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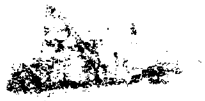

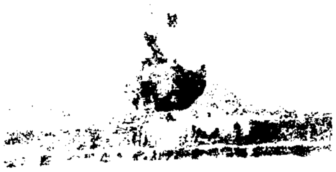

HYDRAULICS LABORATORY

IMPROVEMENT OF OPERATIONS AND MAINTENANCE TECHNIQUES RESEARCH PROGRAM

TECHNICAL REPORT HL-89-9

FIELD STUDIES OF SEDIMENT RESUSPENSION CHARACTERISTICS OF SELECTED DREDGES

by

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This study describes the operation and potential sediment resuspension points of selected dredges with the objective of identifying sediment resuspension characteristics at the point of dredging. Field studies were conducted to describe and compare the characteristics of resuspended sediment plumes from dredging with conventional equipment such as cutterhead, clamshell, hopper dredges, and special equipment such as the enclosed clamshell dredge and the matchbox dredge. Characteristics of resuspended sediment plumes (far field) and, in selected studies, sediment concentrations at the dredgehead were measured (near field) during the field studies. To depict the dispersion of sediment from the point of dredging, data are presented which show the areal extent of sediment plumes at various depths in the water column. Results showed that the cutterhead dredge resuspends sediment chiefly in the lower portion of the water column. The initial effects of

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Contaminated sediments	Hopper dredge	Sediment resuspension
Cutterhead dredge	Hydraulic dredge	
Dredging	Innovative dredging equipment	

19. ABSTRACT (Continued).

overflow from hopper dredges were seen in the upper portion of the water column. Clamshell dredges impacted water quality near the bottom and may distribute sediment throughout the water column. Resuspended sediment concentrations within a few feet of a cutterhead dredge were used to develop and calibrate an empirical mathematical model to predict sediment resuspension as a function of dredge operation variables.

PREFACE

The field studies and evaluations described in this report were completed through cooperation with the following: US Army Corps of Engineer Districts, Chicago, Savannah, St. Paul, Seattle, and Walla Walla. The Improvement of Operations and Maintenance Techniques (IOMT) research program, Work Unit 32433, provided funding for data analysis and preparation of this report. The IOMT Program is sponsored by the Headquarters, US Army Corps of Engineers (USACE).

The field study designs, data analysis, and report preparation were performed by Messrs. Thomas N. McLellan, Robert N. Havis, Donald F. Hayes, and Gene L. Raymond, Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), Environmental Laboratory (EL), of the US Army Engineer Waterways Experiment Station (WES). Mr. John Sjostrom, Ms. Cheryl Lloyd, and Ms. Katherine Smart, all of WREG, provided technical assistance. Technical review of the report was provided by Dr. John B. Herbich, Director, Center for Dredging Studies, Texas A&M University.

Program Managers of the IOMT was Mr. E. Clark McNair, Jr., and Mr. Robert F. Athow, Jr., Hydraulics Laboratory, WES. Messrs. James L. Gottesman and Charles Hummer were the USACE Technical Monitors. The report was edited by Mrs. Nancy J. Johnson, employed by the WES Information Technology Laboratory under the Inter-Governmental Personnel Act.

This study was conducted under the direct supervision of Dr. Michael R. Palermo, Chief, WREG, and Dr. F. Douglas Shields, Jr., Acting Chief, WREG, and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison Chief, EL.

COL Dwayne G. Lee, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

FIELD STUDIES OF SEDIMENT RESUSPENSION CHARACTERISTICS OF SELECTED DREDGES

PART I: INTRODUCTION

Background

1. During the last 100 years the sediments of many of the nation's rivers and waterways have increasingly become repositories for a variety of contaminants. This contamination is a result of river commerce, industrial activities, the widespread use of pesticides in agriculture, and intentional dumping or inadvertent spillage of pollutants. Contamination can sometimes affect an entire river or estuary system or it can be confined to a few "hot spots." Conventional dredges were not specifically designed or intended to operate in polluted environments. Modification of either existing equipment or operating methods may be necessary when operating dredge plants in highly contaminated sediments.

2. Fine-grained sediments are easily resuspended and can cause chemical transport problems because of their large surface area for contaminant adsorption per unit weight and their affinity for contaminants, particularly chlorinated hydrocarbon pesticides and polychlorinated biphenyls (PCBs). When contaminated sediments are disturbed and resuspended during dredging operations, contaminants that are weakly adsorbed to sediment particles may be transferred to the water column by dispersal of interstitial water or desorption from the resuspended solids. Chemicals that remain strongly adsorbed to sediment particles in suspension are generally not bio-available but may be transported to another part of a water body and redeposited. Investigations by Fulk, Gruber, and Wullsheleger (1975) indicated that for sediment-water concentrations of less than 100 g/ℓ, the amount of pesticides, and PCBs that dissolved into the water column from the resuspended sediment was negligible. They determined that the majority of any contaminants transferred to the water column were attached to resuspended solids. Consequently, the reduction of suspended solids concentrations by settling resulted in a decrease in total contaminant concentrations in the water column. The spread of contaminants

during dredging operations is directly linked to the resuspension of sediments, particularly clay and organic particles.

3. The US Army Engineer Waterways Experiment Station (WES) has initiated studies to determine the effectiveness of various methods of dredging contaminated sediments. These studies are being conducted as part of the Improvement of Operations and Maintenance Techniques (IOMT) research program. The specific environmental concerns addressed are the resuspension of contaminated sediments and the possibility of contaminant release during the dredging operation. These concerns will be approached in three ways: the assembly and evaluation of available domestic and foreign information concerning sediment resuspension and contaminant release, the development of appropriate laboratory tests to predict contaminant release from resuspended sediments, and the use of field studies to monitor and compare dredges operating under various conditions.

Purpose and Scope

4. The purpose of this report is to document the results of field studies of sediment resuspension characteristics of various dredges conducted under the IOMT program. The report will discuss the sediment resuspension characteristics of the major conventional dredge types and prcvide a comparison between dredge types with respect to sediment resuspension and magnitude of water column effects. The effectiveness of selected equipment modifications and operating techniques in reducing sediment resuspension will also be discussed.

PART II: EVALUATION OF DREDGING EQUIPMENT: OPERATIONAL CRITERIA AND SEDIMENT RESUSPENSION POTENTIAL

Introduction

5. The dredging methods employed by the Corps of Engineers vary throughout the United States. Principal dredge types include hydraulic pipeline types (cutterhead, dustpan, and plain suction), hopper dredges, and bucket dredges. Several other dredge types have been designed and are in use. These include sidecaster, dipper, and ladder dredges, along with several special purpose dredges designed to dredge sediments as near as possible to in-situ density without generating a significant sediment plume. The following criteria are used in selecting a specific dredge type:

- a. Physical characteristics of material to be dredged.
- b. Quantities of material to be dredged.
- c. Dredging depth.
- d. Distance to disposal area.
- e. Physical environment of and between the dredging and disposal areas.
- f. Contamination level of the sediments to be dredged.
- g. Method of disposal.
- h. Production required (cost).
- i. Type of dredges available.
- j. Federal/state/local restrictions.

6. This section describes operational criteria and the sediment resuspension potential of the three major dredge types. Special purpose dredges are not covered in this section. Each section begins with a description of the dredging apparatus, their capabilities, and identification of potential points for sediment resuspension. Suggestions are offered for minimizing sediment resuspension through equipment modification and operational control.

Hydraulic Pipeline Dredges

Cutterhead dredges

7. Description. The cutterhead hydraulic pipeline dredge is the most commonly used dredging plant (Figure 1). It performs the major portion of the

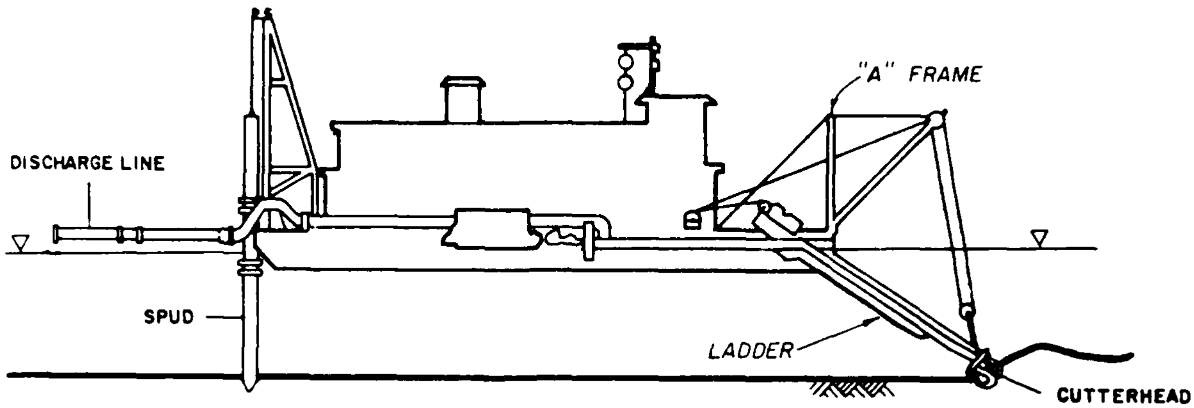


Figure 1. Hydraulic pipeline cutterhead dredge

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 of materials to disposal sites without rehandling. 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 dredges are normally limited to operating in protected waterways and wave heights less than 3 ft.* However, some dredges that are 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 2. 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 then swings back to the starboard side of the cut center line. The port spud

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 7.

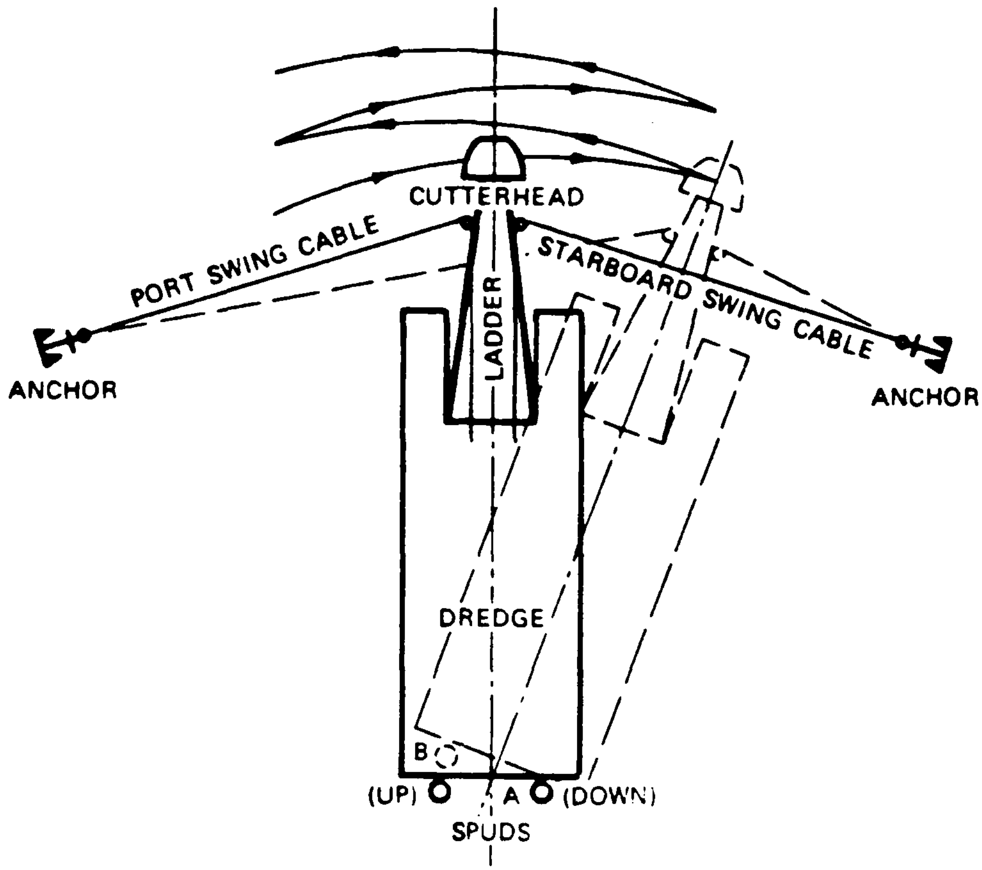


Figure 2. Operation of a cutterhead dredge

is lowered and the starboard spud is lifted to advance the dredge. A new concept developed several years ago consists of a spud carriage, where the working (down) spud is attached to a travelling carriage, activated by a hydraulic cylinder. The material removal efficiency (defined as the average percent solids divided by the highest practical instantaneous percent solids the hydraulic system can transport without causing pump cavitation) is theoretically increased from 50 percent for the spud system to 75 percent for the spud carriage system (Turner 1984).

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 1983; Hayes, Raymond, and McLellan 1984). 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 equipment setup. Aside from "careful"

operation of equipment peripheral to the cutterhead (e.g. limiting anchor dragging and raising spuds slowly), 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 sediment resuspension characteristics of 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).

10. Based on the impact of the factors described above, the following operational controls to reduce levels of sediment resuspension are recommended. These controls will reduce the amount of material disturbed by the cutterhead but not entrained by the suction (Huston and Huston 1976).

a. Large sets (distance that the dredge advances for each cut), very thick cuts, and very shallow cuts should be avoided. Thick cuts tend to bury the cutterhead and may cause high levels of resuspension if the suction cannot pick up all of the dislodged material while in shallow cuts the cutter tends to throw the sediments beyond the intake of the dredge (Hayes, McLellan and Truitt 1984).

b. The leverman should swing the dredge so that the cutterhead will cover as much of the bottom as possible. This minimizes the formation of windrows or ridges of partially disturbed material between the cuts. These windrows tend to slough into the cuts and the material in the windrows may be susceptible to resuspension by ambient currents and turbulence caused by the cutterhead. Windrow formation can be eliminated by swinging the dredge in close concentric arcs over the dredging area. This may involve either modifying the basic stepping methods used to advance the dredge or using a Wagger or spud carriage system.

c. Side slopes of channels are usually dredged by making a vertical box cut; the material on the upper half of the cut then sloughs to the specified slope. The specified slope should be cut by making a series of smaller boxes. This method, called "stepping" the slope, will not eliminate all sloughing, but will help to reduce the sloughing.

d. On some dredging projects, it may be more economical to roughly cut and remove most of the material, leaving a relatively thin layer for final cleanup after the project has been roughed out. However, this remaining material may be subject to resuspension by currents or passing ship traffic.

e. When layer cutting is used, the dredge will remove a single layer of material over a large portion of the channel; the dredge is then set back to dredge another layer. This continues down to the required depth of the project. Since loose material is often left on the bottom after each layer is dredged, this technique should only be used where resuspension of the remaining material will not create sediment resuspension problems.

f. When performing maintenance dredging of many fine-grained materials, the rotating cutterhead may not be necessary. The rotation of the cutterhead in these materials can produce a relatively large turbidity cloud when compared with the dredge working without the rotating cutterhead. Common practice is to use the cutterhead whether it is needed or not. The removal of the cutterhead makes the dredge a plain suction dredge and may reduce sediment resuspension when dredging unconsolidated fine-grained materials.

11. The combination of excavation by the cutterhead and pumping rate greatly influences the dredge production and sediment resuspension rates. The suction pressure, which picks up the material that has been cut by the cutter, can be partially responsible for sediment resuspension around the cutter if the suction provided is insufficient to pick up all of the material dislodged by the cutter. Water-jet booster systems or ladder-mounted submerged pumps installed on cutterhead dredges have been found to enhance the dredge's pickup capability, increase slurry density and potential production rate, and decrease sediment resuspension rates (Huston and Huston 1976).

12. The shape of the cutterhead also affects the quantity of sediment resuspended, particularly if no overdepth is allowed. The cutterheads shown in Figure 3 have the same length and base width. They are also depressed to the same angle and are buried at the same depth. However, with the conical-shaped head (right hand drawing), the suction is brought closer to the material and the chance of entrainment is improved. This shape difference would be particularly important if the head were not completely buried.*

13. The angle α (Figure 4) is called the rake angle. If the rake angle is too large, it will cause a gouging action that will sling soft, fine-grained material outward. If the rake angle is too small, heeling (the striking of the bottom with the heel of the tooth) will occur and increase resuspension. For fine-grained maintenance type material, a rake angle from

* Personal Communication, March 1983, T. M. Turner, Turner Consulting Inc., Sarasota, FL.

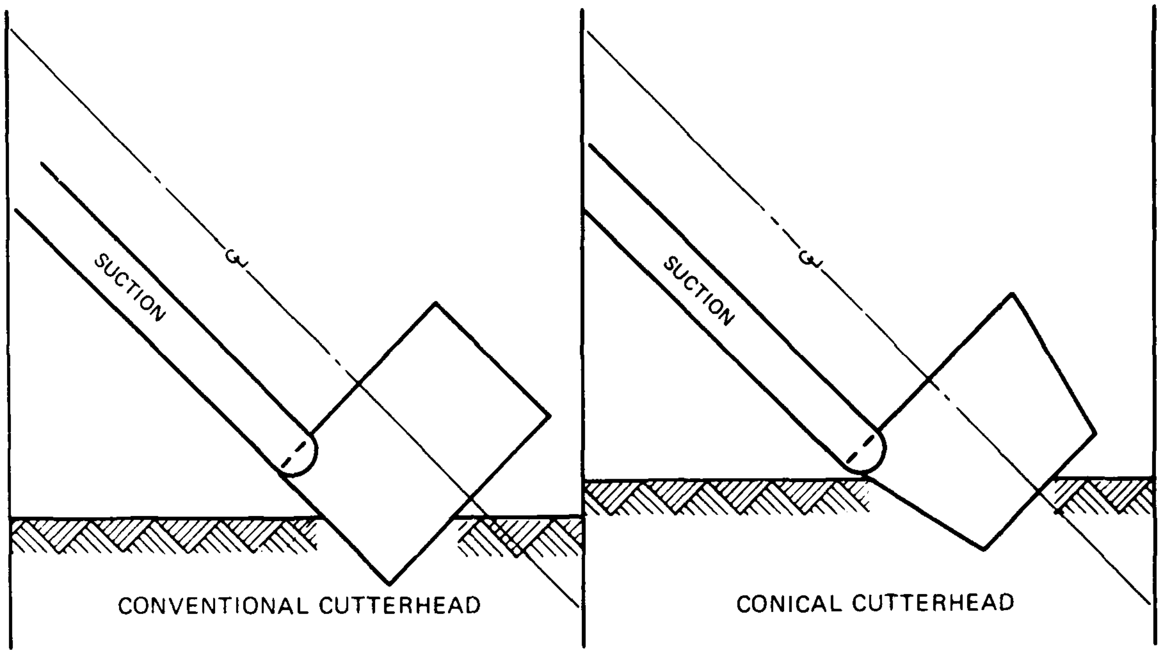
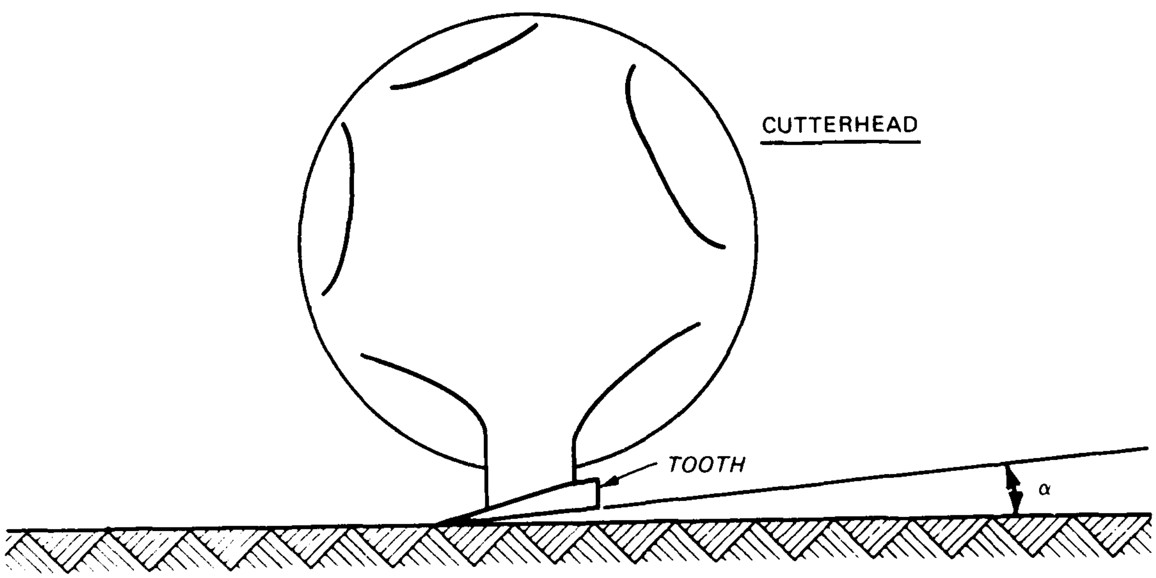


Figure 3. Effect of cutterhead shape on suction height above the bottom (Personal Communication, March 1983, T. M. Turner, Turner Consulting Inc., Sarasota, Florida)



RAKE ANGLE α

Figure 4. Schematic front view of a cutterhead showing the cutter tooth rake angle

20 to 25 deg is best. This would allow a shallow entry that would lift the bottom sediment and guide it toward the suction.*

Matchbox suction head dredge

14. Description. Volker Stevin Dredging Company developed the matchbox suction head (Figure 5; d'Angemond, 1984) to dredge highly contaminated sediments in the Rotterdam harbor. The suction head was designed to dredge sediment as close to in-situ density as possible, keep resuspension to a minimum while dredging layers of varying thickness, and operate with restricted maneuverability. Cutter and water jet devices commonly found on dredgeheads are not used to minimize resuspension.

15. Several innovative design features were incorporated into the matchbox dredgehead construction. These design features included:

a. A plate covering the top of the dredgehead was installed to contain escaping gas bubbles and control the influx of clean water.

b. An adjustable angle was constructed between the dredgehead and ladder to maintain the optimum dredging position regardless of dredging depth. Matchbox positioning was accomplished using hydraulic pistons attached to the dredge head.

c. Openings on both sides of the dredgehead were installed so the dredge could swing in both directions while dredging (the leeward opening must be closed by a valve to avoid clear water influx).

d. Dimensions of the dredging plant were carefully designed to account for the average flow rate and swing speed of the dredge.

e. Vertical positioning equipment (e.g. pressure transducers) was installed to indicate the depth of the head in relation to the seafloor. Horizontal positioning apparatus was used to hold the matchbox parallel to the seafloor.

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

Dustpan dredge

17. Description. The dustpan dredge (Figure 6) is a hydraulic suction dredge that uses a widely flared dredging head along which water jets are mounted (Figure 6). The jets loosen and agitate sediments which are then

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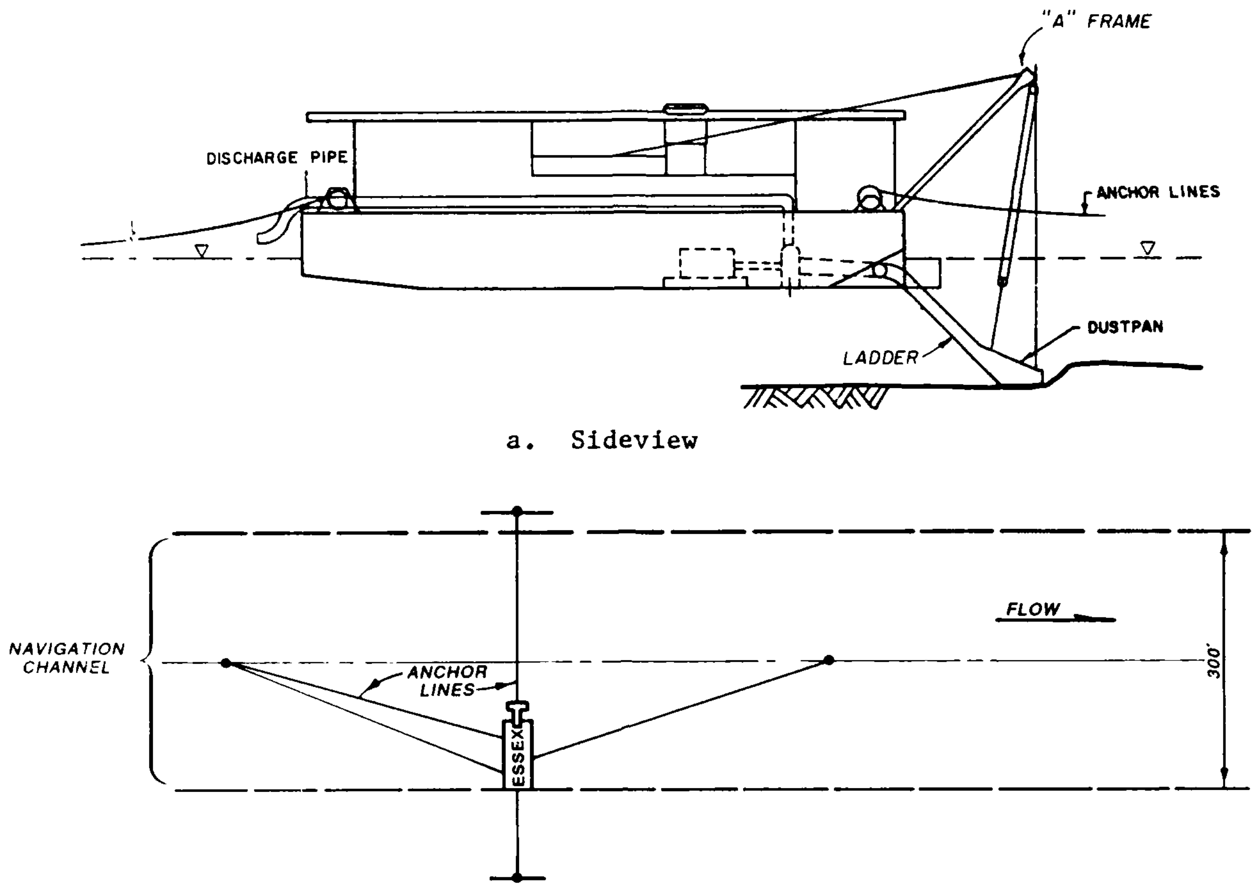
* Personal Communication, March 1983, T. M. Turner, Turner Consulting Inc., Sarasota, FL.

Figure 5. Matchbox suction head

captured in the dustpan head as the dredge itself is winched forward into the excavation. This type of dredge was developed by the Corps of Engineers to maintain navigation channels in uncontrolled rivers with bed loads consisting primarily of sand and gravel. The first dustpan dredge was developed to maintain navigation on the Mississippi River during low river stages. A dredge was needed that could operate in shallow water and be large enough to excavate the navigation channel in a reasonably short time. The dustpan dredge operates with low-head, high-capacity centrifugal pump since the material has to be raised only a few feet above the water surface and pumped a short distance. The dredged material is normally discharged into open water adjacent to the navigation channel through a pipeline, usually only 800 to 1,000 ft long.

18. Sediment resuspension sources. Dustpan dredges generate suspended solids plumes similar to, or in greater concentration than, those generated by cutterhead dredges (Raymond 1983). However, turbidity plumes are less



a. Sideview

b. Plan view of dustpan dredge operation

Figure 6. Dustpan dredge

critical for dustpan dredges since they generally work in highly turbid rivers such as the Mississippi River, and the sediments are relatively clean sands. Sediment resuspension is mainly at the bottom due to the water jets.

Bucket Dredges

Description

19. The bucket type dredge is a mechanical device that utilizes a bucket to excavate the material to be dredged (Figure 7). The material excavated is placed in scows or hopper barges that are towed to the disposal area. 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 crane that operates the bucket can be mounted on a flat-bottomed barge, on fixed-shore

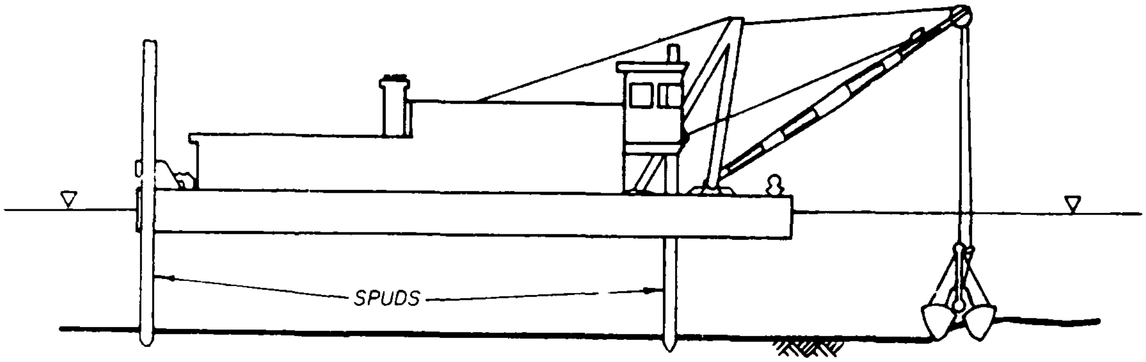


Figure 7. Clamshell bucket dredge

installations, or on a crawler mount. Floating bucket dredges 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. Also, there is little danger of damaging the structures because the dredging process can be controlled accurately. The capacity of bucket dredges normally ranges from 1 to 25 cu yd per cycle. Twenty to fifty cycles per hour is a typical production rate, but large variations exist because of the variability in depths and materials being excavated. The effective working depth is limited to approximately 100 ft.

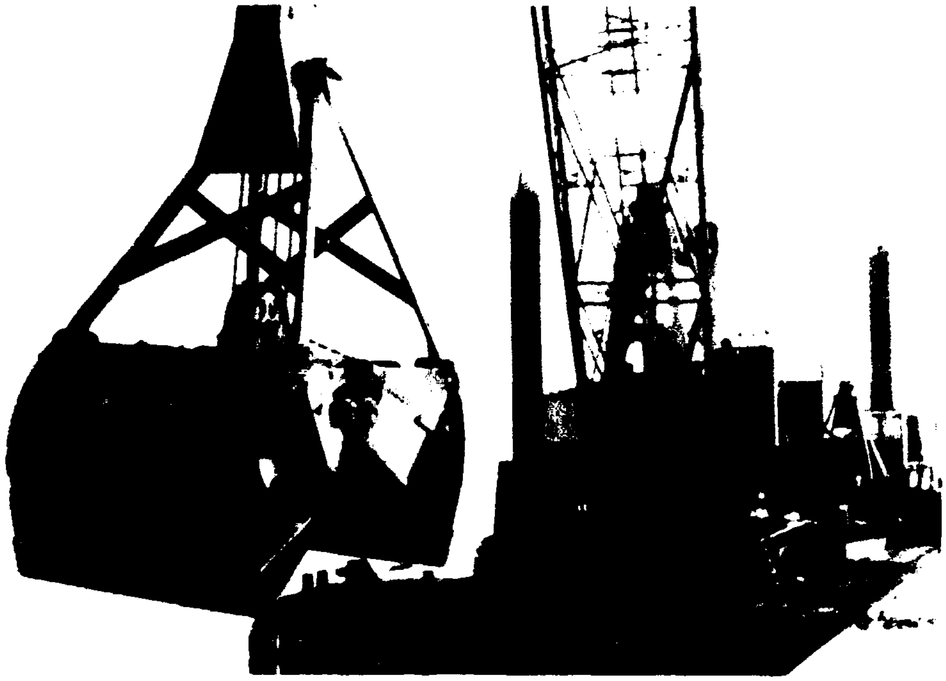
Sediment resuspension sources

20. A majority of the sediment resuspended by a clamshell dredge is from the impact, penetration, and removal of the bucket from the bottom (Hayes, McLellan, and Truitt 1986; Barnard 1978). Bucket dredges usually excavate a heaped bucket of material. During hoisting, material is eroded from the top part of the load. Once the bucket clears the water surface, additional losses occur through rapid drainage of entrapped water and slumping of the material heaped above the rim. The rate of material loss is influenced by the condition of the bucket, the hoisting speed, and the properties of the sediment. Even under ideal conditions, losses of loose and fine sediments will usually occur. Because of this, special buckets should be considered if the bucket dredge is considered for use in dredging contaminated sediments.

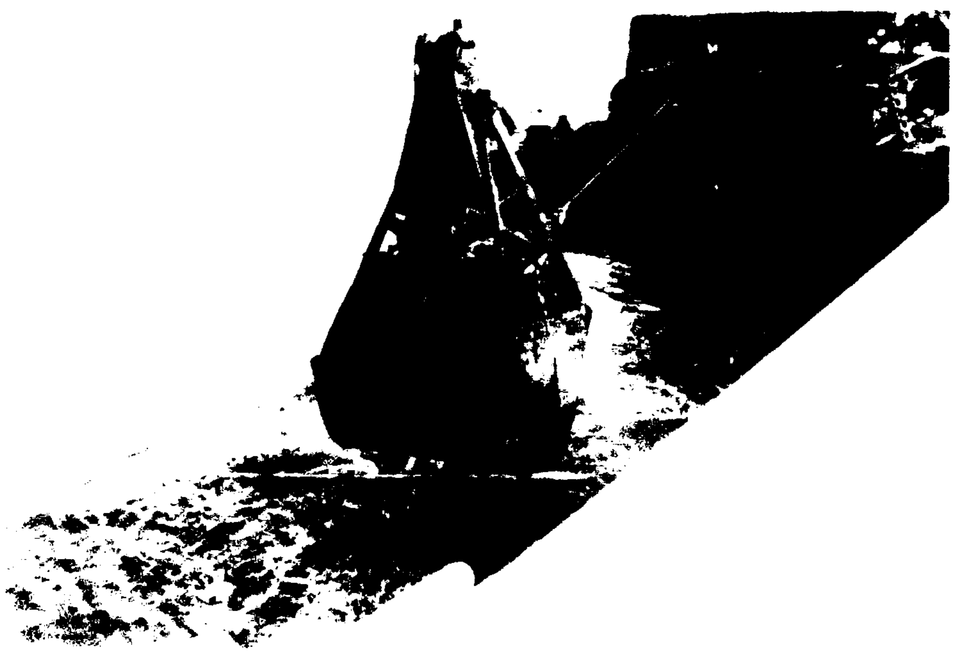
21. Resuspension of sediments during clamshell dredging operations can be reduced by implementing operational controls and/or altering the bucket design. Operational controls can be applied to hoist speed, placement of the dredged material in the hopper barge, loading the hopper past overflow, and dragging the bucket along the bottom. Equipment design modifications include the fit of the bucket and the use of enclosed clamshell buckets.

22. A combination of operational controls can be used during clamshell dredging projects to help reduce sediment resuspension. Controlling the speed of the bucket through the water column is one method of control. The hoist speed of the bucket should be kept below 2.0 ft/sec to keep from washing sediment out of the bucket. The hoisting process should also be as smooth as possible to eliminate jerking the bucket. When the bucket has been brought about to empty the load into the hopper dredge, care should be taken in the placement of the material. The dredged material should be deliberately placed in the hopper, as opposed to dropping or free-fall from several feet above. It should also be placed so that it is evenly distributed throughout the hopper minimizing the risk of spillage and overflow. Often when a clamshell dredge has finished dredging a certain reach, it will drag the bucket along the bottom to create a smoother bottom. This practice should not be used in reaches where resuspension must be limited.

23. A watertight bucket has been developed in which the top is enclosed and the joints are sealed to minimize losses of dredged material to the water column (Figure 8). Comparisons between a standard open clamshell bucket and an enclosed clamshell bucket indicated that enclosed buckets generate 30 to 70 percent less sediment resuspension in the water column than open buckets (Barnard 1978). This reduction was probably due primarily to the fact that leakage of dredged material from enclosed buckets is reduced by approximately 35 percent. The enclosed bucket did, however, produce increased sediment resuspension near the bottom. This was most likely due to a shock wave of water that precedes the watertight bucket due to the enclosed top. Also, the cutting edges of earlier buckets were sealed with rubber gaskets which limited the use of the bucket to soft material and trash-free areas. Current design concepts include the use of an interlocking tongue-and-groove edge to overcome the sealing problems. The operational controls mentioned above can also be used for enclosed buckets to help further reduce resuspension of sediments.



a. Open position



b. Closed position

Figure 8. Open and closed positions of the enclosed bucket

Hopper Dredges

Description

24. Hopper dredges are typically self-propelled seagoing ships of 180 to 550 ft in length with the molded hulls and lines of ocean vessels (Figure 9). They are equipped with propulsion machinery, sediment containers (hoppers), dredge pumps, and other special equipment required to perform their essential function of removing material from a channel bottom or ocean bed. Hopper dredges have propulsion power adequate for required free-running speed and dredging against strong currents and excellent maneuverability for work in open water in significant wave heights up to 6 to 8 ft. Dredged material is raised by dredge pumps through drag arms connected to dragheads in contact with the channel bottom, and discharged into hoppers built in the vessel. Hopper dredges are classified according to hopper capacity; large-class hopper dredges have hopper capacities of 6,000 to 10,000 cu yd, medium-class from 2,000 to 6,000 cu yd, and small-class from less than 2,000 to 500 cu yd. During dredging operations, hopper dredges travel at a ground speed from 2 to 3 knots and can dredge in depths from 10 to over 100 ft. They are equipped with twin propellers, twin rudders, and bow thrusters to provide the required maneuverability.

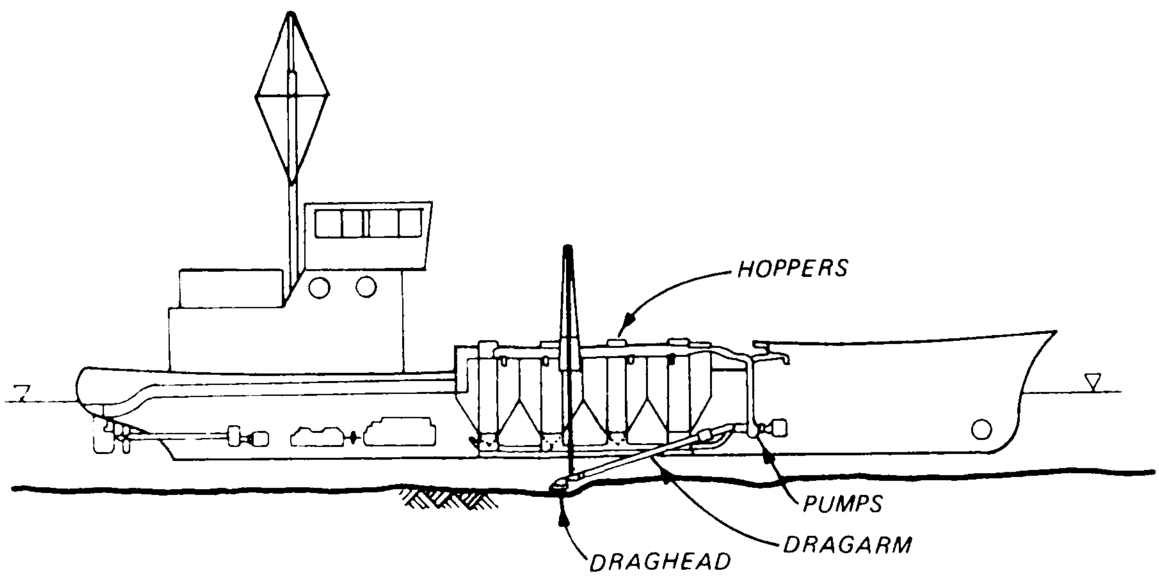


Figure 9. Self-propelled seagoing hopper dredge

Sediment resuspension sources

25. Sources of sediment resuspension during hopper dredge operation are from the draghead, propwash, and pumping past overflow. Pumping past overflow, often referred to as economic loading, is a practice that increases the effective capacity of the hopper by allowing dredged supernatant to overflow while retaining settled solids in the hopper. This practice is most effective when sediments separate quickly from water, such as granular sediments. Of the sources of sediment resuspension from hopper dredges, the overflow of material from the hopper produces by far the highest sediment concentrations in the water column (Hayes, Raymond, and McLellan 1984). This cause of resuspension can be addressed in several ways. The first is to assess the type of material being dredged and its environmental impact. If the material being dredged is clean sand, the percentage of solids in the overflow may be small, and economic loading may be achieved by pumping past overflow. In the case of fine-grained materials, the settling properties of silt and clay sediments may be such that only a minimal load increase will be achieved by pumping past overflow.

26. Reduction of sediment resuspension due to overflow can be accomplished by reducing the flow rate of the slurry being pumped into the hopper during the latter phases of the hopper-filling operation. This operational procedure reduces the solids concentration in the plume by reducing the sediment concentration in the overflow. By using this technique, the solids content of the overflow can be reduced by as much as 50 percent while the loading efficiency of the dredge is simultaneously increased over the no-overflow option (Barnard 1978).

27. Another approach that has been developed is a submerged discharge system for hopper dredge overflow, called an anti-turbidity overflow system (ATOS). Ofuji and Naoshi (1976) describe an overflow collection system streamlined to minimize incorporation of air bubbles with the overflow discharge ports moved from the sides to the bottom of the hull (Figure 10). With this arrangement, the discharge descends rapidly to the bottom with a minimum amount of dispersion within the water column. The system can be incorporated in existing dredges through modification of their overflow systems. It should be pointed out, however, that the ATOS system is intended only to reduce near-surface resuspension, not overall resuspension. A disadvantage of the ATOS

system is that overflow does not receive beneficial aeration before it is released into the water column.

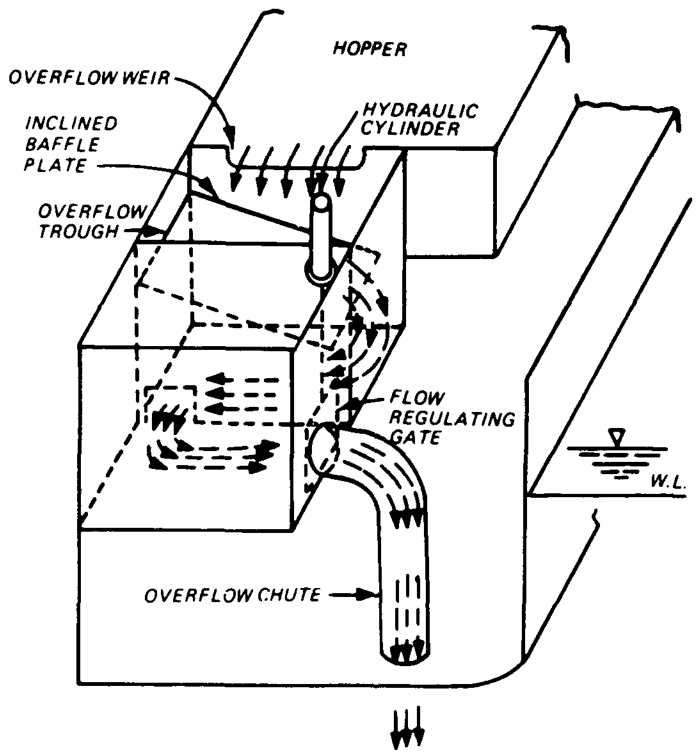


Figure 10. Schematic drawing of a hopper dredge bin equipped with ATOS

PART III: SAMPLING METHODS AND DATA ANALYSIS

Resuspended Sediment Sample Measurement

28. The basic objective of the IOMT field studies was to determine the levels of sediment resuspended by various dredging operations. Attempts to synthesize earlier research in this area were hampered by the lack of uniformity in data collection and the methods used to measure sediment resuspension. Both Barnard (1978) and Stern and Stickle (1978) point out the problem of finding a commonly accepted method of suspended sediment measurement. They indicate that the majority of previous efforts were concerned with the measurement of turbidity, which is an optical property of water sediment mixture rather than gravimetrically measuring total suspended solids. Turbidity is the reduction of light passage through water due to suspended particles. Although turbidity is relatively easy to measure and can be monitored continuously, it cannot be reliably correlated with weight concentration of suspended matter because the optically important factors of size, shape, and refractive index of the particulate materials bear little relationship to the concentration and specific gravity of the suspended matter. This fundamental problem is exacerbated by the fact that there are two major optical means of turbidity measurement, transmissometery (percent of light passing directly through) and nephelometery (amount of light scattered); therefore, results may be reported in terms of several different types of turbidity units.

29. To facilitate comparison of dredging operations, a single method of suspended sediment determination was chosen. The primary method of measurement for the IOMT field studies was gravimetric, providing a value for the total suspended solids concentration (TSS) in milligrams per litre, rather than optical. Optical means were occasionally used to supplement data collection. The gravimetric method allows for a more direct comparison of different dredging operations involving different sediment types and gives a better indication of what is actually occurring during a dredging operation. This method used in conjunction with grain distribution analysis permits more precise estimates of the settleable solids, which is a major factor in determining the effect of dredging on aquatic organisms (Stern and Stickle 1978). The gravimetric method used throughout these field studies follows Section 209C of Standard Methods (American Public Health Association 1980).

Sampling Scheme

30. Because sediment concentration was measured gravimetrically, data were collected by discrete point sampling rather than by continuous monitoring. Resuspension of sediment during dredging can occur from several different sources including leaking pipes, spuds, and inadvertent spillage. The majority of the sediment plume, however, originates at the point of sediment removal or from a hopper dredge overflow. It has been recognized (Bohlen 1978; Nakai 1978; Barnard 1978) that the highest suspended sediment concentration is found at the source or point of dredging. While the rate of sediment resuspension is controlled by the dredging operation, the resulting plume characteristics are controlled by convection and dispersion into the overlying water. Whenever possible, sampling at the point of dredging was accomplished by sampling tubes attached directly to the dredgehead. This was not possible in the case of bucket or hopper dredges; therefore, samples were collected as close to the dredging operation as safety would permit. The size and concentration of the suspended sediment plumes were estimated by sampling along radials emanating from the point of dredging. In some cases two dredges operated at different times in the same reach, allowing a direct comparison of the resuspension characteristics of each.

Dredgehead sampling

31. Concentrations of TSS near the dredgehead (near field) are useful for estimating the source strength or rate of sediment resuspension at the point of dredging. Dredgehead 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 suction intake (Figure 11). 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. The location of the sampling array varied in the three studies where it was used: 2 ft from the suction intake at Calumet, 10 ft from the suction intake at James River, and 20 ft from the suction intake in the Savannah study.

Figure 11. Field (dredgehead) sampling array attached to the ladder of a cutterhead

32. Samples were obtained from each of the six tubes at each sampling interval after purging the tubes. The near field water quality samples were taken in the order the tubes are shown in Figure 12, but in the opposite direction of the swing (e.g. for a port-starboard swing, samples were collected sequentially from tubes 1-6). The direction of swing (port-starboard or starboard-port) was alternated between sampling intervals. Each water sample taken from the tubes was analyzed for suspended solids concentration.

Radial sampling

33. The radial sampling plan used was based on a review of similar studies (e.g. Nichols, Thompson, and Fass 1978), standard open channel suspended sediment load sampling procedures, and experiences of the investigators during preliminary sampling efforts. Radial sampling of the suspended sediment plume consisted of collecting discrete water column samples at geometrically increasing distances at stations along radials originating from the point of dredging. Stations were established at distances of 50 (when safe), 100, 200, 400, 800, and, conditions permitting, 1,600 ft from the point of dredging. At each station a profile of the vertical plume distribution was

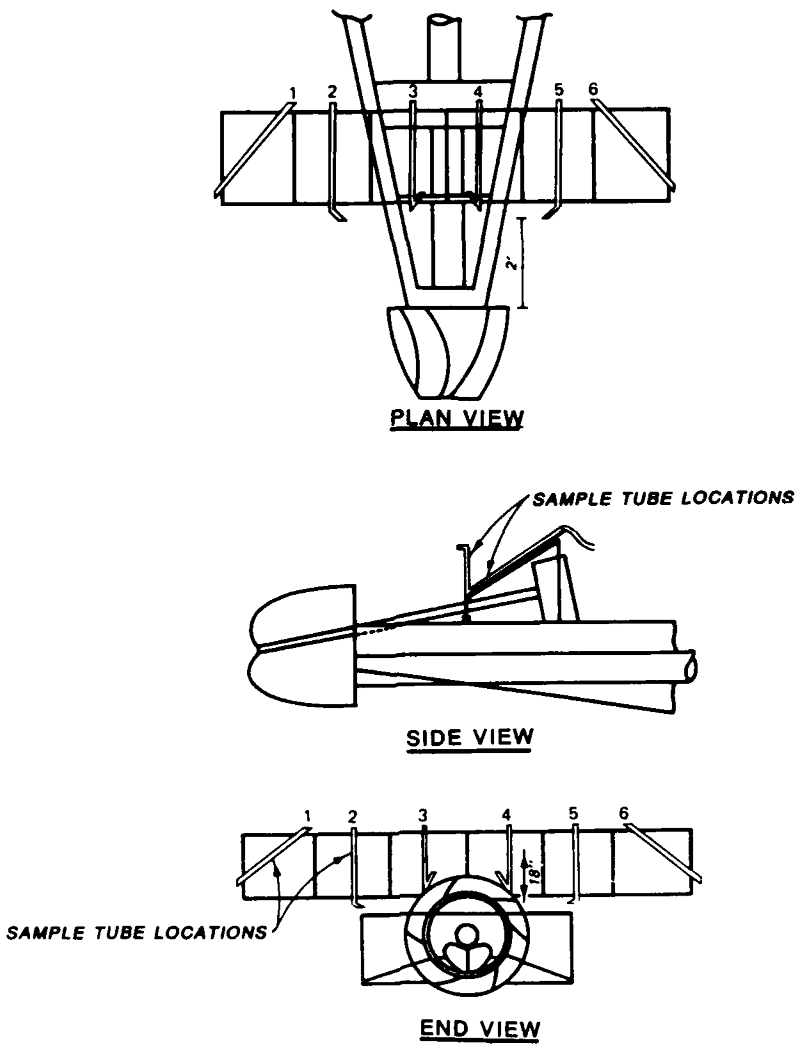


Figure 12. Location of tubes in the near field sampling array

determined by collecting discrete water column samples at the near surface (1 to 5 ft deep), the near bottom (1 to 3 ft above the bottom), and at two or three intermediate depths. Typical sample locations around the point of dredging are shown in Figure 13. The radials were generally oriented along the direction of flow, although supplemental radials of different orientations were also obtained. Current direction and speed were measured one to five times for each radial sampled.

34. Sampling of the suspended sediment plume for the different field studies consisted of collecting discrete water column samples at the stations

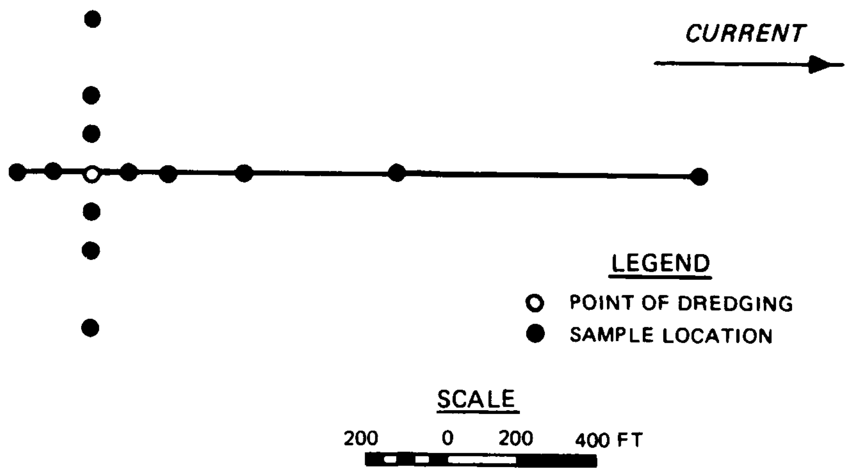


Figure 13. Typical radial resuspended sediment sampling plan

and radials mentioned earlier. When the correct distance along each radial was reached, the sample vessel would anchor and the distance and azimuth to the dredge were checked to ensure proper location. If the vessel drifted during the anchoring procedure, it was repositioned. All water column samples were normally collected from small (18 to 20 ft) aluminum boats or directly from the dredge.

35. Equipment used to collect water column samples included both centrifugal pumps and Van Dorn type water samplers. When using a centrifugal pump, a long flexible tube was attached to a marked nylon cord. The markings on the line allowed the user to deploy the sample collection tube to the desired depth. The nylon cord would be weighted to ensure tautness. The pump was turned on when the tube entered the water and pumping continued until all the samples, at that particular station, were collected. At each sample depth the pump was allowed time, approximately 30 sec, to clear the tube of water from the preceding sample. Samples of approximately 200 mℓ were collected from the pump's outflow. The prepared Van Dorn water samplers were deployed to the desired depth where the triggering mechanism was released and the sample collected. The sampler was then brought to the surface and transferred to a plastic container.

36. The distance to the dredge was normally measured by a hand-held rangefinder or an electronic distance measuring (EDM) device. The azimuth was normally measured by a hand-held compass. The accuracy of this equipment ranged from ±0.005 to ±0.10 percent of the distance or angle measured.

Current measurements were obtained using electromagnetic current meters. The direction of the current was normally measured by a geometric compass located within the current meter. The accuracy of the speed and direction of the current measurements were on the order of ±2 and ±10 percent, respectively, of the scale of the meter.

Background sampling

37. To determine the net effect of the dredging operation on the water column, background samples were collected for each study. Background water samples and current measurements were normally collected in the study reach for 1 to 2 days prior to the initiation of dredging. During the background sampling, a control station was located upstream from the dredging reach which was used to check background levels of TSS during the dredging operation. This control station was normally sampled before and after completion of each radial. The salinity, for studies located in saline environments, was determined in the laboratory prior to gravimetric analysis. Salinity above 1 ppt affects the settling rates of clay particles by increasing flocculation.

Data analyses

38. Transformation of the TSS data into a consistent format to facilitate comparisons was accomplished by a method developed by Hayes, McLellan, and Truitt (1985). In this method, the depth scale is normalized using the total depth to allow comparison of concentrations at stations with different water depths. At each station the TSS values of discrete samples collected at each depth were weighted based on the depth increment. The weighted TSS levels were then used to compute averages over consistent increments of depth. Figure 14 shows a TSS profile with suspended sediment concentrations averaged over 1/3- and 1/4-depth intervals. At each station, the TSS data were temporally averaged over the study duration for each depth interval. Combining the depth, distance to point of dredging, and average concentration data, isopleths were generated to describe the TSS plume.

39. Two types of plots showing resuspended sediment isopleths to describe the plumes were developed using a regional variable theory technique called kriging to develop the TSS isopleths (Golden Software Inc. 1984). The first type of plot was generated when radials were sampled only in the direction of flow, i.e. directly upstream or downstream from the point of dredging. The isoconcentration lines were depicted on a plot of percent depth versus distance from dredge (Figure 15). This plot depicts the dispersion of the

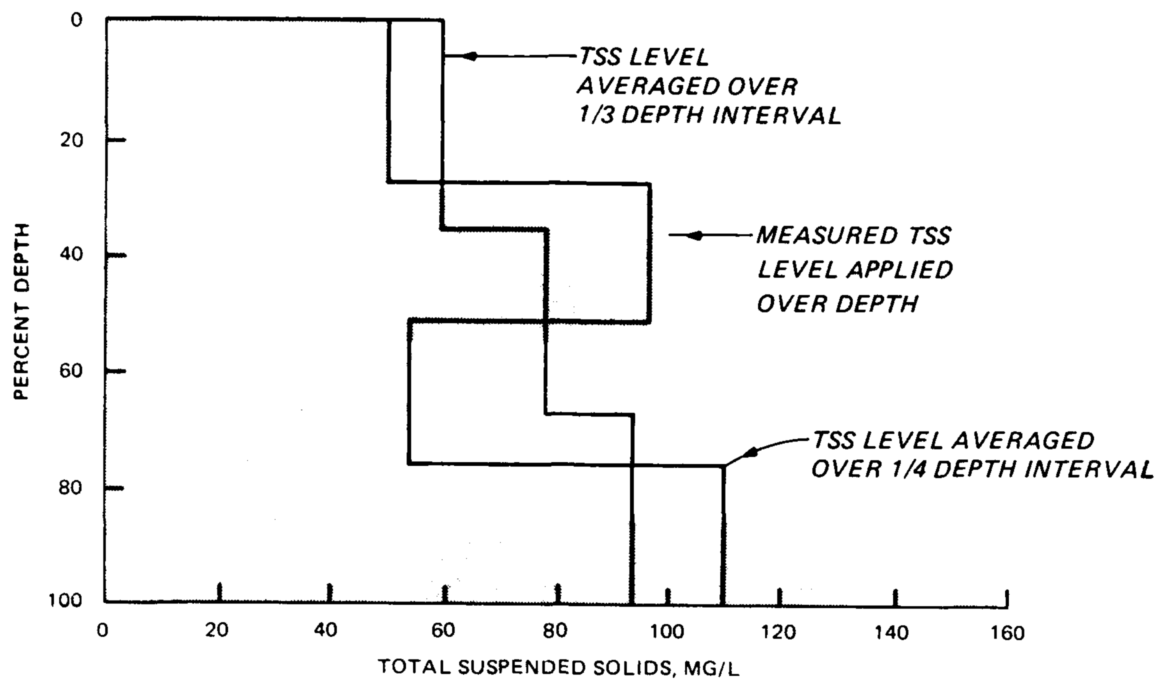


Figure 14. Vertical profile of averaged resuspended sediment concentrations plotted against percent of total depth

plume away from the point of dredging but allows no estimate of plume width. The second type of plot was developed when radials were sampled in the direction of flow and at least one additional orientation to the current direction. For these plots an estimation of the plume's width could be determined, and plots similar to Figure 16 were developed. Figure 16 represents a plan view of the isoconcentration lines at 25-percent depth. By generating plots for several different depths, the figures depict the plume's concentration over depth and width of the study area.

40. A majority of the water column stations involved collection of discrete water samples at four different depth intervals. To best represent this data and depict the TSS plume, the 1/4-depth interval was used for data analysis. All the plume data developed in this study for the purpose of dredge comparison used the 1/4-depth averaged total suspended solids values as shown in Figure 14.

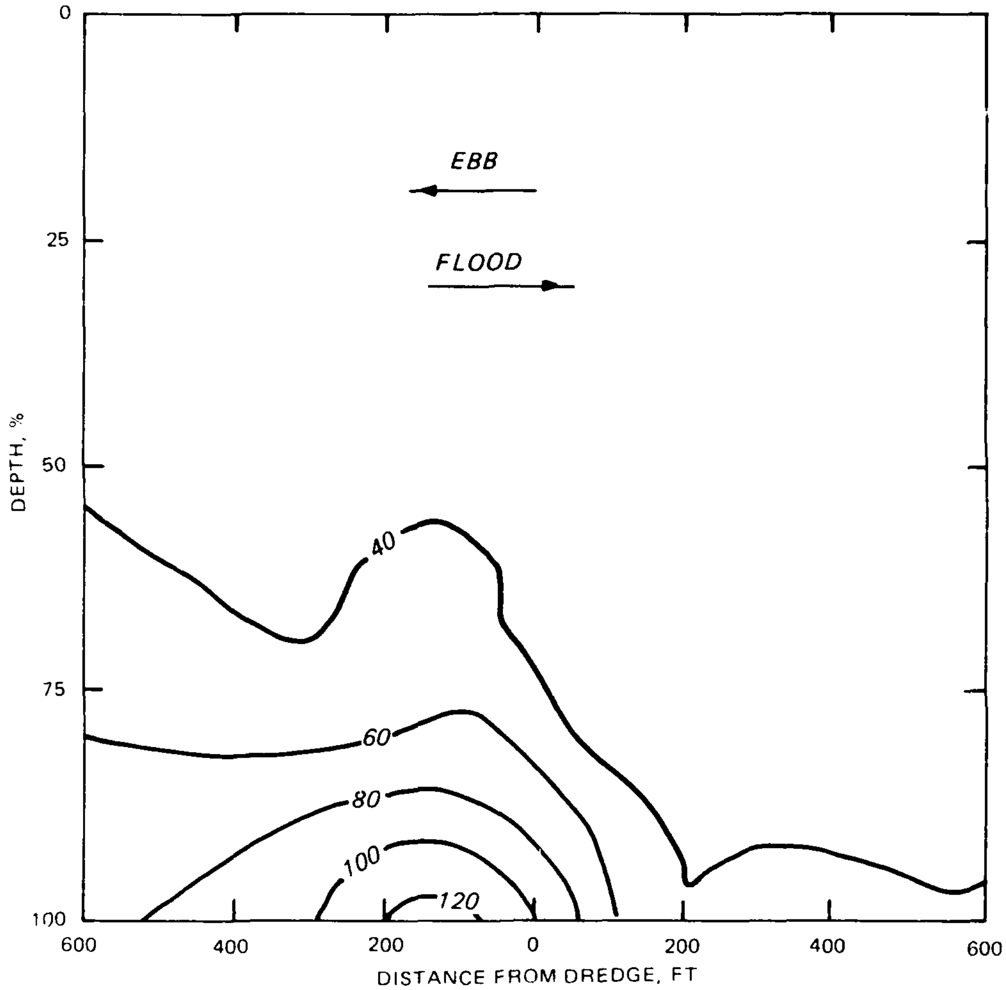


Figure 15. Vertical water column section showing resuspended sediment isoconcentration lines on a plot of percent depth versus distance from dredge

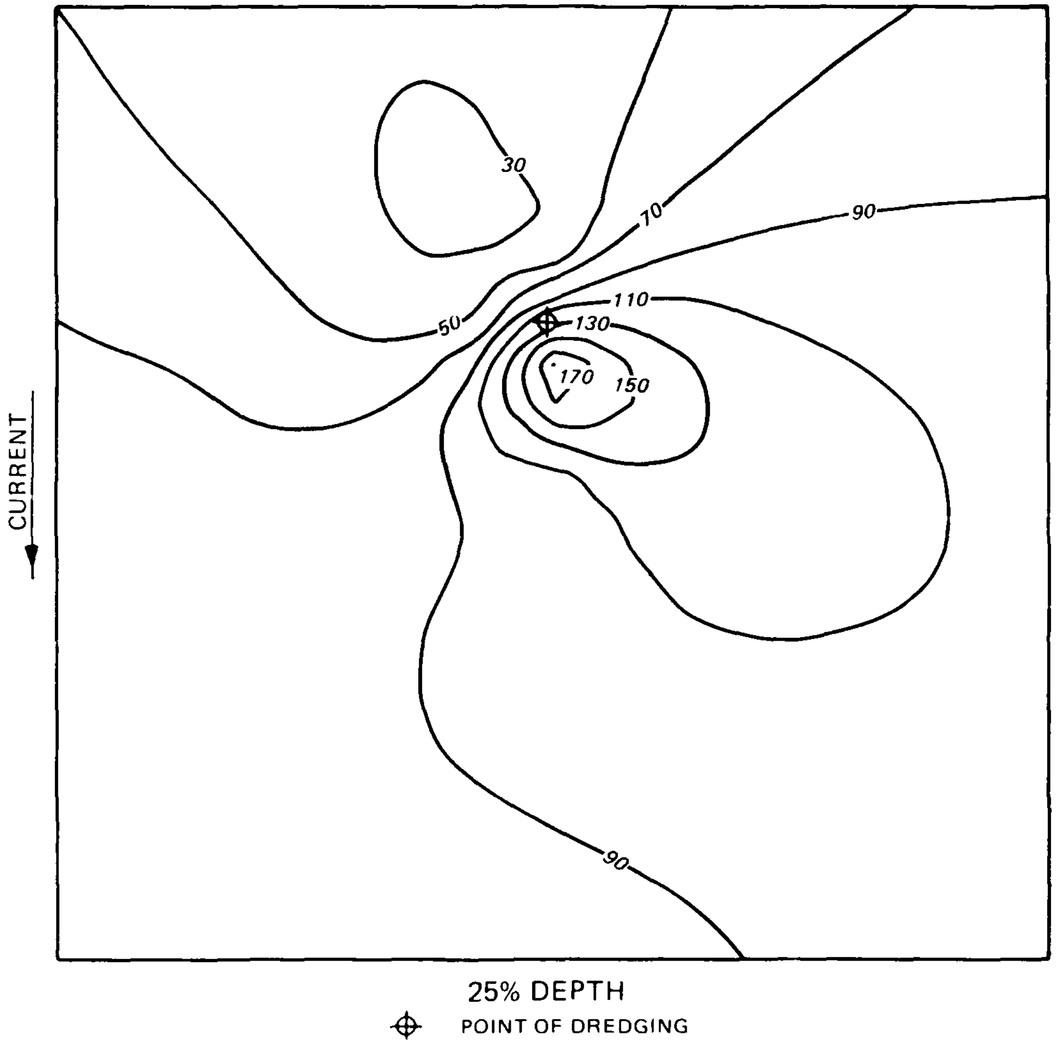


Figure 16. Plan view of a resuspended sediment concentration plume

PART IV: HYDRAULIC PIPELINE DREDGE FIELD STUDIES

41. This part describes three field studies where the sediment resuspension characteristics of five hydraulic pipeline dredge configurations were examined. The results of each field study are presented, and a summary and comparison of the sediment resuspension characteristics of all dredges tested appear at the end of this part.

Calumet Harbor Field Study

Site description and project background

42. WES, in cooperation with the US Army Engineer District (USAED), Chicago, conducted a direct comparison between a matchbox suction head dredge and a conventional cutterhead suction dredge. Both dredge heads were fitted onto the Corps-owned suction dredge DUBUQUE (Figure 17). The field demonstration of the matchbox suction head was conducted in Calumet Harbor, IL, during October 1985. In conjunction with this demonstration, water quality samples were collected within 10 ft of the point of dredging and along a grid pattern beginning near the dredge and extending outward while the dredge operated in the exit channel from 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.

43. Calumet Harbor is located south of Chicago, IL, along the western shore of Lake Michigan. The harbor is located at the point where the Calumet River joins Lake Calumet and is protected from the northeast by a breakwater extending from the shore. The Chicago Area confined disposal facility (CDF) is located where the Calumet River joins Lake Michigan, and its north dike extends outward along the south edge of the channel. Current velocities were low during the study (0.1 to 0.3 ft/sec), and current direction was not constant. The area dredged during the equipment demonstrations was in the Calumet River channel along this north dike (Figure 18). The material dredged was silty loam with a specific gravity of 2.71 and an average moisture content of 71.1 percent. The liquid limit was 25.4, the plastic limit was 25.0, and the plasticity index was 0.4.

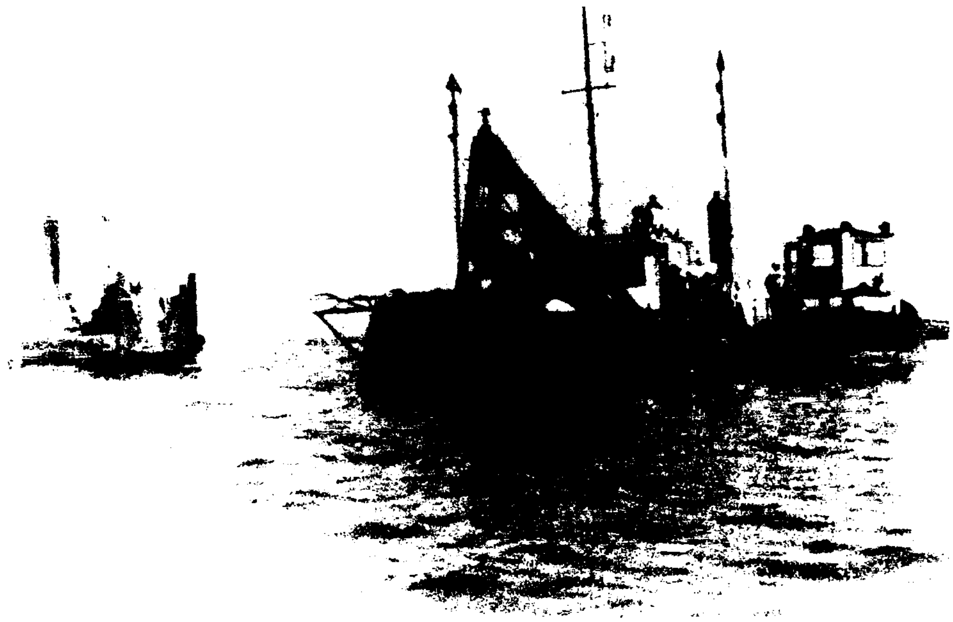


Figure 17. The DUBUQUE with the matchbox suction head attached

Equipment description

44. The dredge DUBUQUE is a 12-in. (inside diameter (ID) of discharge pipe) suction dredge. 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 six-blade (with serrated edges) cutterhead which 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 (min) and 120 (max) ft.

45. The DUBUQUE has the standard array of gauges found on most conventional cutterhead dredges--vacuum pressure, discharge pressure, depth, motor rpm, etc. In addition, a Texas Nuclear integrated flow and density meter, which continuously displays the real time velocity and solids concentration in the discharge pipe as well as the total sediment removed, discharge flow rate, and operating time, was installed just prior to this testing. As the study progressed, the dredge operator became familiar with the density meter and began using it almost exclusively as an indicator of the dredge's performance.

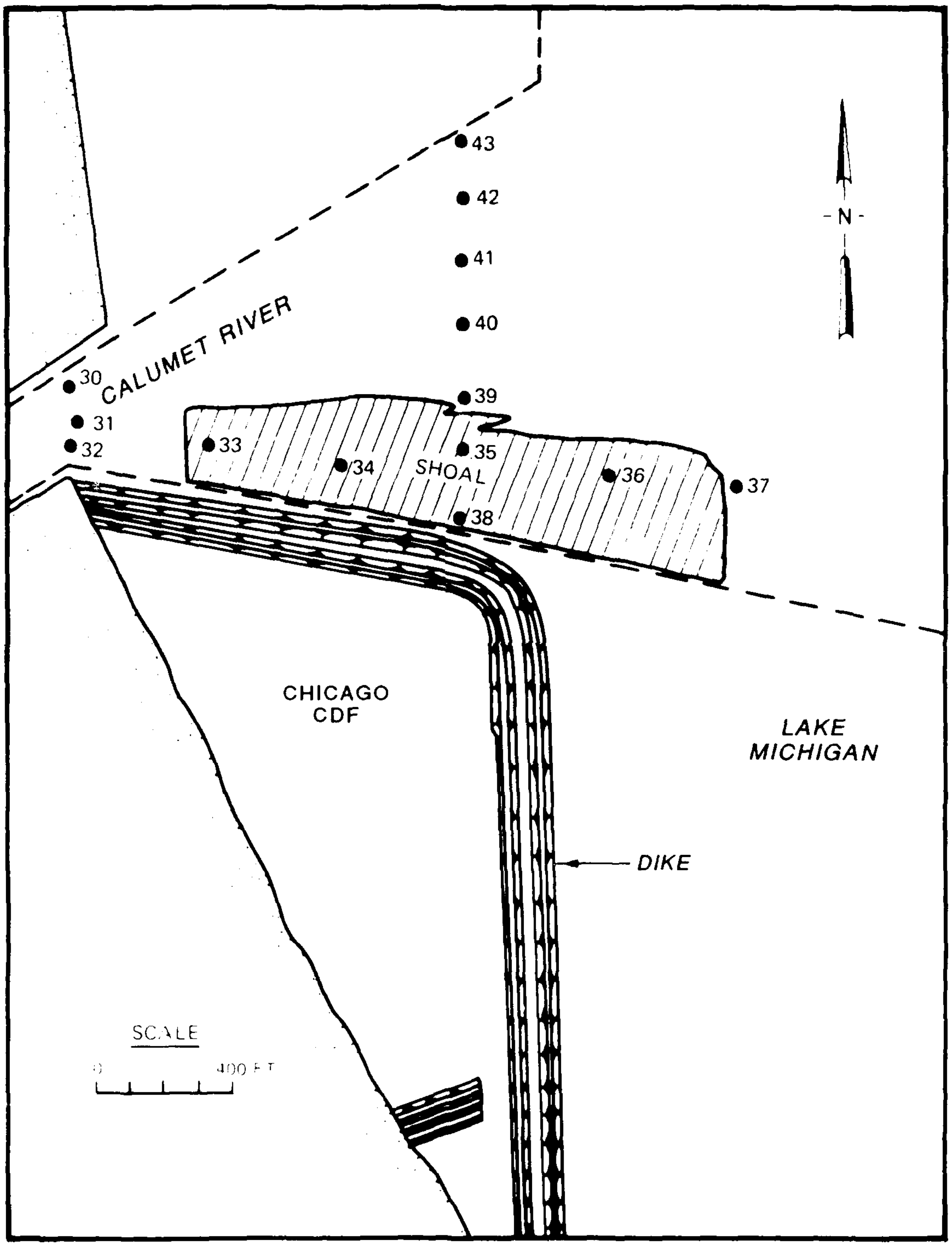


Figure 18. Dredging area and background sampling grid

46. The DUBUQUE used normal operating procedures during the cutterhead testing periods except for the swing speed and cutter rotation speed. A constant swing speed of either 0.7 or 1.1 ft/sec (velocity at cutterhead tip) was used with cutterhead rotation speeds of either 15, 20, or 27 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. 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.

Cutterhead sampling

47. Data collection. The dredgehead sampling apparatus with the sampling tube array located about 2 ft from the suction intake, was described in Part II (see Figures 5 and 12). Sampling intervals were arranged so the direction of dredgehead swing was alternated from sample to sample. After purging the tubes, samples were obtained from each of the six tubes at each sampling interval. The near field water samples were taken in the order the tubes are numbered in Figure 12, but in the opposite direction of the swing (e.g. for a port-starboard swing), samples were collected sequentially from tubes 1-6. Each water sample taken from the tubes was analyzed for suspended solids concentration. The dredging operation was carefully controlled at Calumet Harbor so that one variable (e.g. swing speed or cutter rotation rate) was changed while holding the others constant. This provided data for a mathematical analysis of near field TSS concentration as a function of dredge operation variables. This analysis appears in Appendix A, and summary statistics of near field TSS concentration is provided for comparison with data from similar studies at Savannah and James Rivers.

48. Matchbox operations. The DUBUQUE used similar operating procedures during the matchbox testing periods as normally would be used with the cutterhead attached. 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 at different cutterhead rotation speeds. Table 2 summarizes the test periods and the swing speeds used along with the average measured flow rate for each test period. A constant 100-ft-wide cutting path was used during the test periods. A normal 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.

49. Since the matchbox suction head is new to this country, the operational techniques used were established by the dredge operator as he gained experience. The matchbox operation proved to be very similar to cutterhead operation with only a few minor modifications. One problem which persisted throughout the testing of the matchbox, which affected the quality of the near field samples, was the lack of instrumentation on the dredge DUBUQUE to accurately position the matchbox. Proper positioning for the matchbox head requires vertical and horizontal controls. The vertical positioning could be controlled by including instrumentation that indicates the depth of the top of the head in relation to the seafloor. The precision of the head placement has a direct impact on dredging efficiency and sediment resuspension. Horizontal controls would ensure that the dredgehead remained parallel to the bottom over varying depths. A hydraulic piston located on the dredgehead could be used for this purpose. Without this instrumentation, it was difficult for the operator to accurately position the matchbox head, sometimes causing material to pile up on the side of the dredgehead and clog the sample tubes.

50. Another persistent problem with the matchbox during the study was the clogging of the suction intake. The debris lodged in the suction intake rendered the valve designed to regulate water intake inoperable on several occasions. This in turn reduced dredging efficiency. A new debris rack for the matchbox suction head may help to control this problem.

51. Results. Concentrations of TSS, measured within 2 ft of the cutterhead, using the sampling array shown in Figure 12, varied with depth and with direction of swing. Details on these data can be found in Hayes, McLellan, and Truitt (1986). Table 3 shows summary statistics (mean $\bar{x}$ and standard deviation σ) on all samples taken with the cutterhead sampling apparatus for each day of the cutterhead dredge demonstration. Mean values of TSS concentrations ranged from 6.6 to 14.1 mg/ℓ above background and the overall mean was 9.6 mg/ℓ. Background levels were 2.0 to 5.0 mg/ℓ.

Data collection plume studies

52. Data collection for the Calumet Harbor matchbox suction head dredge and cutterhead field studies was conducted in accordance with the sample collection methodology described in Part III. Further details of the study may be obtained from Hayes, McLellan, and Truitt (1986). The following paragraphs

describe characteristics of the resuspended sediment plumes generated by operation of cutterhead and matchbox heads. As shown in Tables 1 and 2, the production rates of both dredge suction configurations were very nearly equal.

53. Cutterhead results. Figure 19 shows plan views of the resuspended sediment plume for 25, 50, 75 and 100 percent of the water column depth. These data represent average TSS values for the duration of the dredging operation and are not adjusted for background concentrations. As expected from a cutterhead dredge operation, the resuspended sediment plume increases in size and concentration from the surface to the bottom. As indicated in Figure 19, the entire water column is affected by the dredging operation with above-background concentrations indicated at all four levels. To facilitate dredge comparisons, the plume boundaries were delineated using multiples (2×, 4×, and 6×) of the measured background TSS level. Table 4 is a tabulation of the plume areas representing the measured concentrations levels at the four depths. Table 4 shows that although all depths are affected by the dredging operation, the greatest plume area is at the 75- and 100-percent depths. The largest area, 1.03 acres, is located at the 75-percent depth.

54. Matchbox results. Figure 20 shows plan views of the resuspended sediment plumes for the 25, 50, 75, and 100 percent of the water column depth. As with the cutterhead dredge the maximum size and concentration of the plume were located near the bottom and quickly decreased moving upward in the water column. As Figure 20 shows, the dredging operation elevates the level of TSS throughout the water column, but Table 4 shows that the levels do not reach twice the background concentration at any level in the water column above the bottom. At least 10 acres near the bottom had TSS concentrations of at least twice the background level during this study. Concentrations above twice background levels were not recorded above the 100-percent depth. Also, Table 4 indicates that all averaged concentration levels of TSS during the field study remained below four times the background concentration.

55. Comparison of cutterhead and matchbox results. Since the matchbox and cutterhead dredges were operating under similar conditions, i.e. currents and background TSS, a direct comparison of the resuspension characteristics of each was achieved using Figures 19 and 20, and Table 4. A comparison of Figures 19 and 20 shows that the matchbox dredge developed a larger plume, with higher concentration near the bottom, than the cutterhead dredge. Although both dredges elevate TSS levels throughout the water column, the cutterhead

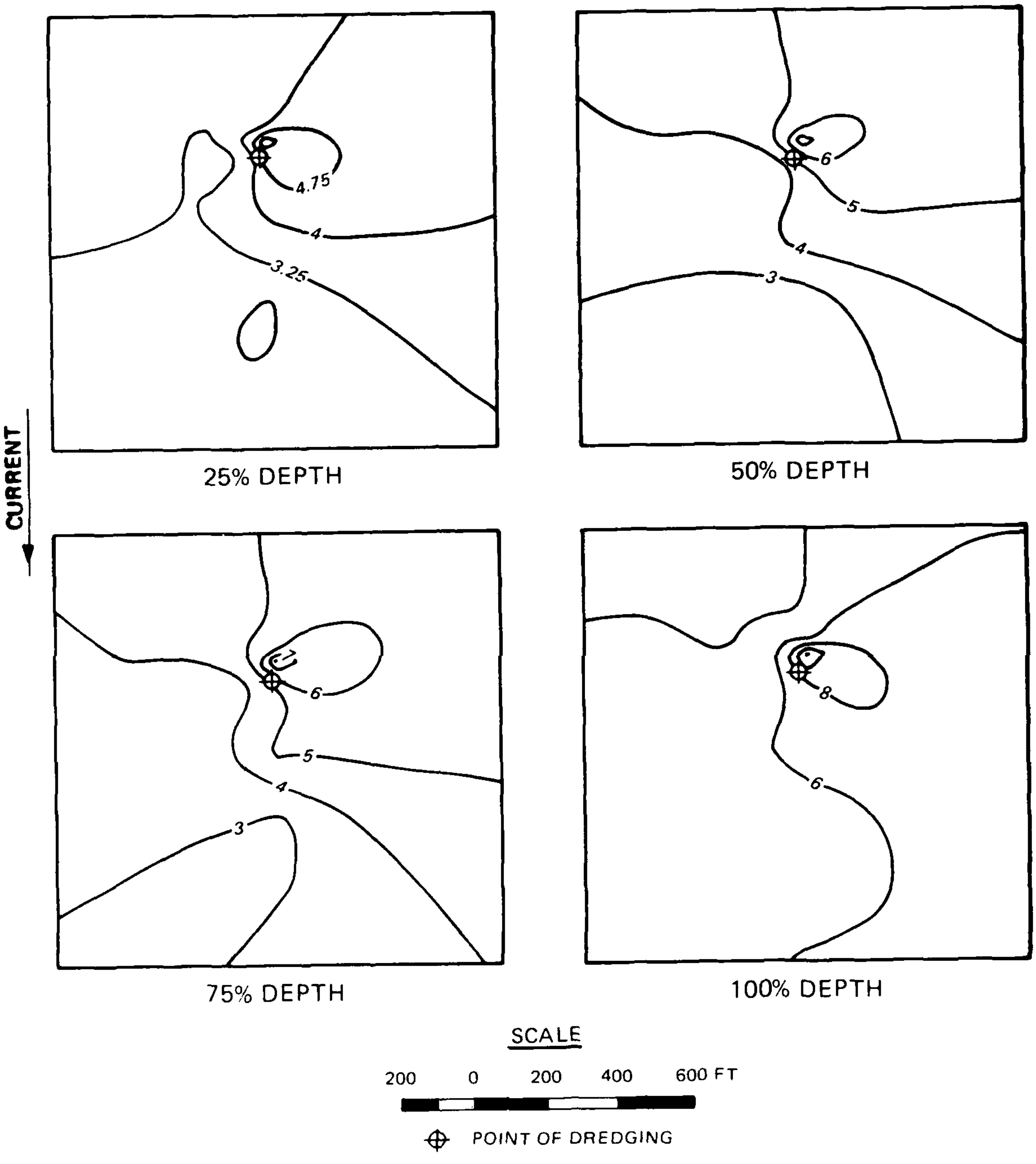


Figure 19. Plan views of resuspended sediment plume caused by a cutterhead dredge at Calumet Harbor; sediment concentration isopleths are shown for 25-, 50-, 75-, and 100-percent depths of the water column

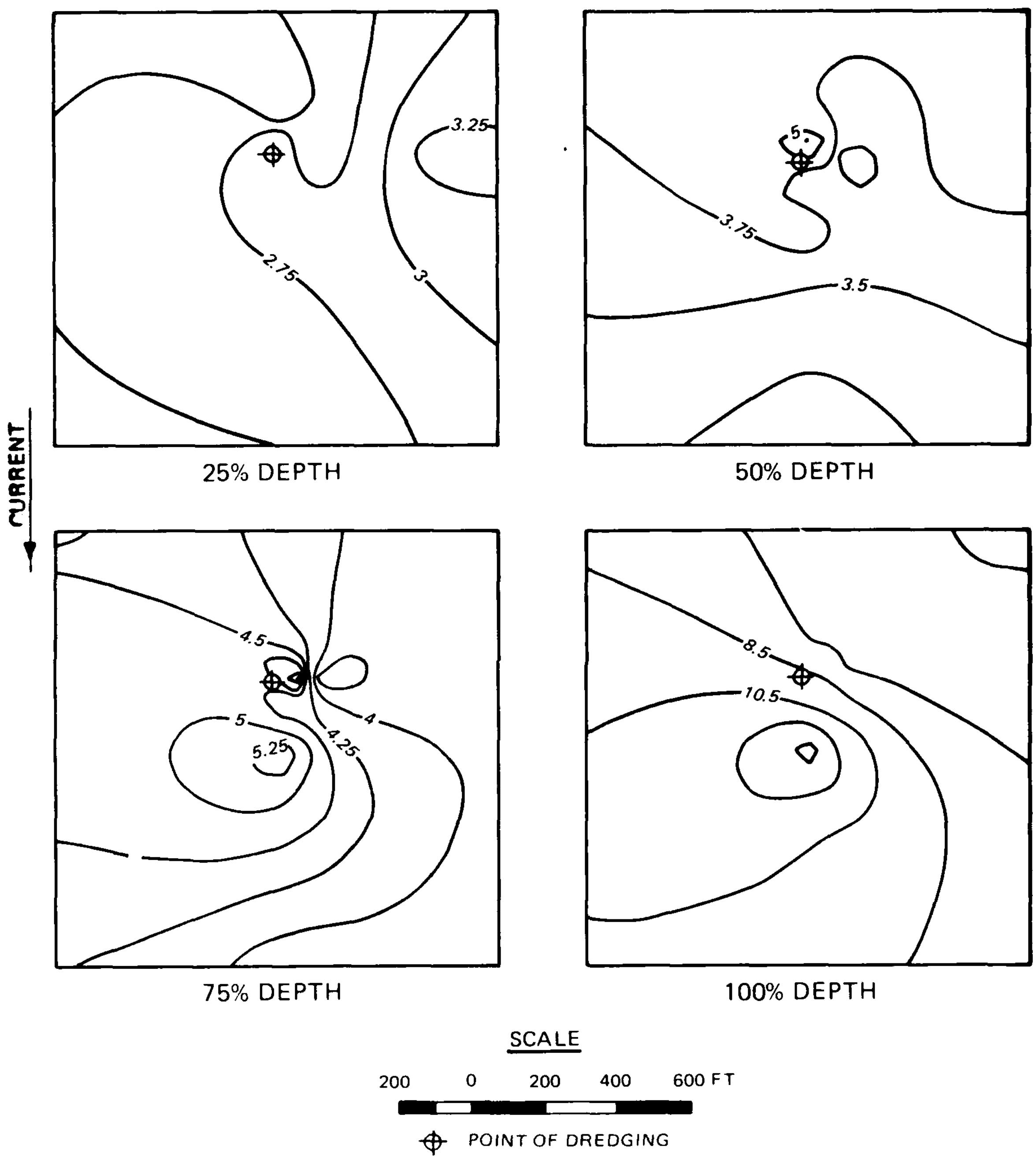


Figure 20. Plan views of resuspended sediment plume caused by a matchbox dredge at Calumet Harbor; sediment concentration isopleths are shown for 25-, 50-, 75-, and 100-percent depths of the water column

dredge produced higher concentrations in the upper water column. Table 4 indicates that the cutterhead did influence the upper portion of the water column to a greater extent than the matchbox dredge. This may be due to the throwing action of the rotating cutter. The high concentrations at the 100-percent depth for the matchbox dredge may occur due to the operator's inexperience and lack of instrumentation to indicate the top of the dredgehead relative to the bottom. The comparison of sediment concentration plumes between the matchbox and cutterhead dredges suggests that the matchbox dredge was effective in limiting the resuspension of sediment to the lower portion of the water column.

Savannah Field Study

Site description and project background

56. This field study was conducted on the dredge CLINTON while dredging in the Back River near Savannah, GA. The CLINTON was under contract with the USAED, Savannah, to perform maintenance dredging in the reach of the Back River referred to as the "Sediment Basin." This quiescent reach was formed in 1969 by placement of tide control gates across the Back River. The Back River lies parallel to the Savannah River along this reach and interconnects with the river at both ends (Figure 21). The tide gates are normally open during the flood tide allowing the sediment-laden water to flow into the Sediment Basin. During the ebb tide the gates are closed to increase flow through the Savannah River and decrease sediment deposition there, while decreasing the flow from the sediment basin and increasing sedimentation. The material dredged was silty clay with an average moisture content of 44.3 percent. The liquid limit was 78, the plastic limit was 51, and the plasticity index was 27. The softness of the material deposited in the sediment basin along with the absence of traffic created almost ideal dredging conditions.

Equipment description

57. The CLINTON is an 18-in. hydraulic cutterhead dredge. The hydraulic system consists of a 2,500-hp main pump and a 750 hp booster pump positioned approximately 50 ft down the 75-ft ladder. Although the CLINTON is classified as an 18-in. dredge because of the 18-in. pumps, the discharge is actually a 20-in.-diam line. During the test, an average of approximately 3,500 ft of discharge pipe was required. Only the main pump was used during the testing period.

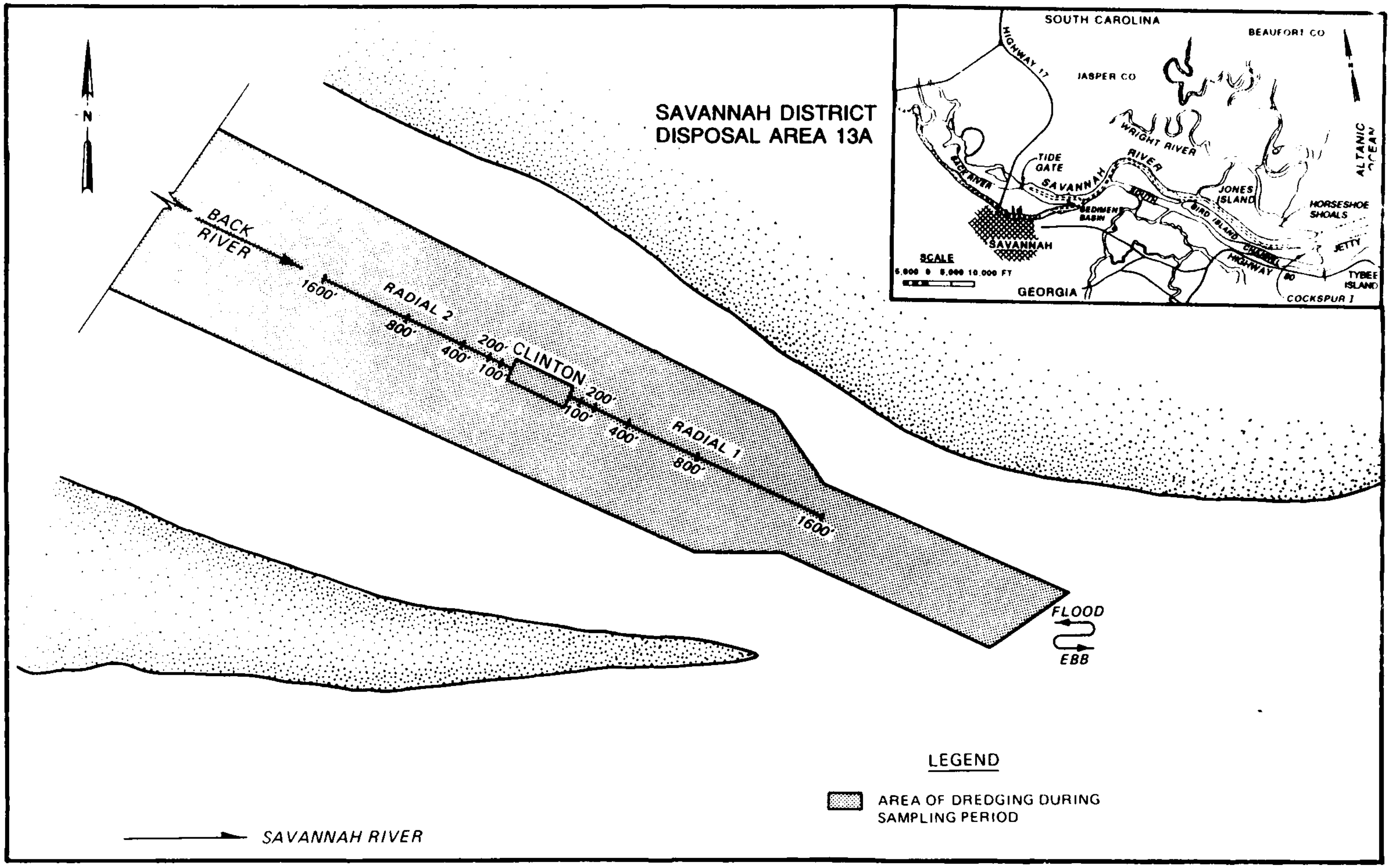


Figure 21. Site map, radials and sampling points for the cutterhead field study, Savannah, GA

58. The Savannah District imposes operational restrictions on dredging within the sediment basin to reduce the resuspension of the light, soft material. The restrictions are specified in each dredging contract for work in the sediment basin. These limitations are usually outlined as:

- a. Tangential swing speed must not exceed 1 ft/sec.
- b. Tangential tip speed of the cutterhead must not exceed 2 ft/sec.
- c. Cutterhead may not be buried more than 50 percent of its diameter below the mudline.

The restrictions were temporarily lifted during the testing period so a wider range of speeds could be evaluated.

Data collection

59. Once the testing began, dredge operational data, samples of the water column near the cutterhead, and production measurements were taken regularly over the 8-hr testing period. Dredgehead samples were taken with an apparatus similar to that used in the Calumet study (Figure 12). Water column samples at several depths at distances of 100, 200, 400, 800, and 1,600 ft from the cutterhead were taken once during each tide cycle or twice per testing day in accordance with the sampling procedures outline in Part II.

Dredgehead sampling

60. Data from dredgehead sampling from the Savannah study were more variable than for the Calumet study and therefore did not warrant analysis based on dredge operational variables. Burial of the sampling tube array in the sediment caused extremely high concentrations and an effort was made to edit these extreme values out of the data set. Mean values ($\bar{X}$), standard deviations (σ), and range of dredgehead TSS samples for each day are given in Table 5. The mean TSS values ranged from 111.5 to 777.6 mg/ℓ and showed high variability.

61. The average background suspended solids concentrations during the Savannah River cutterhead study ranged from 17 mg/ℓ near the surface to 67 mg/ℓ near the bottom. Tides and gates influenced the currents, and the speeds ranged 0.24 to 1.1 ft/sec for the ebb tide and 0.67 to 1.56 ft/sec for the flood tide. Figure 22 depicts the average suspended solids concentrations collected during the field study. Samples were collected only downcurrent of the dredge so Figure 22 represents the plume boundaries over an entire tidal cycle. The cutterhead dredge again limits the majority of the sediment

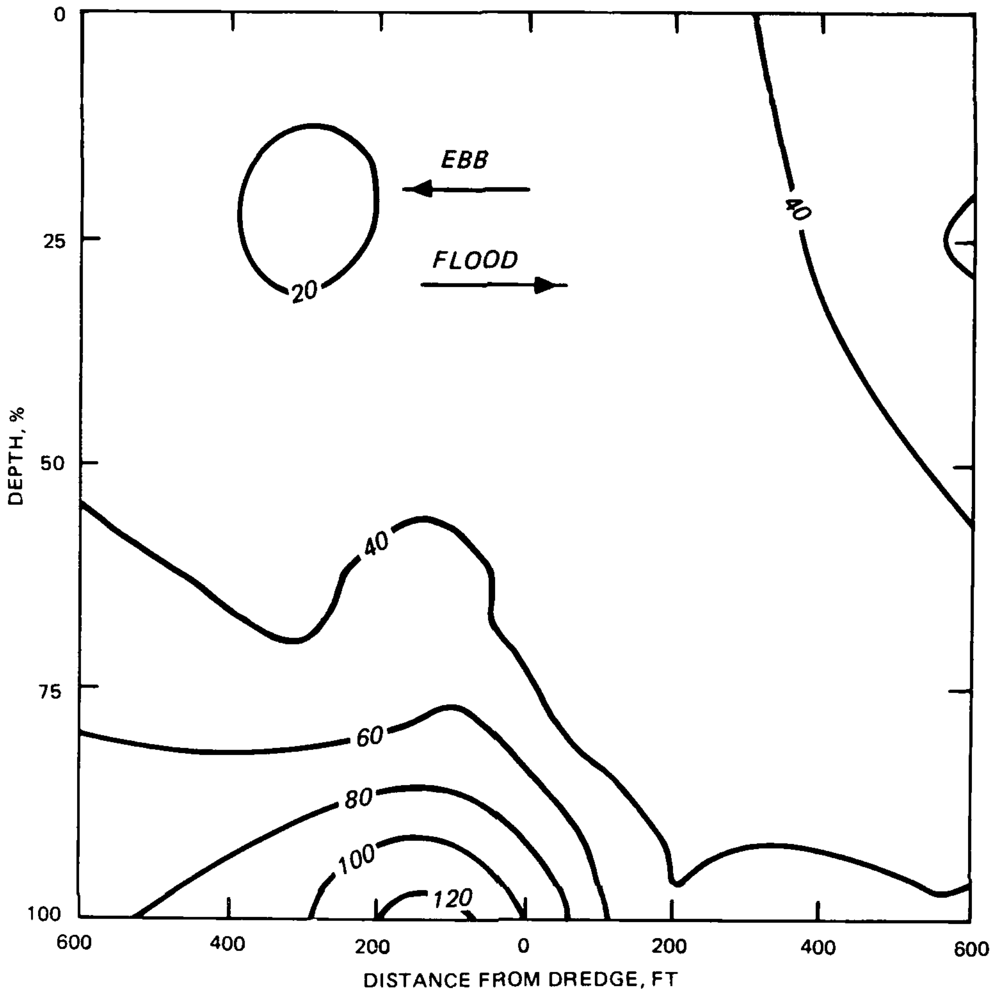


Figure 22. Concentration profiles in a vertical section of the water column taken along a horizontal transect describe a resuspended sediment plume resulting from conventional cutterhead dredging in the Back River near Savannah, GA

resuspension to the lower portion of the water column. The 120-mg/ℓ isopleths located near the bottom represents approximately 1.7 times the background level and extends for 150 ft. Applying the respective background concentrations for each depth increment, the 50-percent depth would have a background concentration of 45 mg/ℓ. Therefore, the 40-mg/ℓ contour represents a conservative estimate of the plume's boundaries and it indicates that the plume remains below middepth of the water column. Figure 22 indicates that the lower speed ebb currents may retain more material in suspension than the higher speed flood currents. It could also be caused by the influence of the Savannah River (Figure 21), which had ambient TSS levels up to 150 mg/ℓ, measured during the field study. However, using the 40 mg/ℓ contour as the plume's boundary, the dredge-induced plume covers approximately 1,200 ft during the tidal cycle. By considering a less conservative estimate, i.e. taking into account the change of background concentration with depth, the plume extends approximately 800 ft in either direction of the dredge.

James River Demonstration Project

Site description and project background

62. The James River Demonstration Project, conducted by the USAED, Norfolk, provided an opportunity to monitor cutterhead resuspension, compare a cutterhead to a dustpan dredge, and investigate the effectiveness of the cutterhead in removing a layer of contaminated sediments.

63. During the period 1967 to 1975, the James River, a major tributary of the Chesapeake Bay, was polluted with a chlorinated hydrocarbon pesticide known as kepone. The kepone became adsorbed onto the fine-grained, organic-rich sediments of the river, with the bulk accumulating in the zone of maximum turbidity in the middle estuary. Within this zone, the kepone is stored in sites of high deposition, i.e., in dredged ship channels, tributary mouths, and reaches of wide cross section where tidal currents are reduced (Hugget, Nichols, and Bender 1980).

64. Because of the kepone contamination, the USAED, Norfolk, decided to conduct a dredging demonstration project as part of the normal maintenance of the James River channel. The goals of the demonstration were to achieve removal of a layer of polluted sediment, to minimize resuspension at the dredge head, and to remove the sediment at in-situ density. In order to achieve these goals, a dustpan suction head was specially adapted as a "clean-up" head and fitted on a typical hydraulic pipeline dredge. The dredge was operated using a dredging method designed to obtain precise positioning of the suction head within the specified layer of polluted sediment. The dredge was also operated as a conventional cutter suction dredge for comparison with the dustpan arrangement. Monitoring of operating parameters on board the dredge, and of water quality parameters around the perimeter of the operation, was conducted with appropriate instrumentation to document the effectiveness of the two dredging methods. It was anticipated that results from the

dredging demonstration might yield a method of adapting readily available cutterhead dredge plants for the cleanup of polluted sediments (Vann undated).

65. The areas dredged during the James River demonstration project were Goose Hill Flats and the Dancing Point - Swann Point Shoal (Figure 23). The excavated material consisted of an underconsolidated, very soft, saturated silty clay (CH) with a specific gravity of 2.73, an average moisture content of 186 percent, and a wet unit weight of 77 lb/cu ft. Liquid limits are greater than 120, with plasticity indices greater than 80. The kepone concentration in the sediment averaged 0.045 ppm (USAED, Norfolk 1981).

Equipment description

66. The dredge used in all phases of the James River Demonstration Project was the 18-in. cutter suction dredge ESSEX, belonging to the Norfolk Dredging Company, Norfolk, VA (Figure 24). The ESSEX, built in 1978, is 140 ft long, 36 ft wide, with a 10-ft-high hull pontoon. The ESSEX is equipped with a single centrifugal dredge pump, a 21-in.-diam suction, and an 18-in.-diam discharge. A 5-ft-diam basket cutterhead was used during the cutterhead phase. For the demonstration purposes the cutterhead was removed, and the modified dustpan head (the normally used water jets were disabled) was attached. The basic dustpan head, suction pipes, and dredging ladder were taken from the retired Corps dredge KENNEDY. Following extension of the ladder and modification of the suction piping, the modified dustpan head was attached (Figure 24). The dustpan phase of the demonstration project was conducted from 13 April to 15 May 1982. Following the dustpan demonstration, the ESSEX was restored to its normal cutterhead configuration for the cutterhead phase of the demonstration project. The ESSEX took 5 min to swing from starboard to port and 2 min, 45 sec to swing from port to starboard. The average cutter speed was 16 rpm. This relatively slow turning speed was chosen to lessen resuspension of the bottom material (Amalgamated Dredge Design, Inc., undated).

Data collection

67. Data collection was conducted in accordance with the sample plan described in Part II. The location of sampling points relative to the dredge is shown in Figure 25 for the cutterhead and in Figure 26 for the dustpan head. Additional details of the study are described by Raymond (1984).

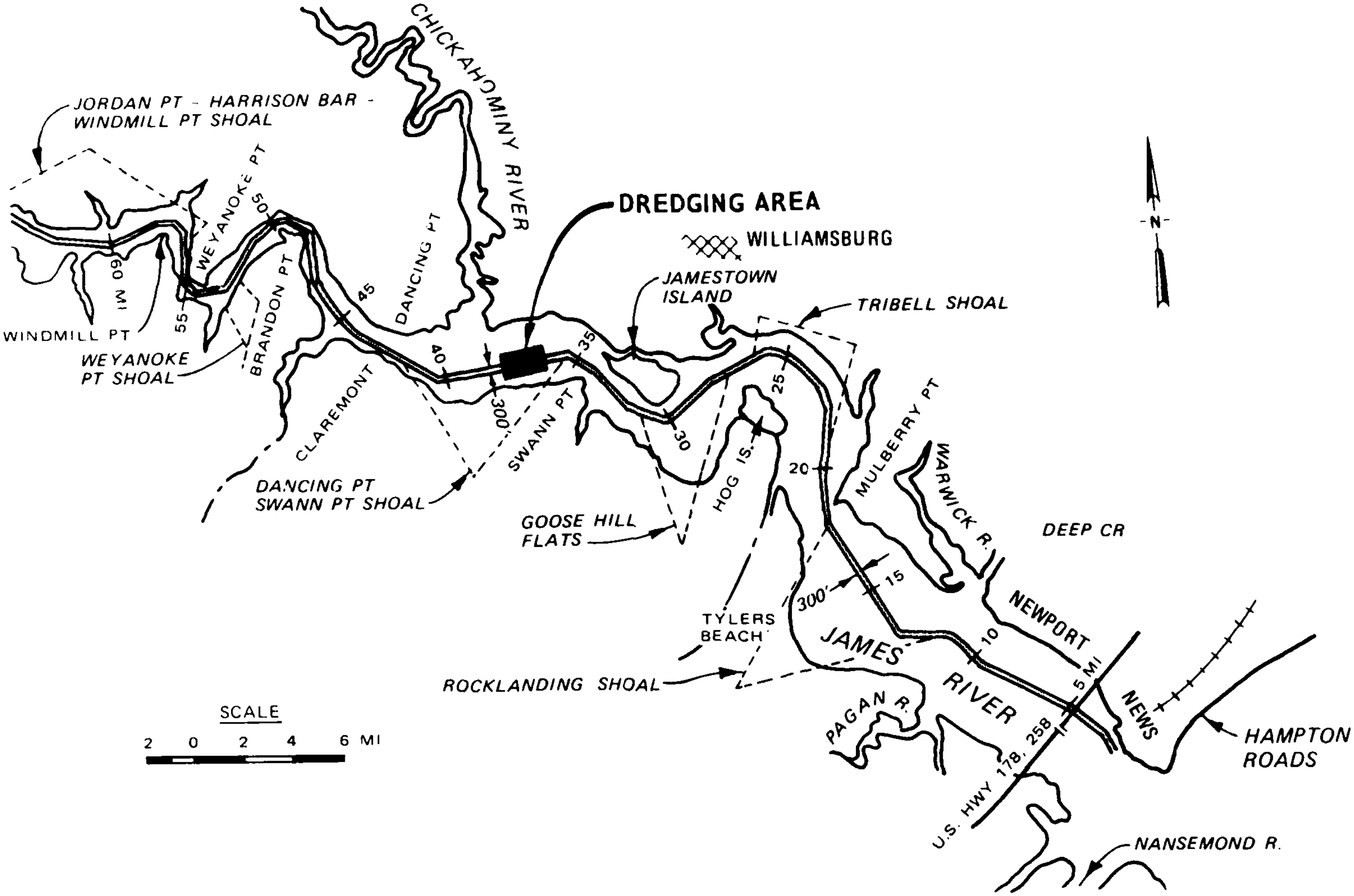


Figure 23. James River demonstration area

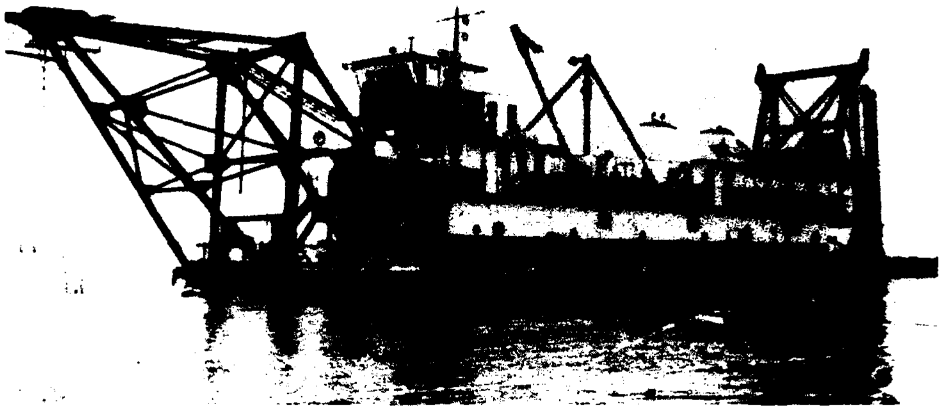


Figure 24. Cutter suction dredge ESSEX

Dredgehead sampling

68. Control over dredge operation parameters (swing speed, cutter speed, etc.) in the James River study was not possible. Summary statistics, $\bar{X}$, σ , and range) were therefore computed for all dredgehead samples taken each day and are shown in Table 6 for cutterhead and dustpan dredges. The background TSS concentration was subtracted from the TSS measurements resulting in the zero background-corrected entries in the "Min" column in Table 6. The mean dredgehead TSS concentrations for the cutterhead are about the same magnitude as those for the dustpan dredge.

69. Cutterhead plume measurement. The average background TSS concentrations ranged from 42 mg/ℓ near the surface to 86 mg/ℓ near the bottom of the water column. The current speed and direction were tide influenced with the average speed being 2.1 ft/sec during the ebb and 1.1 ft/sec during the flood phases. Figure 27 shows plan views of the sediment plume generated at the James River cutterhead demonstration. Since the samples were collected only downcurrent of the dredge, the figure represents the maximum average concentration over a tidal cycle. Figure 27 indicates that the higher currents during the ebb tide increased the size and downcurrent concentration of the plume when compared to the flood tide. A second source of suspended sediment located approximately 1,600 ft downcurrent from the dredge has concentrations exceeding those generated by the dredge. The source of this plume is unknown but is most likely due either to a tributary, the Chickahominy River, or to a

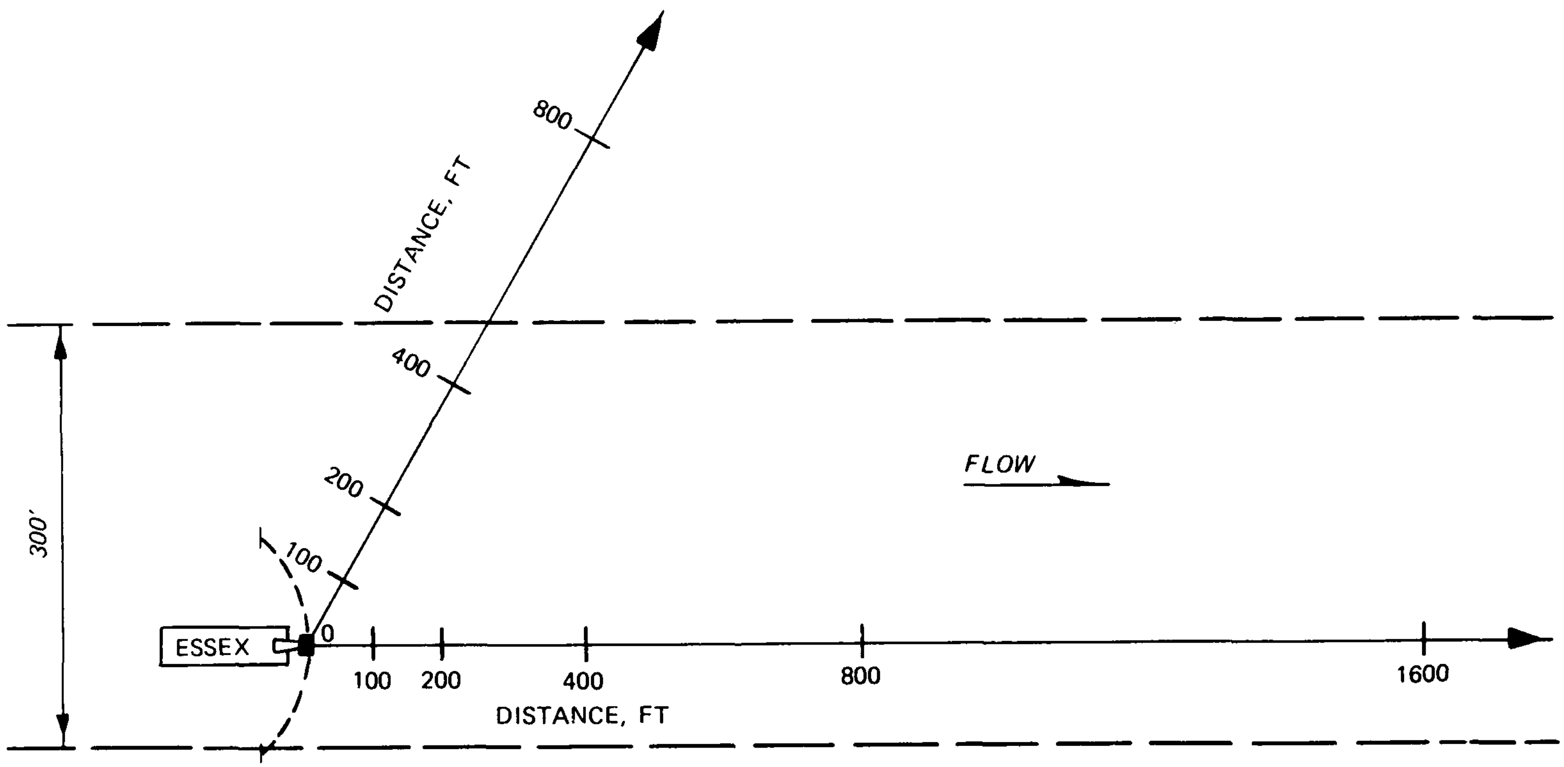


Figure 25. Location of sampling points for the James River cutterhead dredge study

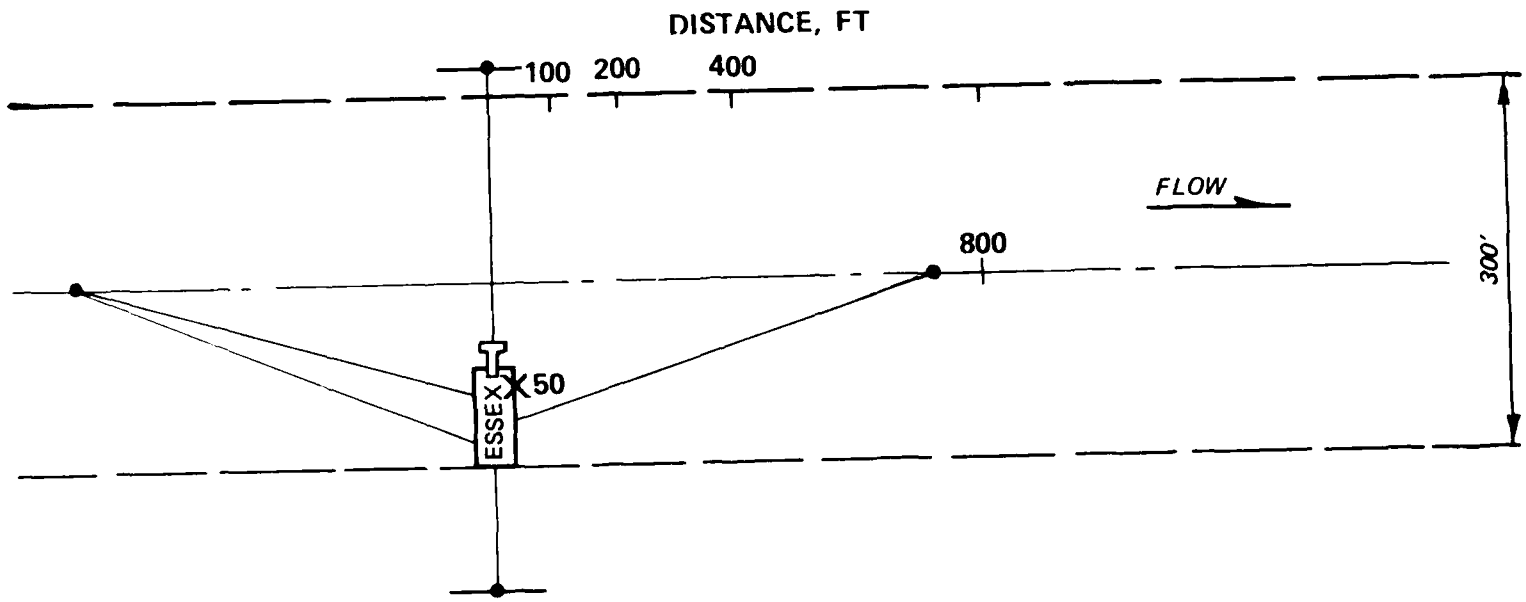


Figure 26. Location of sampling points for the James River dustpan head dredge study

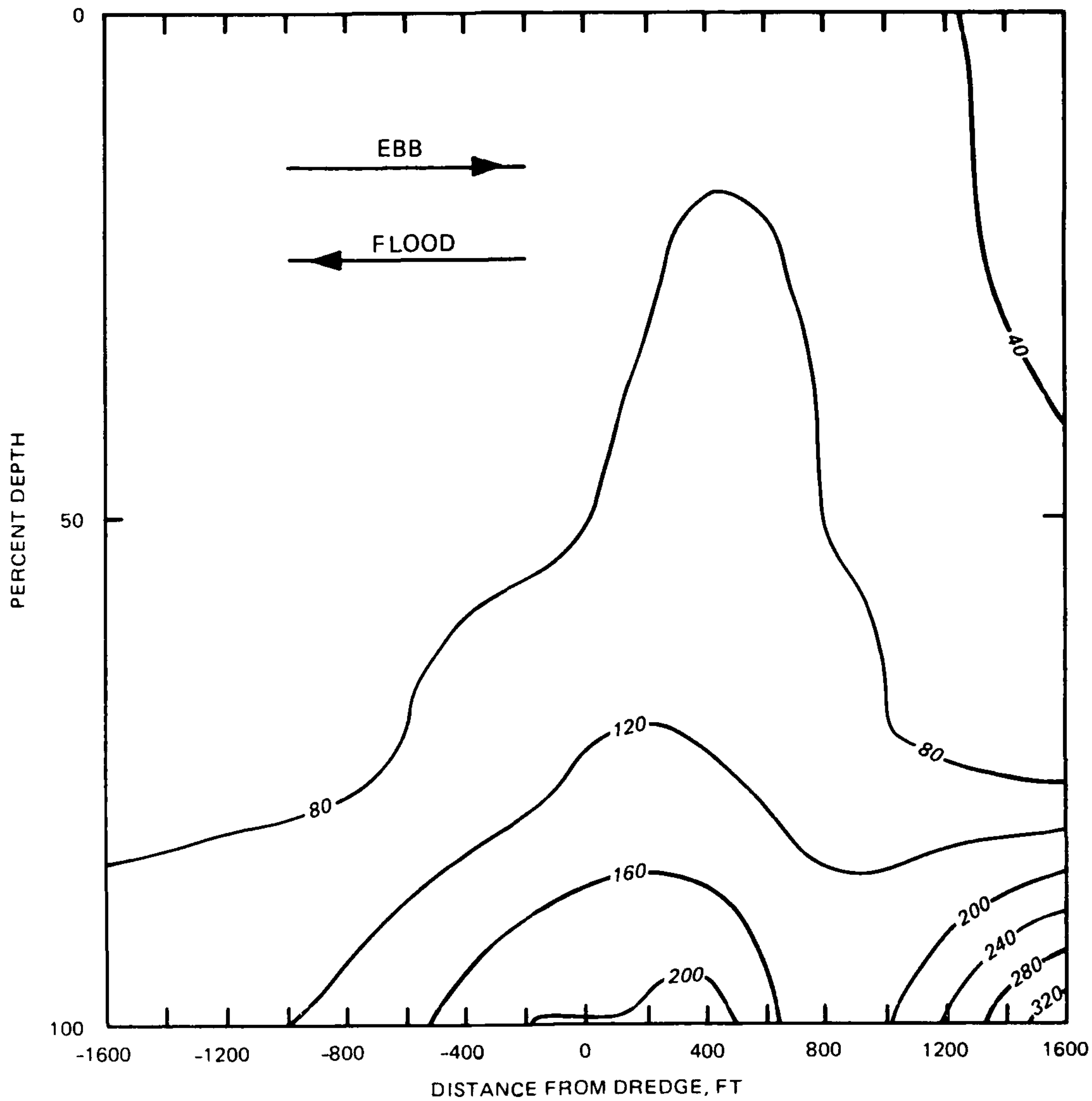


Figure 27. Contours of resuspended sediment plume for James River cutterhead demonstration

halocline located downcurrent. Using the 80-mg/ℓ contour, twice the ambient surface TSS level, as the plume boundary, Figure 27 shows that the cutterhead induced sediment plume affects 80 percent of the water column at least 1,000 ft in both the ebb and flood directions. The dredge-induced plume shows a maximum contour at 200 mg/ℓ (2.5 times background), which covers 700 ft during the tidal cycle.

70. <u>Dustpan plume measurement.</u> The background TSS levels during the James River dustpan study ranged from 53 mg/ℓ near the surface to 90 mg/ℓ near the bottom. The average current speed during the ebb phase of the tidal cycle

was 1.7 ft/sec and 1.1 ft/sec during the flood phase. Figure 28 shows the average suspended sediment levels during the dustpan demonstration. Since all samples were collected downcurrent of the dredge, the figure represents the highest average levels over a tidal cycle. Again the size and concentration of the suspended solids plume are higher in the ebb portion of the tidal cycle. This is most likely due to the higher current velocities during ebb tide. If the 100-mg/ℓ contour, or twice the surface background TSS, is used as the plume's boundary, the plume affects 40 percent of the water column and extends for 950 ft over the course of a tidal cycle. The highest sustained plume concentration was 340 mg/ℓ (3.8 times background TSS concentrations) and extends approximately 50 ft.

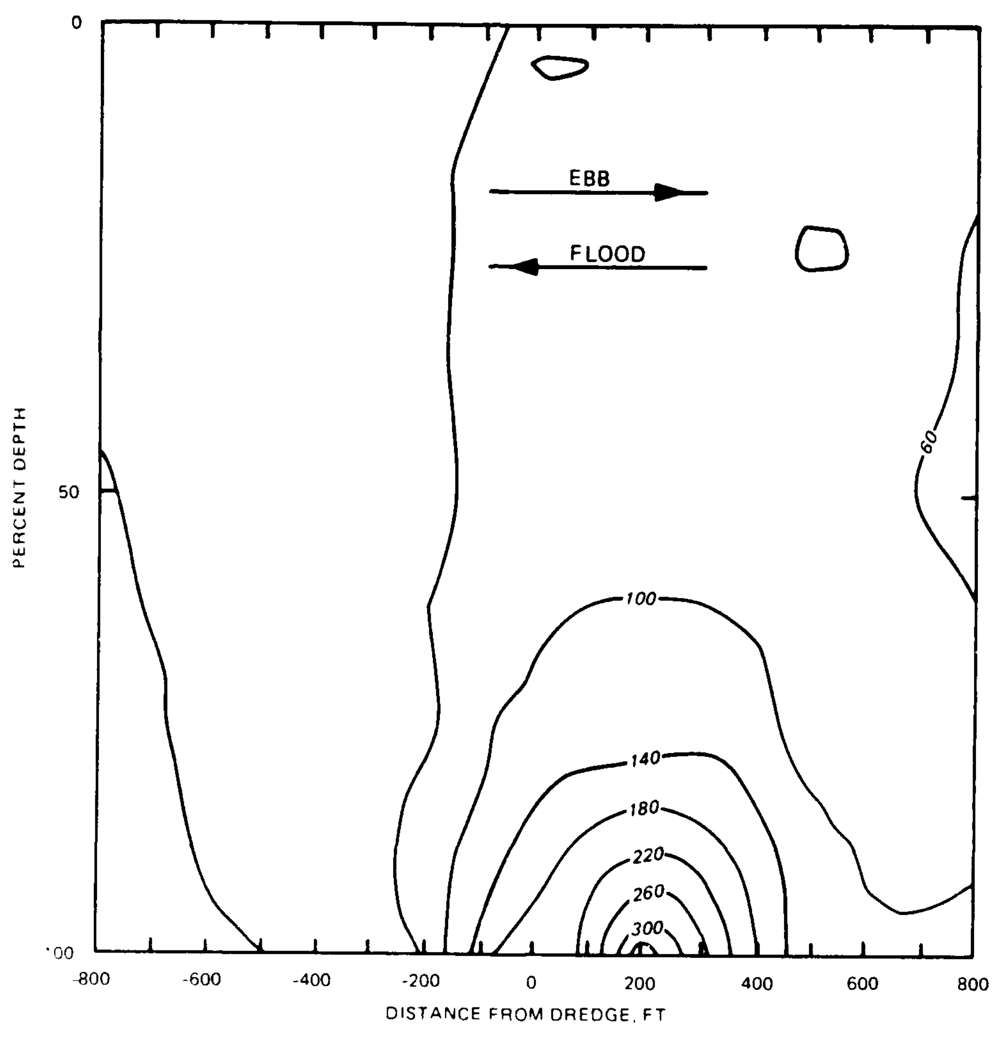


Figure 28. Contours of resuspended sediment plume for the James River dustpan demonstration

71. Comparison of cutterhead and dustpan results. Although the operating procedures of the dustpan and cutterhead dredges were somewhat different, a comparison of the two dredges can still be made. Comparing Figures 27 and 28 indicates that the cutterhead dredge generated a larger if somewhat lower concentration plume than the dustpan dredge. The apparent smaller plume for the dustpan may be caused by the operation of the dredge. The dustpan dredge operated perpendicularly to the current direction which made downcurrent sampling of the center of the plume difficult. A better indication of the dredge's performance may be the maximum sustained level of TSS generated near the dredge. Table 7 shows the limits and maximum concentrations of the plumes shown in Figures 27 and 28. As Table 7 indicates, the maximum TSS level above background for the dustpan dredge is 3.8 times background, while the maximum TSS level for the cutterhead dredge is 2.2 times background. These results suggest that the modified dustpan reduced the size of the suspended sediment plume significantly, although higher concentrations were observed near the dredge.

Summary of Results

72. Hydraulic pipeline monitoring operation involved three studies that included three cutterhead suction dredges, a matchbox suction dredge, and a modified dustpan head dredge. The studies were conducted at Calumet Harbor IL; Savannah River, GA; and James River, VA. Results from the studies are given in Table 8.

73. Previous analyses plus Table 8 show that for all the hydraulic pipeline studies, surface TSS levels were near background levels while bottom TSS levels were one to several times background levels. Absolute TSS levels near the bottom ranged from 10.0 mg/ℓ for Calumet Harbor cutterhead to 340 mg/ℓ for James River dustpan. The ratio of maximum plume TSS to background TSS varied from 1.8 for Savannah River cutterhead to 3.8 for James River dustpan. From the results, hydraulic pipeline dredges appear to limit the resuspension of sediments to the lower water column and generate plumes with average TSS concentrations 1.8 to 3.8 times background measurements.

74. Direct comparisons between hydraulic dredges, i.e. Calumet Harbor and James River, indicated no significant advantages for the alternate dredge type over the cutterhead dredge. In Calumet Harbor a matchbox suction head

dredge was compared to a cutterhead dredge. Although the matchbox did not significantly reduce bottom resuspension in comparison to the cutterhead dredge, it was successful in reducing upper water column turbidity. Further improvement of the matchbox performance can be expected with increased leverman experience and improved instrumentation. The main goal of the comparison between the dustpan and the cutterhead dredge in the James River field study was to evaluate sediment resuspension near the dredgehead. Although dredgehead samples did not indicate a difference in near field TSS (Table 8), samples collected downstream from the dredge indicated higher TSS values for the dustpan head, but a larger plume for the cutterhead.

75. Dredge-generated levels of TSS ranged from 10.0 mg/ℓ for Calumet Harbor to 200 mg/ℓ for James River for the cutterhead dredges. The background levels of TSS ranged from 5 mg/ℓ to 86 mg/ℓ for Calumet Harbor and James River, respectively. The ratio of maximum dredge-generated concentration to background concentration (Table 8) ranged from 1.8 to 2.5 for Savannah River and James River, respectfully. The studies described above were conducted in various site conditions and dredge sizes with the main similarities being fine-grained material and relatively deep water, several times the cutterhead diameter. These results indicate that, of all the hydraulic pipeline dredge types tested, the cutterhead dredge is most effective in limiting sediment resuspension while removing fine-grained unconsolidated material.

PART V: BUCKET DREDGE FIELD STUDIES

76. This chapter describes three field studies where the sediment resuspension characteristics of various bucket dredge configurations were examined. The results of each field study are presented, and a summary and comparison of the sediment resuspension characteristics of all dredges tested appears at the end of this part.

Calumet River Field Study

Site description and project background

77. The Calumet River clamshell dredge field demonstration was performed in August of 1985 in the upper portion of the Calumet River (Figure 29). The field study was incorporated into an ongoing dredging operation to remove approximately 215,000 cu yd of shoaled material from a 2-mile-long segment of the navigational channel and approach to Lake Calumet thereby maintaining a 27-ft project depth. During the time of the field study the dredge was operating near the northern bank of Turning Basin No. 5.

Equipment description

78. A 10-cu-yd capacity clamshell bucket was used to remove the soft, organic clay/silt mixture (OH). The dredging plant worked with three scows that were continually rotated when filled. When a scow filled, it was transported to the Chicago Confined Disposal Facility located six miles away at the mouth of the Calumet River (Figure 29). 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, 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 clear a cut approximately 100 ft wide. The bucket would then be lowered to the bottom and dragged across the freshly cut surface several times to smooth the bottom. The dredge would then readjust the crane or move the dredge to begin a new cut. The dredge was repositioned 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

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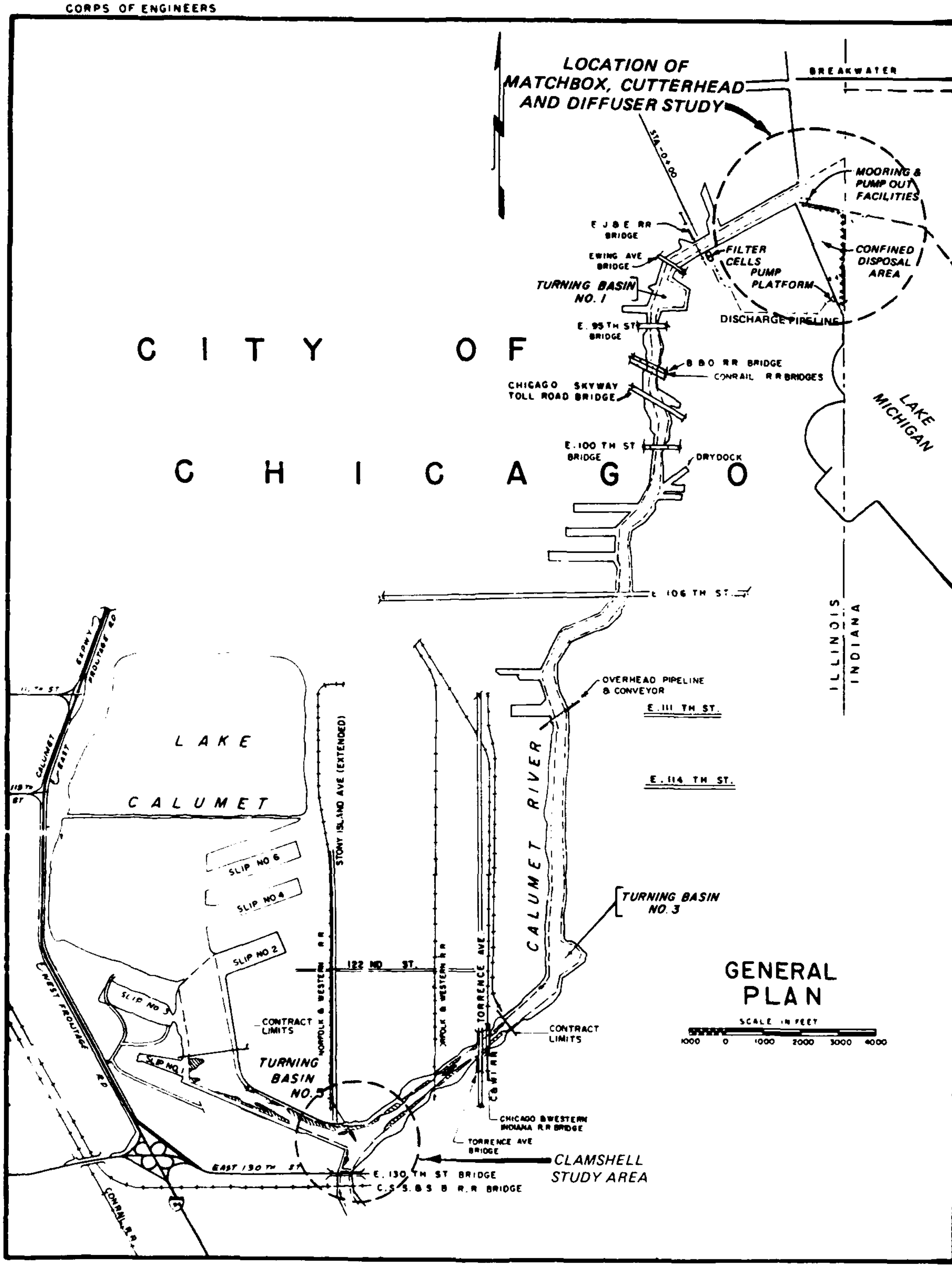

Figure 29. Field location of the Calumet River clamshell study

periods when the scows were repositioned adjacent to the dredge. Approximately 10 min was required to reposition a scow.

Data collection

79. 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. Sampling to establish background levels of suspended sediments was conducted 20 August 1985 and sampling of the dredge plume was completed on 22 and 23 August.

80. Seven background stations were established throughout the dredging reach and discrete water samples were collected at the surface, middepth, and near bottom. To sample the suspended sediment plume 13 stations were incorporated into the sampling effort (Figure 30) with the assumption of plume symetry. Sampling procedures are outlined in Part II and further details of the Calumet River demonstration can be obtained from Hayes, McLellan and Truitt (1986).

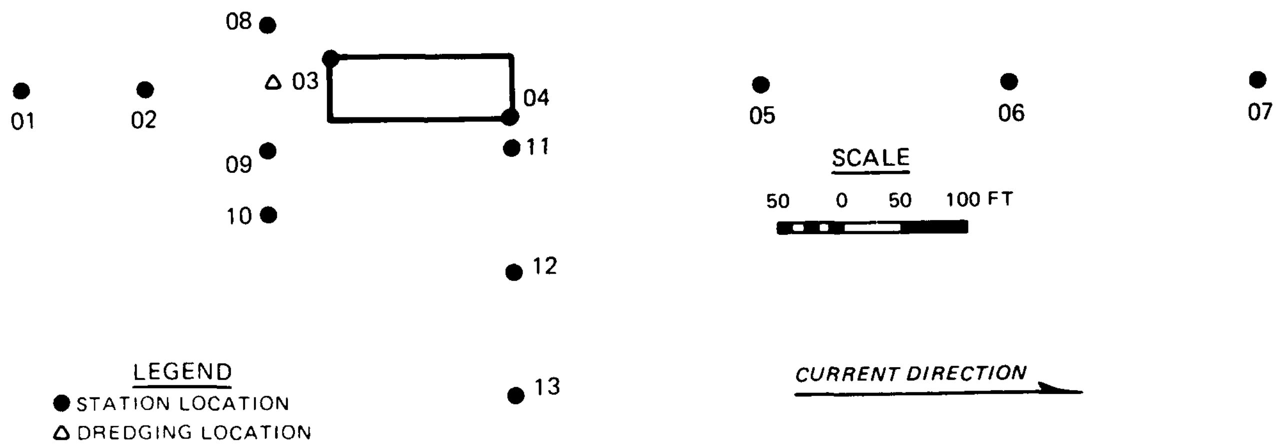

Figure 30. Location of sampling stations at Calumet River

Results

81. Background average suspended solids levels during the Calumet River clamshell study ranged between 10 and 12 mg/ℓ from the surface to bottom. The current speed ranged from 0 to 0.18 ft/sec. Sediment concentration isopleths for the 25-, 50-, 75-, and 100-percent depth intervals are shown in Figure 31. The effects of the clamshell operation can be observed throughout the water column with increasing plume size and TSS concentration from the surface to the bottom. Table 9 shows the area impacted by the contours which represent

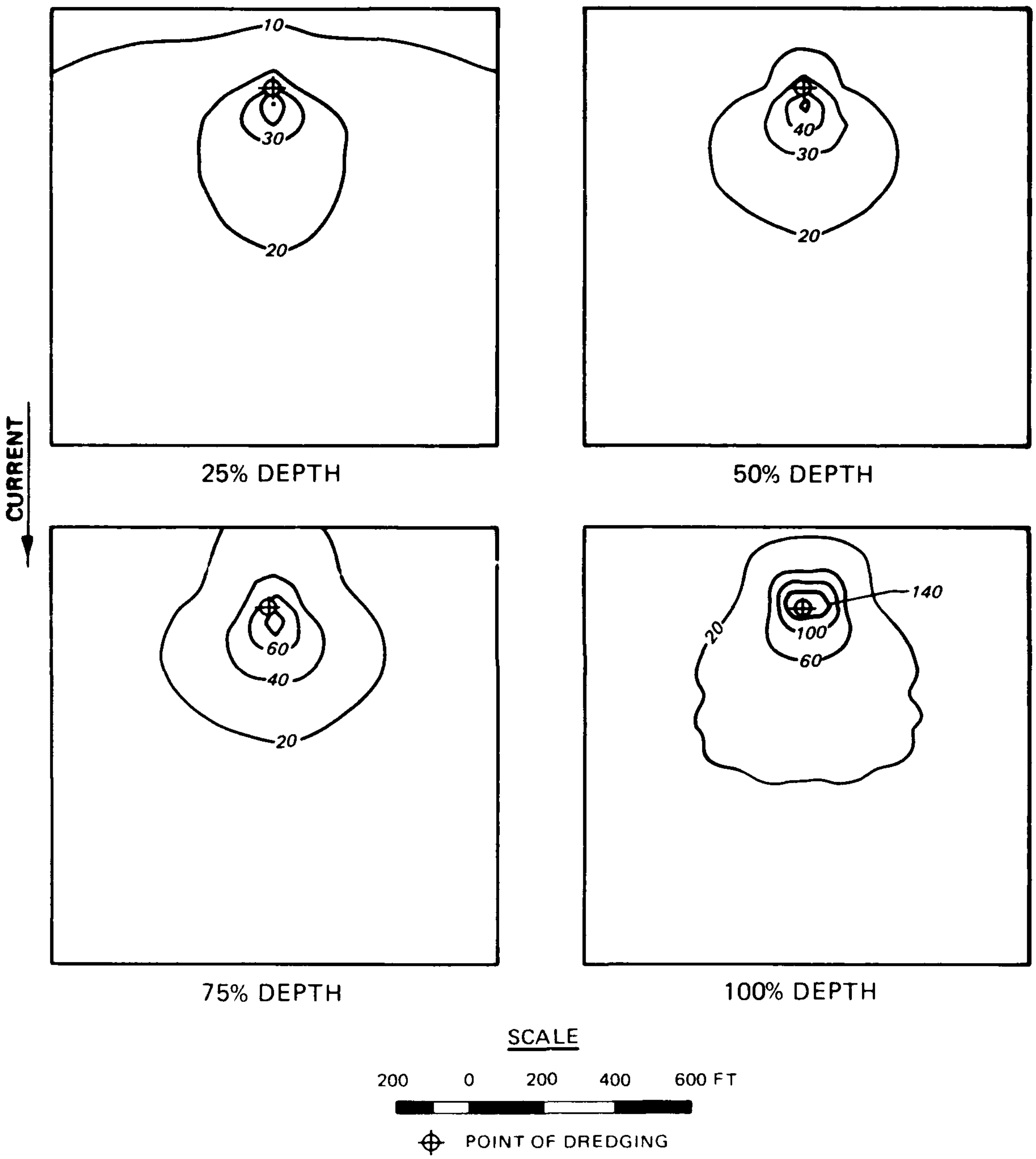

Figure 31. Plan views of resuspended sediment plume caused by a clamshell dredge at Calumet Harbor; sediment concentration isopleths are shown for 25-, 50-, 75-, and 100-percent depths of the water column

two, four, and six times (2×, 4×, and 6×, respectively) the background TSS concentrations for the four depth increments. The highest concentrations and greatest impact of the plume are located between the bottom and the 75-percent depth contour. The plume area changed from 3.5 acres (bottom) to 0.3 acre (75-percent depth) for a reduction in size of 91 percent. The reduction in area enclosed by the 4× contour between 75- and 50-percent depth and between 50- and 25-percent depth was only 33 and 50 percent, respectively. The majority of the suspended sediment remains near the bottom with secondary resuspension occurring due to leakage from the bucket to the water column. These data tend to confirm that the impact, penetration and withdrawal of the bucket from the bottom generate the majority of the sediment resuspension.

Black Rock Harbor Field Study

Site description and project background

82. The Black Rock Harbor field study was conducted in Bridgeport, CT, during the dredging of Black Rock Harbor channel (Figure 32). This was the first maintenance dredging of Black Rock Harbor in 20 years. At the time of this field study, the operation was located in the vicinity of Burr Creek anchorage (Figure 33). This study was conducted in cooperation with the US Army Engineer Division, New England.

83. Sediments dredged during the study were classified as sandy organic clay with greater than 90-percent fines. The liquid limit was 170, plastic limit was 65, and the wet weight was 72 lb/cu ft with 25-percent solids content. The sediments were dark black in color; contaminants included PCB's and petroleum products. The salinity in the area ranged from 10 to 21 ppt, with an average value of 18 ppt with little difference in the average salinity between tidal phases. There was little freshwater input into the Harbor, and most of the current was tide related.

Equipment description

84. The dredging operation was accomplished with a 10-cu-yd capacity standard clamshell bucket, owned and operated by the J. M. Cashman Co. The project required the removal of a 3- to-4-ft depth of material. The dredge excavated 55- by 30-ft sections or "cut" before moving forward. A "grading" or "sweeping" technique was used to smooth the bottom of the cut. All excavated material was transported by scow to Long Island Sound for open-water

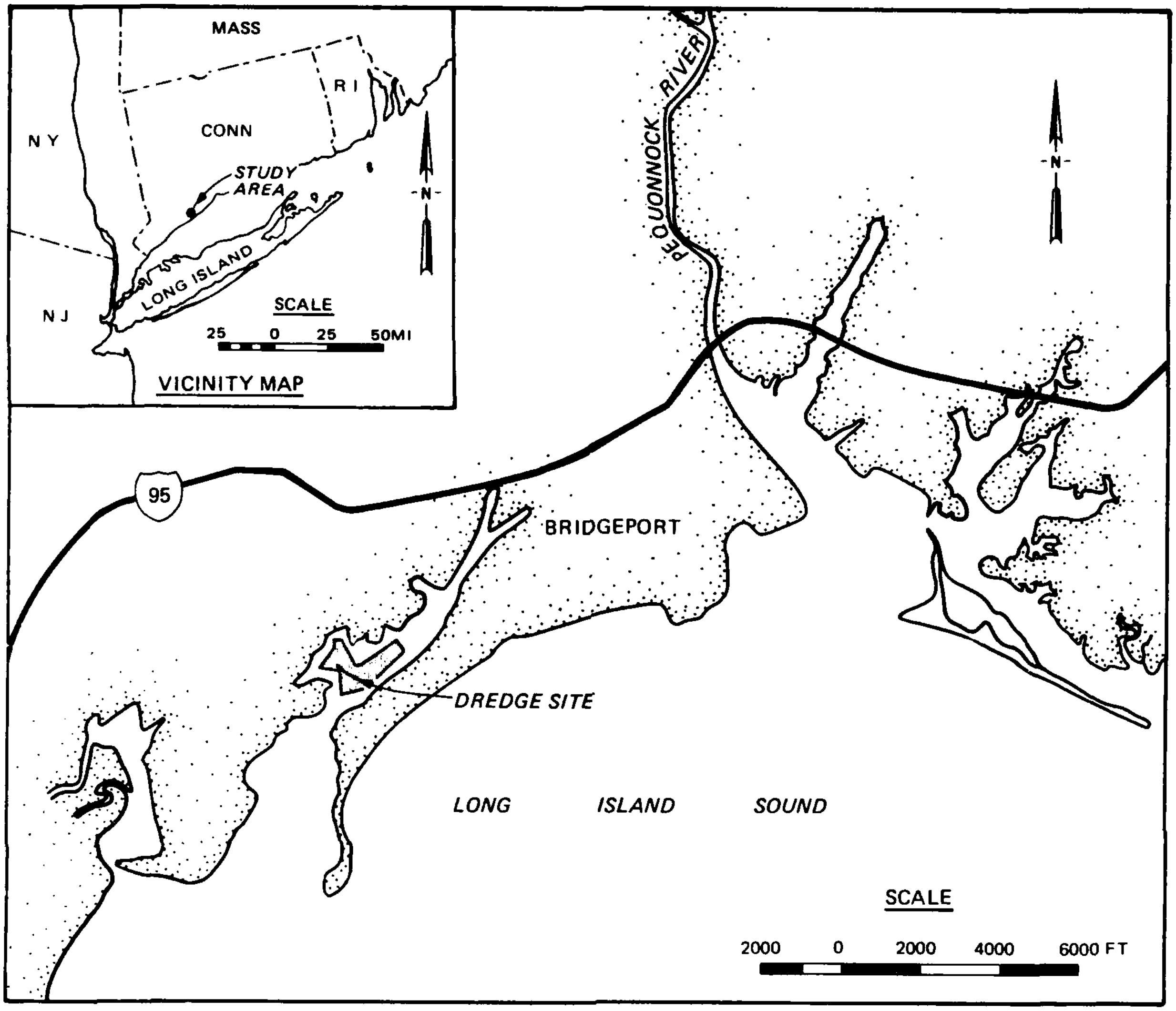

Figure 32. Site location map for the Black Rock Harbor dredging project in Bridgeport, CT

disposal. The average hourly production was 275 yd/hr with an average cycle time of 40 sec.

Data collection

85. Water column sampling during dredging was conducted on 5 and 6 May 1983. Background sampling in the area was conducted on 2 May, during a 12-hr nonoperational period, and at various times on 5 and 6 May when background sampling locations were 2,500 to 5,500 ft upstream of the operation. Figure 33 shows the dredge locations and sample radials used on 5 and 6 May. On 5 May, radial 7 was sampled once during the ebb tide, radial 2 twice during the flood tide, and radial 4 once during the flood tide. Radial 3, which was

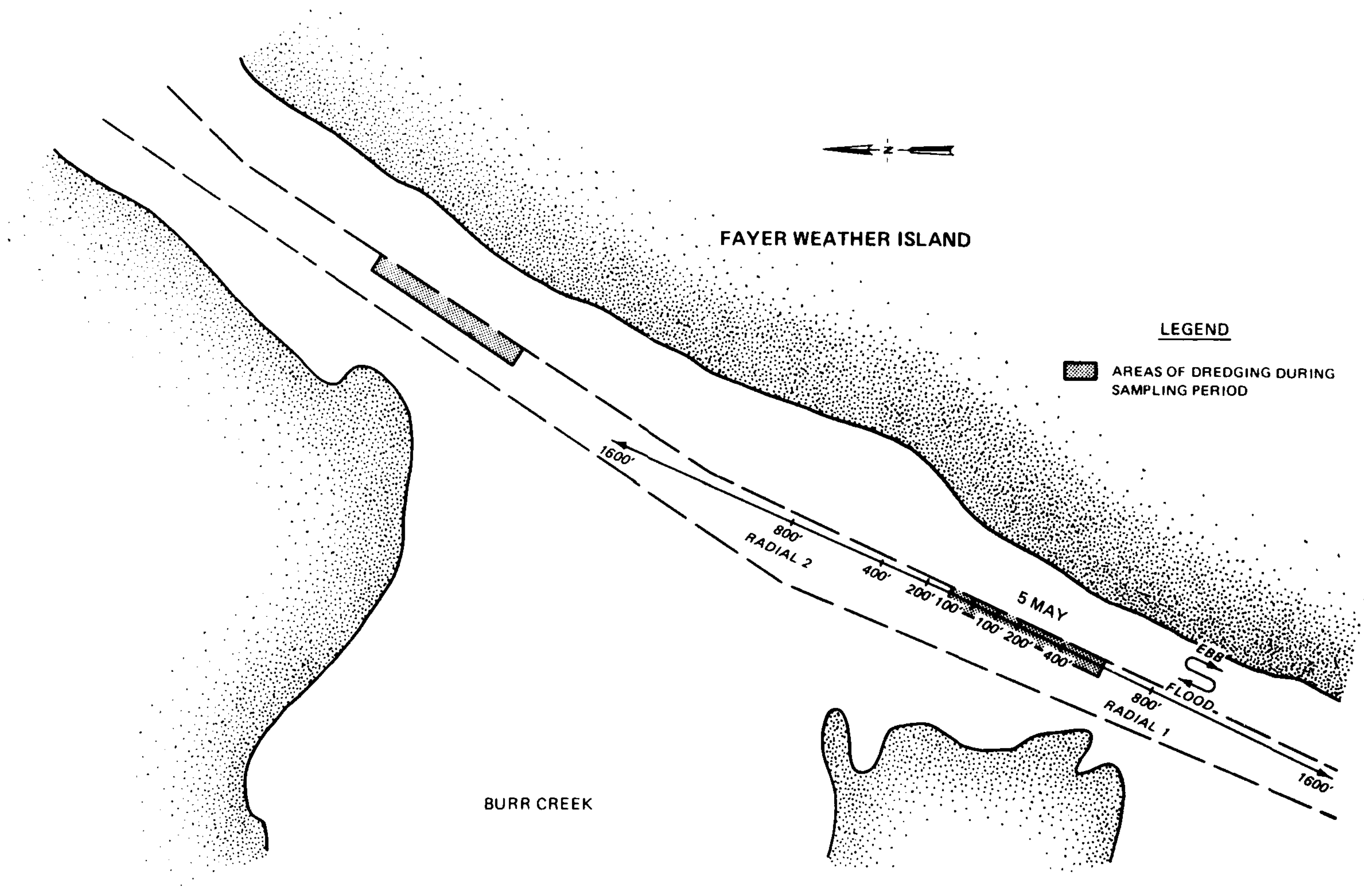

Figure 33. Dredge locations and sample radials used on 5 and 6 May 1983 at Black Rock Harbor, Bridgeport, CT

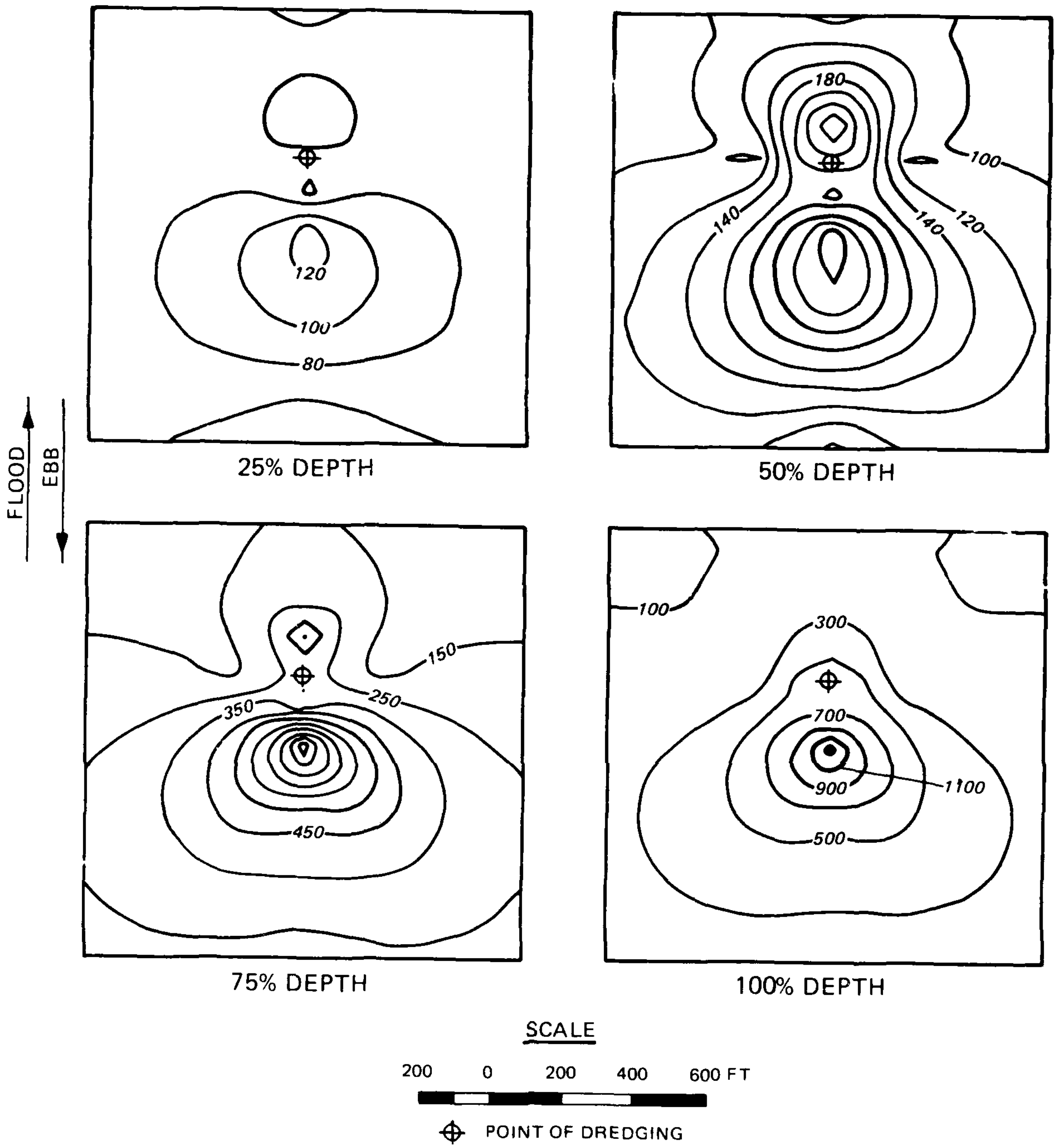

Figure 34. Plan views of resuspended sediment plumes for 25-, 50-, 75-, and 100-percent depths (sediment concentration isopleths are shown)

sampled concurrently with radial 2, was sampled once during the ebb tide as an "out of current" radial. On 6 May, radial 7 was sampled three times during the ebb tide.

Results

86. The average background suspended solids levels for the Black Rock clamshell study ranged from 45 mg/ℓ near the surface to 69 mg/ℓ near bottom. Salinity ranged from 10 to 21 ppt, and the current speed varied from about 0.8 ft/sec during the ebb tidal cycle to about 0.2 ft/sec during the flood. Figure 34 depicts the plume measured around the clamshell operation for the 25-, 50-, 75-, and 100-percent depth increments. The figures represent both ebb (lower portion of the each figure) and flood cycles of the plume. This is the reason for the two apparent plume sources. Since the majority of samples were collected downcurrent of the plume, for any given sample period, this does not represent a "snapshot" of the plume but a depiction of highest plume averages over an entire tidal cycle. The highest sustained contour located near the bottom was 1,300 mg/ℓ or approximately 19 times the background level. Table 10 indicates the plume area over the tidal cycle. These areas are somewhat larger than other studies. The large plume areas were most likely due to the change of current direction during the study. There was no apparent reason, however, for the levels of suspended solids in the water column to be elevated so dramatically. Highest TSS concentrations and greatest plume area were again observed near the bottom. The biggest change in the area of the 4× contour occurs between the 75- and 50-percent depths: the 4× contour area changes 18.5 acres for a reduction of 95 percent. From the bottom to 75-percent depth, the area actually increases by 5 acres for an increase of 34 percent. This increase may have resulted from the surge of material from the bucket when it impacts the bottom or from density-driven currents.

Duwamish Waterway Field Study

Site description and project background

87. Located in a heavy industrial and commercial area near Seattle, WA (Figure 35), sediments in the Duwamish Waterway contain elevated concentrations of heavy metals and chlorinated hydrocarbons. The USAED, Seattle, and WES cooperated in the dredging and disposal of material from a small contaminated shoal (1,100 cu yd) that had reduced the controlling channel depth to 25 ft.

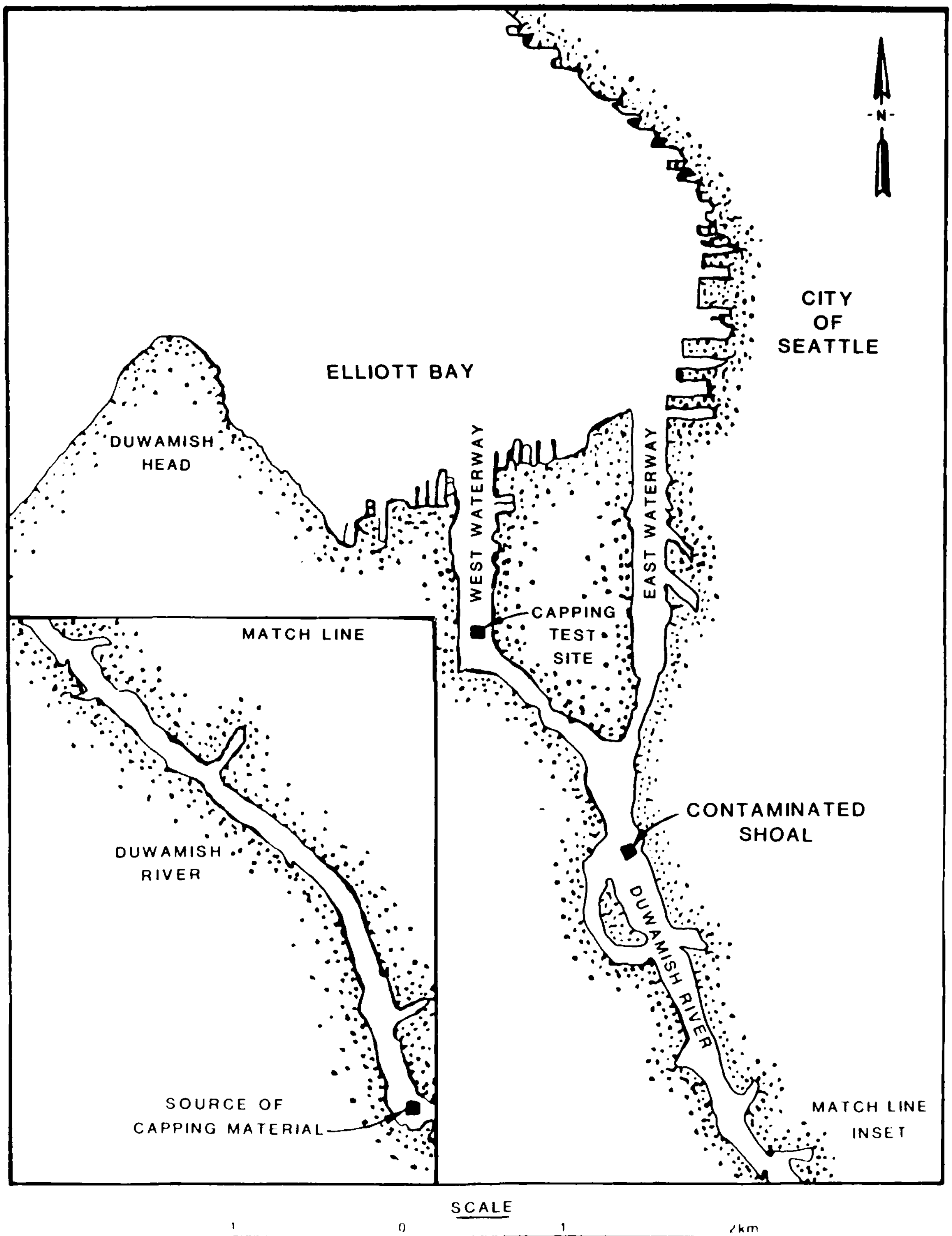

Figure 35. Site location map for the Duwamish Waterway dredging project

Equipment description

88. A conventional clamshell dredge was used to remove the contaminated sandy clayey silt sediments (Sumeri 1984, Truitt 1986). Ambient current speeds were typically under 1 ft/sec. Dredged material was placed into a split-hull, bottom-dumping barge controlled by a separate tug. Overflow was not permitted, and clamshell bucket loads of sediment were carefully placed rather than allowed to free-fall into the barge, to retain sediment cohesive strength and bulk density for subsequent disposal.

Data collection

89. The reader is referred to Part III, paragraphs 33 through 36 for a description of the radial sampling plan.

Results

90. The average background suspended sediment levels varied from 11 mg/ℓ near the surface to 26 mg/ℓ near bottom. Currents ranged from 0.3 to 1.1 ft/sec and the salinity fluctuated between 12 and 21 ppt. Figure 36 depicts the suspended sediment levels measured near the clamshell dredging operation. As with previously described clamshell plumes, the dredging operation affected the entire water column with resuspended sediment concentrations of 20 mg/ℓ evident in 75 percent of the lower water column and stretching for 700 ft near the bottom. The maximum sustained TSS level was 160 mg/ℓ (seven times the background) and was located at 75-percent depth. The Duwamish field study was conducted under controlled conditions and may, therefore, be indicative of lower suspended sediment levels than would be expected from conventional clamshell dredging operations where sediment resuspension was not of concern.

St. Johns River: A Comparison Between a Conventional and an Enclosed Clamshell Bucket Dredge

Site description and project background

91. This field study was conducted in the St. Johns River near Jacksonville, FL, 1982 to directly compare sediment resuspension from conventional and enclosed clamshell dredges. The USAED, Jacksonville, was performing maintenance dredging at Pier Basin 139, US Naval Air Station, Jacksonville (Figure 37). The Florida State Department of Environmental Regulation (DER) required that the Jacksonville District use a special enclosed clamshell

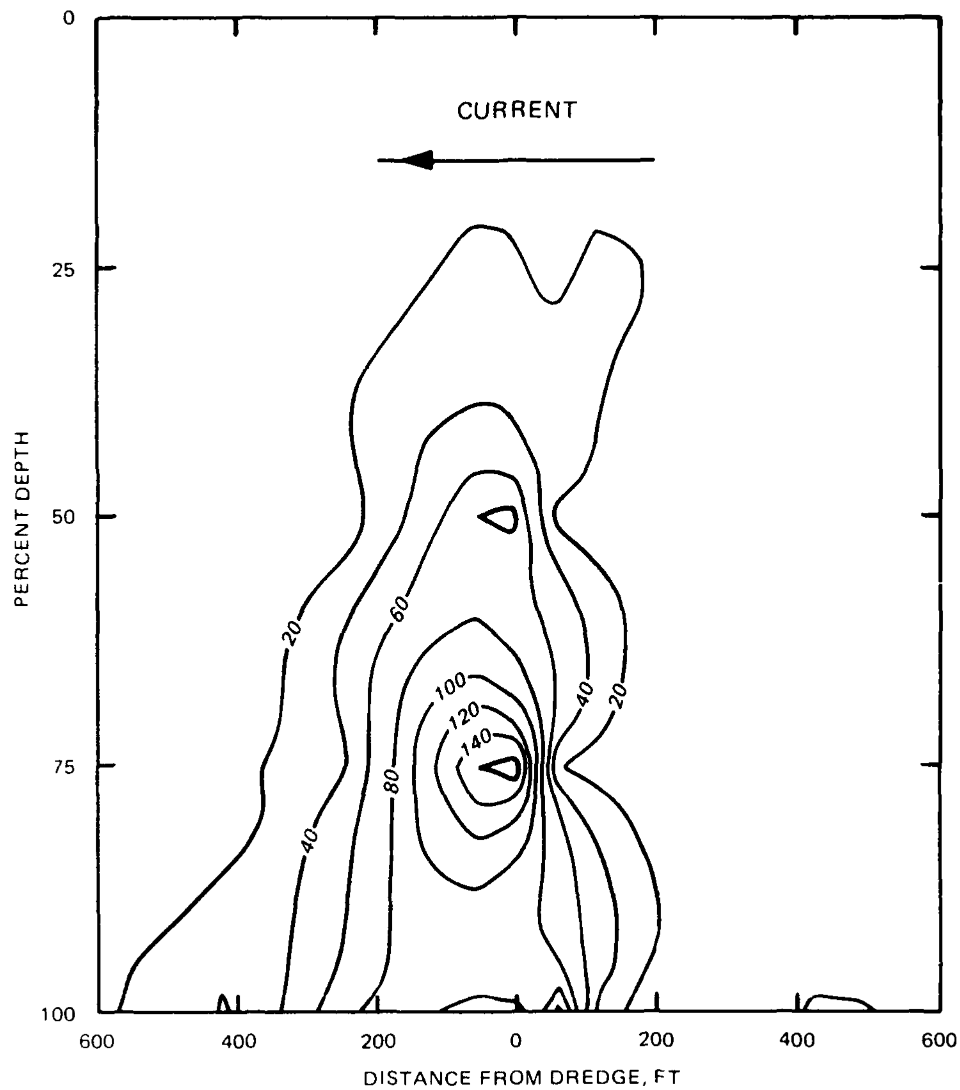

Figure 36. Concentration profiles in a vertical section of the water column collected along a horizontal transect describe a resuspended sediment plume generated by a conventional clamshell dredge operating in the Duwamish Waterway near Seattle, WA

bucket during this project. WES requested and obtained permission from the DER to allow the brief use of a standard open bucket for comparison purposes. Monitoring and sampling of both the enclosed and open bucket operations were conducted on 9-11 February 1982.

92. The dredging work performed during this project was the deepening of the pier basin to 15 ft. The dredge generally operated for approximately 10 hr a day (0700 to 1700). This operating schedule allowed a certain amount of flushing by tidal currents during "nondredging" hours. During the period

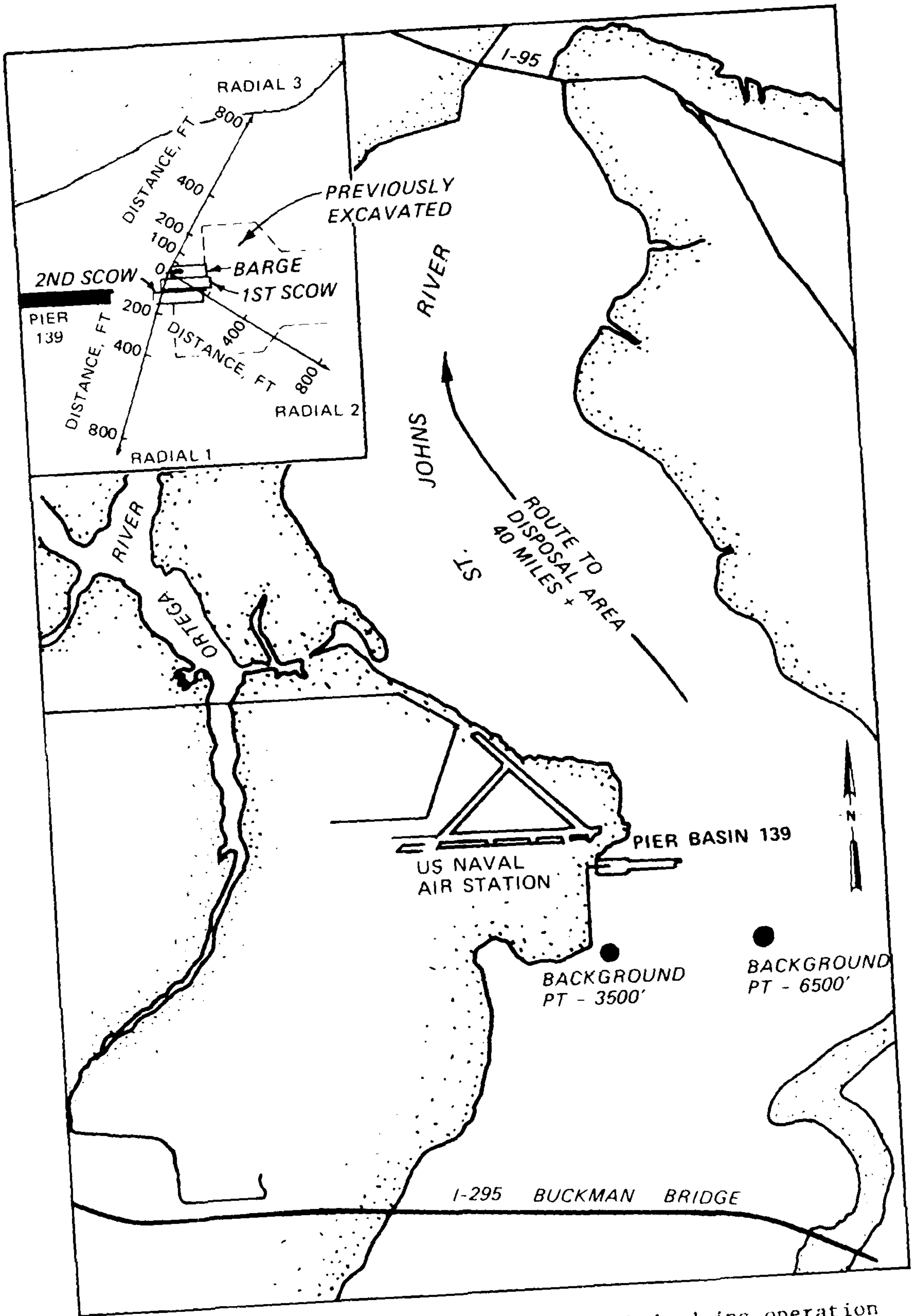

Figure 37. Location map of the clamshell dredging operation at the US Naval Air Station, Jacksonville, FL

of sampling, the nondredging hours coincided with the maximum ebb tide. Subsurface data accompanying the bid invitation characterized the bottom as silt (MH) with a specific gravity of 2.4 and black in color. Ninety-eight percent of the sediment was finer than 0.062 mm.

Equipment description

93. The enclosed bucket used was a modified Yawn-Williams 13-cu-yd clamshell type bucket. The modification consisted of welding side and top plates onto a standard bucket. The edge of each half was lined with rubber to assure a watertight seal. A rectangular opening was left in the top of the box for the pulley, and to allow air to escape during submersion. The contractor estimated that the addition of the sides and top probably increased the bucket's capacity to approximately 15 cu yd. The nonenclosed open clamshell bucket used on 10 February was a standard 12-cu-yd Yawn-Williams bucket.

94. The excavation was accomplished using standard bucket dredging procedures. Once anchored, the bucket was positioned above the water and lowered open onto the material to be dredged. The operator found that the watertight bucket had to be lowered more slowly at the start of the descent to allow the air trapped in the bucket to escape. Penetration of the sediment was achieved solely by means of the bucket's weight. Once the jaws were closed, the bucket was lifted to the height of the scow, swung over to the scow, and emptied. The bucket was then positioned adjacent to the previous excavation point and lowered for another grab. Due to the shallow water depth, this cycle of lowering, digging, raising, swinging, dumping, and returning took only approximately 45 sec. The dredge would clear a cut about 60 ft wide before moving forward 4 or 5 ft to the next cut. The dredge usually went over a cut twice to ensure proper depth. No sweeping was done in order to keep resuspension to a minimum.

Data collection

95. The sampling radials and background sampling radials used during data collection are shown on Figure 37. Data collection was based on the previously described sampling methodology. Due to the shallow depths, fewer samples were taken than originally planned. Additionally, the location of the barges made sampling more difficult. Background samples were collected each day at locations 3,500 ft south of the operation along the shoals, and 6,500 ft southeast in the main ship channel. All samples taken were returned to WES for gravimetric analysis. Monitoring of the enclosed bucket was

conducted on 11 February, with monitoring of the open bucket occurring on 10 February. As indicated earlier a 12- to 14-hr period of "nondredging" preceded each sampling day.

Results

96. Average suspended sediment levels were 47 mg/ℓ near the surface and 72 mg/ℓ near the bottom for the St. Johns River clamshell study. Current measurements remained below 0.2 ft/sec. Figures 38 and 39 depict the plume contours for the open and enclosed clamshell operations, respectively. Both plumes affect the entire water column with area and concentrations increasing from surface to bottom. Comparing the two sets of figures, the open bucket (Figure 38) consistently had higher concentration than the enclosed bucket (Figure 39), but the enclosed bucket influenced a greater area. The highest sustained contour for the open clamshell were 480 mg/ℓ, 6.7 times background, and 360 mg/ℓ, 5 times background, for the enclosed bucket. Table 11 provides a direct comparison between the open and enclosed bucket.

97. Table 11 shows that near the bottom the enclosed bucket influenced an area 5.9 acres (24 percent) greater than the open bucket. This may have been a result of the additional shock wave created by the enclosed bucket as it moved through the water column. The enclosed bucket did have lower levels of suspended sediment near the point of dredging which indicated that less material was lost as the bucket moved through the water column.

Summary of Results for Bucket Dredges

98. Bucket dredge monitoring operations involved four field studies that included conventional open clamshell buckets and enclosed clamshell buckets. Studies were conducted at Calumet River, IL; Black Rock Harbor, CT; St. Johns River, FL; and Duwamish Waterway, WA. Table 12 shows a summary of the results from these field studies.

99. From inspection of Table 12 plus review of the individual clamshell studies, it is evident that the concentration level and size of the dredge-induced plumes were highly variable. All the clamshell operations do, however, affect the entire water column with the TSS levels decreasing from surface to bottom. The sharpest increase in TSS always occurs near the bottom, the 75-percent level and below, indicating that the majority of the

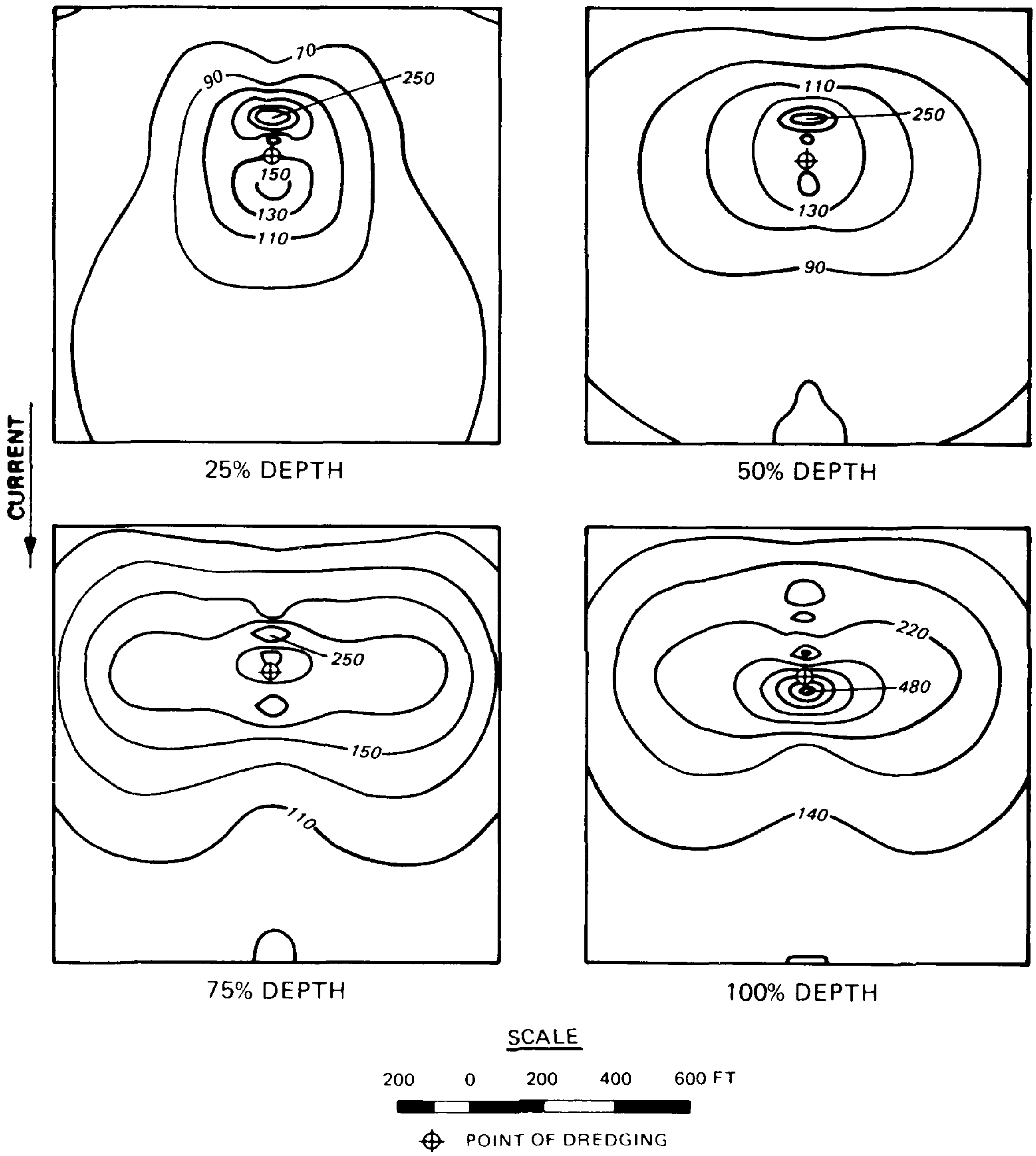

Figure 38. Plan views of resuspended sediment plume from conventional clamshell dredging at the St. Johns River field site; concentration isopleths are shown for 25-, 50-, 75-, and 100-percent depths

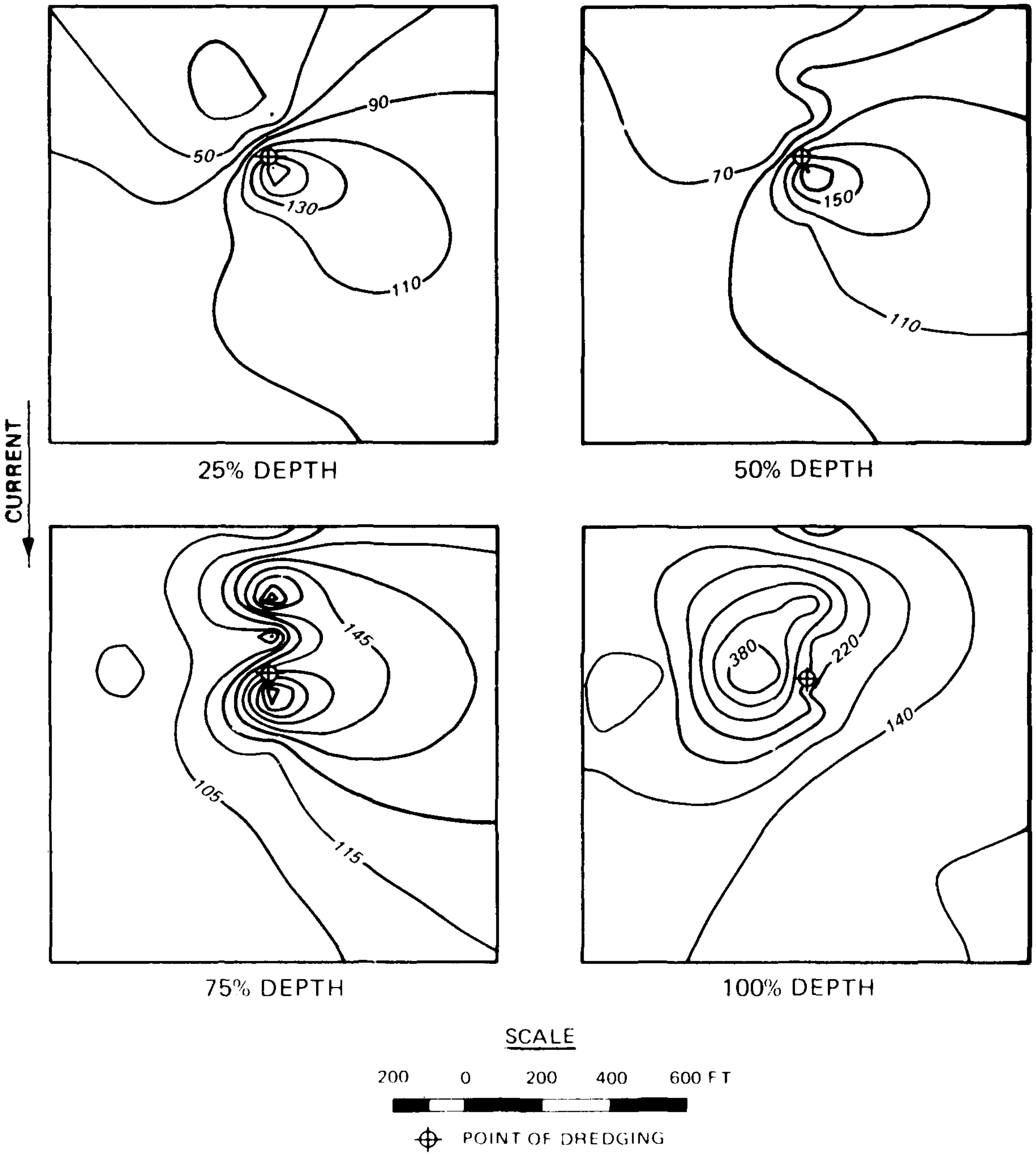

Figure 39. Plan views of resuspended sediment plume from an enclosed clamshell dredging at the St. Johns River field site; sediment concentration isopleths are shown for 25-, 50-, 75-, and 100-percent depths

sediment resuspension occurs from the impact, with penetration, into and removal of the bucket from the bottom.

100. In addition to the conventional clamshell field studies, a direct comparison between an enclosed and open bucket was conducted in the St. Johns River study. Table 12 shows that the enclosed bucket was successful in reducing the concentration of the suspended sediment plume but produced a larger plume than the conventional clamshell. The reason for increased plume size was probably due to the increased shock wave that precedes the enclosed clamshell bucket as it impacts the bottom. The enclosed bucket was more successful in reducing sediment resuspension in the upper water column because spillage was reduced as the enclosed bucket was brought through the water column.

101. Results of the field studies confirm that the majority of resuspension from clamshell dredging is a result of the impact, penetration, and withdrawal of the clamshell from the bottom. The results also show that TSS concentrations several times background levels can be expected throughout the water column for any clamshell operation. A direct comparison between an enclosed and open clamshell bucket also suggests that the enclosed bucket helps to reduce TSS levels in the upper water column but may increase the overall size of the plume.

PART VI: HOPPER DREDGE FIELD STUDY

102. This part describes a field study where the sediment resuspension characteristics of a large hopper dredge were examined during periods of overflow and periods when overflow was not allowed. The results of these test periods are presented and a summary and comparison of the sediment resuspension appears at the end of this part.

Site Description and Project Background

103. To measure the suspended sediment plume generated by a seagoing hopper dredge, WES, in cooperation with the USAED, Seattle, conducted tests around ongoing dredging operations in Grays Harbor, WA. Dredging was underway to remove shoaled material from the navigation channel near the Port of Grays Harbor, Aberdeen, WA (Figure 40). During the study period different dragheads were tested to compare their production capabilities. The dragheads tested were the IHC California draghead, the BIDDLE California draghead, and the Portland Mud draghead (Case, Walley, and Perkins 1984).

Equipment Description

104. The US Army Corps of Engineers hopper dredge ESSAYONS is a bottom dump trailing suction arm hopper dredge, which is propelled by twin 3,000-hp diesel engines with controllable pitch propellers. It has a 6,000 cu yd hopper capacity, a 365-ft length, and a 68-ft beam. The dredging system consists of a 1,450-hp pump mounted on each 28-in. drag arm. The ESSAYONS was removing a deposit of sandy silt material (ML) during this dredging operation.

105. During the study period the dredge was allowed to economically load and overflow. The ESSAYONS would normally take 10 to 15 min to reach overflow conditions and would continue dredging another 10 to 15 min thereafter. The ESSAYONS is equipped with overflow ports located below the waterline. Normal operation for the dredge was to dredge upstream, turn and continue dredging downstream until the hopper was full, and then depart for the disposal site. Round trip to the disposal site took 1-1/2 to 2 hr. The dredge operated in this reach only during daylight hours from 0630 to 2000 hr.

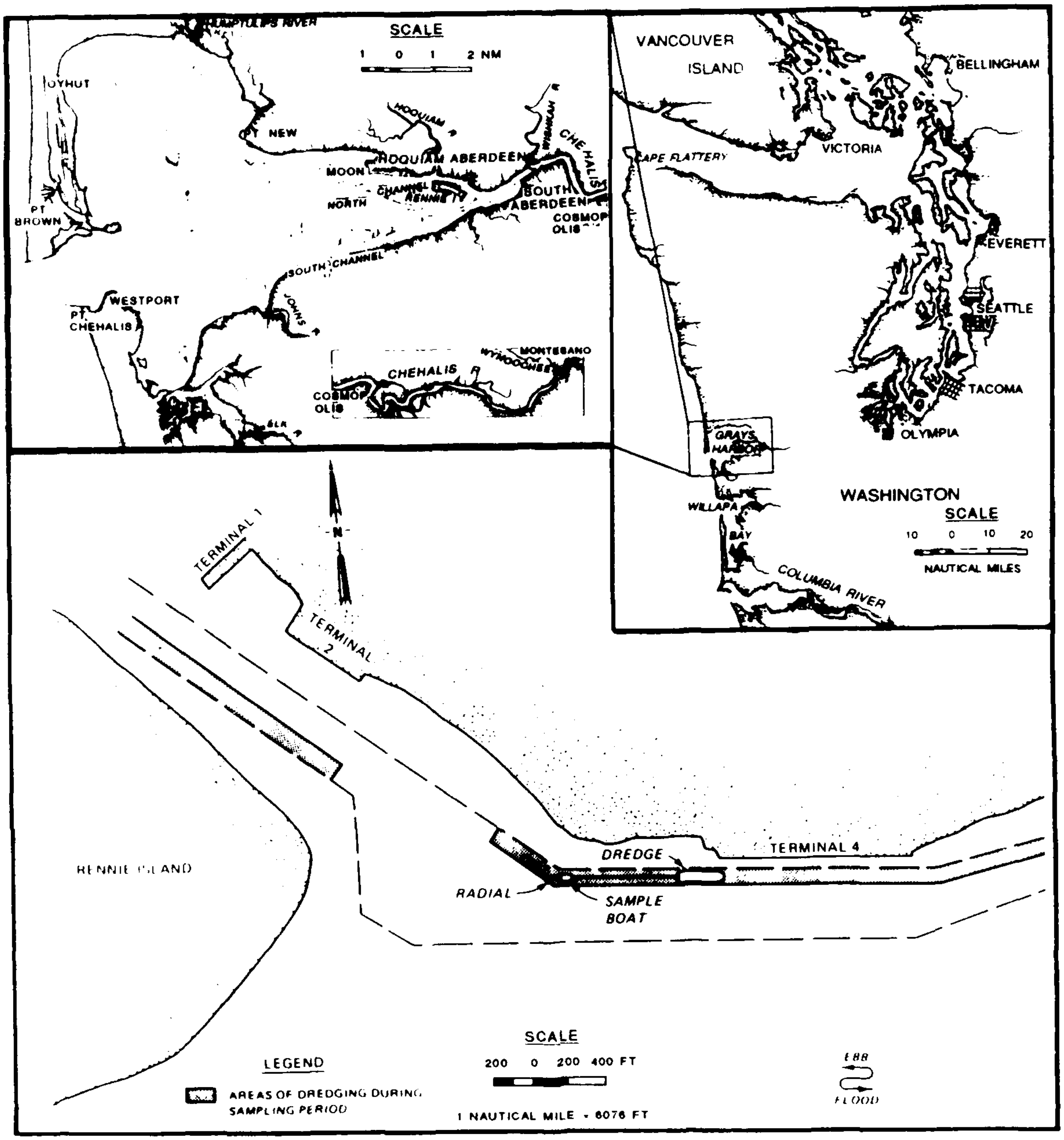

Figure 40. Hopper dredge field study, Grays Harbor, WA

Data Collection

106. Sampling of the suspended sediment plume began on 1 November 1983 and continued on 2, 3, 5, 6, 8, 9, and 10 November. The dredge was operating in the reaches shown in Figure 40. Obtaining representative samples was made difficult by the approximately 11-ft tide range. This large tide range meant

that measurements of salinity and current velocity and direction had to be frequent enough to describe the hydraulic regime in the area.

107. Sampling of the suspended solids plume at Grays Harbor consisted of collecting discrete water column samples at stations located near the dredging operation. This also included collection of background samples so that the plume samples could be normalized under the varying hydraulic conditions that occurred. Two sampling schemes were incorporated into the monitoring effort. One was to anchor the sample boat and obtain samples to observe the growth and decay of the plume at the fixed location. This effort included several cycles of positioning the sample boat within 50 ft of the stern of the dredge, anchoring, and sampling at intervals to measure plume decay. The second sampling scheme was to shadow the dredge, maintaining a constant distance between the sampling boat and the dredge while samples were collected. These sampling procedures are somewhat different than outlined in Part III so a more detailed description of the sampling effort follows.

108. For the first sampling scheme, the sample boat would align itself so that the dredge would pass from 50 to 400 ft from the anchor position. Discrete water samples were collected at three to four locations (near surface, middepth and near bottom) to describe background conditions. As the hopper dredge approached, samples were collected continually to measure the suspended solids plume generated by the hopper dredge. The second phase of this sampling scheme was to approach the dredge from the rear and anchor as close as possible to the operating dredge. Water samples were then collected (near surface, middepth, and near bottom) to describe the plume. By measuring the distance the dredge moved during the sample period, the length of the plume could be determined.

109. The second sampling scheme consisted of maintaining a constant distance behind the dredge. The sample boat would move behind the dredge and obtain samples at varying depths. This method was used to establish the varying suspended solids levels in the water column at a constant distance behind the dredge.

110. All water samples, currents, and salinity measurements were collected from a 20-ft sample boat. Water samples were collected using either a centrifugal pump with a long flexible tube or a van dorn water sampler. Water column samples were collected either in the channel before the dredge passed or when the sample boat anchored and waited for the dredge to pass.

Background samples were collected near surface, middepth, and near bottom. Often samples would be collected at one or two additional depths if the water was sufficiently deep.

111. Observations aboard the dredge included the position of the drag-arms, clock times dredging began and ended, dredge speed (anywhere from 1.5 to 5 knots), and time and duration of overflow.

112. The distance to the dredge was measured by a hand-held range finder. A check on these distances was made by noting the time-duration of distance measurements and the speed of the dredge. By multiplying the speed of the dredge by the time between readings the distance the dredge traveled could be calculated.

Data Analysis

113. Preliminary results from this study and others (Smith and Phipps 1983) indicated that the background TSS levels and current speeds were highly variable in the Gray's Harbor region. As mentioned in paragraph 105, the dredge would also turn while dredging and cover the same reach before TSS levels could return to background. This method of dredging together with the already variable background conditions suggested that the data analysis routine needed to be slightly altered. To normalize the data, the background concentration was subtracted from TSS plume data before the plotting routine was implemented. Background levels were established the samples collected immediately before each dredge pass. The data analysis routine mentioned in Part III was then implemented to derive plots of the normalized plume data for overflow and nonoverflow conditions.

Overflow Results

114. The currents measured during the Grays Harbor field study ranged from 0.4 to 2.5 ft/sec, and the salinity ranged from 1 to 20 ppt. Background suspended sediment concentrations during the overflow portion of the study ranged from 8.0 to 104.7 mg/ℓ near the surface and 21.5 to 236.3 mg/ℓ near the bottom. The relatively high background levels of TSS for some of the observations occurred after the dredge had turned, and elevated levels of TSS still existed.

115. Figure 41 depicts the TSS plume generated during overflow. The plume extended for over 7,000 ft at levels of 100 mg/ℓ above background. Most of the material evidently fell through the water column and reached the bottom 3,000 to 4,000 ft behind the dredge. Elevated concentrations of TSS persisted up to 1 hr after completion of the dredging operation.

Nonoverflow Results

116. Background TSS levels ranged from 7.7 to 35.8 mg/ℓ near the surface and 25.8 to 89.3 mg/ℓ near the bottom. Figure 42 shows the plume generated by the nonoverflow portion of the dredging operation. This plume represents resuspension generated by the ESSAYONS' drag arms and propwash. As Figure 42 indicates, the plume remains in the lower 50 percent of the water column and extends for approximately 3,000 ft. The average background TSS level during this field study was 54 mg/ℓ so the 50-mg/ℓ isopleth represents an overall concentration of approximately twice the background. The 3,000-ft length corresponds to a 20-min duration period of the plume based on an average dredge speed of 2.5 ft/sec.

Comparison of Nonoverflow to Overflow

117. Comparison of Figures 41 and 42 clearly shows the impact of overflow during hopper dredging. The overflow plume is twice as long, and the maximum TSS concentration is 16 times greater than nonoverflow conditions. The comparison also indicates that resuspended sediment from the overflow affects a greater portion of the water column for a greater period of time. Table 13 shows a direct comparison between the overflow and nonoverflow plume. From the table the effect of resuspended sediment from the overflow on water quality and duration of the plume is obvious. From these results it is clear that when sediment resuspension must be controlled during a hopper dredging operation, overflow control measures must be used.

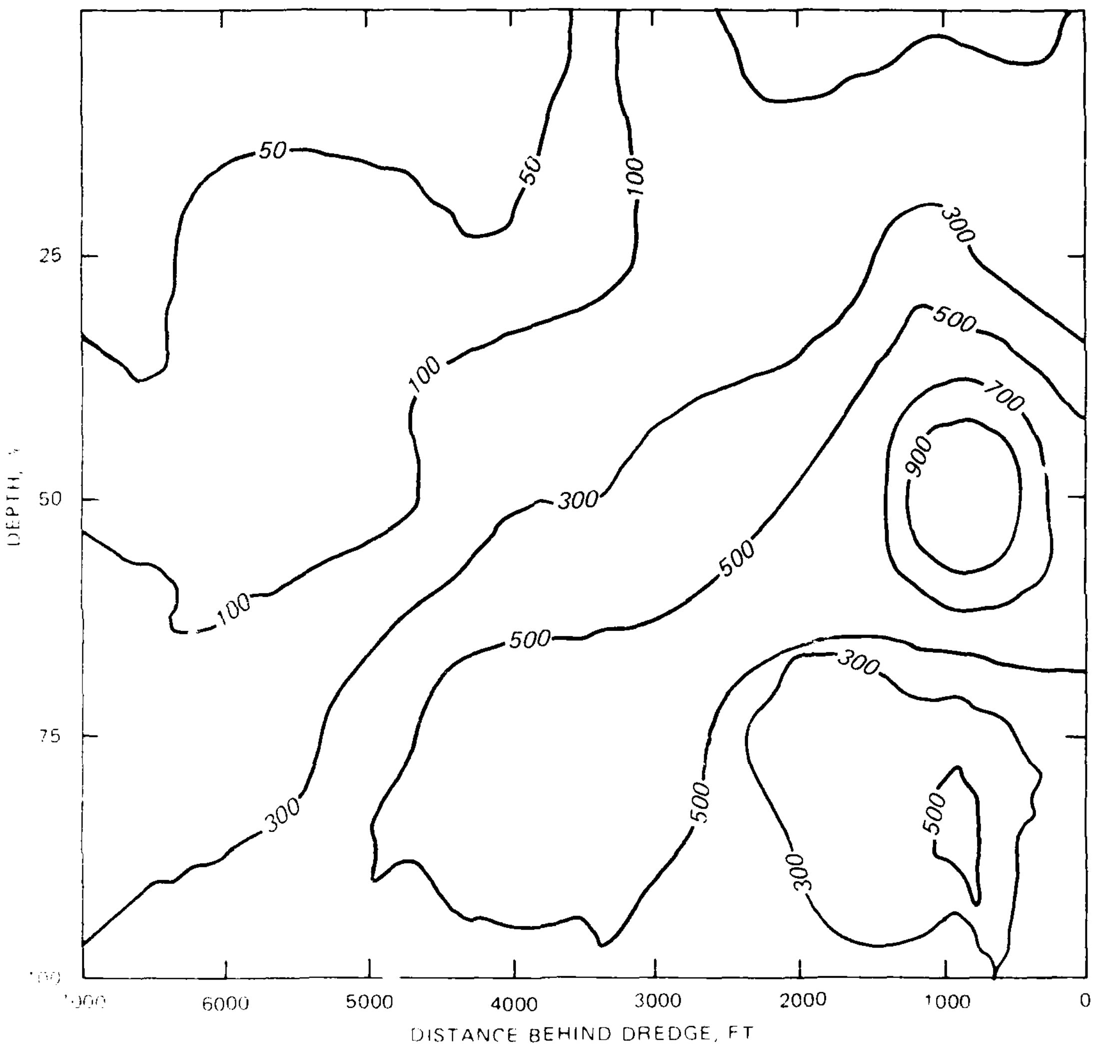

Figure 41. Concentration profiles in a vertical section of the water column directly behind a hopper dredge during overflow operations in Grays Harbor, WA

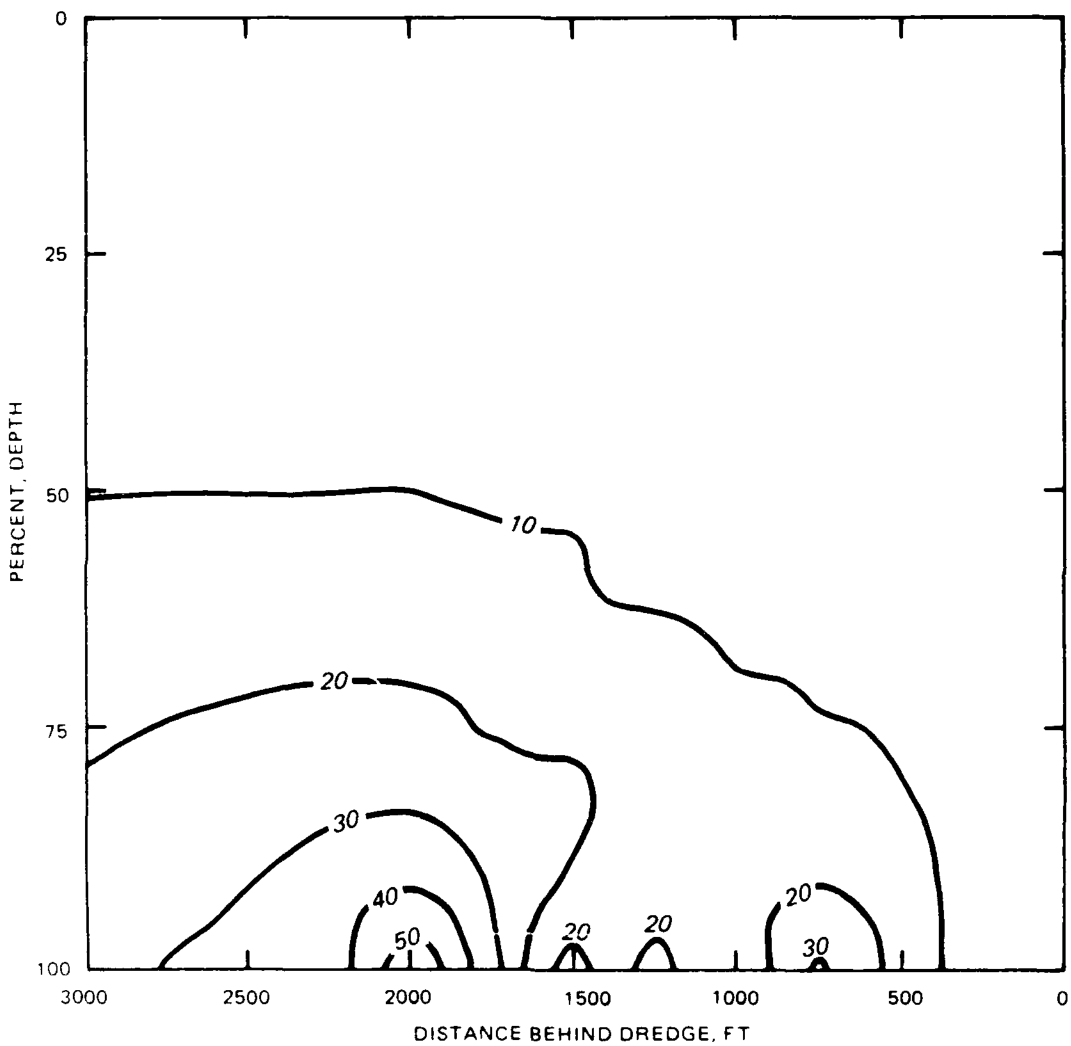

Figure 42. Concentration profiles in a vertical section of the water column directly behind a hopper dredge during nonoverflow operations in Grays Harbor, WA

PART VII: SUMMARY

118. Through the IOMT research program and in cooperation with District and Division offices in the Corps of Engineers, WES has measured the suspended sediment plumes resulting from several conventional and nonconventional dredge operations. Preliminary work has also been conducted to define the effects of various operational parameters on the source strength of these plumes. The types of dredges monitored during these research programs include hydraulic pipeline, bucket, and hopper dredges.

119. The suspended sediment plumes in these studies were represented by total suspended solids (TSS) concentration. To measure TSS, discrete water samples had to be collected around each dredging operation to delineate the suspended sediment plume. Background TSS, current, and dredge operation parameters were also collected to help define sources of the sediment plume. The suspended sediment data collected from the field studies were vertically and temporally averaged using a method developed by Hayes, McLellan, and Truitt (1985). A brief description of the site, background conditions, and dredging operation is given in Table 14 for all of the field studies. Software developed by the Golden Graphics System (1984) was used to plot isoconcentration contours based on the averaged TSS data to define the TSS plume surrounding the dredging operation. All field studies were conducted in areas with primarily fine-grained sediments. Since grain size has a substantial impact on resuspension, the resulting plume may vary accordingly.

Hydraulic Pipeline Dredges

120. Hydraulic pipeline monitoring operations were performed at Calumet Harbor, IL; Savannah River, GA; and James River, VA. Each project involved a cutterhead dredge for comparison purposes. In addition, a matchbox dredge was used at Calumet Harbor, and a modified dustpan head was used at James River. Results presented in this report show that hydraulic pipeline dredges resuspend sediment mainly in the lower portion of the water column. The hydraulic pipeline dredges elevate the background suspended sediment concentration from [illegible].8 to [illegible].8 times the background concentration (Table 14). The cutterhead dredges proved to be the most consistent hydraulic pipeline dredges in reducing resuspension and limiting the plume to the lower portion of the water

column. Direct comparisons between cutterhead dredges and a matchbox dredge and a modified dustpan dredge did not indicate that the specialty dredges reduce the suspended sediment plume substantially over the cutterhead. However, with improved instrumentation and increased leverman experience, the matchbox head may limit resuspension to that of the cutterhead dredge.

Bucket Dredges

121. Bucket dredge monitoring operations occurred at Calumet River, IL; Black Rock Harbor, CT; Duwamish Waterway, WA; and the St. Johns River, FL. Each project included a conventional clamshell dredge with the St. Johns River study also using an enclosed clamshell bucket for comparison purposes. The clamshell buckets generated a plume several times that of the ambient background TSS levels. This plume affects the entire water column and can increase TSS levels 6.1 to 15.9 times the ambient TSS concentrations near the bottom. A direct comparison between an enclosed and open clamshell bucket at a site in the St. Johns River showed that the TSS concentration was reduced in the upper water column while the lower water column plume size increased for the enclosed bucket.

Hopper Dredges

122. One hopper dredge study was performed at Grays Harbor, WA. The study was designed to determine the effects of overflow on the subsequent suspended sediment plume. The results of the field study show that the nonoverflow portion of the dredging operation generates very little suspended sediment, less than 50 mg/ℓ, while the overflow portion generated levels up to 800 mg/ℓ (Table 14). The overflow plume also affects the entire water column and can obtain lengths up to 7,000 ft. The nonoverflow plume affects only the lower water column and extends for approximately 3,000 ft.

Comparison of Conventional Dredge Resuspension Plumes

123. From inspection of Table 14, it is evident that the concentration of sediment resuspended by a dredge is partly site specific. However, expected ranges and trends of sediment resuspension for the various dredge types can be inferred from observations and used for comparison purposes. To

facilitate these inferences, Table 15 was constructed using data presented in other parts of this study. Table 15 shows the maximum concentration of the suspended sediment plume at the depth increments for which observations were made. Table 15 also shows the ratio of the plume concentration to the background concentration for each depth.

124. As mentioned in PART IV, the majority of the cutterhead plume is located near the bottom. The ability of the cutterhead to limit resuspension in comparison to the clamshell or hopper dredge is evident in Table 15. For the cutterhead dredge, the ratio of maximum to background TSS concentration does not go above 3.0, and 6 percent of all the maximum concentration ratios are equal to or below 2.0. For the clamshell dredges, 80 percent of the maximum to background concentration ratios are above 3.0 and all of them are above 3.0 for the hopper dredge with overflow. The only conventional dredge that compares favorably with the cutterhead dredge is the hopper dredge without overflow.

125. To facilitate a comparison between conventional dredges operating under normal procedures, Figure 43 was developed. This figure shows the maximum TSS contour levels observed during the monitoring program. The dotted line indicates background TSS concentrations for the study. In the upper water column, the cutterhead dredge showed a slight advantage in limiting resuspension over the clamshell and hopper dredge. This advantage increased in lower parts of the water column. Near the bottom, the clamshells and hopper dredge suspended four to six times more sediment than the cutterhead dredges. The clamshells and hopper dredge resuspended similar amounts of sediment in the upper water column, but the clamshell dredges tended to resuspend 1.5 to 2 times the material in the lower portion of the water column (75-percent depth and below) than the hopper dredge.

126. Another consideration in defining dredge resuspension characteristics is the duration of the plumes at elevated suspended sediment concentrations. These elevated levels will persist as long as the dredging operation is in progress. A cutterhead or clamshell dredge may dredge continuously 24 hr a day until the project is complete, while a hopper dredge normally dredges for 30 to 60 min and then transfers the material to the disposal site. Time to travel to the disposal site and return may be anywhere from 30 min to 3 hr, allowing time for the suspended sediment levels to return to near ambient conditions.

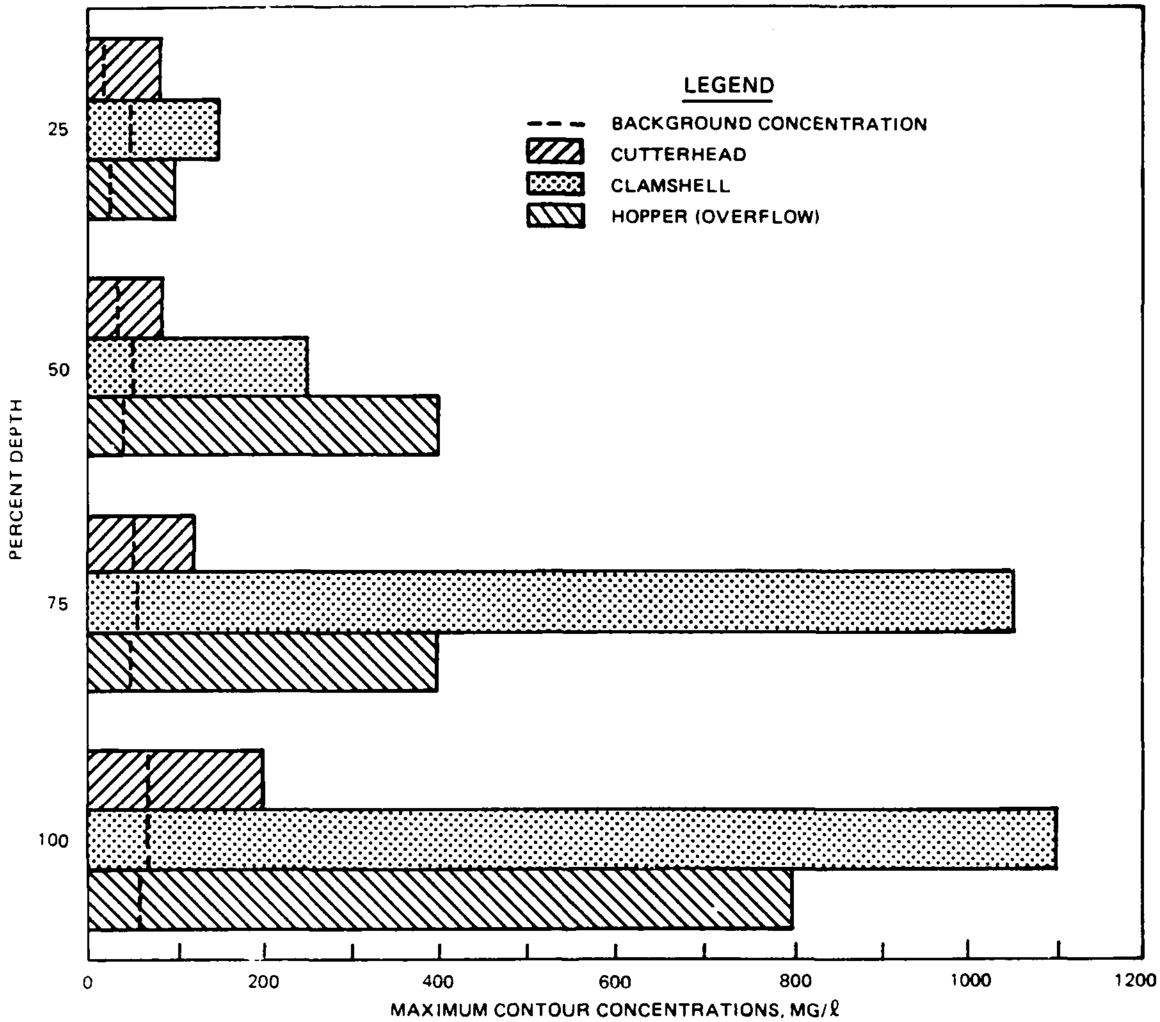

Figure 43. Maximum TSS contour levels encountered for cutterhead, clamshell, and hopper dredges during field studies

127. Eight field studies were conducted to investigate sediment resuspension characteristics of conventional and nonconventional dredges. Dredge types investigated included cutterhead, enclosed clamshell, open clamshell, hopper, modified dustpan, and matchbox dredges. Of the conventional dredges, the cutterhead dredge had the lowest plume TSS concentrations followed by the hopper dredge with clamshell dredges having the highest TSS concentrations. TSS concentrations in the hopper dredge and clamshell dredge plumes were four to six times higher than TSS concentrations from the cutterhead dredge. Direct comparisons between the cutterhead, matchbox, and modified dustpan

failed to show significant advantages of using the specialty dredges to reduce sediment resuspension. With improved instrumentation, however, the matchbox dredge may be able to substantially reduce resuspension. Direct comparison between an enclosed and open clamshell showed that the enclosed bucket reduced TSS concentration but produced a larger suspended sediment plume in the lower parts of the water column.

PART VIII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

128. Based on the results from the IOMT field studies the follow conclusions can be drawn:

- a. The major factors in sediment resuspension during a cutterhead dredging operation are the swing speed, depth of burial of the cutterhead below the bottom, and cutter rotation speed. Proper controls of these parameters during a cutterhead dredging operation can help reduce sediment resuspension.
- b. During a clamshell dredging operation, the major factors influencing the amount of sediment resuspension are the impact, penetration, and withdrawal of the bucket from the bottom. Additional losses of material occur when the bucket is lifted through the water column. Some resuspension control can be accomplished during a clamshell operation by the use of an enclosed bucket, limiting the speed of the bucket through the water column, and eliminating the practice of "sweeping" the bottom to smooth it out.
- c. The majority of sediment resuspension during a hopper dredging operation occurs while the dredge is economically loading (overflow). Additional sediment resuspension occurs due to the dragheads on the bottom and propwash. Sediment resuspension can be limited by reducing slurry pumping into the hopper during overflow periods or by not allowing overflow at all.
- d. Of the conventional dredges tested, the cutterhead was the most successful in limiting sediment resuspension. It was followed by the hopper dredge, and then by the clamshell dredge. Modifications such as overflow prevention or use of an enclosed bucket may improve the resuspension characteristics of the hopper and clamshell dredges.
- e. Comparisons between a cutterhead and a modified dustpan and a cutterhead and matchbox dredge failed to show reduction in sediment resuspension for the specialty dredges. However, with improved instrumentation and increased operational experience, use of these or similar dredges may help to decrease sediment resuspension.

Recommendations

129. Evaluations of dredging equipment and field test studies reported in this document suggest that the following areas of research receive

attention with the goal of reducing sediment resuspension at the point of dredging:

- a. Source strength models should be developed and tested for conventional and specialty dredges. These models will probably take the form of empirical equations composed of relevant dimensionless variables. Dredgehead suspended solids concentration measurements collected with accurate dredge operational data are necessary to adjust and test these important models.
- b. Review literature should be reviewed and mathematical models of plume transport should be adapted to route resuspended sediment. These models require rate of sediment mass resuspension as input from source strength models.
- c. In order to extend sediment resuspension information to predict contaminant release to the water column, laboratory test methods should be used in conjunction with mathematical models of chemical sorption and sediment and contaminant dispersion.
- d. Items a, b, and c should be integrated into a model for predicting the effects of dredging on ambient water quality. A simplified mathematical model should be developed and tested for general use by engineers to evaluate dredge selection and operation when dredging contaminated sediments.

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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
24 Oct 85	1	0,830	1,200	0.7	27	4,200
	2	1,200	1,530	0.7	20	3,200
25 Oct 85	3	0,800	1,130	0.7	15	4,300
	4	1,130	1,500	1.1	15	4,200
26 Oct 85	5	0,800	1,130	1.1	20	5,300
	6	1,130	1,500	1.1	27	4,600

Table 2

Operational Parameters for the Matchbox Test Periods

Date	Test Period	Beginning Time	Ending Time	Swing Speed ft/sec	Flow Rate gpm
21 Oct 85	1	1,025	1,410	0.6	4,200
22 Oct 85	2	0,935	1,140	1.3	4,300
22 Oct 85	3	1,210	1,515	0.5	4,200

Table 3

Dredgehead Sample Data for the Calumet Harbor Demonstration Study*

Date	Day	No. of Samples	$\bar{X}$ mg/ℓ	σ	Min mg/ℓ	Max mg/ℓ
24 Oct 85	1	102	8.34	8.0	0.0	60.0
25 Oct 85	2	102	6.6	9.4	0.0	57.0
26 Oct 85	3	96	14.1	12.6	0.0	84.0
Overall mean			9.6			

* Samples from dredgehead sampling apparatus were analyzed for each day and corrected for background concentrations.

Table 4

Area Affected by Resuspended Sediment Plume, for Various Depths, at Calumet Harbor

Dredge	Concentration*	Plume Area, acres 25% Depth	50% Depth	75% Depth	100% Depth
Cutterhead	2× background	0.7	0.4	1.03	0.74
	4× background	0	0	0	0
	6× background	0	0	0	0
Matchbox	2× background	0	0	0	10.5
	4× background	0	0	0	0
	6× background	0	0	0	0

* Background multiplier indicating relative plume TSS concentration.

Table 5

Dredgehead Sample Data for the Savannah Cutterhead Study*

Day	No. of Samples	$\bar{X}$ mg/ℓ	σ	Min mg/ℓ	Max mg/ℓ
1	38	148.8	268.7	11.7	911.3
2	30	244.4	203.2	26.0	877.7
3	12	777.6	481.8	118.6	1,964.5
4	43	301.3	281.0	10.9	914.8
5	43	153.0	112.6	22.8	572.9
6	28	282.8	268.7	44.7	1,106.7
7	27	317.3	180.5	91.5	748.1
8	58	111.5	164.4	8.2	1,123.3
Overall mean		292.1			

* All samples from the dredgehead sampling apparatus were summarized for each day and corrected for background concentrations.

Table 6

Dredgehead Sample Data for the James River Cutterhead and Dustpan Studies*

Day	No. of Samples	$\bar{X}$ mg/ℓ	σ	Min mg/ℓ	Max mg/ℓ
		Cutterhead			
1	12	15.2	11.5	0.0	32.0
2	20	65.5	43.1	9.0	166.0
3	13	99.9	34.9	11.0	143.0
4	20	65.5	45.0	0.0	147.0
	Overall mean	63			
		Dustpan			
1	20	66.5	45.0	0.0	147.0
2	27	101.3	78.8	6.0	302.0
3	20	42.2	28.2	0.0	130.0
4	28	34.5	40.7	0.0	122.0
	Overall mean	62			

* Samples from the dredgehead sampling apparatus were summarized for each day and corrected for background concentrations.

Table 7

Comparison between Cutterhead and Dustpan Dredges

Dredge	Length of Plume, ft	Max TSS divided by Background TSS, mg/ℓ
Cutterhead	2,000	2.2
Dustpan	950	3.8

Table 8

Results from Hydraulic Pipeline Studies

Study	Dredge Plant	Background TSS mg/ℓ Surface	Background TSS mg/ℓ Bottom	Max Contour mg/ℓ Surface	Max Contour mg/ℓ Bottom	Ration of Max Concentration to Background Concentration	Mean Dredge Head TSS, mg/ℓ (above background)	Standard Deviation
Calumet Harbor	Cutterhead, 12 in.	2	5	5	10.0	2.0	9.6	10
	Matchbox	2	5	2.5	15.5	2.9		
Savannah River	Cutterhead, 18 in.	17	67	20	120	1.8	292.1	210.9
James River	Cutterhead, 18 in.	42	86	40	200	2.5	61.5	34.9
	Dustpan	53	90	60	340	3.8	61.1	30.0

Table 9

Impacted Areas (acres) from Calument Clamshell Demonstration

	Area, acres			
Concentration*	25% Depth	50% Depth	75% Depth	100% Depth
2× background	3.2	3.9	5.9	6.9
4× background	0.1	0.2	0.3	3.5
6× background	0	0	0	1.04

* Background multiplier indicating relative plume TSS concentration.

Table 10

Impact Area (acres) from Black Rock Clamshell Demonstration

	Area, acres			
Concentration*	25% Depth	50% Depth	75% Depth	100% Depth
2× background	4.66	25	**	**
4× background	0	0.9	19.4	14.4
6× background	0	0	6.2	7.8

* Background multiplier indicating relative plume TSS concentration.
** Unable to measure area for contours which failed to close the bottom.

Table 11

Impacted Area (acres) for the St. Johns River Study

Bucket type	Concentration*	Area, acres 25% Depth	50% Depth	75% Depth	100% Depth
Open	2	6.23	4.17	14.4	18.9
	4	0	0	0	0.515
	6	0	0	0	0
Enclosed	2	**	9.25	0.47	24.8
	4	0	0	0	2.0
	6	0	0	0	0

* Background multiplier indicating relative plume TSS concentration.
** Unable to obtain area for contour which did not close.

Table 12
Summary of Results from Bucket Dredge Studies

Study	Bucket Type	Background TSS mg/ℓ Surface	Background TSS mg/ℓ Bottom	Min-Max Contour mg/ℓ	Ratio of Max Concentration to Background	Area of 4× Background Plume on Bottom acres
Calumet River	Open	10	12	20-140	11.7	3.5
Black Rock	Open	45	69	80-1100	15.9	14.4
Duwamish Waterway	Open	11	26	20-160	6.1	--
St. Johns River	Open	47	72	70-480	6.7	0.515
	Enclosed	47	72	50-380	5.0	2.0

Table 13

Comparison of Nonoverflow and Overflow Condition for

the Grays Harbor Field Study

Condition	Plume Length ft	Maximum Average TSS Concentration Above Background mg/ℓ	Duration of Plume min
Overflow	3,000	50	20
Nonoverflow	6,000	800	40

Table 14

Summary of Field Studies

Study	Dredge Plant	Site Conditions	Sediment Characteristics*	Current ft/sec	Background TSS, mg/ℓ Surface	Background TSS, mg/ℓ Bottom	Min-Max Contour mg/ℓ	Ratio of Max TSS Concentration to Background Concentration
Calumet Harbor	Cutterhead 12 in. Matchbox, 12 in.	Freshwater Lake	Soft organic clay/ silt, OH, 80% Fines, SG 2.71	0-0.2 0-0.2	2 2	5 5	5.0-10.0 2.5-14.5	2.0 2.9
Savannah River	Cutterhead, 18 in.	Estuary	Soft silty clay (OL)	0.2-1.6	17	67	20-120	1.8
James River	Cutterhead 18 in. Dustpan 18 in.	Estuary <1 ppt	Unconsolidated, saturated silty clay (CH) LL 120 PI 80	0.5-2.3	42 53	86 90	40-200 60-340	2.3 3.8
Calumet River	Open clamshell, 10 yd^3	Riverine	Soft organic clay, silt (OH)	0-0.18	10	12	20-140	11.7
Black Rock Harbor	Open clamshell, 10 yd^3	Estuary 10-21 ppt	Sandy organic clay, 90% fines LL 170 PI 65	0.2-0.8	45	69	80-1,100	15.9
Duwamish Waterway	Open clamshell	Estuary 12-21 ppt	Sandy clayey silt (MH)	0.3-1.1	11	26	20-160	6.1
St. Johns River	Enclosed clamshell 13 yd^3 Open clamshell, 12 yd^3	Estuary	Silty (MH) SG 2.4, 98% <0.002 in.	 0-0.2	47 47	72 72	50-380 70-480	5.0 6.7
Grays Harbor	Overflow hopper 6,000 yd^3 Nonoverflow	Estuary 1-20 ppt	Sandy silt (MI)	0.4-2.5 0.4-2.5	27.9 12.4	60.4 53.7	100-800 10-50	13.2 0.9

Table 15

Maximum Plume Concentrations and Ratio of Concentration to Background Levels for the Analyzed Depth Intervals from Field Studies

Study Area	25% Depth mg/ℓ	50% Depth mg/ℓ	75% Depth mg/ℓ	100% Depth mg/ℓ
		Cutterhead		
Calumet Harbor	5.25(2.6)	7 (2.3)	7 (1.8)	10 (2.0)
Savannah River	40 (2.3)	40 (1.2)	60 (1.2)	120 (1.8)
James River	80 (1.9)	80 (1.4)	120 (1.7)	200 (2.3)
		Open Clamshell		
Calumet River	30 (3.0)	40 (3.8)	60 (5.3)	140(11.7)
Black Rock Harbor	120 (2.7)	240 (4.5)	1050(17.2)	1100(15.9)
Duwamish Waterway	20 (1.8)	60 (3.8)	160 (7.6)	160 (6.1)
St. Johns River	150 (3.2)	250 (4.5)	250 (3.9)	480 (6.7)
		Enclosed Clamshell		
St. Johns River	170 (3.6)	170 (3.1)	185 (2.9)	380 (5.3)
		Hopper Dredge		
Overflow*	100 (3.6)	400(10.3)	400 (8.0)	800(13.2)
Nonoverflow*	--	10 (0.4)	20 (0.5)	50 (0.9)

* Plume concentrations levels are above background concentration.

APPENDIX A: MATHEMATICS OF CUTTERHEAD SOURCE STRENGTH MODEL

1. To evaluate the effect of cutterhead dredge operational variables on sediment resuspension rates release, Hayes (1986)* identified dimensionless variables (p_1, p_2, and p_3) to describe the sediment resuspension process.

$$p_1 = \frac{V_s}{V_i} \tag{A1}$$

$$p_2 = \frac{V_t}{V_i} \tag{A2}$$

$$p_3 = \frac{t_c + D_c}{2D_c} \tag{A3}$$

where

V_s = absolute value of the swing velocity at the tip of the cutter, L/t

V_i = suction intake velocity at the cutter blades, L/t

V_t = tangential tip speed of the cutter blades at the top of the rotation relative to the channel bottom, L/t

t_c = thickness of cut, L

D_c = average diameter of cutter, L

D = predredging depth, L

and

$$V_i = \frac{Q}{\frac{\pi^2}{2} (L_c)(R_c)} \tag{A4}$$

where

Q = volumetric flow rate of dredge, L^3/t

L_c = length of cutter, L

R_c = radius of cutter at maximum point, L

---

* See References at the end of the main text.

Equation A4 computes the average suction velocity along the edge of the cutter through a truncated elipsoidal surface area. Although this is not the suction velocity of the particles at the edge of the cutter, it is much simpler to compute and should be suitable for an estimate.

2. The tangential velocity of the cutter blades V_t is the relative speed of the cutter blades with respect to the channel bottom. This term varies depending upon the direction of the swing. Assuming the rotation of the cutter is clockwise when looking toward the dredge, the tangential velocity may be expressed as follows:

For port to starboard swings:

$$V_t = V_c - V_s \tag{A5}$$

For starboard to port swings:

$$V_t = V_c + V_s \tag{A6}$$

and

$$V_c = \frac{V_r R_c}{\frac{60}{2\pi}} \tag{A7}$$

where

V_c = tangential velocity of the cutter blades, ft/sec

V_r = rotational velocity of the cutter blades, rpm

3. A power equation was selected to relate total suspended solids (TSS) concentration near the cutterhead (C_{ss}) to the operational parameters p_1 and P_2 . Equation A8 (R = 0.85) was developed using a linear least square multiple regression technique and transformed variables. Hayes (1986) used dredgehead data from the Calumet Harbor demonstration study described in Part IV of main text. From these data he obtained 12 averaged data points obtained from 2 different swing directions and 6 sets of operation conditions tested.

$$C_{ss} = 0.150 \left(\frac{V_s}{V_i}\right)^{2.869} \left(\frac{V_t}{V_i}\right)^{1.027} \tag{A8}$$

Equation A8 is plotted with the 12 data points and error bars showing 95-percent confidence limits in Figure A1.

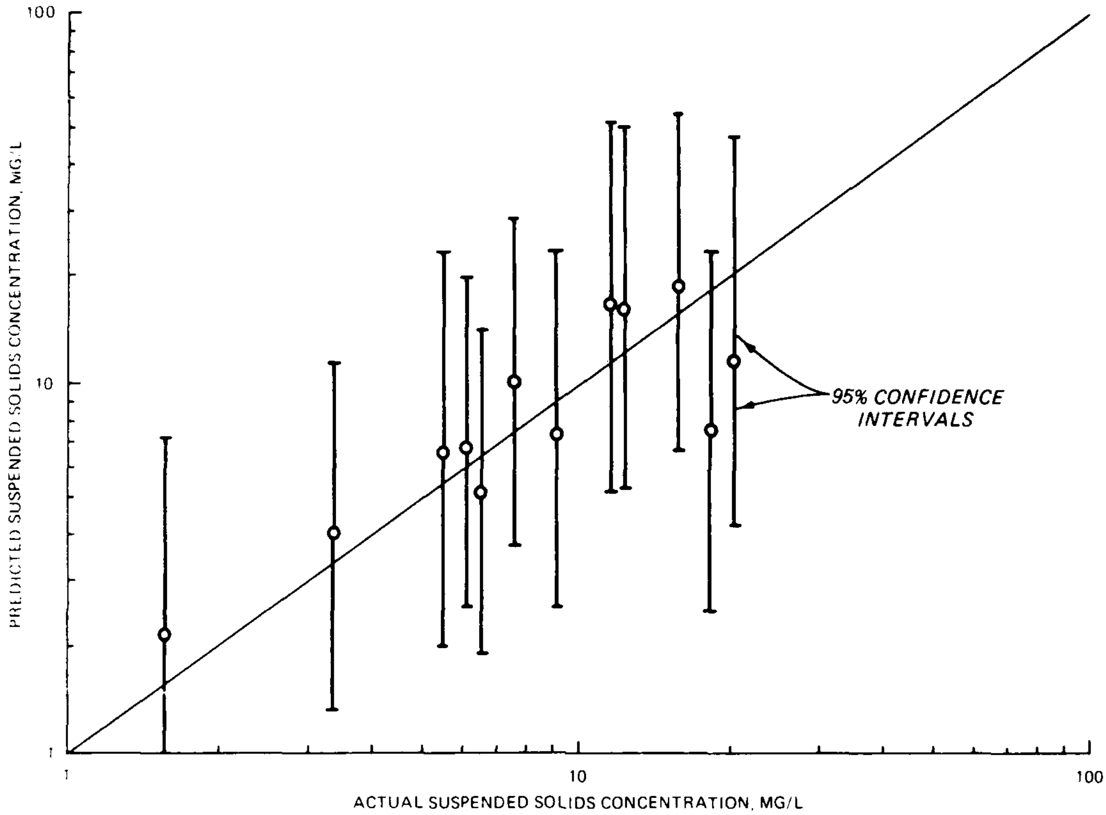


Figure A1. Predicted versus actual suspended solids concentrations (from Hayes 1986)

4. Figure A2 shows the 12 averaged data points and the range of expected values for the dimensionless parameters $\frac{V_s}{V_i}$ and $\frac{V_t}{V_i}$.

$$0.3 < \frac{V_s}{V_i} < 5 \qquad \text{(A9)}$$

$$0.3 < \frac{V_t}{V_i} < 30 \qquad \text{(A10)}$$

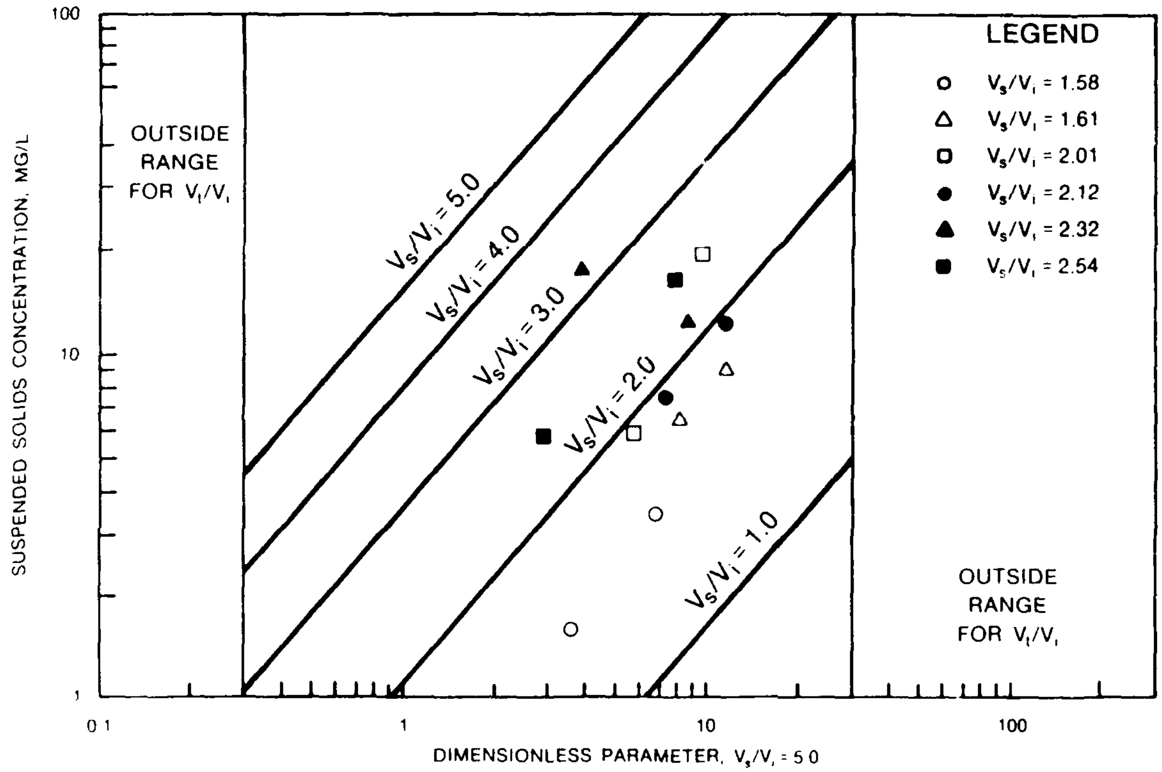
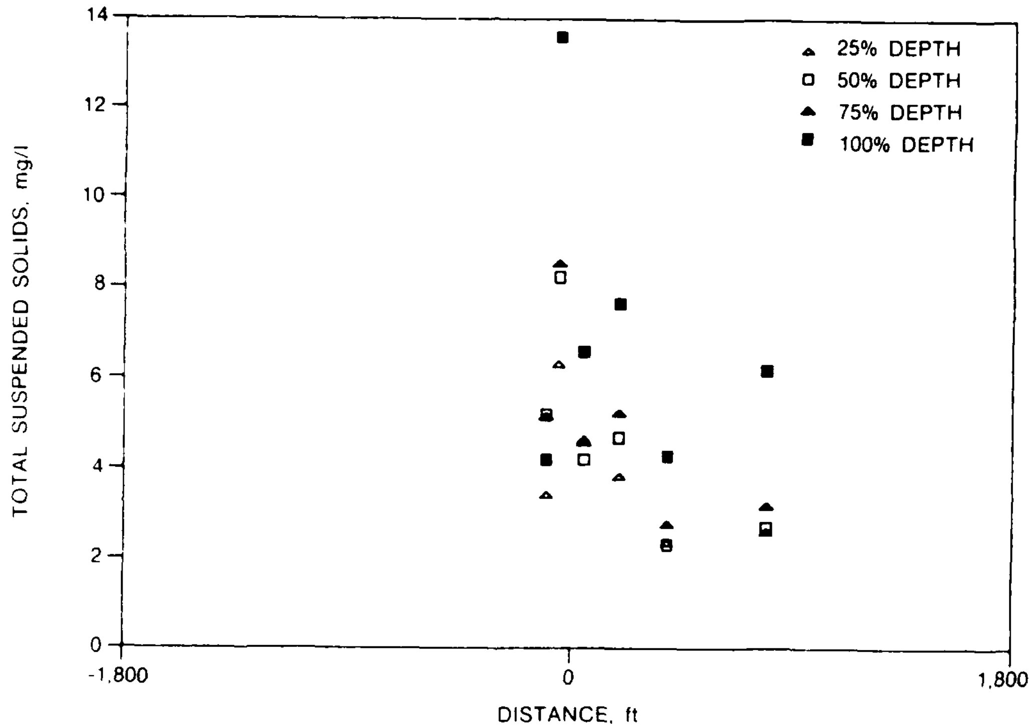


Figure A2. Simulated values for the resuspended sediment concentr^tion from a cutter suction dredge (from Hayes 1986)

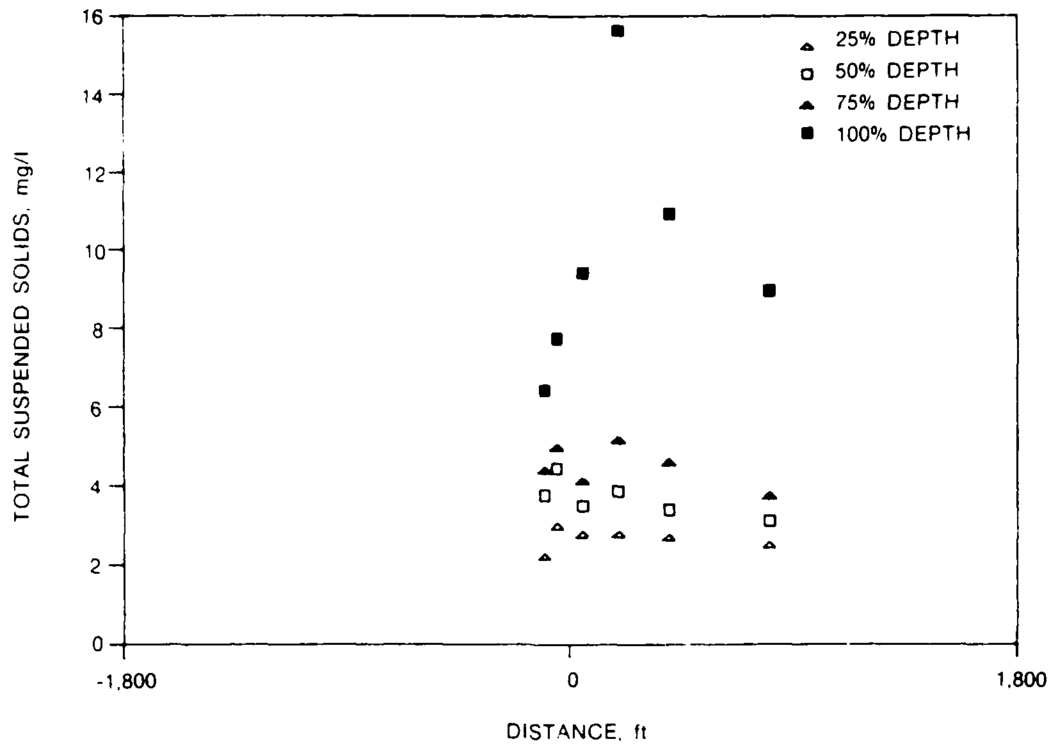
APPENDIX B: DATA FROM FIELD STUDIES

1. Figure B1 shows total suspended solids concentrations (TSS) plotted against distance from the point of dredging for 25-, 50-, 75-, and 100-percent depths of the water column. Each data point is an average of approximately four samples taken over time at a constant depth and distance from the point of dredging.

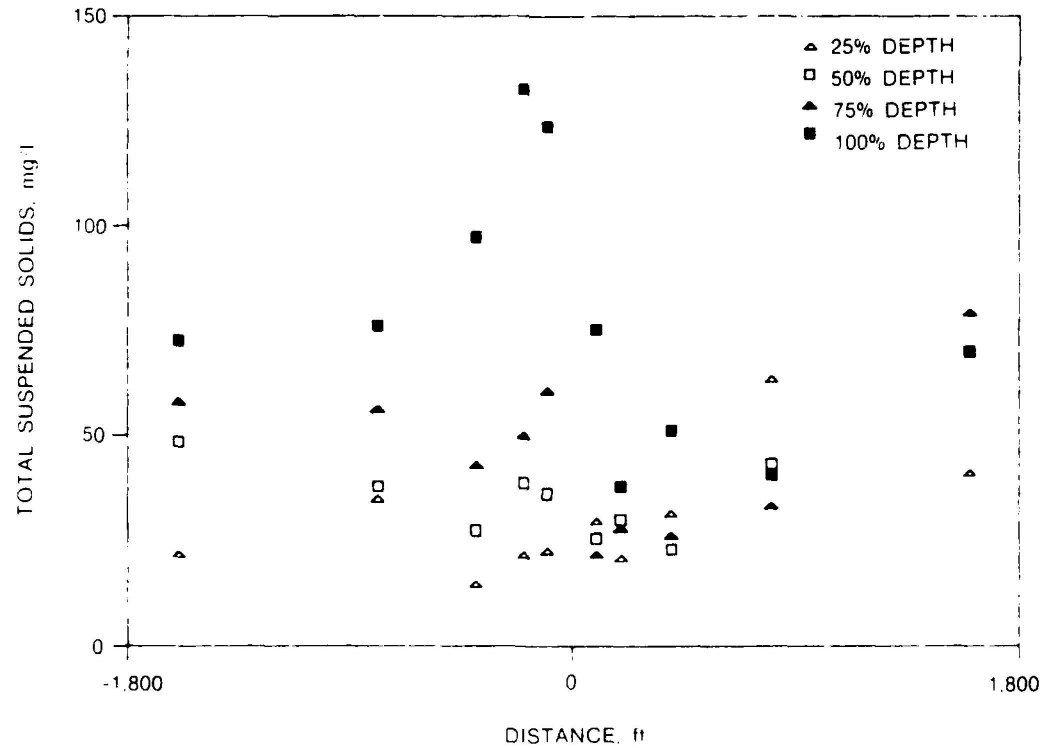


a. Calumet River cutterhead study

Figure B1. TSS concentration plotted against distance from the point of dredging for various depths for the field studies (Sheet 1 of 7)

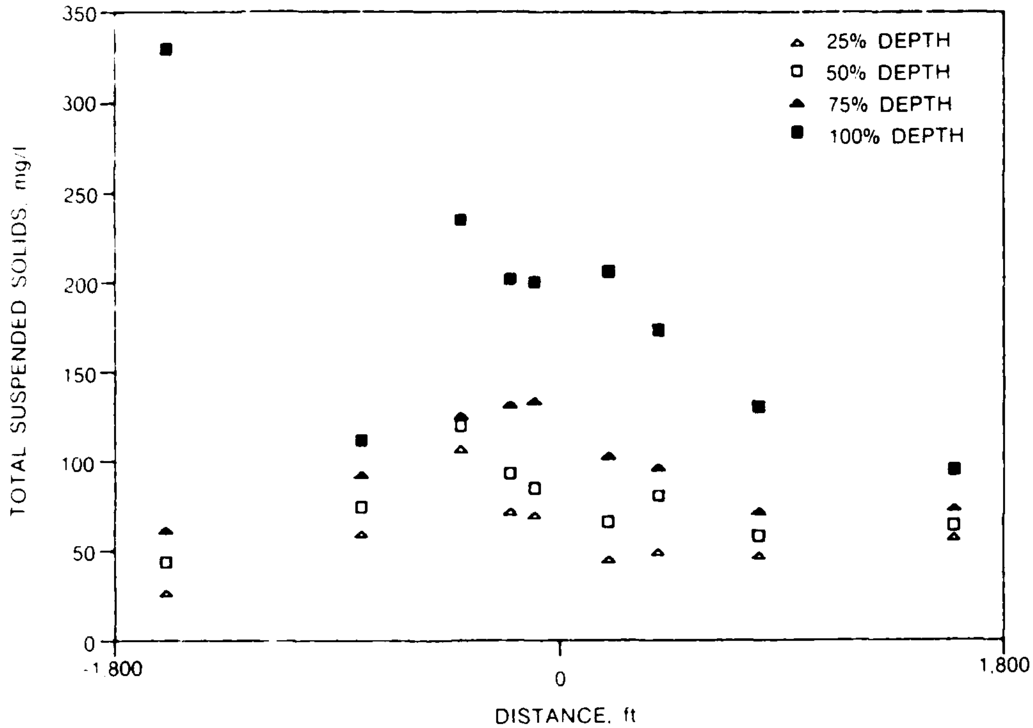


b. Calumet River matchbox study

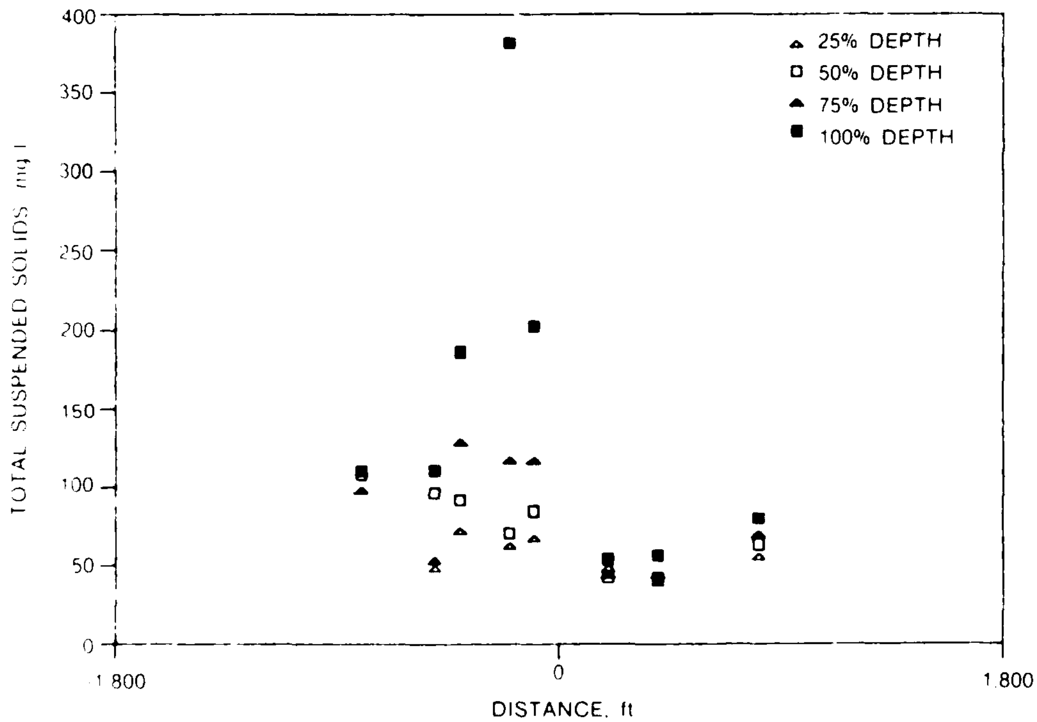


c. Savannah cutterhead study

Figure B1. (Sheet 2 of 7)

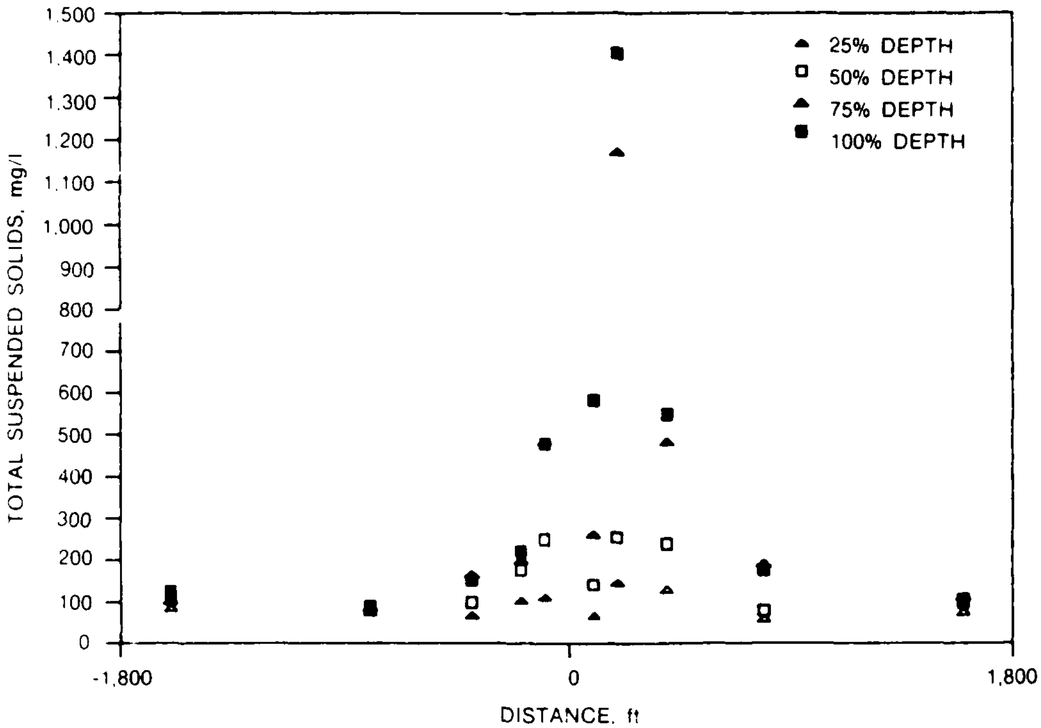


d. James River cutterhead study

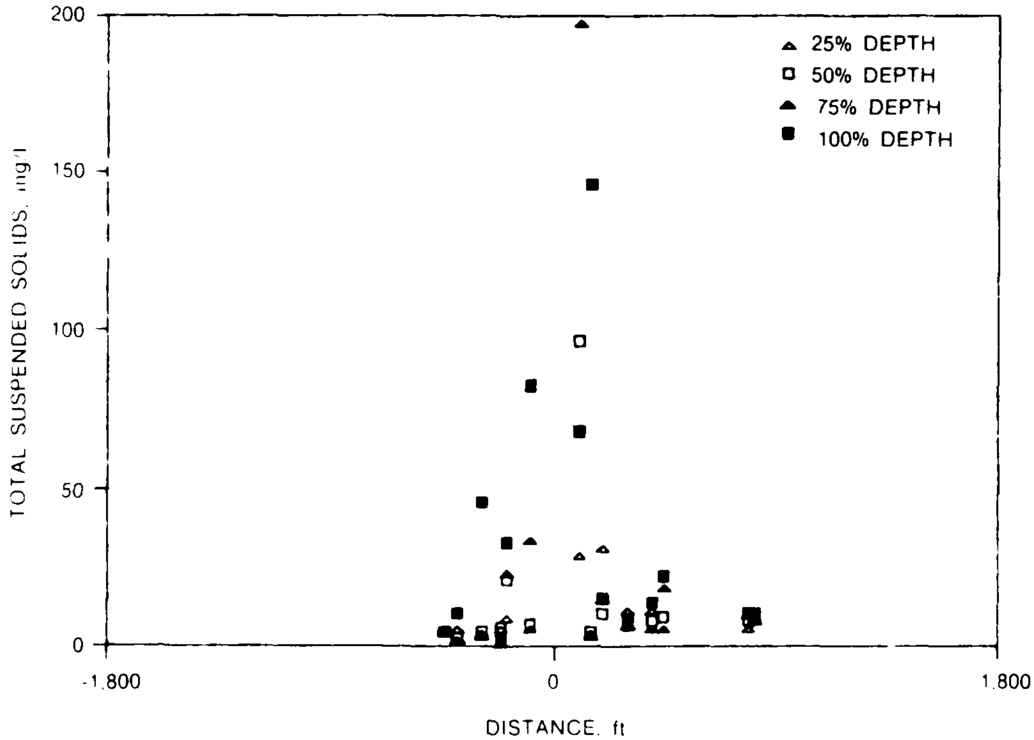


e. James River dustpan study

Figure B1. (Sheet 3 of 7)

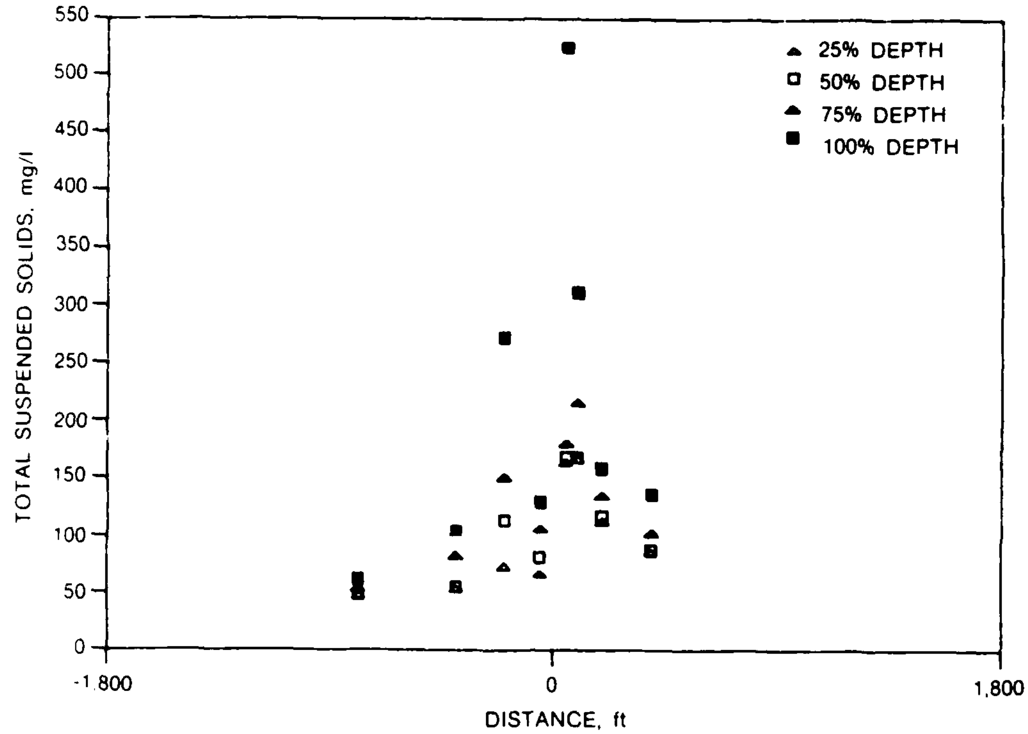


f. Black Rock clamshell study

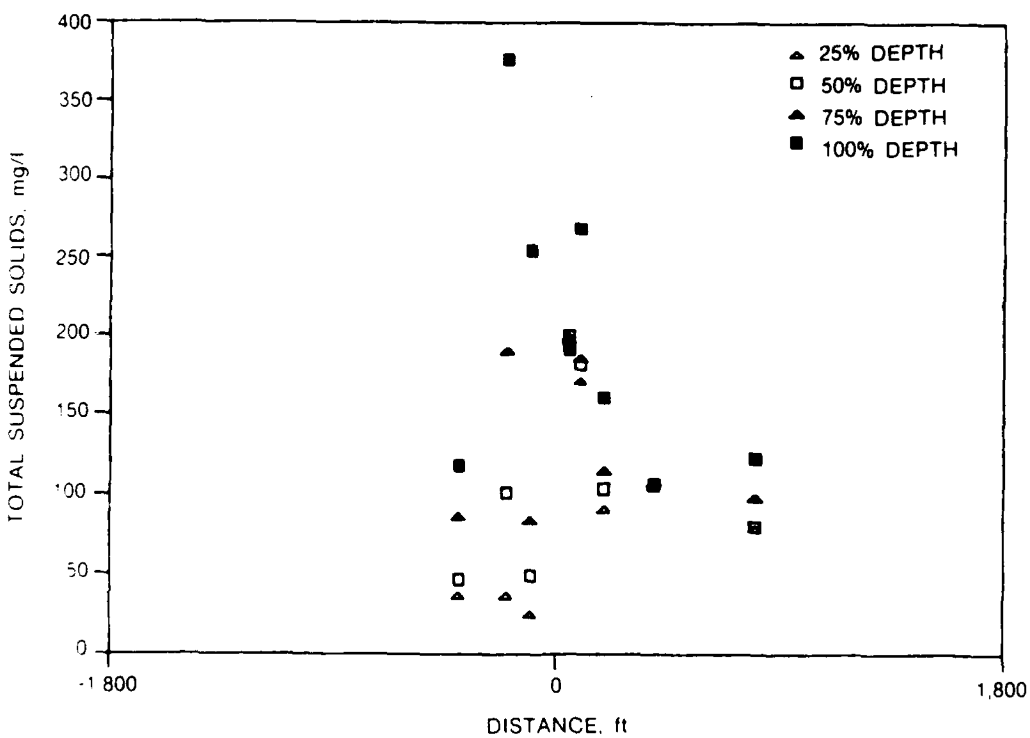


g. Duwamish clamshell study

Figure B1. (Sheet 4 of 7)

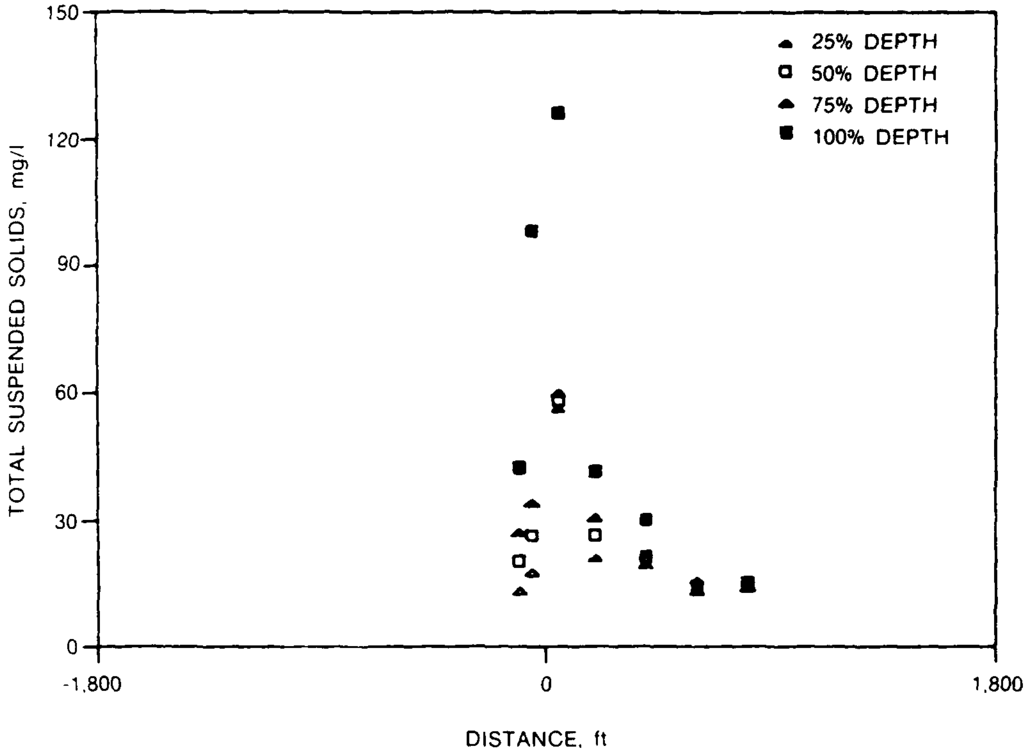


h. Jacksonville open clamshell bucket study

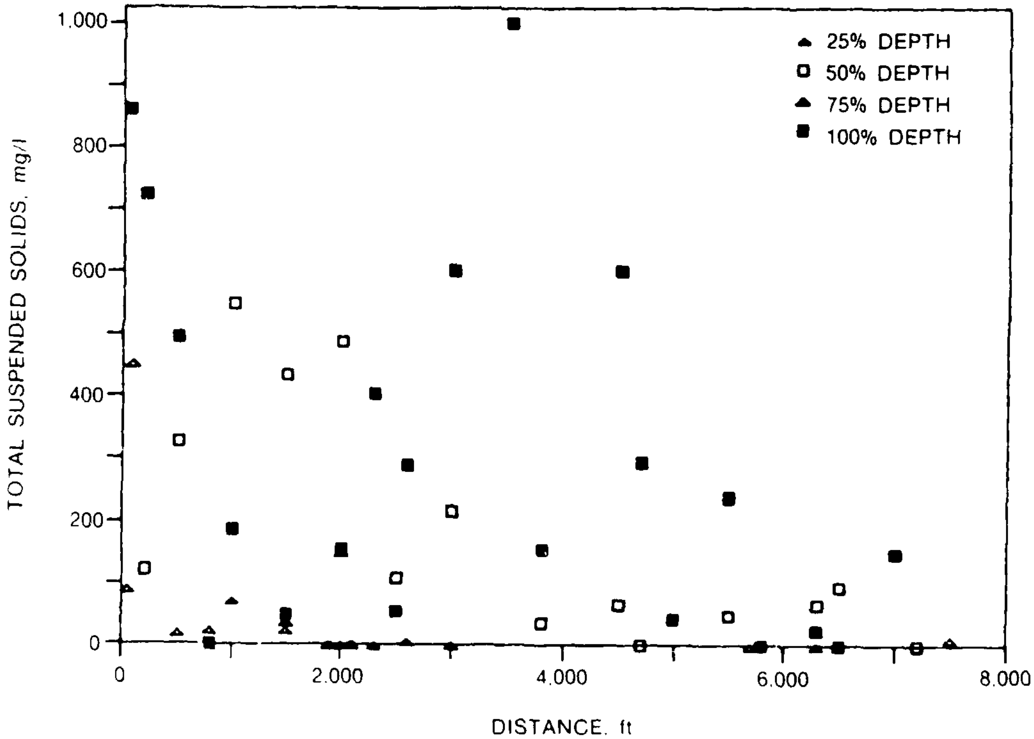


i. Jacksonville enclosed bucket study

Figure B1. (Sheet 5 of 7)

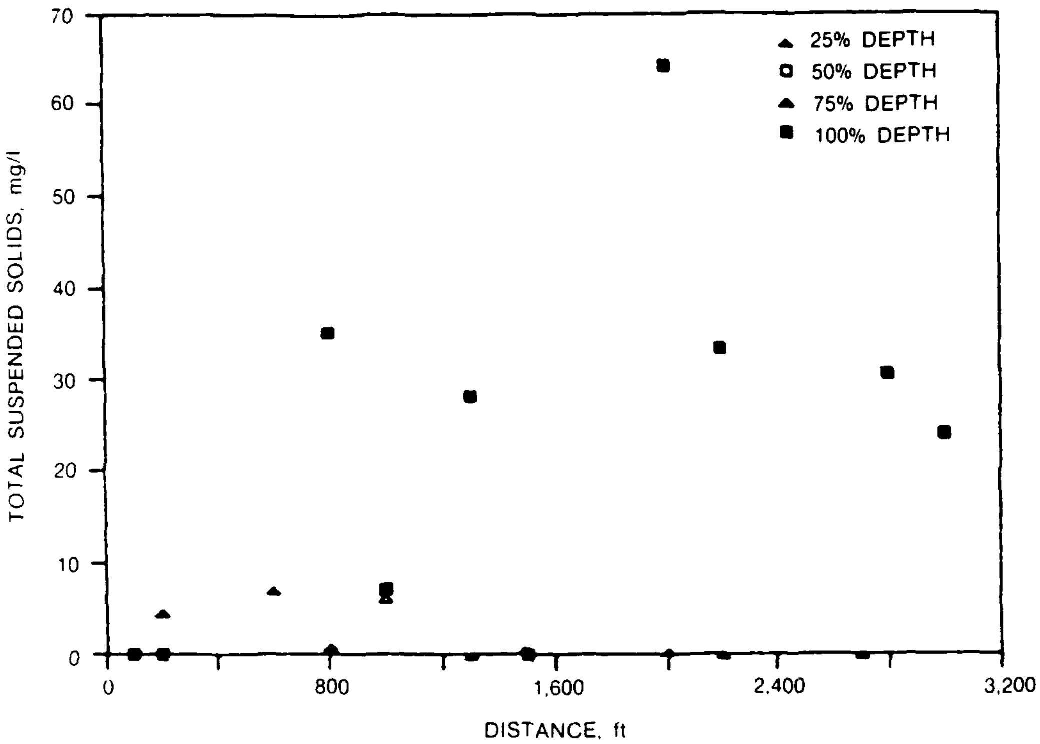


j. Calumet River clamshell bucket study



k. Grays Harbor hopper study during overflow

Figure B1. (Sheet 6 of 7)



1. Grays Harbor hopper study during no overflow

Figure B1. (Sheet 7 of 7)