.6 | 2 |
| 5 | 25 | 1432 | 30.9 | 2 |
| 6 | 25 | 1021 | 2 | 3 |
| 6 | 25 | 1021 | 16.5 | 2 |
| 6 | 25 | 1021 | 28 | 4 |
| 6 | 25 | 1021 | 31.5 | 2 |
| 6 | 25 | 1128 | 2 | 2 |
| 6 | 25 | 1128 | 17 | 4 |
| 6 | 25 | 1128 | 28.5 | 4 |
| 6 | 25 | 1128 | 32 | 4 |
| 6 | 25 | 1339 | 2 | 2 |
| 6 | 25 | 1339 | 17.5 | 3 |
| 6 | 25 | 1339 | 30 | 5 |
| 6 | 25 | 1339 | 33.5 | 5 |
| 6 | 25 | 1450 | 2 | 3 |
| 6 | 25 | 1450 | 17 | 4 |
| 6 | 25 | 1450 | 29 | 4 |
| 6 | 25 | 1450 | 32.5 | 3 |
| 7 | 25 | 1027 | 2 | 3 |
| 7 | 25 | 1027 | 14 | 4 |
| 7 | 25 | 1027 | 24 | 5 |
| 7 | 25 | 1027 | 26.5 | 8 |
| 7 | 25 | 1134 | 2 | 4 |
| 7 | 25 | 1134 | 14.5 | 5 |
| 7 | 25 | 1134 | 25 | 4 |
| 7 | 25 | 1134 | 27.5 | 9 |
| 7 | 25 | 1343 | 2 | 3 |
| 7 | 25 | 1343 | 15 | 2 |
| 7 | 25 | 1343 | 25 | 4 |
| 7 | 25 | 1343 | 27.5 | 5 |
| 7 | 25 | 1455 | 2 | 3 |

(Continued)

(Sheet 6 of 11)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 7 | 25 | 1455 | 13.5 | 3 |
| 7 | 25 | 1455 | 23 | 2 |
| 7 | 25 | 1455 | 25.5 | 3 |
| 8 | 25 | 1010 | 1.7 | 2 |
| 8 | 25 | 1010 | 16.5 | 2 |
| 8 | 25 | 1010 | 28.1 | 3 |
| 8 | 25 | 1010 | 31.4 | 4 |
| 8 | 25 | 1122 | 1.8 | 3 |
| 8 | 25 | 1122 | 17.8 | 4 |
| 8 | 25 | 1122 | 27.2 | 5 |
| 8 | 25 | 1122 | 30.4 | 9 |
| 8 | 25 | 1333 | 1.6 | 2 |
| 8 | 25 | 1333 | 15.5 | 2 |
| 8 | 25 | 1333 | 26.4 | 2 |
| 8 | 25 | 1333 | 29.5 | 2 |
| 8 | 25 | 1439 | 1.6 | 3 |
| 8 | 25 | 1439 | 16.3 | 2 |
| 8 | 25 | 1439 | 27.6 | 2 |
| 8 | 25 | 1439 | 30.9 | 2 |
| 9 | 25 | 1019 | 1.7 | 3 |
| 9 | 25 | 1019 | 16.5 | 3 |
| 9 | 25 | 1019 | 28.1 | 2 |
| 9 | 25 | 1019 | 31.4 | 4 |
| 9 | 25 | 1132 | 1.7 | 2 |
| 9 | 25 | 1132 | 11.5 | 3 |
| 9 | 25 | 1132 | 28.1 | 4 |
| 9 | 25 | 1132 | 31.4 | 3 |
| 9 | 25 | 1342 | 1.6 | 2 |
| 9 | 25 | 1342 | 16 | 2 |
| 9 | 25 | 1342 | 27.2 | 2 |
| 9 | 25 | 1342 | 30.4 | 5 |
| 9 | 25 | 1447 | 1.6 | 4 |
| 9 | 25 | 1447 | 16 | 4 |
| 9 | 25 | 1447 | 27.2 | 5 |
| 9 | 25 | 1447 | 30.4 | 9 |
| 10 | 25 | 1035 | 2 | 4 |
| 10 | 25 | 1035 | 17.5 | 5 |
| 10 | 25 | 1035 | 30 | 2 |
| 10 | 25 | 1035 | 33.5 | 3 |
| 10 | 25 | 1140 | 2 | 2 |
| 10 | 25 | 1140 | 17.5 | 3 |
| 10 | 25 | 1140 | 39.5 | 3 |
| 10 | 25 | 1140 | 33 | 5 |
| 10 | 25 | 1348 | 2 | 2 |
| 10 | 25 | 1348 | 17 | 2 |

(Continued)

(Sheet 7 of 11)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 10 | 25 | 1348 | 29 | 2 |
| 10 | 25 | 1348 | 32.5 | 3 |
| 10 | 25 | 1500 | 2 | 3 |
| 10 | 25 | 1500 | 17.5 | 4 |
| 10 | 25 | 1500 | 30 | 6 |
| 10 | 25 | 1500 | 33 | 5 |
| 1 | 26 | 945 | 1.5 | 2 |
| 1 | 26 | 945 | 14.5 | 3 |
| 1 | 26 | 945 | 24.7 | 6 |
| 1 | 26 | 945 | 27.6 | 5 |
| 1 | 26 | 1050 | 1.5 | 2 |
| 1 | 26 | 1050 | 15 | 2 |
| 1 | 26 | 1050 | 25.9 | 5 |
| 1 | 26 | 1050 | 29 | 25 |
| 1 | 26 | 1315 | 1.5 | 2 |
| 1 | 26 | 1315 | 15 | 2 |
| 1 | 26 | 1315 | 25.5 | 9 |
| 1 | 26 | 1315 | 28.5 | 33 |
| 1 | 26 | 1415 | 1.5 | 2 |
| 1 | 26 | 1415 | 15 | 2 |
| 1 | 26 | 1415 | 25.5 | 4 |
| 1 | 26 | 1415 | 28.5 | 4 |
| 2 | 26 | 958 | 2 | 5 |
| 2 | 26 | 958 | 15.5 | 2 |
| 2 | 26 | 958 | 26.5 | 2 |
| 2 | 26 | 958 | 28.5 | 2 |
| 2 | 26 | 1057 | 2 | 4 |
| 2 | 26 | 1057 | 16.5 | 3 |
| 2 | 26 | 1057 | 28 | 4 |
| 2 | 26 | 1057 | 31.5 | 7 |
| 2 | 26 | 1323 | 2 | 5 |
| 2 | 26 | 1323 | 16 | 5 |
| 2 | 26 | 1323 | 27 | 5 |
| 2 | 26 | 1323 | 30.5 | 5 |
| 2 | 26 | 1427 | 2 | 4 |
| 2 | 26 | 1427 | 17 | 3 |
| 2 | 26 | 1427 | 29.5 | 2 |
| 2 | 26 | 1427 | 32.5 | 5 |
| 3 | 26 | 952 | 2 | 2 |
| 3 | 26 | 952 | 15 | 2 |
| 3 | 26 | 952 | 25.5 | 2 |
| 3 | 26 | 952 | 28.5 | 2 |
| 3 | 26 | 1053 | 2 | 7 |
| 3 | 26 | 1053 | 13.5 | 6 |
| 3 | 26 | 1053 | 23 | 11 |

(Continued)

(Sheet 8 of 11)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 3 | 26 | 1053 | 25.5 | 10 |
| 3 | 26 | 1319 | 2 | 9 |
| 3 | 26 | 1319 | 15 | 6 |
| 3 | 26 | 1319 | 25.5 | 6 |
| 3 | 26 | 1319 | 28.5 | 12 |
| 3 | 26 | 1422 | 2 | 5 |
| 3 | 26 | 1422 | 16 | 2 |
| 3 | 26 | 1422 | 27 | 9 |
| 3 | 26 | 1422 | 30.5 | 8 |
| 4 | 26 | 947 | 2 | 2 |
| 4 | 26 | 947 | 15.5 | 4 |
| 4 | 26 | 947 | 26.5 | 10 |
| 4 | 26 | 947 | 29.5 | 9 |
| 4 | 26 | 1048 | 2 | 4 |
| 4 | 26 | 1048 | 16 | 6 |
| 4 | 26 | 1048 | 27 | 7 |
| 4 | 26 | 1048 | 30.5 | 13 |
| 4 | 26 | 1315 | 2 | 6 |
| 4 | 26 | 1315 | 16 | 6 |
| 4 | 26 | 1315 | 27 | 22 |
| 4 | 26 | 1315 | 30.5 | 38 |
| 4 | 26 | 1415 | 2 | 4 |
| 4 | 26 | 1415 | 16.5 | 4 |
| 4 | 26 | 1415 | 28 | 5 |
| 4 | 26 | 1415 | 31.5 | 8 |
| 5 | 26 | 950 | 1.5 | 4 |
| 5 | 26 | 950 | 15 | 2 |
| 5 | 26 | 950 | 25.5 | 2 |
| 5 | 26 | 950 | 28.5 | 4 |
| 5 | 26 | 1056 | 1 | 2 |
| 5 | 26 | 1056 | 15 | 2 |
| 5 | 26 | 1056 | 25.5 | 2 |
| 5 | 26 | 1056 | 28.5 | 2 |
| 5 | 26 | 1320 | 1.5 | 3 |
| 5 | 26 | 1320 | 15 | 2 |
| 5 | 26 | 1320 | 25.5 | 4 |
| 5 | 26 | 1320 | 28.5 | 5 |
| 5 | 26 | 1422 | 1.5 | 2 |
| 5 | 26 | 1422 | 15 | 3 |
| 5 | 26 | 1422 | 25.5 | 3 |
| 5 | 26 | 1422 | 28.5 | 4 |
| 6 | 26 | 1002 | 2 | 3 |
| 6 | 26 | 1002 | 17.5 | 2 |
| 6 | 26 | 1002 | 30 | 5 |
| 6 | 26 | 1002 | 33.5 | 3 |

(Continued)

Table A4 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 6 | 26 | 1102 | 2 | 3 |
| 6 | 26 | 1102 | 17.5 | 4 |
| 6 | 26 | 1102 | 30 | 4 |
| 6 | 26 | 1102 | 33.5 | 4 |
| 6 | 26 | 1327 | 2 | 5 |
| 6 | 26 | 1327 | 17 | 4 |
| 6 | 26 | 1327 | 29 | 4 |
| 6 | 26 | 1327 | 32.5 | 4 |
| 6 | 26 | 1431 | 2 | 2 |
| 6 | 26 | 1431 | 17.5 | 2 |
| 6 | 26 | 1431 | 30 | 2 |
| 6 | 26 | 1431 | 33.5 | 5 |
| 7 | 26 | 1006 | 2 | 2 |
| 7 | 26 | 1006 | 15 | 2 |
| 7 | 26 | 1006 | 25.5 | 2 |
| 7 | 26 | 1006 | 28.5 | 4 |
| 7 | 26 | 1107 | 2 | 6 |
| 7 | 26 | 1107 | 14 | 8 |
| 7 | 26 | 1107 | 24 | 8 |
| 7 | 26 | 1107 | 26.5 | 8 |
| 7 | 26 | 1333 | 2 | 3 |
| 7 | 26 | 1333 | 14.5 | 11 |
| 7 | 26 | 1333 | 25 | 14 |
| 7 | 26 | 1333 | 28 | 14 |
| 7 | 26 | 1436 | 2 | 7 |
| 7 | 26 | 1436 | 17.5 | 5 |
| 7 | 26 | 1436 | 30 | 9 |
| 7 | 26 | 1436 | 33.5 | 7 |
| 8 | 26 | 1000 | 1.5 | 2 |
| 8 | 26 | 1000 | 14.5 | 2 |
| 8 | 26 | 1000 | 24.7 | 2 |
| 8 | 26 | 1000 | 27.6 | 2 |
| 8 | 26 | 1105 | 1.6 | 2 |
| 8 | 26 | 1105 | 16 | 2 |
| 8 | 26 | 1105 | 27.6 | 4 |
| 8 | 26 | 1105 | 30.9 | 5 |
| 8 | 26 | 1330 | 1.5 | 2 |
| 8 | 26 | 1330 | 14.5 | 2 |
| 8 | 26 | 1330 | 24.7 | 3 |
| 8 | 26 | 1330 | 27.6 | 10 |
| 8 | 26 | 1428 | 1.5 | 3 |
| 8 | 26 | 1428 | 14.5 | 2 |
| 8 | 26 | 1428 | 17.6 | 9 |
| 8 | 26 | 1428 | 24.7 | 4 |
| 9 | 26 | 1010 | 1.5 | 2 |

(Continued)

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Table A4 (Concluded)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 9 | 26 | 1010 | 15.2 | 2 |
| 9 | 26 | 1010 | 26.4 | 3 |
| 9 | 26 | 1010 | 29.5 | 3 |
| 9 | 26 | 1111 | 1.6 | 2 |
| 9 | 26 | 1111 | 16 | 2 |
| 9 | 26 | 1111 | 27.6 | 4 |
| 9 | 26 | 1111 | 30.9 | 8 |
| 9 | 26 | 1337 | 1.5 | 3 |
| 9 | 26 | 1337 | 15 | 2 |
| 9 | 26 | 1337 | 25.5 | 4 |
| 9 | 26 | 1337 | 28.5 | 48 |
| 9 | 26 | 1435 | 1.7 | 2 |
| 9 | 26 | 1435 | 16.5 | 2 |
| 9 | 26 | 1435 | 28.1 | 10 |
| 9 | 26 | 1435 | 31.4 | 18 |
| 10 | 26 | 1011 | 2 | 5 |
| 10 | 26 | 1011 | 17.5 | 2 |
| 10 | 26 | 1011 | 30 | 2 |
| 10 | 26 | 1011 | 33.5 | 4 |
| 10 | 26 | 1112 | 2 | 3 |
| 10 | 26 | 1112 | 17.5 | 4 |
| 10 | 26 | 1112 | 30 | 5 |
| 10 | 26 | 1112 | 33.5 | 5 |
| 10 | 26 | 1337 | 2 | 5 |
| 10 | 26 | 1337 | 17.5 | 2 |
| 10 | 26 | 1337 | 30 | 5 |
| 10 | 26 | 1337 | 33.5 | 3 |
| 10 | 26 | 1414 | 2 | 6 |
| 10 | 26 | 1414 | 17.5 | 6 |
| 10 | 26 | 1414 | 30 | 7 |
| 10 | 26 | 1414 | 33.5 | 7 |

Table A5

Calumet Harbor Matchbox TSS Data

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 1 | 21 | 1210 | 1.7 | 4 |
| 1 | 21 | 1210 | 16.5 | 7 |
| 1 | 21 | 1210 | 28.1 | 6 |
| 1 | 21 | 1210 | 31.4 | 6 |
| 1 | 21 | 1315 | 1.8 | 4 |
| 1 | 21 | 1315 | 17.5 | 6 |
| 1 | 21 | 1315 | 30.2 | 9 |
| 1 | 21 | 1315 | 33.7 | 12 |
| 2 | 21 | 1155 | 2 | 2 |
| 2 | 21 | 1155 | 17.5 | 6 |
| 2 | 21 | 1155 | 30 | 10 |
| 2 | 21 | 1155 | 34 | 20 |
| 2 | 21 | 1326 | 2 | 3 |
| 2 | 21 | 1326 | 17 | 5 |
| 2 | 21 | 1326 | 29 | 6 |
| 2 | 21 | 1326 | 32 | 5 |
| 3 | 21 | 1205 | 2 | 3 |
| 3 | 21 | 1205 | 19.5 | 3 |
| 3 | 21 | 1205 | 33 | 5 |
| 3 | 21 | 1205 | 37 | 18 |
| 3 | 21 | 1332 | 2 | 4 |
| 3 | 21 | 1332 | 19 | 6 |
| 3 | 21 | 1332 | 32 | 7 |
| 3 | 21 | 1332 | 36 | 30 |
| 4 | 21 | 1215 | 2 | 3 |
| 4 | 21 | 1215 | 17 | 5 |
| 4 | 21 | 1215 | 20 | 26 |
| 4 | 21 | 1215 | 28.5 | 7 |
| 4 | 21 | 1338 | 1.5 | 3 |
| 4 | 21 | 1338 | 16 | 6 |
| 4 | 21 | 1338 | 27.5 | 7 |
| 4 | 21 | 1338 | 31 | 9 |
| 5 | 21 | 1220 | 1.6 | 3 |
| 5 | 21 | 1220 | 16 | 8 |
| 5 | 21 | 1220 | 27.2 | 8 |
| 5 | 21 | 1220 | 28 | 8 |
| 5 | 21 | 1325 | 1.5 | 2 |
| 5 | 21 | 1325 | 15.3 | 4 |
| 5 | 21 | 1325 | 25.9 | 8 |
| 5 | 21 | 1325 | 29 | 12 |
| 6 | 21 | 1228 | 2 | 2 |
| 6 | 21 | 1228 | 17 | 3 |
| 6 | 21 | 1228 | 29 | 2 |
| 6 | 21 | 1228 | 32.5 | 20 |

(Continued)

(Sheet 1 of 6)

Table A5 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 6 | 21 | 1345 | 1.5 | 2 |
| 6 | 21 | 1345 | 16.5 | 4 |
| 6 | 21 | 1345 | 28 | 3 |
| 6 | 21 | 1345 | 31.5 | 40 |
| 7 | 21 | 1237 | 2 | 3 |
| 7 | 21 | 1237 | 31.5 | 17 |
| 7 | 21 | 1237 | 35 | 16 |
| 7 | 21 | 1351 | 2 | 2 |
| 7 | 21 | 1351 | 18.5 | 4 |
| 7 | 21 | 1351 | 31.5 | 16 |
| 7 | 21 | 1351 | 35 | 30 |
| 8 | 21 | 1245 | 1.4 | 5 |
| 8 | 21 | 1245 | 12.5 | 8 |
| 8 | 21 | 1245 | 21.3 | 12 |
| 8 | 21 | 1245 | 23.8 | 9 |
| 8 | 21 | 1331 | 1.1 | 2 |
| 8 | 21 | 1331 | 11 | 4 |
| 8 | 21 | 1331 | 18.7 | 34 |
| 8 | 21 | 1331 | 20.9 | 6 |
| 9 | 21 | 1250 | 1.4 | 4 |
| 9 | 21 | 1250 | 14 | 4 |
| 9 | 21 | 1250 | 23.8 | 11 |
| 9 | 21 | 1250 | 24.6 | 29 |
| 9 | 21 | 1350 | 1.5 | 2 |
| 9 | 21 | 1350 | 15 | 2 |
| 9 | 21 | 1350 | 25.5 | 5 |
| 9 | 21 | 1350 | 29 | 5 |
| 10 | 21 | 1247 | 2 | 8 |
| 10 | 21 | 1247 | 19.5 | 6 |
| 10 | 21 | 1247 | 33 | 4 |
| 10 | 21 | 1247 | 37 | 7 |
| 10 | 21 | 1357 | 2 | 3 |
| 10 | 21 | 1357 | 19.5 | 5 |
| 10 | 21 | 1357 | 33 | 6 |
| 10 | 21 | 1357 | 37 | 4 |
| 1 | 22 | 1140 | 1.5 | 2 |
| 1 | 22 | 1140 | 15 | 3 |
| 1 | 22 | 1140 | 25.5 | 4 |
| 1 | 22 | 1140 | 28.5 | 6 |
| 1 | 22 | 1424 | 1.5 | 2 |
| 1 | 22 | 1424 | 15 | 4 |
| 1 | 22 | 1424 | 25.5 | 9 |
| 1 | 22 | 1424 | 29.5 | 29 |
| 1 | 22 | 1501 | 2 | 3 |

(Continued)

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Table A5 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 1 | 22 | 1501 | 15 | 3 |
| 1 | 22 | 1501 | 25 | 4 |
| 1 | 22 | 1501 | 28 | 4 |
| 2 | 22 | 1035 | 2 | 2 |
| 2 | 22 | 1035 | 16.5 | 2 |
| 2 | 22 | 1035 | 28 | 4 |
| 2 | 22 | 1035 | 31.5 | 5 |
| 2 | 22 | 1145 | 2 | 2 |
| 2 | 22 | 1145 | 16 | 2 |
| 2 | 22 | 1145 | 27 | 2 |
| 2 | 22 | 1145 | 30.5 | 8 |
| 2 | 22 | 1423 | 2 | 3 |
| 2 | 22 | 1423 | 16 | 4 |
| 2 | 22 | 1423 | 27 | 6 |
| 2 | 22 | 1423 | 30.5 | 6 |
| 2 | 22 | 1509 | 2 | 2 |
| 2 | 22 | 1509 | 16 | 4 |
| 2 | 22 | 1509 | 27.5 | 3 |
| 2 | 22 | 1509 | 31 | 8 |
| 3 | 22 | 1040 | 2 | 3 |
| 3 | 22 | 1040 | 17 | 2 |
| 3 | 22 | 1040 | 29 | 3 |
| 3 | 22 | 1040 | 32 | 6 |
| 3 | 22 | 1154 | 2 | 2 |
| 3 | 22 | 1154 | 18.5 | 5 |
| 3 | 22 | 1154 | 31.5 | 12 |
| 3 | 22 | 1154 | 35 | 25 |
| 3 | 22 | 1432 | 2 | 2 |
| 3 | 22 | 1432 | 19 | 3 |
| 3 | 22 | 1432 | 32 | 6 |
| 3 | 22 | 1432 | 36 | 14 |
| 3 | 22 | 1514 | 2 | 3 |
| 3 | 22 | 1514 | 18.5 | 3 |
| 3 | 22 | 1514 | 31.5 | 8 |
| 3 | 22 | 1514 | 35 | 21 |
| 4 | 22 | 1045 | 2 | 3 |
| 4 | 22 | 1045 | 18.5 | 6 |
| 4 | 22 | 1045 | 31.5 | 24 |
| 4 | 22 | 1045 | 35 | 10 |
| 4 | 22 | 1149 | 2 | 2 |
| 4 | 22 | 1149 | 17.5 | 5 |
| 4 | 22 | 1149 | 30 | 12 |
| 4 | 22 | 1149 | 33 | 8 |
| 4 | 22 | 1426 | 2 | 4 |

(Continued)

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Table A5 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 4 | 22 | 1426 | 18.5 | 3 |
| 4 | 22 | 1426 | 31.5 | 6 |
| 4 | 22 | 1426 | 35 | 10 |
| 4 | 22 | 1505 | 2 | 4 |
| 4 | 22 | 1505 | 17 | 4 |
| 4 | 22 | 1505 | 29 | 6 |
| 4 | 22 | 1505 | 32 | 4 |
| 5 | 22 | 1037 | 1.5 | 2 |
| 5 | 22 | 1037 | 15.5 | 3 |
| 5 | 22 | 1037 | 24.7 | 4 |
| 5 | 22 | 1037 | 27.6 | 4.5 |
| 5 | 22 | 1145 | 1.5 | 2 |
| 5 | 22 | 1145 | 15 | 3 |
| 5 | 22 | 1145 | 25.5 | 4 |
| 5 | 22 | 1145 | 28.5 | 6 |
| 5 | 22 | 1427 | 1.5 | 2 |
| 5 | 22 | 1427 | 15 | 3 |
| 5 | 22 | 1427 | 25.5 | 5 |
| 5 | 22 | 1427 | 28.5 | 19 |
| 5 | 22 | 1505 | 1.4 | 3 |
| 5 | 22 | 1505 | 14 | 4 |
| 5 | 22 | 1505 | 23.8 | 5 |
| 5 | 22 | 1505 | 26.6 | 6 |
| 6 | 22 | 1051 | 2 | 2 |
| 6 | 22 | 1051 | 17 | 5 |
| 6 | 22 | 1051 | 29 | 8 |
| 6 | 22 | 1051 | 32 | 10 |
| 6 | 22 | 1203 | 2 | 4 |
| 6 | 22 | 1203 | 18 | 2 |
| 6 | 22 | 1203 | 30.5 | 4 |
| 6 | 22 | 1203 | 34 | 2 |
| 6 | 22 | 1440 | 2 | 2 |
| 6 | 22 | 1440 | 17 | 2 |
| 6 | 22 | 1440 | 29 | 2 |
| 6 | 22 | 1440 | 32 | 25 |
| 6 | 22 | 1523 | 2 | 3 |
| 6 | 22 | 1523 | 17 | 5 |
| 6 | 22 | 1523 | 29 | 4 |
| 6 | 22 | 1523 | 32 | 2 |
| 7 | 22 | 1056 | 2 | 2 |
| 7 | 22 | 1056 | 19 | 4 |
| 7 | 22 | 1056 | 32 | 11 |
| 7 | 22 | 1056 | 36 | 78 |
| 7 | 22 | 1159 | 2 | 5 |

(Continued)

Table A5 (Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 7 | 22 | 1159 | 18 | 5 |
| 7 | 22 | 1159 | 30.5 | 8 |
| 7 | 22 | 1159 | 34 | 18 |
| 7 | 22 | 1436 | 2 | 3 |
| 7 | 22 | 1436 | 18 | 2 |
| 7 | 22 | 1436 | 30.5 | 6 |
| 7 | 22 | 1436 | 34 | 24 |
| 7 | 22 | 1518 | 2 | 2 |
| 7 | 22 | 1518 | 19 | 5 |
| 7 | 22 | 1518 | 32.5 | 11 |
| 7 | 22 | 1518 | 36 | 17 |
| 8 | 22 | 1044 | 1.5 | 2 |
| 8 | 22 | 1044 | 15 | 3 |
| 8 | 22 | 1044 | 25.5 | 3 |
| 8 | 22 | 1044 | 28.2 | 4 |
| 8 | 22 | 1154 | 1.5 | 2 |
| 8 | 22 | 1154 | 14.5 | 2 |
| 8 | 22 | 1154 | 24.7 | 5 |
| 8 | 22 | 1154 | 27.6 | 6 |
| 8 | 22 | 1435 | 1.3 | 3 |
| 8 | 22 | 1435 | 13 | 2 |
| 8 | 22 | 1435 | 22.1 | 6 |
| 8 | 22 | 1435 | 24.7 | 7 |
| 8 | 22 | 1512 | 1.4 | 2 |
| 8 | 22 | 1512 | 13.5 | 2 |
| 8 | 22 | 1512 | 23 | 12 |
| 8 | 22 | 1512 | 24.5 | 4 |
| 9 | 22 | 1053 | 2 | 2 |
| 9 | 22 | 1053 | 16 | 5 |
| 9 | 22 | 1053 | 25 | 29 |
| 9 | 22 | 1053 | 28 | 5 |
| 9 | 22 | 1204 | 1.5 | 2 |
| 9 | 22 | 1204 | 14.5 | 2 |
| 9 | 22 | 1204 | 24.5 | 2 |
| 9 | 22 | 1204 | 27.6 | 2 |
| 9 | 22 | 1445 | 1.6 | 2 |
| 9 | 22 | 1445 | 15.5 | 3 |
| 9 | 22 | 1445 | 26.4 | 6 |
| 9 | 22 | 1445 | 29.5 | 5 |
| 9 | 22 | 1522 | 2 | 3 |
| 9 | 22 | 1522 | 18 | 4 |
| 9 | 22 | 1522 | 30 | 5 |
| 9 | 22 | 1522 | 33 | 5 |
| 10 | 22 | 1100 | 2 | 2 |

(Continued)

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Table A5 (Concluded)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 10 | 22 | 1100 | 19.5 | 2 |
| 10 | 22 | 1100 | 33 | 4 |
| 10 | 22 | 1100 | 37 | 4 |
| 10 | 22 | 1207 | 2 | 2 |
| 10 | 22 | 1207 | 20 | 3 |
| 10 | 22 | 1207 | 32 | 2 |
| 10 | 22 | 1207 | 38 | 7 |
| 10 | 22 | 1445 | 2 | 2 |
| 10 | 22 | 1445 | 20 | 4 |
| 10 | 22 | 1445 | 32 | 4 |
| 10 | 22 | 1445 | 38 | 28 |
| 10 | 22 | 1529 | 2 | 3 |
| 10 | 22 | 1529 | 20 | 4 |
| 10 | 22 | 1529 | 32 | 3 |
| 10 | 22 | 1529 | 38 | 4 |

(Sheet 6 of 6)

# APPENDIX B:  CALUMET RIVER CLAMSHELL DATA

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 1B | 20 | 1717 | 27 | 18 |
| 1B | 20 | 1718 | 15 | 12 |
| 1B | 20 | 1719 | 5 | 11 |
| 2B | 20 | 1722 | 27 | 11 |
| 2B | 20 | 1723 | 15 | 12 |
| 2B | 20 | 1724 | 5 | 10 |
| 3B | 20 | 1731 | 27 | 12 |
| 3B | 20 | 1732 | 15 | 10 |
| 3B | 20 | 1733 | 5 | 10 |
| 4B | 20 | 1736 | 27 | 10 |
| 4B | 20 | 1739 | 15 | 12 |
| 4B | 20 | 1740 | 5 | 10 |
| 5B | 20 | 1742 | 27 | 13 |
| 5B | 20 | 1744 | 15 | 12 |
| 5B | 20 | 1745 | 5 | 18 |
| 6B | 20 | 1746 | 27 | 11 |
| 6B | 20 | 1747 | 15 | 11 |
| 6B | 20 | 1749 | 5 | 10 |
| 7B | 20 | 1752 | 27 | 10 |
| 7B | 20 | 1754 | 15 | 10 |
| 7B | 20 | 1755 | 5 | 9 |
| 4 | 22 | 1055 | 27 | 54 |
| 4 | 22 | 1103 | 27 | 56 |
| 4 | 22 | 1110 | 27 | 56 |
| 4 | 22 | 1117 | 15 | 36 |
| 4 | 22 | 1122 | 15 | 38 |
| 4 | 22 | 1128 | 15 | 50 |
| 4 | 22 | 1136 | 5 | 22 |
| 5 | 22 | 1201 | 27 | 57 |
| 5 | 22 | 1203 | 15 | 21 |
| 5 | 22 | 1204 | 5 | 20 |
| 3 | 22 | 1519 | 27 | 85 |
| 3 | 22 | 1531 | 15 | 122 |
| 3 | 22 | 1544 | 5 | 33 |
| 11 | 22 | 1500 | 27 | 24 |
| 11 | 22 | 1502 | 15 | 16 |
| 11 | 22 | 1504 | 5 | 18 |
| 12 | 22 | 1515 | 27 | 14 |
| 12 | 22 | 1518 | 15 | 14 |
| 12 | 22 | 1519 | 5 | 14 |
| 13 | 22 | 1528 | 27 | 16 |
| 13 | 22 | 1530 | 25 | 16 |
| 13 | 22 | 1531 | 5 | 14 |
| 7 | 22 | 1544 | 27 | 15 |
| 7 | 22 | 1546 | 27 | 15 |
| 7 | 22 | 1547 | 15 | 14 |

(Continued)

(Sheet 1 of 3)

(Continued)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 7 | 22 | 1549 | 5 | 14 |
| 2 | 23 | 945 | 27 | 140 |
| 2 | 23 | 946 | 15 | 20 |
| 2 | 23 | 947 | 5 | 12 |
| 1 | 23 | 957 | 27 | 37 |
| 1 | 23 | 958 | 15 | 18 |
| 1 | 23 | 959 | 5 | 11 |
| 8 | 23 | 1002 | 27 | 79 |
| 8 | 23 | 1004 | 15 | 26 |
| 8 | 23 | 1005 | 15 | 25 |
| 8 | 23 | 1006 | 5 | 13 |
| 9 | 23 | 1009 | 27 | 540 |
| 9 | 23 | 1010 | 15 | 33 |
| 9 | 23 | 1011 | 5 | 13 |
| 10 | 23 | 1019 | 27 | 20 |
| 10 | 23 | 1021 | 15 | 16 |
| 10 | 23 | 1022 | 5 | 11 |
| 12 | 23 | 1026 | 27 | 14 |
| 12 | 23 | 1028 | 15 | 14 |
| 12 | 23 | 1029 | 5 | 12 |
| 12 | 23 | 1030 | 5 | 13 |
| 6 | 23 | 1037 | 27 | 14 |
| 6 | 23 | 1038 | 15 | 14 |
| 6 | 23 | 1039 | 5 | 13 |
| 2 | 23 | 1136 | 27 | 49 |
| 2 | 23 | 1137 | 15 | 30 |
| 2 | 23 | 1138 | 5 | 14 |
| 8 | 23 | 1140 | 27 | 210 |
| 8 | 23 | 1141 | 15 | 56 |
| 8 | 23 | 1143 | 5 | 10 |
| 1 | 23 | 1145 | 27 | 49 |
| 1 | 23 | 1146 | 27 | 52 |
| 1 | 23 | 1147 | 15 | 37 |
| 1 | 23 | 1148 | 5 | 15 |
| 9 | 23 | 1203 | 27 | 62 |
| 9 | 23 | 1204 | 15 | 38 |
| 9 | 23 | 1205 | 5 | 40 |
| 10 | 23 | 1206 | 27 | 49 |
| 10 | 23 | 1207 | 15 | 29 |
| 10 | 23 | 1209 | 5 | 20 |
| 3 | 23 | 1226 | 27 | 285 |
| 3 | 23 | 1227 | 15 | 51 |
| 3 | 23 | 1228 | 15 | 45 |
| 3 | 23 | 1229 | 5 | 52 |
| 4 | 23 | 1232 | 27 | 45 |

(Continued)

(Sheet 2 of 3)

(Concluded)

| Station Number | Date | Time | Depth ft | TSS mg/ℓ |
|---|---|---|---|---|
| 4 | 23 | 1234 | 15 | 34 |
| 4 | 23 | 1235 | 5 | 45 |
| 5 | 23 | 1237 | 27 | 22 |
| 5 | 23 | 1238 | 15 | 23 |
| 5 | 23 | 1239 | 5 | 34 |
| 6 | 23 | 1242 | 27 | 14 |
| 6 | 23 | 1243 | 15 | 12 |
| 6 | 23 | 1244 | 5 | 18 |
| 6 | 23 | 1245 | 5 | 15 |
| 3 | 23 | 852 | 27 | 98 |
| 3 | 23 | 857 | 27 | 130 |
| 3 | 23 | 901 | 27 | 76 |
| 3 | 23 | 906 | 15 | 33 |
| 3 | 23 | 911 | 15 | 56 |
| 3 | 23 | 934 | 15 | 36 |
| 3 | 23 | 938 | 5 | 58 |
| 3 | 23 | 941 | 5 | 68 |
| 3 | 23 | 944 | 5 | 70 |
| 4 | 23 | 1000 | 27 | 31 |
| 4 | 23 | 1005 | 27 | 29 |
| 4 | 23 | 1012 | 27 | 30 |
| 4 | 23 | 1018 | 15 | 30 |
| 4 | 23 | 1040 | 15 | 15 |
| 4 | 23 | 1046 | 15 | 14 |
| 4 | 23 | 1053 | 5 | 14 |
| 4 | 23 | 1058 | 5 | 15 |
| 4 | 23 | 1103 | 5 | 14 |
| 4 | 23 | 1114 | 5 | 17 |
| 2 | 23 | 1139 | 27 | 130 |
| 2 | 23 | 1147 | 27 | 140 |
| 2 | 23 | 1156 | 27 | 69 |
| 2 | 23 | 1203 | 15 | 50 |
| 2 | 23 | 1225 | 15 | 55 |
| 2 | 23 | 1230 | 15 | 53 |
| 2 | 23 | 1232 | 5 | 10 |
| 2 | 23 | 1237 | 5 | 9 |
| 2 | 23 | 1243 | 5 | 44 |

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# APPENDIX C: CALUMET HARBOR CUTTERHEAD, BACKGROUND TSS DATA

TABLE C1

CALUMET HARBOR CUTTERHEAD, BACKGROUND TSS DATA

| Date | Time | TSS mg/ℓ | Depth ft | Station Number |
|---|---|---|---|---|
| 21 | 1210 | 4 | 1.7 | 1 |
| 21 | 1315 | 4 | 1.8 | 1 |
| 21 | 1155 | 1 | 2 | 1 |
| 21 | 1326 | 1 | 2 | 1 |
| 21 | 1205 | 2 | 2 | 1 |
| 21 | 1332 | 2 | 2 | 1 |
| 21 | 1215 | 3 | 3 | 1 |
| 21 | 1338 | 3 | 1.5 | 1 |
| 21 | 1220 | 4 | 1.6 | 1 |
| 21 | 1325 | 4 | 1.5 | 1 |
| 21 | 1228 | 1 | 2 | 1 |
| 21 | 1345 | 1 | 1.5 | 1 |
| 21 | 1237 | 2 | 2 | 1 |
| 21 | 1351 | 2 | 2 | 1 |
| 21 | 1245 | 4 | 1.4 | 1 |
| 21 | 1331 | 4 | 1.1 | 1 |
| 21 | 1250 | 4 | 1.4 | 1 |
| 21 | 1350 | 4 | 1.5 | 1 |
| 21 | 1247 | 1 | 2 | 1 |
| 21 | 1357 | 1 | 2 | 1 |
| 22 | 1424 | 4 | 1.5 | 1 |
| 22 | 1140 | 4 | 1.5 | 1 |
| 22 | 1501 | 4 | 2 | 1 |
| 22 | 1035 | 1 | 2 | 1 |
| 22 | 1423 | 1 | 2 | 1 |
| 22 | 1145 | 1 | 2 | 1 |
| 22 | 1509 | 1 | 2 | 1 |
| 22 | 1040 | 2 | 2 | 1 |
| 22 | 1432 | 2 | 2 | 1 |
| 22 | 1154 | 2 | 2 | 1 |
| 22 | 1514 | 2 | 2 | 1 |
| 22 | 1045 | 3 | 2 | 1 |
| 22 | 1426 | 3 | 2 | 1 |
| 22 | 1149 | 3 | 2 | 1 |
| 22 | 1505 | 3 | 2 | 1 |
| 22 | 1037 | 4 | 1.5 | 1 |
| 22 | 1427 | 4 | 1.5 | 1 |
| 22 | 1145 | 4 | 1.5 | 1 |
| 22 | 1505 | 4 | 1.4 | 1 |
| 22 | 1051 | 1 | 2 | 1 |
| 22 | 1440 | 1 | 2 | 1 |
| 22 | 1203 | 1 | 2 | 1 |
| 22 | 1523 | 1 | 2 | 1 |

(Continued)

(Sheet 1 of 6)

TABLE C1 (Continued)

| Date | Time | TSS mg/ℓ | Depth ft | Station Number |
|---|---|---|---|---|
| 22 | 1056 | 2 | 2 | 1 |
| 22 | 1436 | 2 | 2 | 1 |
| 22 | 1159 | 2 | 2 | 1 |
| 22 | 1518 | 2 | 2 | 1 |
| 22 | 1044 | 4 | 1.5 | 1 |
| 22 | 1435 | 4 | 1.3 | 1 |
| 22 | 1154 | 4 | 1.5 | 1 |
| 22 | 1512 | 4 | 1.4 | 1 |
| 22 | 1053 | 4 | 2 | 1 |
| 22 | 1445 | 4 | 1.6 | 1 |
| 22 | 1204 | 4 | 1.5 | 1 |
| 22 | 1522 | 4 | 2 | 1 |
| 22 | 1100 | 1 | 2 | 1 |
| 22 | 1445 | 1 | 2 | 1 |
| 22 | 1207 | 1 | 2 | 1 |
| 22 | 1529 | 1 | 2 | 1 |
| 21 | 1210 | 4 | 16.5 | 2 |
| 21 | 1315 | 4 | 17.5 | 2 |
| 21 | 1155 | 1 | 17.5 | 2 |
| 21 | 1326 | 1 | 17 | 2 |
| 21 | 1205 | 2 | 19.5 | 2 |
| 21 | 1332 | 2 | 19 | 2 |
| 21 | 1215 | 3 | 17 | 2 |
| 21 | 1338 | 3 | 16 | 2 |
| 21 | 1220 | 4 | 16 | 2 |
| 21 | 1325 | 4 | 15.3 | 2 |
| 21 | 1228 | 1 | 17 | 2 |
| 21 | 1345 | 1 | 16.5 | 2 |
| 21 | 1237 | 2 | 18.5 | 2 |
| 21 | 1351 | 2 | 18.5 | 2 |
| 21 | 1245 | 4 | 12.5 | 2 |
| 21 | 1331 | 4 | 11 | 2 |
| 21 | 1250 | 4 | 14 | 2 |
| 21 | 1350 | 4 | 15 | 2 |
| 21 | 1247 | 1 | 19.5 | 2 |
| 21 | 1357 | 1 | 19.5 | 2 |
| 22 | 1424 | 4 | 15 | 2 |
| 22 | 1140 | 4 | 15 | 2 |
| 22 | 1501 | 4 | 15 | 2 |
| 22 | 1035 | 1 | 16.5 | 2 |
| 22 | 1423 | 1 | 16 | 2 |
| 22 | 1145 | 1 | 16 | 2 |
| 22 | 1509 | 1 | 16 | 2 |
| 22 | 1040 | 2 | 17 | 2 |

(Continued)

TABLE C1 (Continued)

| Date | Time | TSS mg/ℓ | Depth ft | Station Number |
|---|---|---|---|---|
| 22 | 1432 | 2 | 19 | 2 |
| 22 | 1154 | 2 | 18.5 | 2 |
| 22 | 1514 | 2 | 18.5 | 2 |
| 22 | 1045 | 3 | 18.5 | 2 |
| 22 | 1426 | 3 | 18.5 | 2 |
| 22 | 1149 | 3 | 17.5 | 2 |
| 22 | 1505 | 3 | 17 | 2 |
| 22 | 1037 | 4 | 15.5 | 2 |
| 22 | 1427 | 4 | 15 | 2 |
| 22 | 1145 | 4 | 15 | 2 |
| 22 | 1505 | 4 | 14 | 2 |
| 22 | 1051 | 1 | 17 | 2 |
| 22 | 1440 | 1 | 17 | 2 |
| 22 | 1203 | 1 | 18 | 2 |
| 22 | 1523 | 1 | 17 | 2 |
| 22 | 1056 | 2 | 19 | 2 |
| 22 | 1436 | 2 | 18 | 2 |
| 22 | 1159 | 2 | 18 | 2 |
| 22 | 1518 | 2 | 19 | 2 |
| 22 | 1044 | 4 | 15 | 2 |
| 22 | 1435 | 4 | 13 | 2 |
| 22 | 1154 | 4 | 14.5 | 2 |
| 22 | 1512 | 4 | 13.5 | 2 |
| 22 | 1053 | 4 | 16 | 2 |
| 22 | 1445 | 4 | 15.5 | 2 |
| 22 | 1204 | 4 | 14.5 | 2 |
| 22 | 1522 | 4 | 18 | 2 |
| 22 | 1100 | 1 | 19.5 | 2 |
| 22 | 1445 | 1 | 20 | 2 |
| 22 | 1207 | 1 | 20 | 2 |
| 22 | 1529 | 1 | 20 | 2 |
| 21 | 1210 | 4 | 28.1 | 3 |
| 21 | 1315 | 4 | 30.2 | 3 |
| 21 | 1155 | 1 | 30 | 3 |
| 21 | 1326 | 1 | 29 | 3 |
| 21 | 1205 | 2 | 33 | 3 |
| 21 | 1332 | 2 | 32 | 3 |
| 21 | 1215 | 3 | 20 | 3 |
| 21 | 1338 | 3 | 27.5 | 3 |
| 21 | 1220 | 4 | 27.2 | 3 |
| 21 | 1325 | 4 | 25.9 | 3 |
| 21 | 1228 | 1 | 29 | 3 |
| 21 | 1345 | 1 | 28 | 3 |
| 21 | 1237 | 2 | 31.5 | 3 |
| 21 | 1351 | 2 | 31.5 | 3 |

(Continued)

(Sheet 3 of 6)

TABLE C1 (Continued)

| Date | Time | TSS mg/ℓ | Depth ft | Station Number |
|---|---|---|---|---|
| 21 | 1245 | 4 | 21.3 | 3 |
| 21 | 1331 | 4 | 18.7 | 3 |
| 21 | 1250 | 4 | 23.8 | 3 |
| 21 | 1350 | 4 | 25.5 | 3 |
| 21 | 1247 | 1 | 33 | 3 |
| 21 | 1357 | 1 | 33 | 3 |
| 22 | 1424 | 4 | 25.5 | 3 |
| 22 | 1140 | 4 | 25.5 | 3 |
| 22 | 1501 | 4 | 25 | 3 |
| 22 | 1035 | 1 | 28 | 3 |
| 22 | 1423 | 1 | 27 | 3 |
| 22 | 1145 | 1 | 27 | 3 |
| 22 | 1509 | 1 | 27.5 | 3 |
| 22 | 1040 | 2 | 29 | 3 |
| 22 | 1432 | 2 | 32 | 3 |
| 22 | 1154 | 2 | 31.5 | 3 |
| 22 | 1514 | 2 | 31.5 | 3 |
| 22 | 1045 | 3 | 31.5 | 3 |
| 22 | 1426 | 3 | 31.5 | 3 |
| 22 | 1149 | 3 | 30 | 3 |
| 22 | 1505 | 3 | 29 | 3 |
| 22 | 1037 | 4 | 24.7 | 3 |
| 22 | 1427 | 4 | 25.5 | 3 |
| 22 | 1145 | 4 | 25.5 | 3 |
| 22 | 1505 | 4 | 23.8 | 3 |
| 22 | 1051 | 1 | 29 | 3 |
| 22 | 1440 | 1 | 29 | 3 |
| 22 | 1203 | 1 | 30.5 | 3 |
| 22 | 1523 | 1 | 29 | 3 |
| 22 | 1056 | 2 | 32 | 3 |
| 22 | 1436 | 2 | 30.5 | 3 |
| 22 | 1159 | 2 | 30.5 | 3 |
| 22 | 1518 | 2 | 32.5 | 3 |
| 22 | 1044 | 4 | 25.5 | 3 |
| 22 | 1435 | 4 | 22.1 | 3 |
| 22 | 1154 | 4 | 24.7 | 3 |
| 22 | 1512 | 4 | 23 | 3 |
| 22 | 1053 | 4 | 25 | 3 |
| 22 | 1445 | 4 | 26.5 | 3 |
| 22 | 1204 | 4 | 24.5 | 3 |
| 22 | 1522 | 4 | 30 | 3 |
| 22 | 1100 | 1 | 33 | 3 |
| 22 | 1445 | 1 | 32 | 3 |
| 22 | 1207 | 1 | 32 | 3 |
| 22 | 1529 | 1 | 32 | 3 |

(Continued)

(Sheet 4 of 6)

TABLE C1 (Continued)

| Date | Time | TSS mg/ℓ | Depth ft | Station Number |
|---|---|---|---|---|
| 21 | 1210 | 4 | 31.4 | 4 |
| 21 | 1315 | 4 | 33.7 | 4 |
| 21 | 1155 | 1 | 34 | 4 |
| 21 | 1326 | 1 | 32 | 4 |
| 21 | 1205 | 2 | 37 | 4 |
| 21 | 1332 | 2 | 36 | 4 |
| 21 | 1215 | 3 | 28.5 | 4 |
| 21 | 1338 | 3 | 31 | 4 |
| 21 | 1220 | 4 | 28 | 4 |
| 21 | 1325 | 4 | 29 | 4 |
| 21 | 1228 | 1 | 32.5 | 4 |
| 21 | 1345 | 1 | 31.5 | 4 |
| 21 | 1237 | 2 | 35 | 4 |
| 21 | 1351 | 2 | 35 | 4 |
| 21 | 1245 | 4 | 23.8 | 4 |
| 21 | 1331 | 4 | 20.9 | 4 |
| 21 | 1250 | 4 | 24.6 | 4 |
| 21 | 1350 | 4 | 29 | 4 |
| 21 | 1247 | 1 | 37 | 4 |
| 21 | 1357 | 1 | 37 | 4 |
| 22 | 1424 | 4 | 29.5 | 4 |
| 22 | 1140 | 4 | 28,5 | 4 |
| 22 | 1501 | 4 | 28 | 4 |
| 22 | 1035 | 1 | 31.5 | 4 |
| 22 | 1423 | 1 | 30.5 | 4 |
| 22 | 1145 | 1 | 30.5 | 4 |
| 22 | 1509 | 1 | 31 | 4 |
| 22 | 1040 | 2 | 32 | 4 |
| 22 | 1432 | 2 | 36 | 4 |
| 22 | 1154 | 2 | 35 | 4 |
| 22 | 1514 | 2 | 35 | 4 |
| 22 | 1045 | 3 | 35 | 4 |
| 22 | 1426 | 3 | 35 | 4 |
| 22 | 1149 | 3 | 33 | 4 |
| 22 | 1505 | 3 | 32 | 4 |
| 22 | 1037 | 4 | 27.6 | 4 |
| 22 | 1427 | 4 | 28.5 | 4 |
| 22 | 1145 | 4 | 28.5 | 4 |
| 22 | 1505 | 4 | 26.6 | 4 |
| 22 | 1051 | 1 | 32 | 4 |
| 22 | 1440 | 1 | 32 | 4 |
| 22 | 1203 | 1 | 34 | 4 |
| 22 | 1523 | 1 | 32 | 4 |
| 22 | 1056 | 2 | 36 | 4 |
| 22 | 1436 | 2 | 34 | 4 |

(Continued)

(Sheet 5 of 6)

TABLE C1 (Concluded)

| Date | Time | TSS mg/ℓ | Depth ft | Station Number |
|---|---|---|---|---|
| 22 | 1159 | 2 | 34 | 4 |
| 22 | 1518 | 2 | 36 | 4 |
| 22 | 1044 | 4 | 28.2 | 4 |
| 22 | 1435 | 4 | 24.7 | 4 |
| 22 | 1154 | 4 | 27.6 | 4 |
| 22 | 1512 | 4 | 24.5 | 4 |
| 22 | 1053 | 4 | 28 | 4 |
| 22 | 1445 | 4 | 29.5 | 4 |
| 22 | 1204 | 4 | 27.6 | 4 |
| 22 | 1522 | 4 | 33 | 4 |
| 22 | 1100 | 1 | 37 | 4 |
| 22 | 1445 | 1 | 38 | 4 |
| 22 | 1207 | 1 | 38 | 4 |
| 22 | 1529 | 1 | 38 | 4 |

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