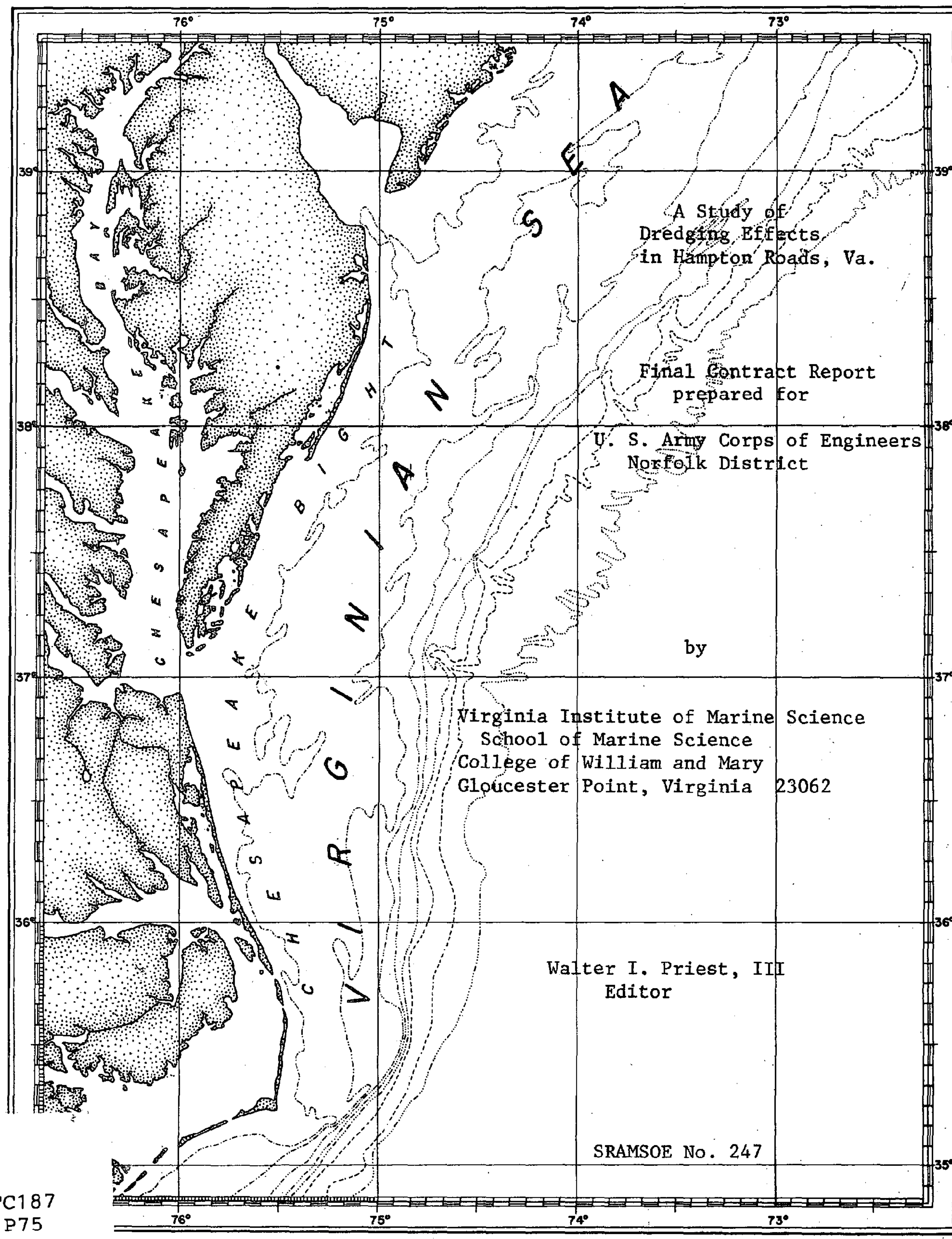

A Study of Dredging Effects in Hampton Roads, Va.

Final Contract Report
prepared for

U. S. Army Corps of Engineers
Norfolk District

by

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

Walter I. Priest, III
Editor

SRAMSOE No. 247

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803 Front Street
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March, 1981

Special Report in Applied Marine Science
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Introduction

The environmental consequences of dredging and spoil disposal are among the most extensively studied of all of the impacts associated with construction activities performed in aquatic ecosystems. Because the dredged material must be disposed of, the operations are often considered synonymous. This can present problems when assessing the environmental impacts of a project because the majority of adverse impacts are associated with the disposal operations in open-water rather than the dredging per se. This synonymy is unfortunate when the dredged material is being placed in a confined upland site whereby a major portion of the adverse impacts to the environment are being eliminated or greatly reduced.

The intent of this report is to identify and quantify, in part, the adverse effects associated with the dredging operation itself and those segments of the ecological community which might be adversely affected by the levels of suspended solids and sedimentation attributable to the dredge. It consists of three sections including: a comprehensive review of the major marine resources, their location in and utilization of the Hampton Roads Harbor and vicinity; the turbidity model and physical environment, describing the levels and distribution of suspended sediment and sedimentation and local current patterns; and a review of the effects of increased suspended sediment loads on estuarine organisms and water quality.

The first section on marine resources contains chapters of finfish, shellfish and ichthyoplankton. The finfish report summarizes the results of comprehensive trawl surveys performed during 1978 and 1979. These data were analyzed for the seasonal distribution of both resident and migratory species and nursery areas utilized by juveniles.

The shellfish report details the distribution of the oyster, *Crassostrea virginica*, and the hard clam, *Mercenaria mercenaria*, in Hampton Roads and the lower James River. The oyster data are based on the different densities of oysters associated with three types of substrate, oyster rock, mud and shell and sand and shell, which represent the areas where oyster populations are densest. Also included are data on oyster spatfall for the years 1976-1979 at selected stations in the study area. The hard clam data depict their distribution and abundance in the Hampton Roads area.

The ichthyoplankton chapter reports the seasonal distribution of fish eggs and larvae in and near the study area based on recent research. The data from the lower Chesapeake Bay can be extrapolated to a limited extent to include Hampton Roads and that from the Southern Branch of the Elizabeth River is directly applicable to other Hampton Roads tributaries.

The first two chapters of the second section of this report describe the model and the field calibration experiments developed to predict the distribution of dredge-induced suspended solids and sedimentation and the various facets of the dredging operation which influence their generation and distribution. Also included in this section are detailed descriptions of the surface and near bottom currents in the study area which also affect the distribution of the suspended solids.

The final section of this report presents a review of the literature concerning the environmental impacts of increased suspended solids levels created by dredging. These impacts include: increased turbidity levels, changes in dissolved oxygen, sedimentation and their effects on various estuarine organisms.

This report is intended to provide an effective scheme for the evaluation of the impacts of dredging in the Hampton Roads area. By providing detailed quantified distributional data on the important resources of the area, an accurate means of predicting the distribution of increased suspended solids levels and a means of approximating which organisms are going to be affected by the predicted increase, it is hoped that well informed decisions can be made regarding dredging activities in Hampton Roads.

MARINE RESOURCE DESCRIPTIONS

Nekton Utilization of Aquatic Resources in the Elizabeth River and the Lower James River

by

Marion Y. Hedgepeth, John V. Merriner and Frank Wojcik

Virginia Institute of Marine Science
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Introduction

The Chesapeake Bay and its tributaries provide the state of Virginia with some if its' greatest natural resources. Our blue crab, oyster and finfish industries are three of the largest commercial fisheries on the east coast of the United States.

Although a major portion of one of Virginia's largest tributary systems (the James River) has been closed to most shellfishing and finfishing since 1976 due to Kepone contamination, it still provides seasonal and permanent residence for large populations of shellfish and finfish. The lower James River area (Hampton Roads) and the Elizabeth River provide an estuarine habitat for many commercially and recreationally important species. For example, the Elizabeth River and the lower James River are important nursery grounds for spot, Atlantic croaker, Atlantic menhaden, weakfish, striped bass, black seabass, and summer flounder. Furthermore, they are important as feeding grounds for adult bluefish, weakfish, spot, and Atlantic croaker. Anadromous species such as striped bass, American shad, blueback herring and alewife travel through these areas to reach their freshwater spawning grounds.

The purpose of this study was to investigate nekton utilization of the Elizabeth River and the lower James River and to establish specific uses. Subsequently, this information would be used by the Army Corps of Engineers for scheduling dredging projects at times and locations for least impact on the nekton community.

Studies by Virginia Institute of Marine Science (VIMS, Musick et al., 1972 and Rooney-Char, and Ayres, 1978), and the U.S. Army Corps of Engineers (1977) addressed several problems associated with dredging operations and pipeline landfall sites in our present study areas. They concluded that the two major impacts would be the removal of benthic organisms which serve as fish food and the resuspension of sediments. The latter would affect fish by increasing turbidity, altering respiration rates and predator-prey behavior, and by resuspending heavy metals or other toxic substances present. In a report on water quality in the Elizabeth River, Nielson et al. (1978) cited high levels of heavy metals in bottom sediments and high levels of fecal coliforms in water samples. These data suggest that environmental impacts in the Hampton Roads and Elizabeth River must be examined in detail before dredging permits are issued.

Study Area and Methods

The areas included in the nekton resource survey were the eastern, southern, and western branches of the Elizabeth River and the lower James River from the Hampton Roads Bridge Tunnel to the James River Bridge (approximately mile ten).

Bottom trawl surveys utilizing lined 16-foot (5-meter) semi-balloon trawls were conducted on the Elizabeth River during 1978 and 1979. During the month of August, 1978, 22 random stations (Fig. 1) were made in the southern branch of the Elizabeth River. A 42-foot (13-meter) commercial boat, The Three Daughters, was sub-contracted for this survey. In all subsequent Elizabeth River surveys the R/V Restless, a 32-foot (10-meter) vessel, was used. During March, 1978, three fixed stations (Fig. 1) were made in the southern branch. These stations were approximately located at the upper, middle and lower portions of the river. Again, in February, 1979, 22 random stations were made in the southern branch, while 9 fixed stations (three in each branch) were made in August, 1979, (Fig. 2).

Thirty-foot, (9-meter), lined semi-balloon trawls were used on the surveys of the lower James River. Thirty random stations (Fig. 3) were made in this area during February, 1978 from the R/V Langley, an 80-foot (24-meter) steel ferryboat. Trawl data from July, 1978 (consisting of 34 random stations, Fig. 3) and January, 1979 (consisting of 30 random stations, Fig. 4) were taken in conjunction with a Kepone Biomass Study of the James River. Trawl data (consisting of 2 stations) from July, 1979 were taken during a VIMS Crustaceology-Ichthyology Monitoring Survey conducted with the R/V Pathfinder, a 55-foot (17-meter) vessel.

After each five minute tow, fish were identified, counted and weighed by species. Whenever possible, 50 fish of a species were measured for total length in millimeters. Blue crabs were counted, and scored (tallied) by sex and stage of development.

Water quality observations were obtained from surface and bottom readings of dissolved oxygen (mg/l), salinity (ppt.) and temperature (°C). Secchi disk readings (in meters) were used to describe water clarity.

RESULTS

Fish Distributions in the Elizabeth River

During the 1978 Winter Survey, only two fish were captured (a hogchoker and a juvenile blueback herring); therefore, no table was prepared. Water temperatures ranged from 2-7°C. Many species which overwinter in the rivers probably migrated just outside of the mouth of the Chesapeake Bay or offshore.

The 1979 Winter Survey yielded 18 species and a total of 657 fish, (Table 1). The most abundant species were juvenile spot, Atlantic croaker, blueback herring and alewife. Spot, striped bass, American eel, hogchokers and river herring accounted for 90 percent of the total biomass.

Juvenile spot and striped bass were only collected upstream of Mains Creek, (Figs. 5 and 6). Spot ranged in total length from 73-151 millimeters, while striped bass ranged in total length from 117-197 millimeters. Water temperatures below Mains Creek were 8-9°C, while those around Craney Island were 4.3-5.3°C.

Atlantic croaker were collected throughout the river, (Fig. 7). Most of these fish were less than 50 millimeters in total length. Winter kills of Atlantic croaker were noted in trawls made near New Mill Creek, Town Point and upriver from Jones Creek.

Alosines (blueback herring, alewife and American shad) were also collected throughout the river, (Fig. 8). Blueback herring dominated most of the catch of alosines; however, at

Milldam Creek, alewife constituted 99 percent of the catch. Alosines varied in length from 46-170 millimeters.

Summer surveys usually provided more species, more individuals and larger fish. Seventeen species and 3,912 fish were collected in August 1978 from the southern branch. Bay anchovy, spot and weakfish were the most abundant species, (Table 2). Biomass mainly consisted of spot, hogchoker, Atlantic croaker, summer flounder and weakfish. Water temperatures between 26.9 and 32°C were recorded. In the summer of 1979, only nine species were collected from each branch. Again, spot and Atlantic croaker were the dominant species, (Table 3).

Spot were more abundant at stations upstream of Milldam Creek in the southern branch, (Fig. 9), and upriver in the eastern and western branches. Adults as well as juveniles were collected in the waters around Craney Island. Adult summer flounder were also quite abundant near Craney Island.

Atlantic croaker were more abundant at stations in the western and eastern branches, (Fig. 10). Juveniles (22-137 millimeters in total length) were found at stations below Jones Creek on the southern branch while adults (215-355 millimeters in total length) were found near the mouth of the river.

Adult and very small juvenile (18-23 millimeters in total length) weakfish were collected from the mouth of the river to Town Point (Fig. 11). Larger juveniles were collected at upriver stations where temperatures were warmer and salinities were slightly less saline.

Fish Distributions in the Lower James River

Fifteen species and a total of 349 fish were collected in the lower James River during the 1978 Winter Survey. Blueback herring and Atlantic silversides were the dominant species (Table 4). The winter survey of 1979 yielded twenty-three species and a total of 16,405 fish were collected. Atlantic croaker was by far the most abundant species followed by bay anchovy, Atlantic silversides and blueback herring. During the 1978 Winter Survey, water temperatures ranged from 1.0-2.1°C while water temperatures during the 1979 Winter Survey ranged from 5.0-6.0°C.

Atlantic croaker ranged in total length from 32-115 millimeters. Atlantic croaker and spot appeared to be more abundant in waters with depths greater than 13 meters (40 feet). On the otherhand, bay anchovy, Atlantic silversides, blueback herring and Atlantic menhaden appeared to prefer waters with depths of less than 6 meters (20 feet). Furthermore, the Atlantic croaker, herring, and shad appeared to be more abundant on the Norfolk-side of the river, (Figs. 12 and 13).

The 1978 Summer Survey yielded 18 species and a total of 2,470 fish. Striped and bay anchovies were the most abundant species followed by spot, weakfish and hogchokers, (Table 4). In the 1979 Summer Survey, 16 species and a total of 989 fish were collected (Table 5). Bay anchovy was the dominant species, although, weakfish and several other species contributed larger amounts to the total biomass. Water temperatures ranged between 24-28°C in 1978 and between 21-23°C in 1979. The distributions of important species of these surveys were not plotted due to insufficient data.

DISCUSSION AND CONCLUSIONS

The seasonal distributions of finfishes were important in considering specific uses of the study areas; however, much of the discussion was limited to demersal fish (Table 6). Since only bottom trawls were utilized, the distributions and abundances of fishes such as gobies, blennies, killifish, and other finfish species of the beach zone communities and tidal creeks were not examined. Also, data were not available for large predator species such as bluefish which avoid the net.

The location and time of spawning were important in considering the distribution of fishes. Spot spawn at sea during late fall to early spring, while Atlantic croaker spawn at sea during late summer to early winter. Therefore, juvenile Atlantic croaker are found earlier in the Chesapeake Bay than spot. Weakfish spawn during the months of May, June and July at the entrance to the Chesapeake Bay. Later, young-of-the-year migrate into the Chesapeake Bay and its tributaries. Young spot, Atlantic croaker and weakfish remain in inshore nursery grounds for a period of a year or more before making their first migration to sea.

Alosines and striped bass migrate through the Chesapeake Bay and spawn in the freshwater reaches of the Chesapeake Bay's tributaries. Sexually mature alewife and striped bass enter the Chesapeake Bay during the month of February followed approximately four weeks later by blueback herring and

American shad (Hildebrand et al., 1928). Some striped bass are found in the Chesapeake Bay and its tributaries all year. Most young alosines leave the Chesapeake Bay upon the approach of cold weather; therefore populations of these species that remain to overwinter are small.

Small forage fish species such as bay anchovy, Atlantic silverside and naked goby which are permanent residents of the study areas spawn generally during the spring. Merriner et al. (1979) captured bay anchovy eggs, larvae and post-larvae from late spring through early fall in ichthyoplankton samples taken around Hog Island on the James River. Naked goby larvae and post-larvae were captured from May through October, while silverside eggs, larvae and juveniles were captured throughout the spring and summer.

In the U.S. Army Engineering Study (1977), it was suggested that the Elizabeth River was utilized as a nursery ground by Atlantic menhaden, spot and Atlantic croaker. In our study, winter distributions of spot and striped bass indicated that the upper reaches of the southern branch of the Elizabeth River serve as an overwintering ground and/or nursery ground for juveniles of these species. Juvenile Atlantic croaker and alosines were captured evenly throughout the Elizabeth and lower James River. Therefore, these species utilized both river systems as an overwintering-nursery ground. Juvenile Atlantic menhaden and small forage fish species such as bay anchovy and Atlantic silverside preferred the waters of the lower James River as an overwintering nursery ground.

Permanent residents of both study areas included bay anchovy, Atlantic silverside, skilletfish, oyster toadfish, blackcheek tonguefish, and hogchoker. White perch and yellow perch were only captured in the Great Bridge area of the southern branch of the Elizabeth River. Other finfish species that were captured were considered as incidental species; because, only a few individuals of these species were captured in trawls during a survey.

During summer, the Elizabeth River and lower James River continued to be utilized as nursery grounds for juvenile spot, Atlantic croaker and weakfish. Juvenile spot preferred the upper reaches of these tributaries. In fact, during mid-summer juvenile spot were found as far up the James River as Hopewell, Virginia (approximately river mile 65). Adult spot, Atlantic croaker and weakfish preferred the Chesapeake Bay and the lower portions of its tributaries. The Craney Island-Lamberts Point area was a popular feeding area for adult spot, Atlantic croaker and summer flounder. They were rarely captured beyond this area on the Elizabeth River.

Temperature was the major factor in the winter distribution of fishes, while the availability of food was the major factor in the summer distribution of fishes. Principal finfish uses of the Elizabeth River and lower James River areas were (1) the nursery grounds for juvenile spot, Atlantic croaker, alewife, blueback herring, American shad, striped bass and weakfish; (2) the adult feeding grounds for spot, Atlantic croaker, weakfish, summer flounder, etc. and (3) the spawning grounds for important forage species such as bay anchovy and Atlantic silverside. Only minor occurrences of striped bass and alosine spawning were observed in the upper reaches of the Elizabeth River.

Dredging operations in the study areas will have a greater affect on the juvenile fishes of the nursery ground and forage fishes, than on the adult fishes of the summer feeding grounds. Adult fishes are normally more efficient in their daily search for food, and are less subject to capture by prey species than juvenile fishes. Consequently, adult individuals will have a greater chance of finding other food resources beyond the area of a dredging project. The impact of dredging operations would be critical during winter and spring when water temperature and food availability restrict the distribution of permanent residents and fishes of the nursery ground and during summer and fall when many larval and juvenile fishes are abundant in the study areas. Winter dredging projects may increase the frequency of winter fish kills by forcing fish to migrate into colder waters. During spring, several finfish species such as bay anchovy and Atlantic silverside spawn in the study areas. Eggs and larvae of these species may be affected by dredging operations.

Other environmental factors to consider in scheduling dredge operations would be those mentioned in the Portsmouth

Refinery Study (1977). They include: the removal of benthic organisms (prey for fishes); respiratory problems; and the uptake of heavy metal and/or other toxic substances. The effect of these factors on fishes would be best observed during an actual dredging operation.

ACKNOWLEDGEMENTS

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Table 1. Elizabeth River Winter Trawl Survey 1979 (22 stations in the southern branch).

Species	Total Number	Total Weight (grams)
American eel	6	850
Blueback	64	252
Alewife	79	634
American shad	5	86
Atlantic menhaden	12	66
Bay anchovy	37	35
Banded killifish	1	1
Striped killifish	1	5
Atlantic silverside	66	235
White perch	2	53
Striped bass	37	1,830
Yellow perch	1	6
Spot	178	2,572
Atlantic croaker	99	57
White mullet	3	204
Naked goby	1	1
Blackcheek tonguefish	5	24
Hogchoker	60	806
	657	7,717
Blue Crabs		
Male	27 (4 soft)	
Female - (mature)	2	
Female - (immature)	25	
	54	

Table 2. Elizabeth River Summer Trawl Survey 1978 (22 stations in the southern branch).

Species	Total Number	Total Weight (grams)
American eel	9	822
Cusk eel	2	37
Atlantic menhaden	9	173
Bay anchovy	1,097	919
Oyster toadfish	9	950
Spotted hake	8	830
White perch	11	414
Yellow perch	1	34
Weakfish	434	2,072
Black seabass	1	30
Spot	1,860	18,822
Atlantic croaker	57	3,940
Naked goby	1	0.5
Butterfish	2	3
Northern searobin	1	5
Summer flounder	24	2,841
Hogchoker	386	6,676
	3,912	38,568.5
Blue Crabs		
Male	87	
Female - (mature)	15	
Female - (immature)	61	
	163	

Table 3. Elizabeth River Summer Trawl Survey 1979 (3 stations in each branch).

Species	Western Branch *TN	Western Branch *TW	Southern Branch TN	Southern Branch TW	Eastern Branch TN	Eastern Branch TW
American eel	1	308	2	150	10	950
Cusk eel	-	-	1	15	-	-
Atlantic menhaden	-	-	-	-	2	47
Gizzard shad	-	-	-	-	1	280
Bay anchovy	47	165	3	10	9	25
Oyster toadfish	1	185	6	410	5	1,020
Weakfish	4	220	17	100	19	277
Spot	431	4,953	160	3,230	175	1,590
Atlantic croaker	97	4,575	63	3,778	139	4,045
Summer flounder	4	377	1	220	-	-
Blackcheek tonguefish	1	10	-	-	-	-
Hogchoker	50	1,380	64	1,295	18	420
	636	11,895	317	9,208	378	8,654
Blue Crabs						
Male	16 (1 soft)		31		37	
Female - (mature)	-		8		7	
Female - (immature)	19		13		16	
Mud crabs	-		1		-	
	35		53		60	

* TN = Total Number
TW = Total Weight (grams)

Table 4. Lower James River Summer (34 stations) and Winter (30 stations) Trawl Surveys 1978.

Species	Total Number Summer	Total Number Winter	Total Weights (grams) Summer	Total Weights (grams) Winter
American eel	1		40	
Blueback herring		150		360
Alewife		7		74
Atlantic menhaden	1		15	
Gizzard shad		3		88
Striped anchovy	981		2,566	
Bay anchovy	581	50	279	39
Inshore lizardfish	2		7	
Oyster toadfish	7	8	205	30
Skilletfish		1		5
Spotted hake	3		230	
Striped cusk eel	18		450	
Atlantic silverside		109		326
Northern pipefish	2	6	2	15
White perch		2		11
Black seabass	5		234	
Weakfish	256		4,891	
Spot	310		7,570	
Atlantic croaker	16	1	3,007	1
Tautog		1		285
Striped blenny		5		40
Naked goby		2		1
Butterfish	17		77	
Norhern sea robin	4		35	
Summer flounder	39		2,417	
Windowpane flounder	3		160	
Hogchoker	224	3	4,973	150
Blackcheek tonguefish		1		1
	2,470	349	27,158	1,426

Table 5. Lower James River Winter (30 stations) and Summer (July only; 2 stations/4 tows) Trawl Surveys 1979.

Species	Total Number Summer	Total Number Winter	Total Weight (grams) Summer	Total Weight (grams) Winter
American eel		3		255
Blueback herring		604		1,184
Gizzard shad		1		21
Alewife		102		896
American shad		54		790
Atlantic menhaden		116		1,816
Bay anchovy	570	5,591	1,752	3,459
Oyster toadfish	5	13	88	1,817
Skilletfish	1	13	1	45
Red hake		1		5
Spotted hake	1	15	100	116
Striped cusk eel	12		115	
Atlantic silverside		765		3,973
Northern pipefish		20		34
Black seabass	6		200	
Weakfish	102		12,070	
Spot	84	152	8,964	1,457
Atlantic croaker	92	8,804	10,370	11,279
Tautog	2		1,880	
Feather blenny		13		100
Naked goby		9		5
Butterfish	1		10	
Northern searobin		1		4
Striped searobin	1		82	
Smallmouth flounder		5		22
Summer flounder	13	49	2,262	3,353
Windowpane flounder	2		95	
Winter flounder		1		670
Hogchoker	96	33	1,830	1,029
Blackcheek tonguefish	1	40	4	152
	989	16,405	39,823	32,482

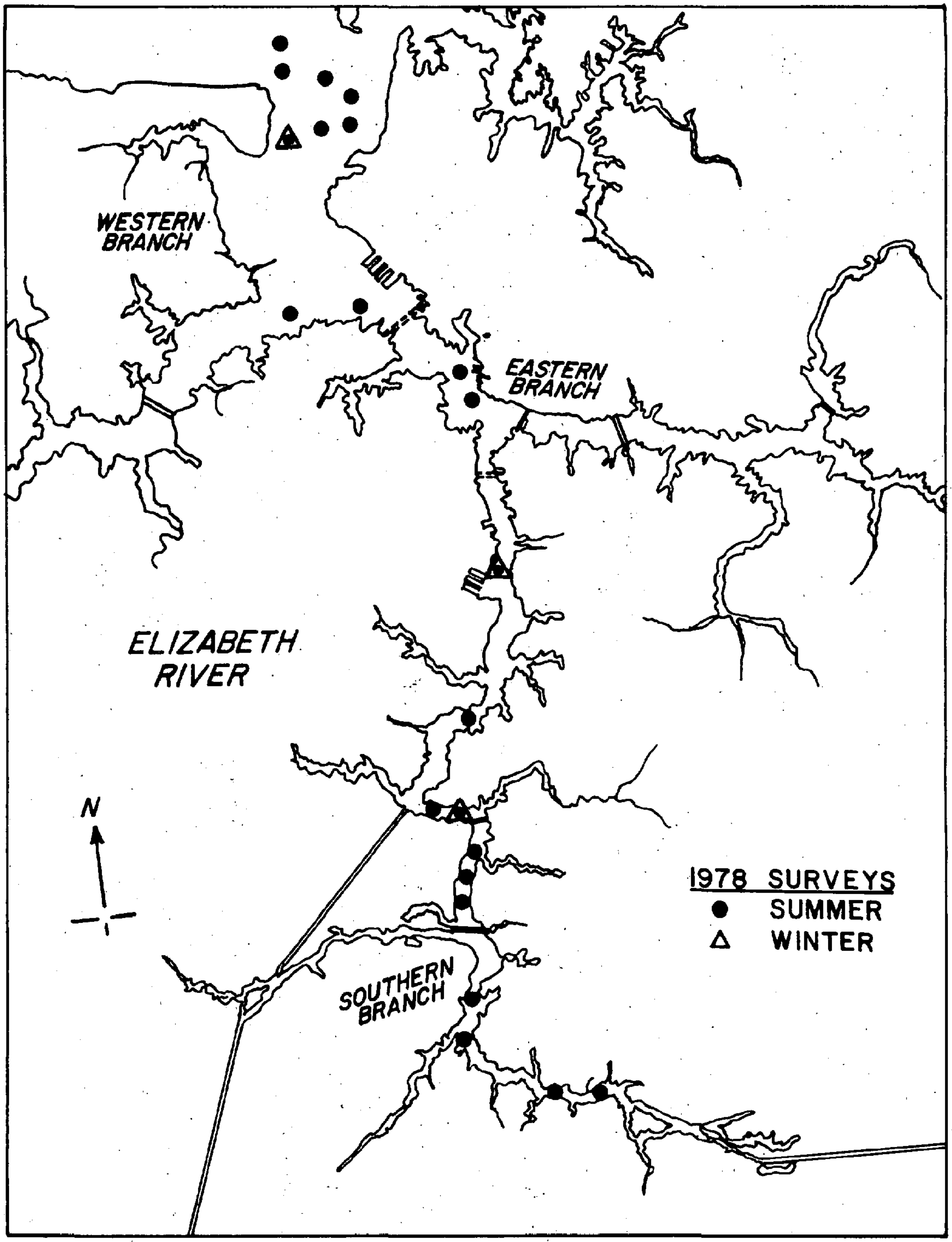
Table 6. Summary of nekton utilization of aquatic resources in the Elizabeth River and lower James River.

Species	
Blueback herring	Winter nursery grounds, spring spawning probably in the upstream tidal creeks of the Elizabeth River
Alewife	" "
American shad	" "
Atlantic menhaden	Probably nursery ground
Bay anchovy	Permanent resident
Striped anchovy	Adult and juvenile summer feeding grounds in the lower James River
Oyster toadfish	Permanent resident
Clingfish	" "
Banded killifish	Permanent resident of beach zone community
Striped killifish	Permanent resident of beach zone community
Atlantic silverside	Permanent resident
Striped bass	Winter nursery ground in the upper reaches of the Elizabeth River, probably some spawning in upstream tidal creeks of the Elizabeth River

Table 6. (continued)

Species	
Weakfish	Summer/fall nursery grounds, adult and juvenile summer, fall feeding ground at the mouth of the Elizabeth River and in the lower James River
Spot	Winter nursery grounds in the upper reaches of the Elizabeth River, adult and juvenile summer feeding grounds
Atlantic croaker	Winter/summer nursery grounds, adult summer feeding grounds at the mouth of the Elizabeth River and in the lower James River
Feather blenny	Permanent resident of oyster communities
Naked goby	" "
Summer flounder	Adult and juvenile summer feeding grounds at the mouth of the Elizabeth River and in the lower James River
Blackcheek tonguefish	Permanent resident
Hogchoker	Permanent resident

Figure 1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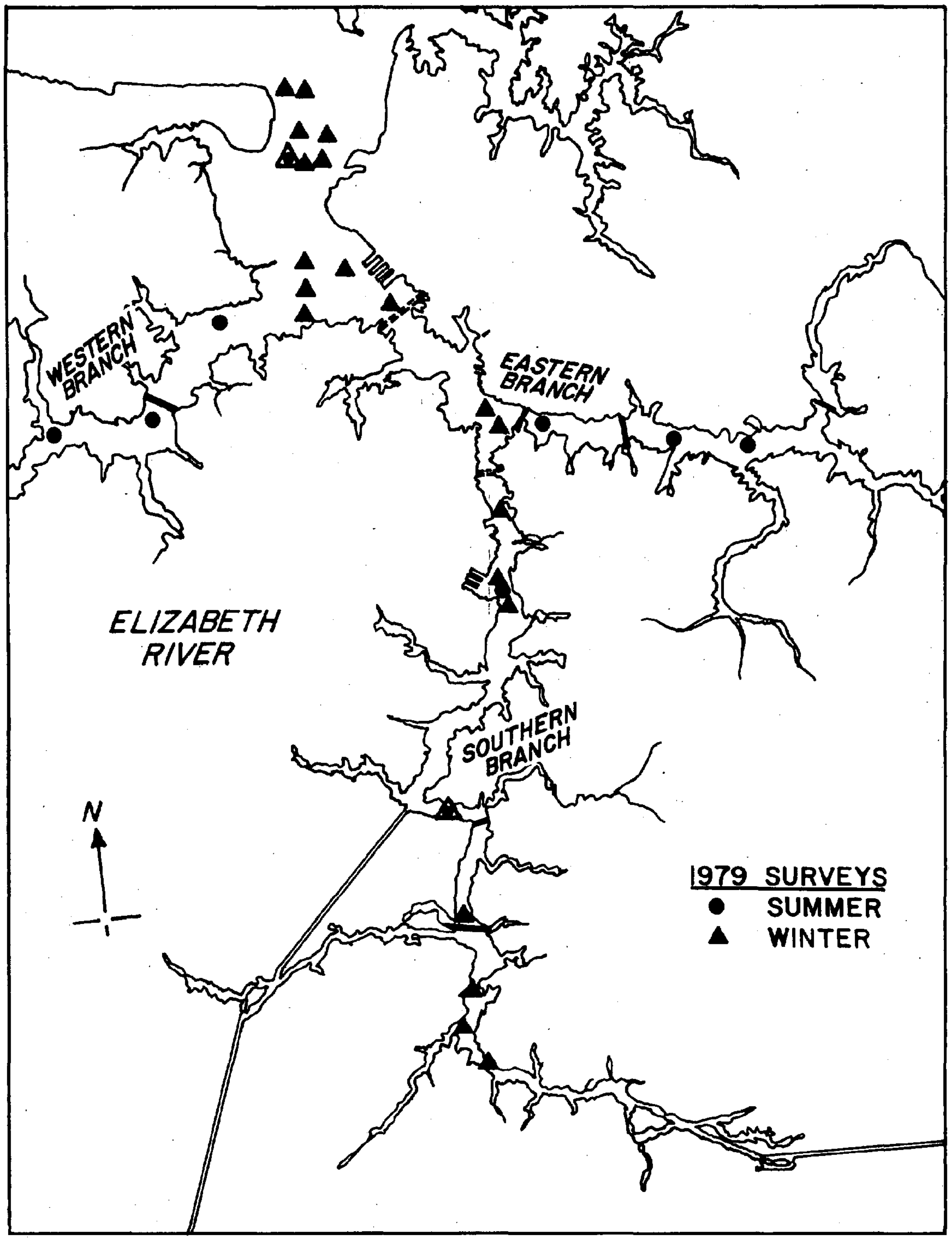
EASTERN BRANCH
ELIZABETH RIVER
N
SOUTHERN BRANCH
1978 SURVEYS
SUMMER
WINTER

Figure 2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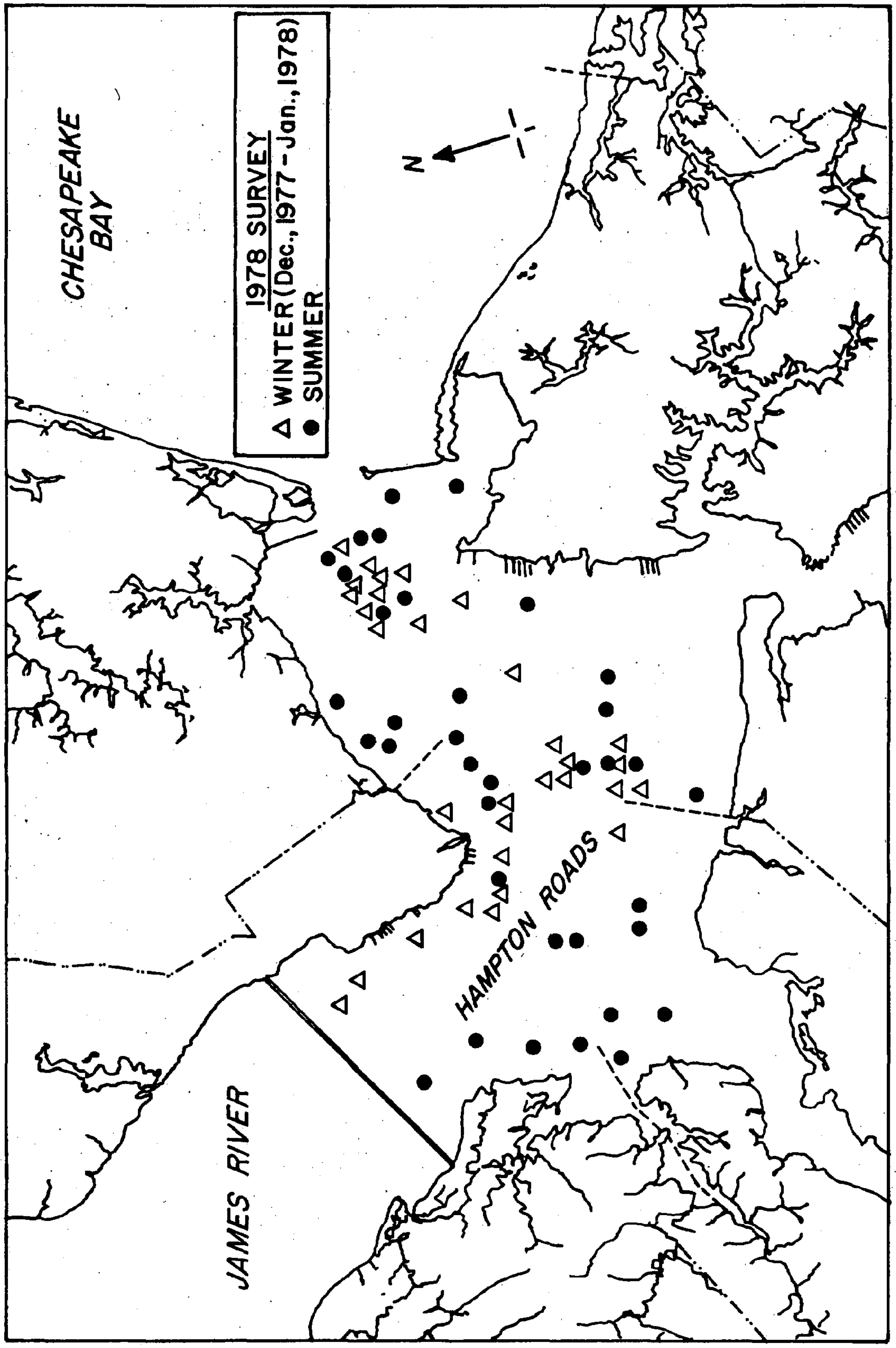
SOUTHERN BRANCH
N
1979 SURVEYS
SUMMER
WINTER

Figure 3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1978 SURVEY
WINTER (Dec., 1977 - Jan., 1978)
SUMMER
N
HAMPTON ROADS
JAMES RIVER

Figure 4

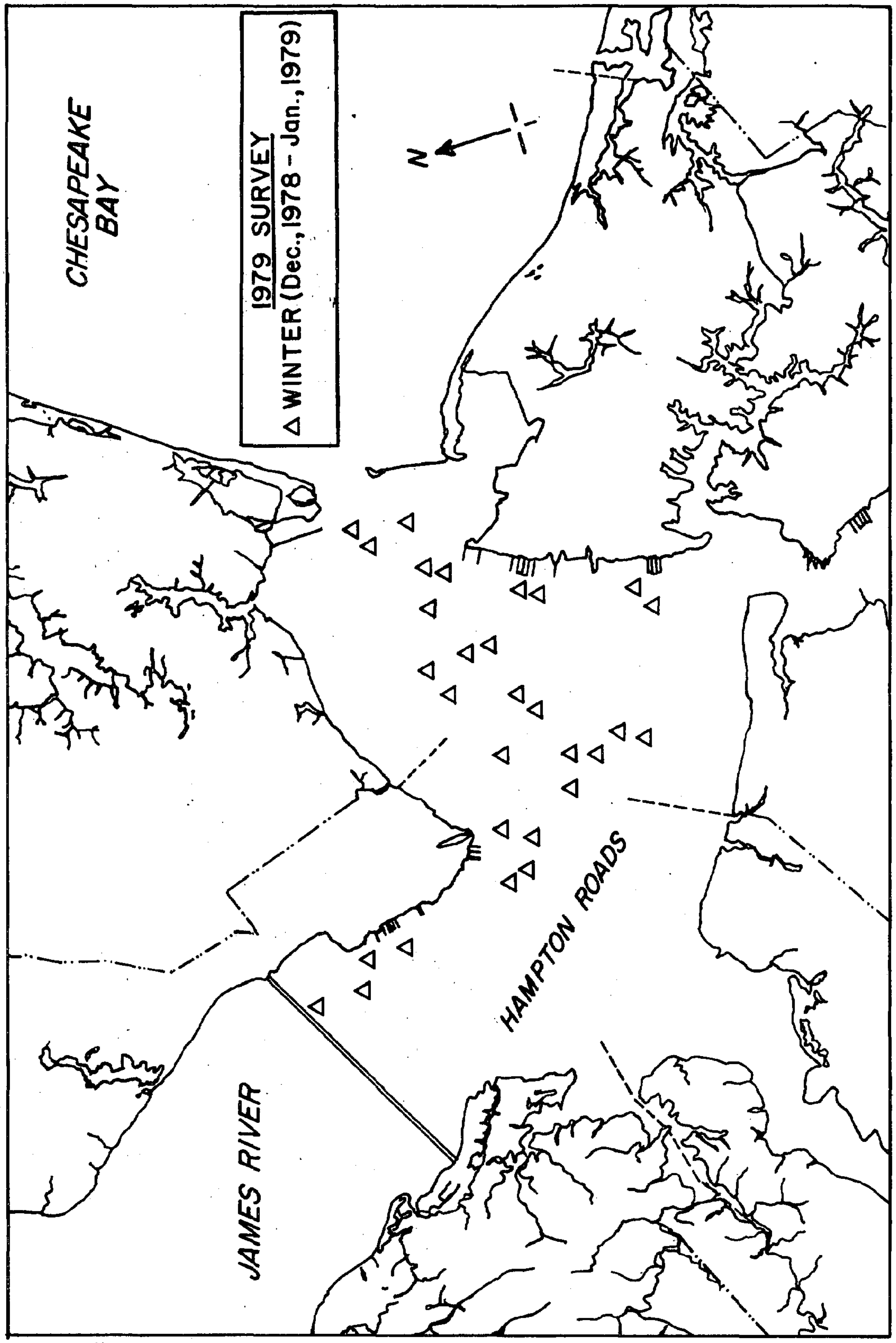
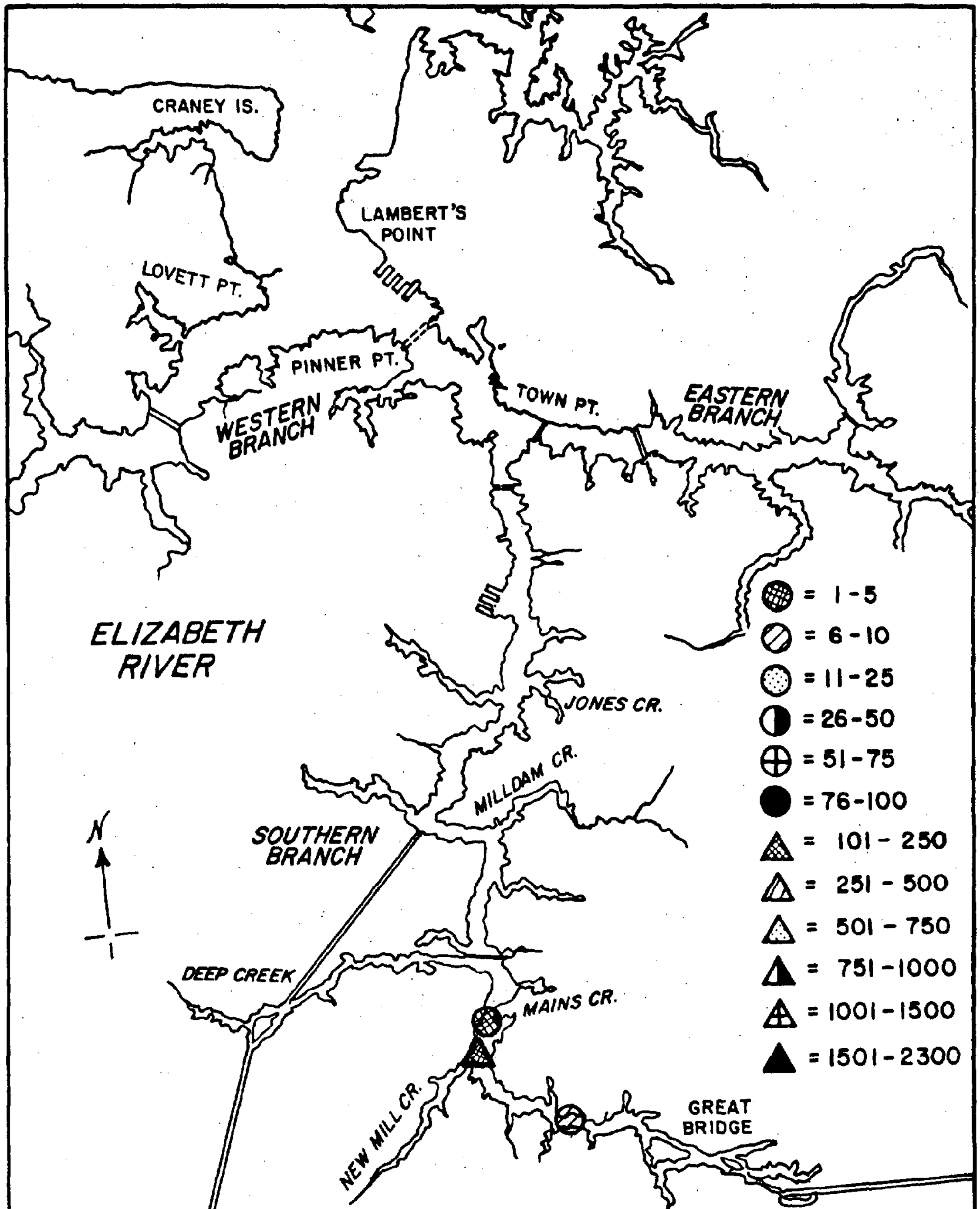
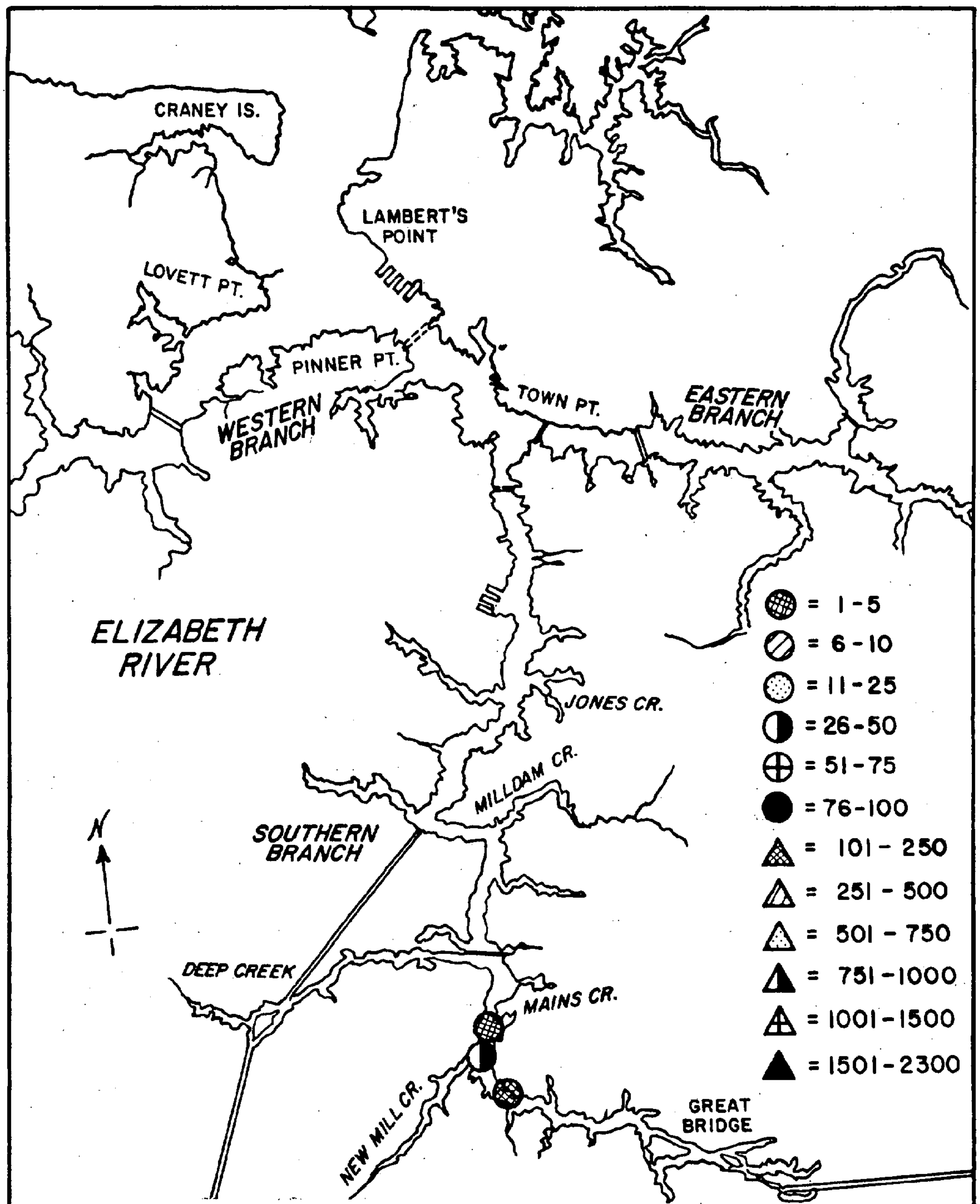

CHESAPEAKE BAY
1979 SURVEY
△ WINTER (Dec., 1978 - Jan., 1979)
N
HAMPTON ROADS
JAMES RIVER

Figure 5



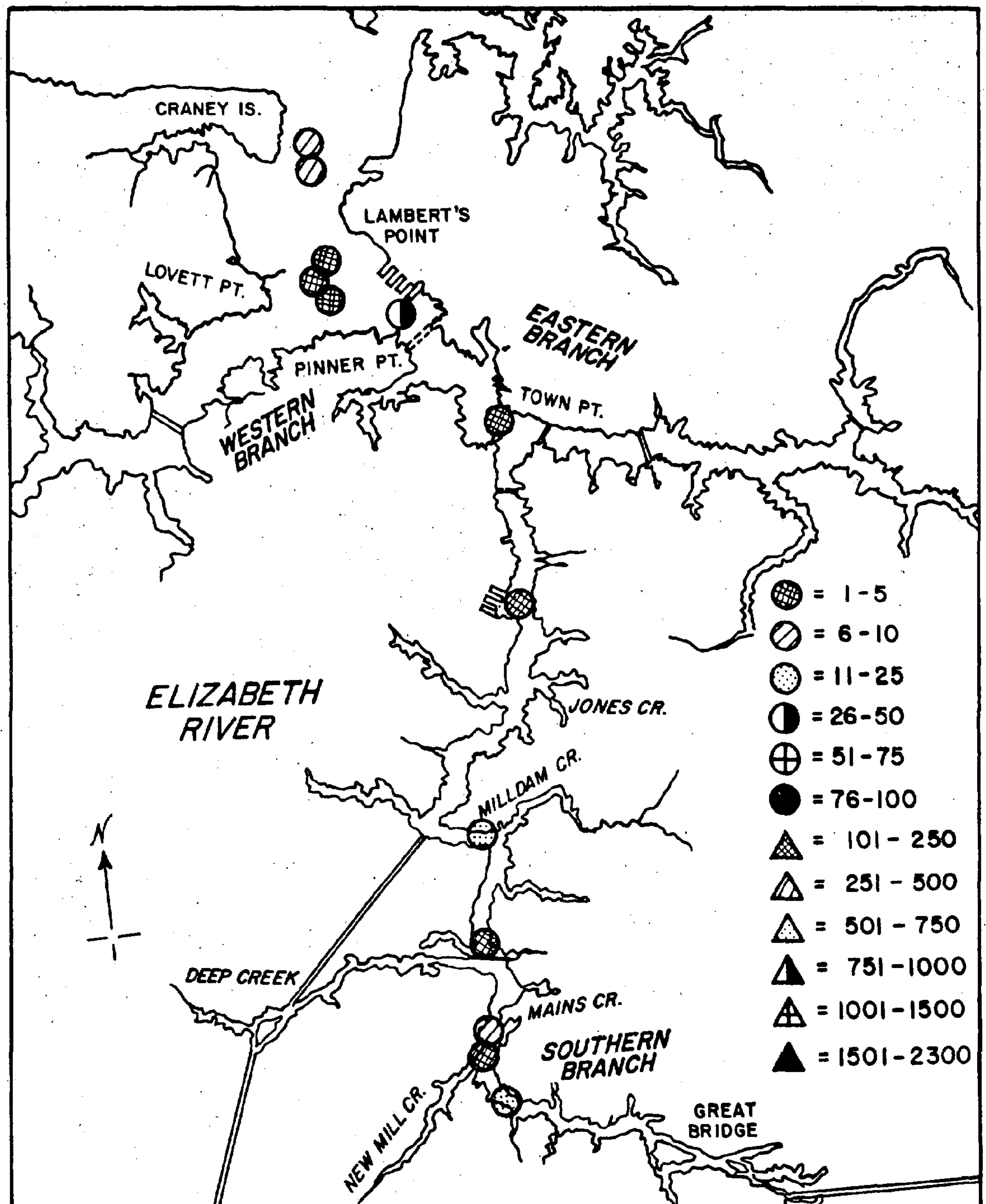
WINTER DISTRIBUTION OF LEIOSTOMUS XANTHURUS
(Spot)

Figure 6



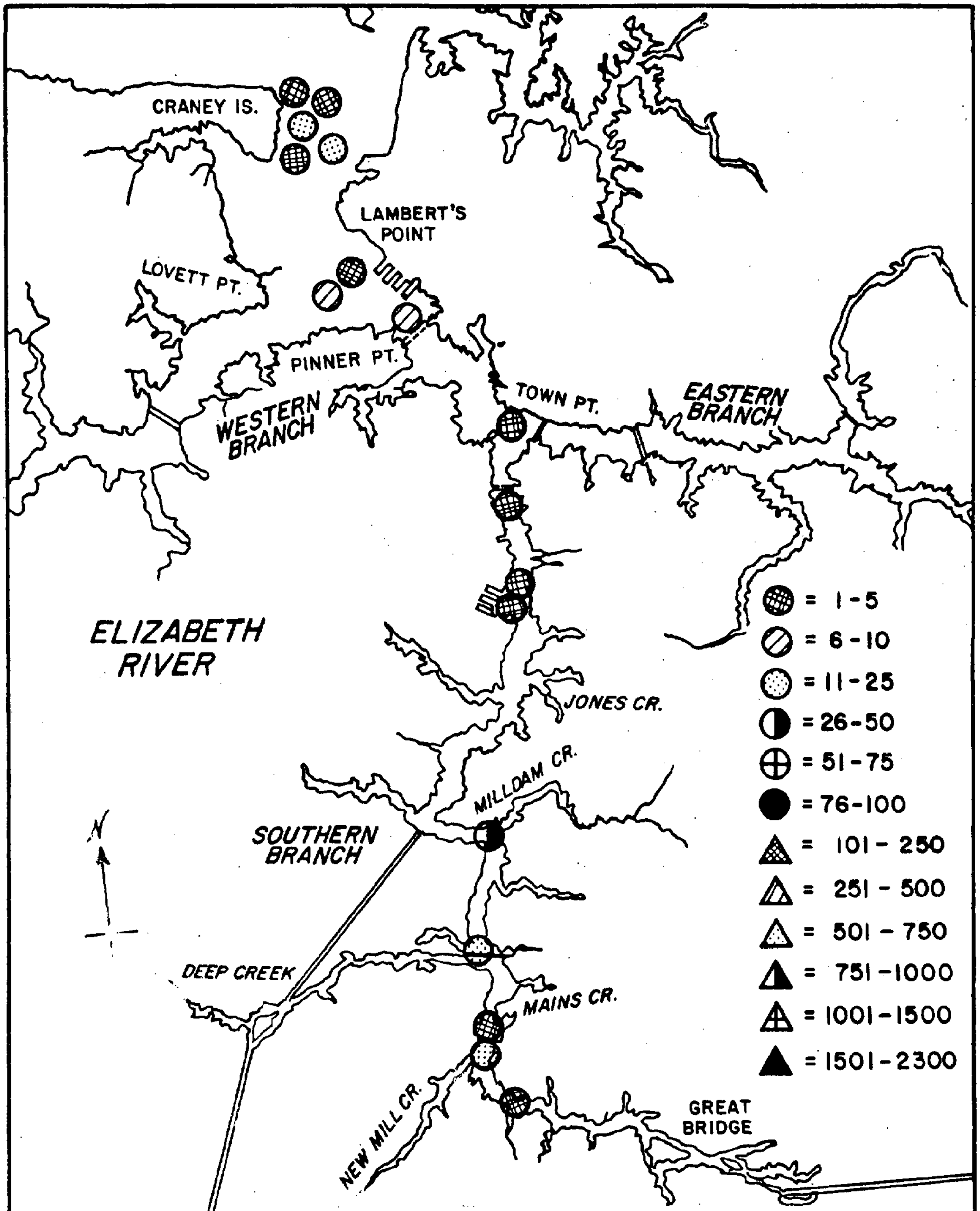
WINTER DISTRIBUTION OF MORONE SAXATILIS
(Striped Bass)

Figure 7



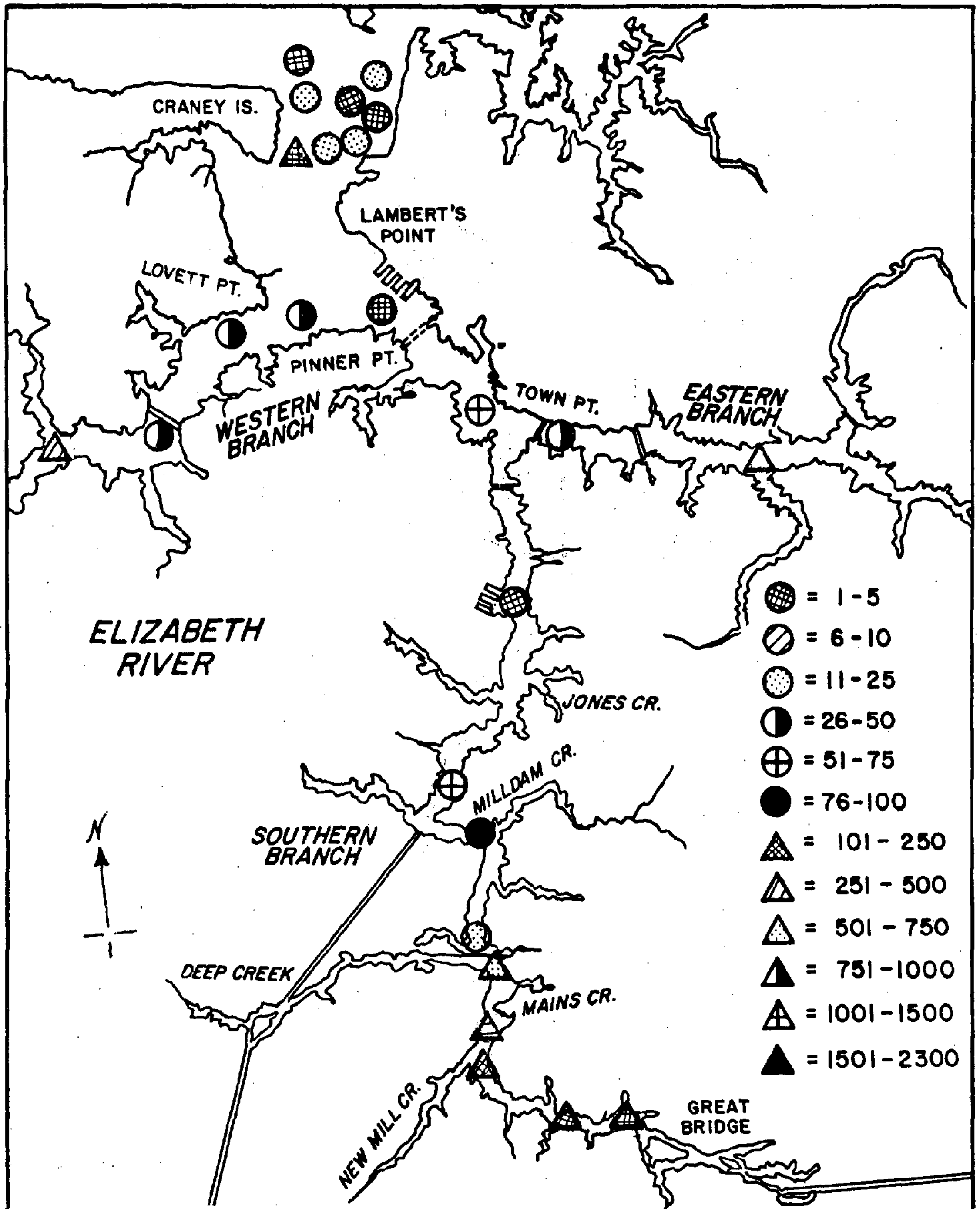
WINTER DISTRIBUTION OF MICROPOGONIAS UNDULATUS
(Atlantic Croaker)

Figure 8



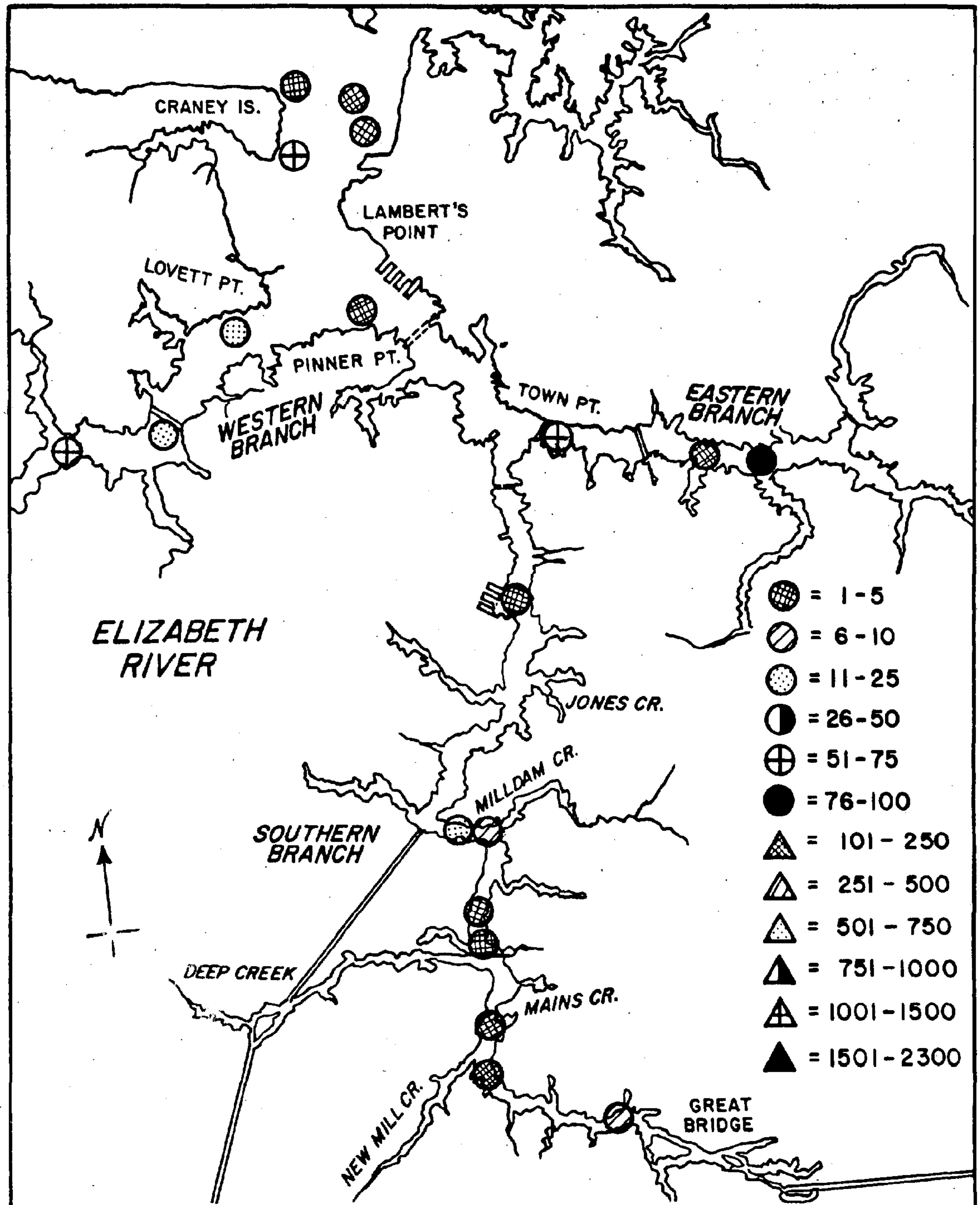
WINTER DISTRIBUTION OF ALOSINES
(Blueback, Alewife, American Shad)

Figure 9



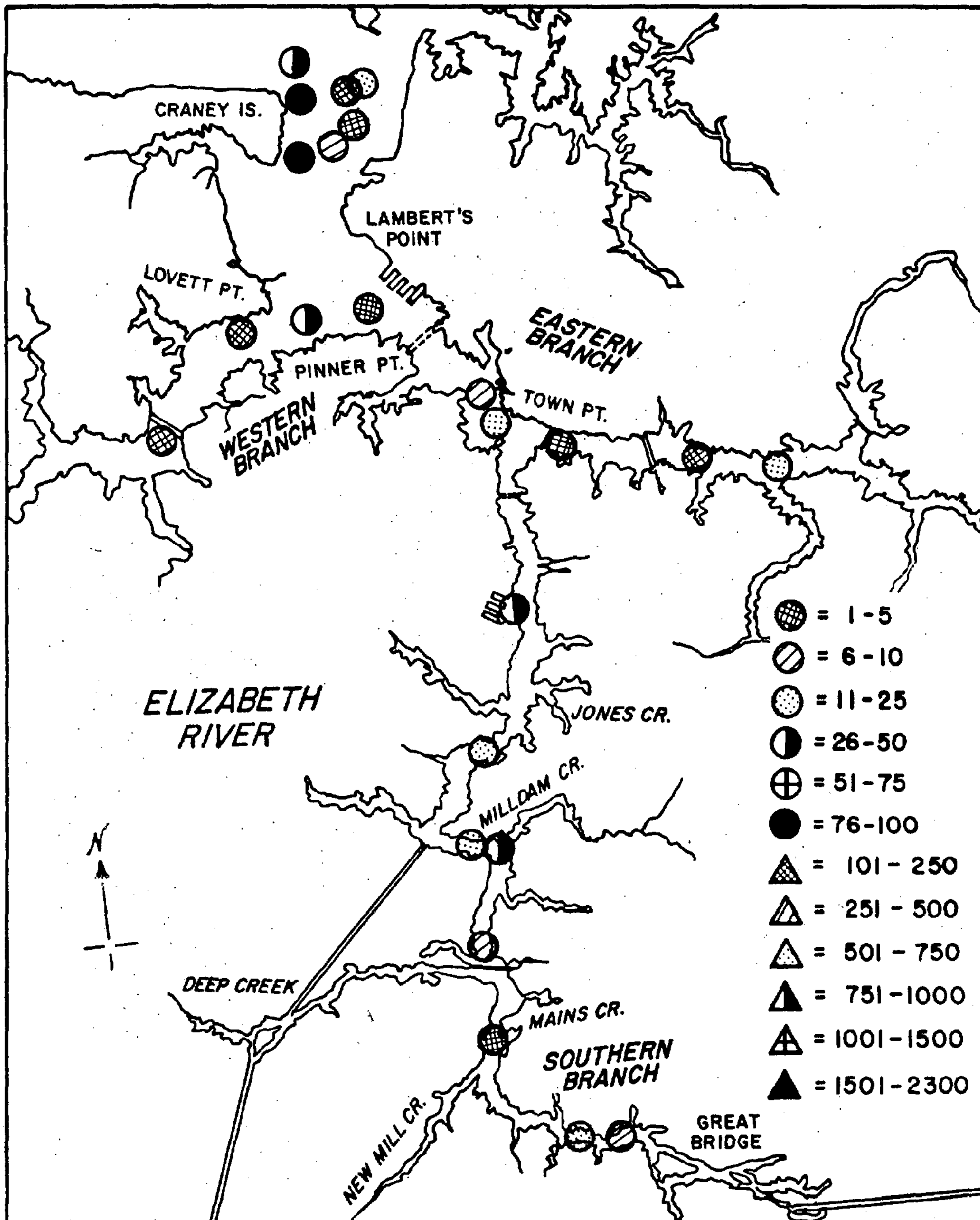
SUMMER DISTRIBUTION OF <u>LEIOSTOMUS</u> <u>XANTHURUS</u>
(Spot)

Figure 10



SUMMER DISTRIBUTION OF MICROPOGONIAS UNDULATUS
(Atlantic Croaker)

Figure 11



SUMMER DISTRIBUTION OF CYNOSCION REGALIS
Weakfish/Grey Trout

Figure 12. Winter Distribution of Herring, Shad, Blueback, Alewife, American shad and Hickory shad) in the Lower James River.

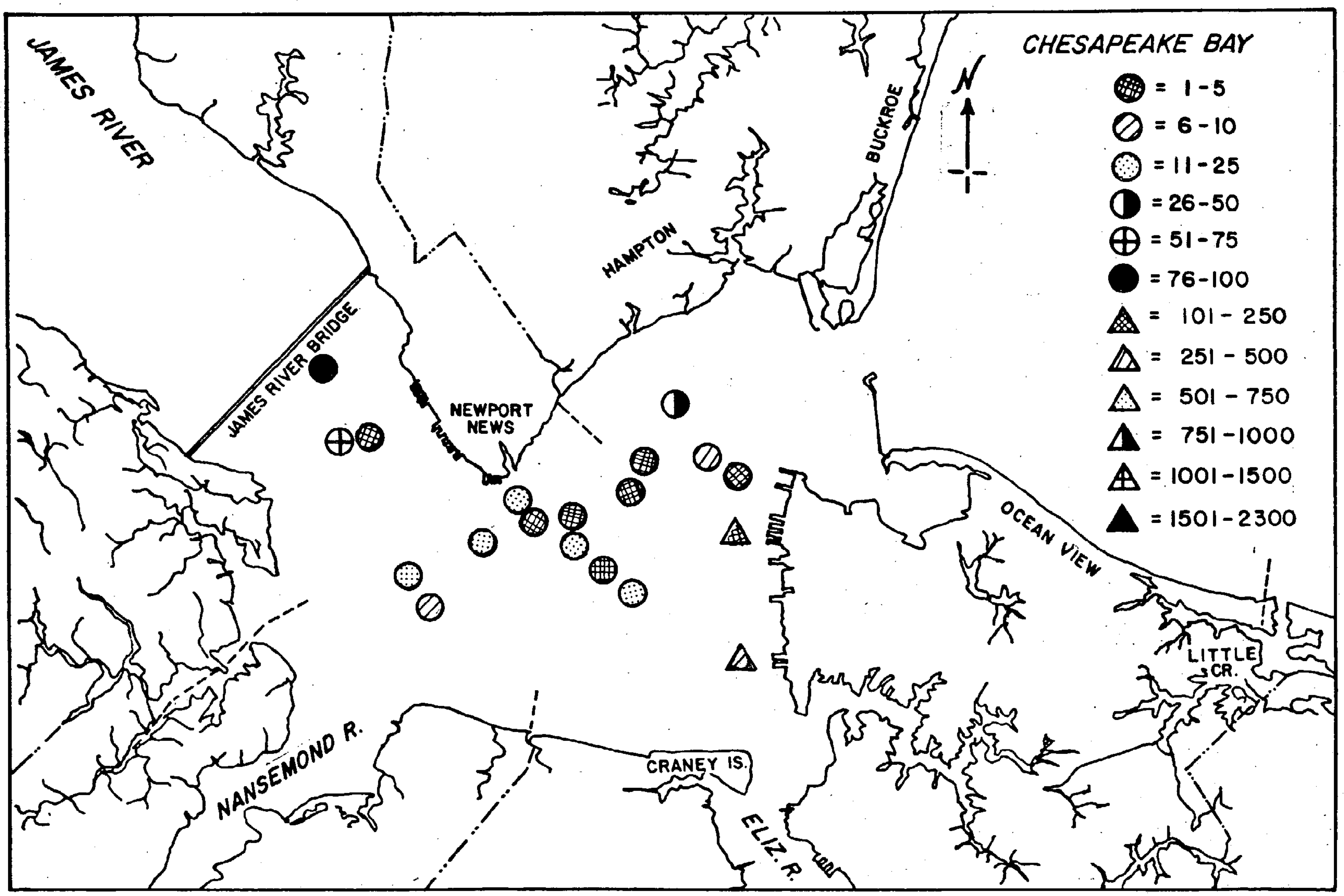
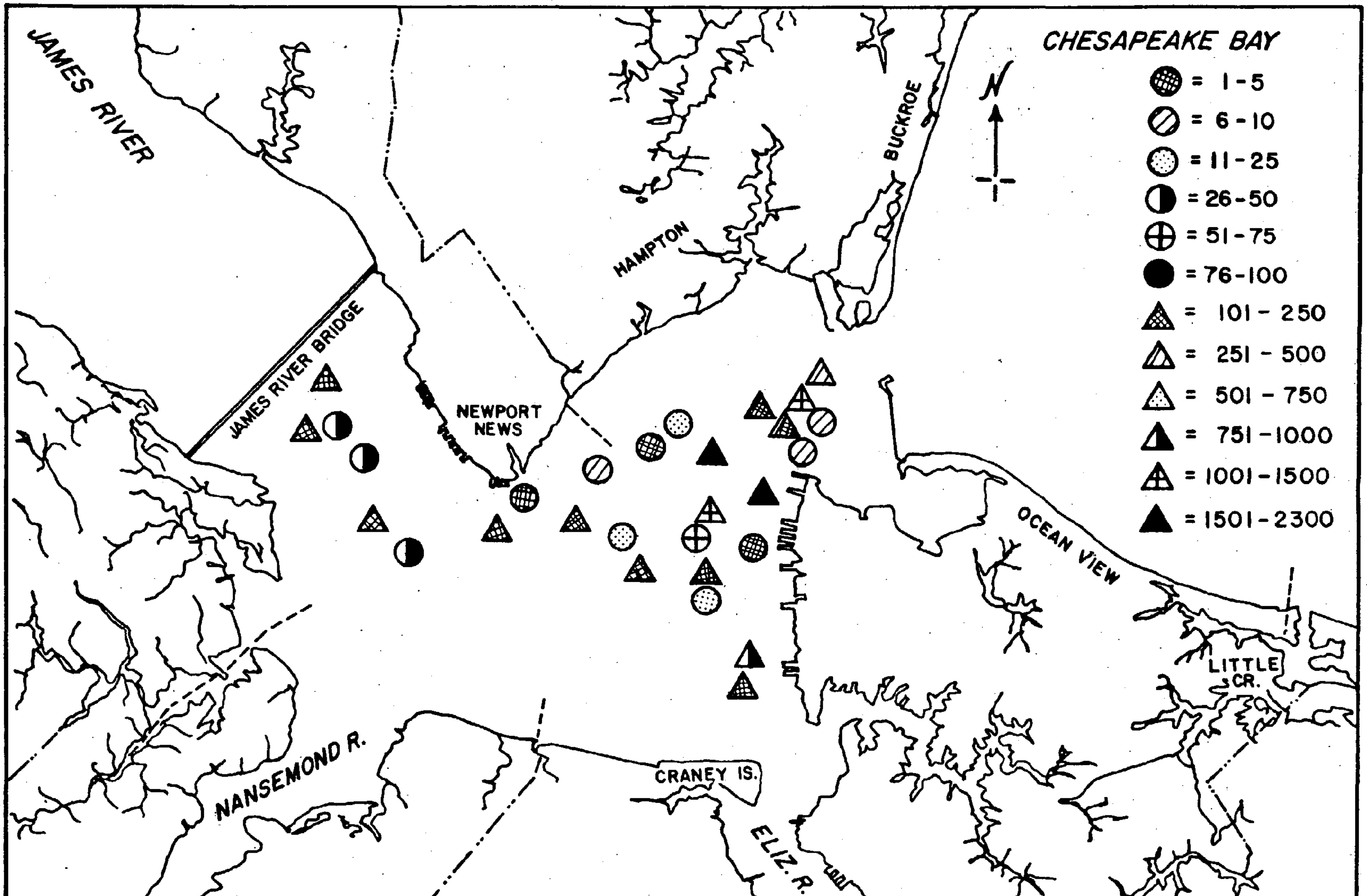


Figure 13. Winter Distribution of Micropogonias undulatus, Atlantic croaker in the Lower James River.



OYSTER AND HARD CLAM DISTRIBUTION AND ABUNDANCE IN HAMPTON ROADS AND THE LOWER JAMES RIVER

by

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Introduction

Hampton Roads and the Lower James River support large populations of oysters, *Crassostrea virginica*, and hard clams, *Mercenaria mercenaria* which are vitally important to the seafood industry as a source of seed oysters and hard clams. They are also the most vulnerable to the impacts of dredging activities because of their non-motile nature.

The most critical stage in the life cycle of the oyster are the egg, larval and setting stages where the free-swimming larvae develop, settle to the bottom and metamorphose into their adult form. The development of the egg to larvae has been shown to be affected by concentrations of suspended solids in the range of 100-200 mg/l (See the section on the effects of suspended solids in this report). These larvae also need a clean hard substrate upon which to strike and metamorphose (spatfall). In order to minimize the impacts on the oyster population it is important to avoid excessive concentrations of suspended solids and concomitant sedimentation during periods when these critical life stages are present in the estuary. Periods of peak spatfall at selected stations in Hampton Roads and the Lower James River are provided in Table 1 and Figure 1.

Adult oysters can withstand several days of elevated suspended solids levels by pumping at reduced rates or even closing their shells completely. However, rapid sedimentation in excess of .25 inch will have an adverse effect on adults and will probably kill newly settled spat.

Clam larvae are less susceptible to adverse effects from increased suspended solids. In fact, they spend most of their early sedentary life stages in the floc layer at the sediment-water interface where suspended solids levels are approximately 150 mg/l. Principal spawning times are June and early July.

Table 1. Spatfall records for the Hampton Roads and lower James River (VIMS data).

Spatfall on Shellstrings*
Annual Summary
1976-1979

JAMES RIVER

Dates Exposed**	Hampton Flats 1976	Hampton Flats 1977	Hampton Flats 1978	Hampton Flats 1979	Nansemond Ridge 1976	Nansemond Ridge 1977	Nansemond Ridge 1978	Nansemond Ridge 1979	Newport News Tax Office 1976	Newport News Tax Office 1977	Newport News Tax Office 1978	Newport News Tax Office 1979
Jun 19-25	--	--	--	--	--	0.0		0.0	0.0	0.0	0.0	0.0
Jun 25-Jul 2	0.0	0.0	0.0	--	--	0.0	0.0	0.0	0.0	0.0		0.0
Jul 2- 9	--		0.0	--	--	--		0.0	--	0.0	0.0	
Jul 9-16	0.2	1.0		0.7	--	0.3	0.0	0.1	0.4	--	0.0	0.0
Jul 16-23	0.3		0.0		0.0	0.0		0.1	--	0.4	0.0	0.1
Jul 23-30	0.3	0.2	0.0	4.0	0.0	--	0.0	--	0.2	0.3	0.0	0.0
Jul 30-Aug 6	0.1	0.6	0.1	0.4	0.0	0.1	0.0	--	0.2	0.7	0.0	0.0
Aug 6-13	0.3	0.8	0.0	3.6	--	0.0	0.8	3.1	0.4	--	0.0	0.6
Aug 13-20		0.7	0.1	7.6	--	0.1	0.2	3.3	1.0	0.6	0.0	1.1
Aug 20-27	1.7	0.5	0.3	1.7	--		0.9	0.4	0.0	0.4		--
Aug 27-Sep 3		2.5	1.3	0.0	0.4	1.6	0.1		1.8		0.1	--
Sep 3-10	1.1	0.2	0.7	1.3	0.4	0.2	0.9	0.1	2.5	1.3	0.2	0.8
Sep 10-17	1.3		0.0	2.5	--	0.1	0.0	0.3	9.5	0.5	0.0	0.5
Sep 17-24	4.4	2.7		0.8	1.1	0.1	0.4	--	0.1	1.0	0.1	0.2
Sep 24-Oct 1			1.2	--	--	--	--	--	0.8	1.0	--	
Oct 1- 8	--	--	1.5	--	--	--	0.0	--	--	--	--	0.2
Oct 8-15	--	--	--	--	--	--	--	--	--	--	--	
TOTALS	9.7	9.2	5.2	22.6	1.9	2.5	3.3	7.4	16.9	6.2	0.7	3.5

* Shows spat per shell (smooth side only).
** Dates shown are for 1979. Dates in other years were approximately the same.
● Not sampled in previous years.

General Guide to Setting:

0.1 to 1.0 spat per shell = fair
1.1 to 10.0 spat per shell = moderate
10.1 to 100 spat per shell = heavy

Table 1. continued

Dates Exposed**	Brown Shoal 1976	Brown Shoal 1977	Brown Shoal 1978	Brown Shoal 1979	Miles Watch House 1976	Miles Watch House 1977	Miles Watch House 1978	Miles Watch House 1979	White Shoal 1976	White Shoal 1977	White Shoal 1978	White Shoal 1979
Jun 19-25	--	0.0	0.0	--	0.0	0.0	0.0	--	0.0	--	0.0	--
Jun 25-Jul 2	0.0		0.0	--	0.0		0.0	--	0.0	0.0	0.0	--
Jul 2- 9	--	0.0	0.0	0.1	--	--	0.0	0.0	0.0	--	0.1	0.0
Jul 9-16	0.9	--	0.0	0.3	0.0	--	0.0	0.5	0.0	0.1	0.0	0.0
Jul 16-23	0.3	0.0	0.0	0.5	0.1	0.0	0.0	0.1	0.1	--	0.0	0.1
Jul 23-30	0.2	0.1	0.0	0.4	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.7
Jul 30-Aug 6	0.0	0.0	0.1	0.4	0.0	0.0	0.1	0.2	0.0	0.1	0.0	1.6
Aug 6-13	0.0	0.5	0.2	0.2	0.0	0.5	0.3	0.4	0.1	3.0	0.1	2.7
Aug 13-20	0.8	0.7	0.2	2.0	0.2	0.5	0.1	2.9	1.3	0.6	0.0	2.0
Aug 20-27	0.5	0.3	0.1	0.0	0.1	0.5	0.2	0.0	0.2	6.0		0.5
Aug 27-Sep 3	0.8	0.6	0.1	0.4	0.1	0.2	--	0.1	0.5	4.1	0.2	0.2
Sep 3-10	3.9	0.5	0.0	0.5	0.1	0.2	0.9	0.2	1.7	0.4	0.3	0.3
Sep 10-17	6.7	0.4	0.5	1.5	0.4		0.3	0.0	2.6	0.0	0.2	0.1
Sep 17-24	3.2	0.5	0.7	1.3	0.6	--	1.0	0.8	2.3	0.7	0.9	0.8
Sep 24-Oct 1	0.3	0.1	0.3	0.0	0.0	0.0	0.7	0.0	0.0	0.8	0.6	0.0
Oct 1- 8	--	--	--	0.0	--	--	0.0	0.0	--	--	0.0	0.0
Oct 8-15	--	--	--		--	--	--		--	--	--	
TOTALS	17.6	3.7	2.2	7.6	1.6	1.9	3.6	5.9	8.8	15.8	2.4	9.0

Date Exposed**	Wreck Shoal 1976	Wreck Shoal 1977	Wreck Shoal 1978	Wreck Shoal 1979	Warwick River Mouth 1976	Warwick River Mouth 1977	Warwick River Mouth 1978	Warwick River Mouth 1979	Point of Shoal 1976	Point of Shoal 1977	Point of Shoal 1978	Point of Shoal 1979
Jun 18-25	0.0	0.0	0.0	--	--	0.0	0.0	--	--	--	0.0	--
Jun 25-Jul 2	0.0	0.0	0.0	--	--	0.0	0.0	--	0.0	0.0	0.0	--
Jul 2- 9	--	0.0	0.0	0.0	--	0.0	0.0	0.0	--	0.0	0.0	0.0
Jul 9-16	0.0	0.0	0.0	0.3	--	--	0.0	0.0	0.0	0.0	0.0	0.1
Jul 16-23	0.0	0.0	0.0	--	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul 23-30	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Jul 30-Aug 6	0.0	0.0	0.2	1.2	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.4
Aug 6-13	0.1	0.4	0.6	1.8	0.1	2.2	0.0	0.3	0.2	5.7	0.0	0.4
Aug 13-20	0.2	0.7	0.0	1.5	0.3	0.3	0.1	--	0.0	2.6	0.2	1.0
Aug 20-27	0.0	0.5	0.0		0.1	0.2		--	0.1	3.5		0.0
Aug 27-Sep 3	--	1.1	0.1	0.2	0.0	0.2	0.1	--	0.0	1.6	0.3	0.1
Sep 3-10	0.0	0.1	0.1	0.1	0.0	0.0	0.4	--	0.0	0.8	0.0	0.0
Sep 10-17	0.7	0.1	0.2	0.5	0.1	0.0	0.3	0.0	0.0	0.1	--	0.0
Sep 17-24	1.1	0.0	0.1	0.7	0.1	0.0	--	0.0	0.2	0.1	0.2	0.2
Sep 24-Oct 1	0.1	0.2	0.4	0.0	0.2	0.0	--	0.0	0.0	0.1	0.0	0.0
Oct 1- 8	--	0.0	0.2	0.1	--	0.1	--	--	--	--	0.2	0.0
Oct 8-15	--	--	--		--		--		--	--	--	
TOTALS	2.2	4.1	1.9	6.9	1.1	3.0	0.9	0.3	0.5	14.9	0.9	2.2

Dates Exposed**	Mulberry Swash 1976	Mulberry Swash 1977	Mulberry Swash 1978	Mulberry Swash 1979	Horsehead Shoal 1976	Horsehead Shoal 1977	Horsehead Shoal 1978	Horsehead Shoal 1979	Deepwater Shoal 1976	Deepwater Shoal 1977	Deepwater Shoal 1978	Deepwater Shoal 1979
Jun 18-25	--	--	0.0	--	--	--	0.0	--	--	--	0.0	--
Jun 25-Jul 2	0.0	0.0	0.0	--	0.0	0.0	0.0	--	0.0	0.0	0.0	--
Jul 2- 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul 9-16	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Jul 16-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0	0.0
Jul 23-30	0.0	0.0	0.0	0.0	--	0.0	0.0	0.0	--	0.0	0.0	0.0
Jul 30-Aug 6	0.0	0.2	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.4	0.5
Aug 6-13	0.0	4.0	0.1	0.7	0.3	1.1	0.1	1.4	0.0	0.6	0.0	0.3
Aug 13-20	0.1	0.0	0.4	1.2	0.1	0.5	0.0	0.7	0.0	0.4	0.0	0.7
Aug 20-27	0.0	1.7		0.5	0.0	2.3	0.1	0.0	0.0	1.5	0.6	0.3
Aug 27-Sep 3	0.0	2.4	0.3	0.3	0.0	0.4	0.0	0.2	0.0	0.4	0.0	0.4
Sep 3-10	0.4	0.1	1.1	0.0	0.1	0.2	0.5	0.0	1.1	0.2	0.4	0.4
Sep 10-17	0.2	0.0	0.7	0.1	0.7	0.1	--	0.0	0.2	0.3	0.0	0.0
Sep 17-24	0.0	0.1	0.4	0.0	0.2	0.0	0.1	0.0	0.2	0.1	0.3	0.0
Sep 24-Oct 1	0.0	0.0	0.7	0.0	0.1	0.0	0.2	0.0	0.3	0.0	0.3	0.0
Oct 1- 8	--	--	0.2	0.0	--	--	--	0.0	--	--	0.2	0.0
Oct 8-15	--	--	--		--	--	--		--	--	--	
TOTALS	0.7	8.5	3.9	4.0	1.5	4.6	1.0	3.0	0.8	3.5	2.2	2.6

SHELLSTRING SURVEY STATIONS

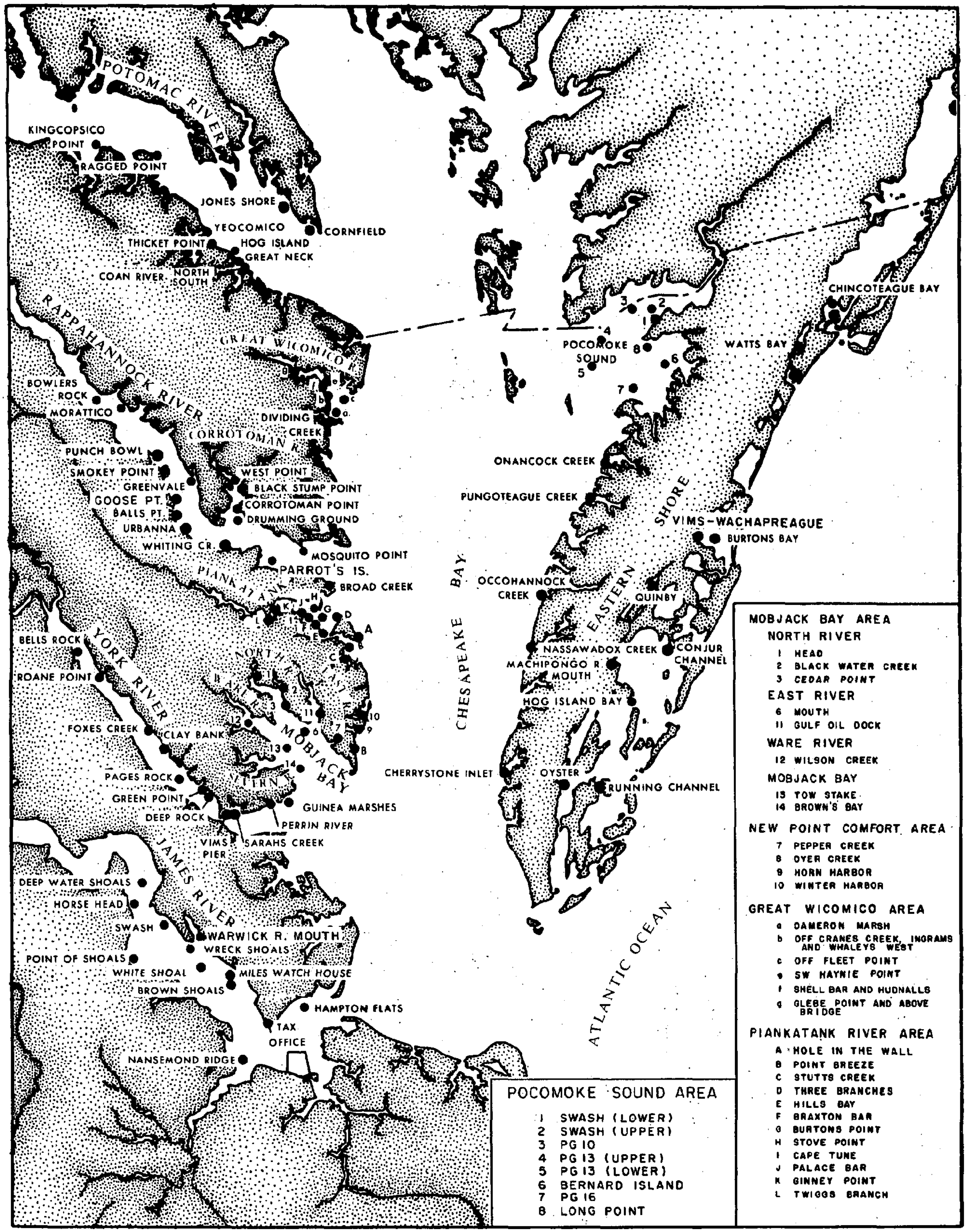
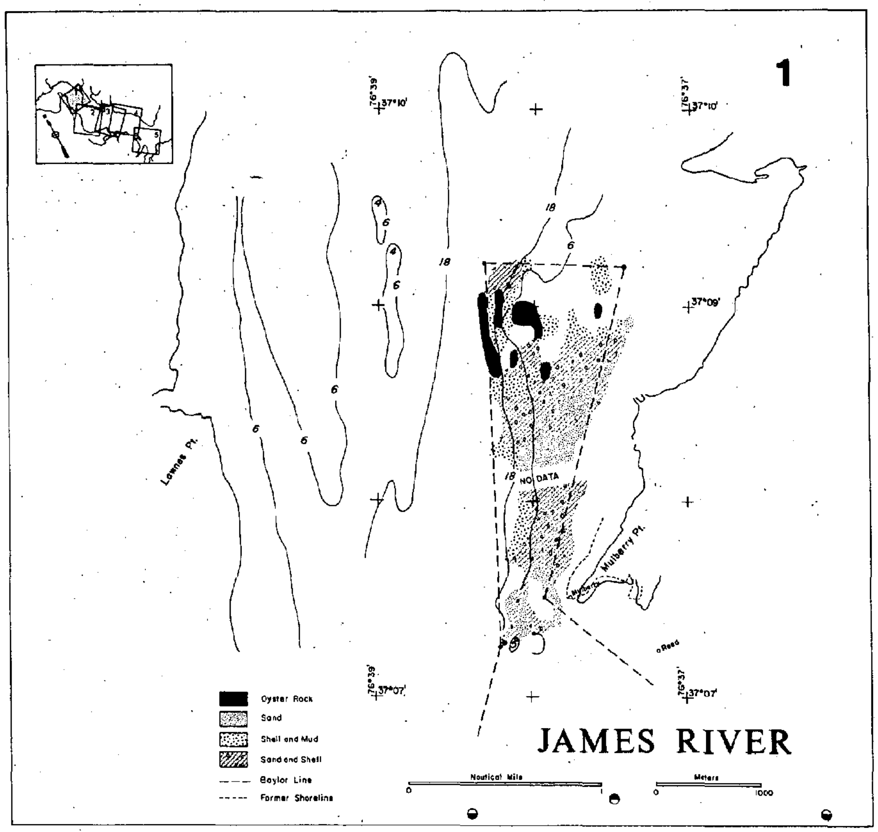
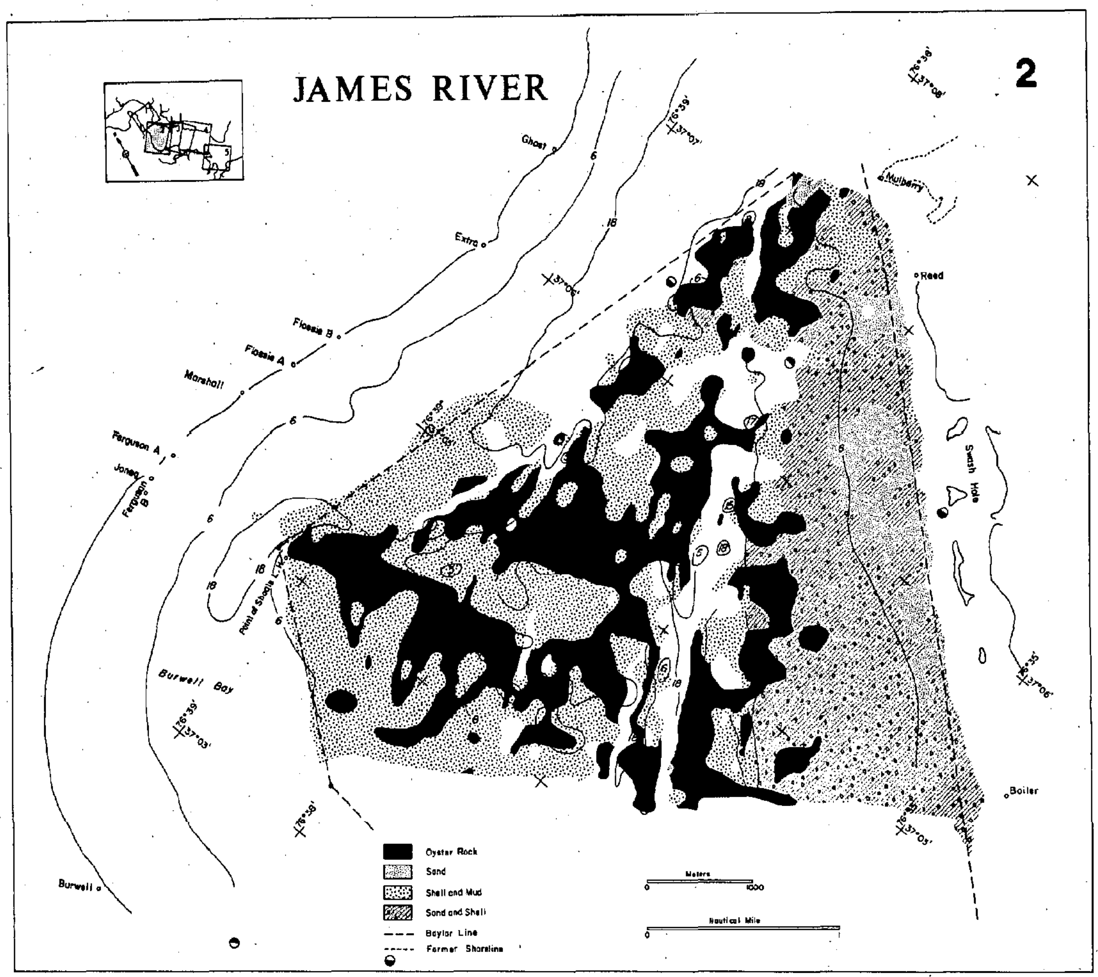


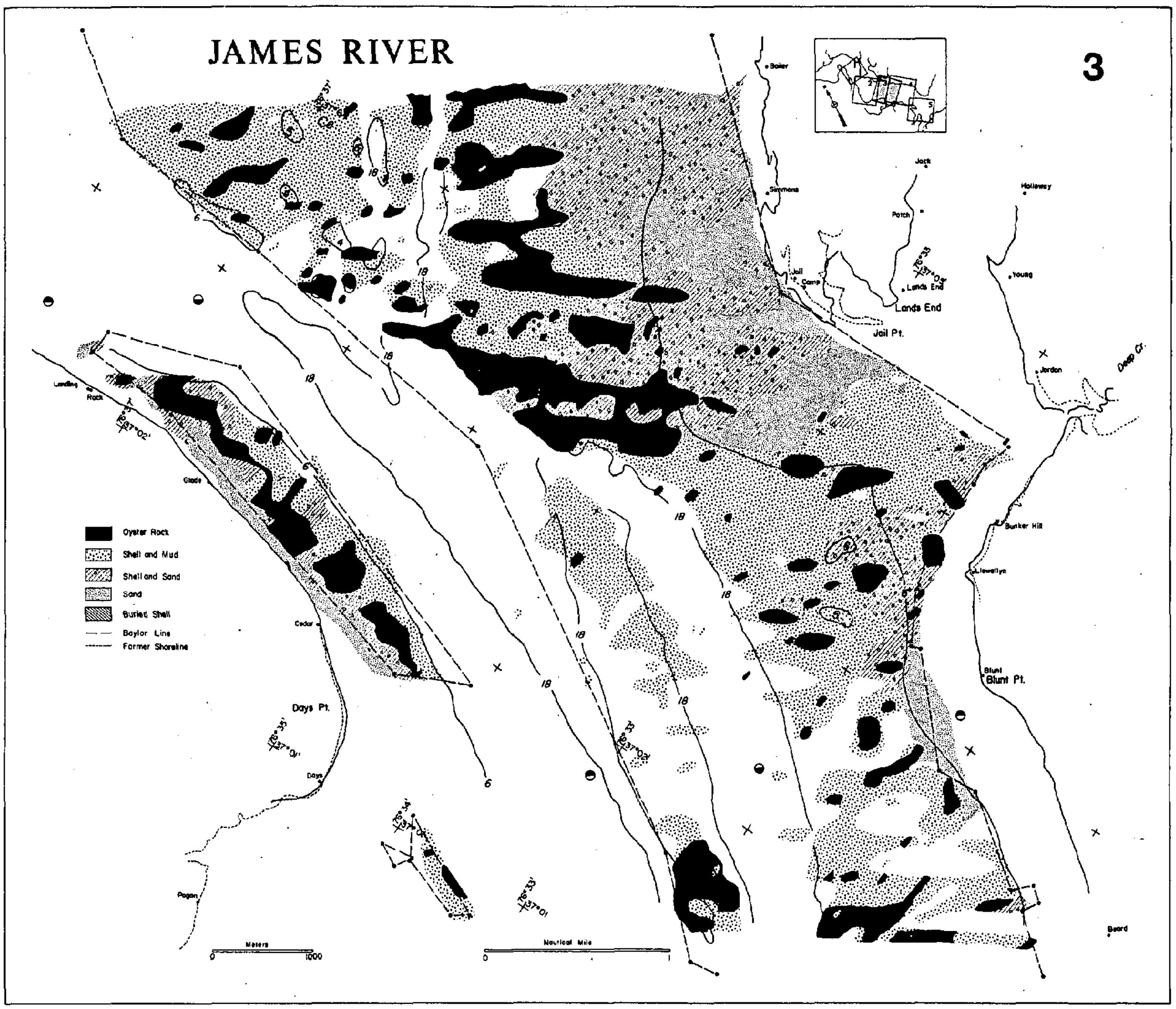
Figure 1. Locations of shellstring spatfall sample stations.

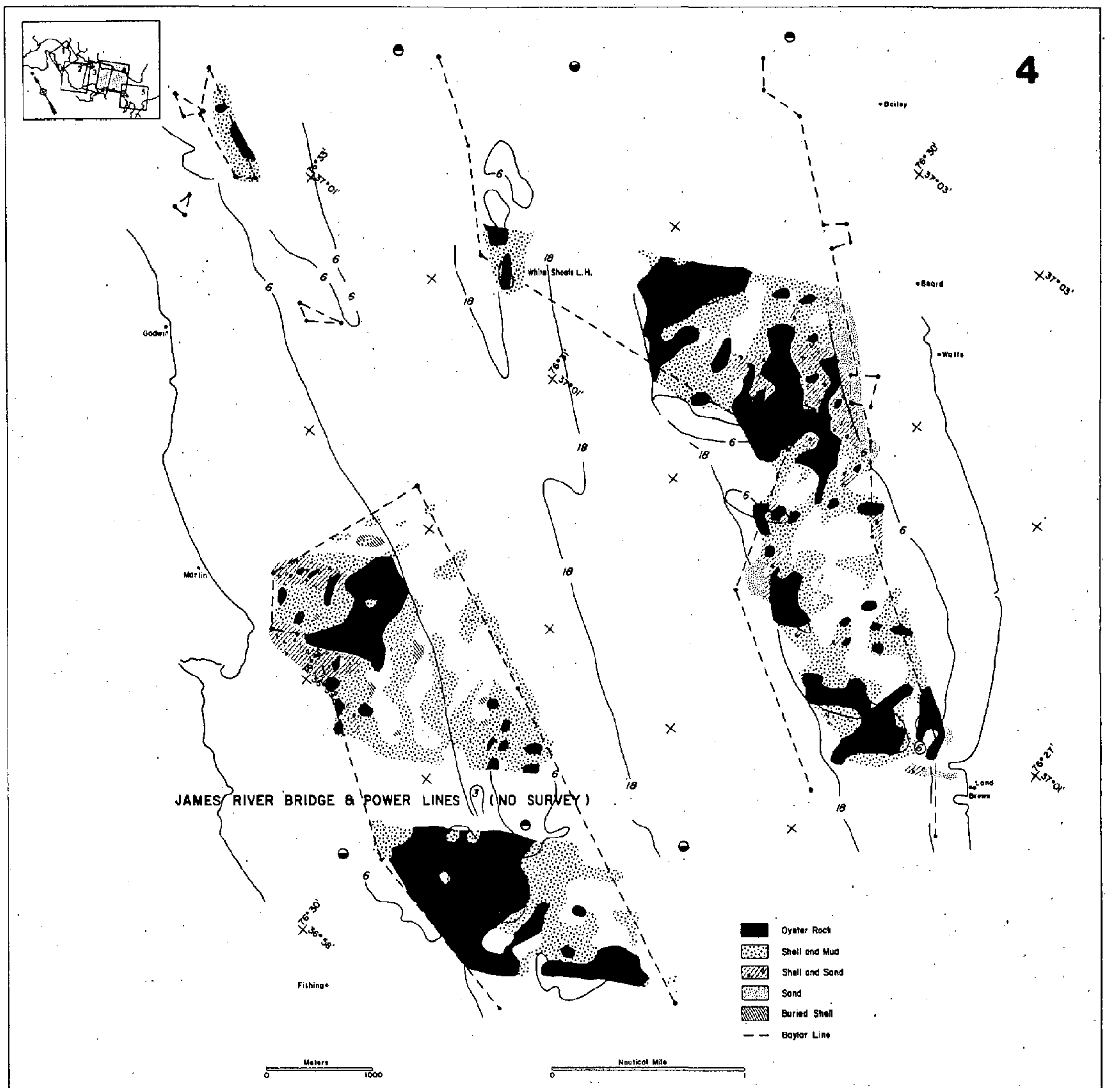
Table 2. Estimated of oyster, *Crassostrea virginica*, densities on different substrates in Baylor Survey public grounds in the Lower James River (Haven. Whitcomb and Kendall, MS in preparation).

Area Designation / Substrate Type	No. Acres	Est. Density (bu/acre)	Total No. Bushels (Millions)
AREA I (Plates 1 and 2)			
Oyster Rock	1812	460	0.833
Mud and Shell	1962	114	0.224
Sand and Shell	1690	125	0.211
Totals	5464		1.268
AREA II (Plate 3)			
Oyster Rock	1348	405	0.546
Mud and Shell	3237	78	0.252
Sand and Shell	1599	75	0.120
Totals	6184		0.918
AREA III (Plates 4 and 5)			
Oyster Rock	1171	471	0.551
Mud and Shell	2475	108	0.267
Sand and Shell	1116	108	0.120
Totals	4762		0.938
TOTALS ALL AREAS	16,410		3.124

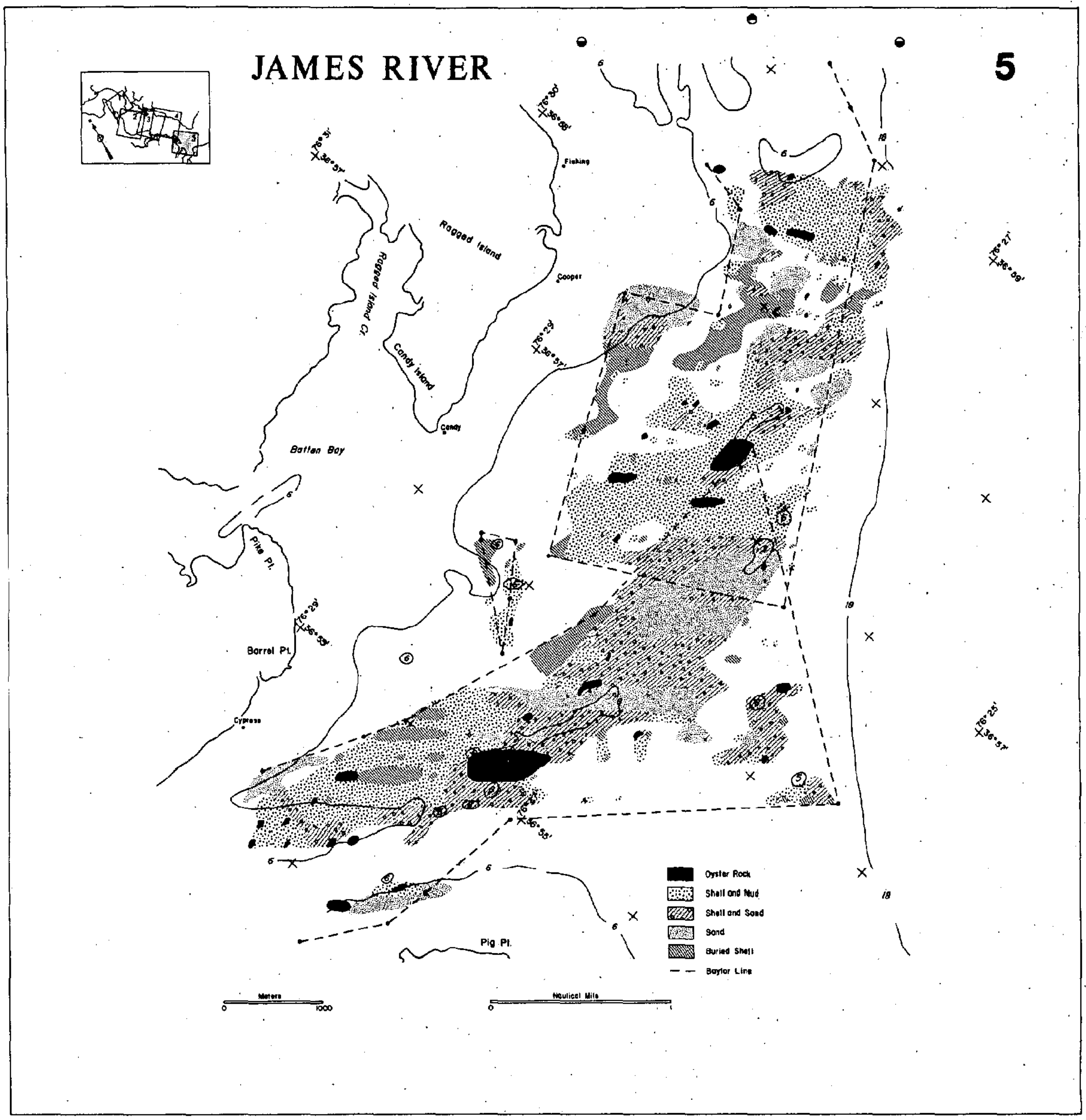

1
76°39'
37°10'
76°37'
37°10'
37°09'
18
6
4
NO DATA
Lawnes Pt.
Mulberry Pt.
Reed
76°39'
37°07'
76°37'
37°07'
Oyster Rock
Sand
Shell and Mud
Sand and Shell
Baylor Line
Former Shoreline
Nautical Mile
0
1
Meters
0
1000
JAMES RIVER


JAMES RIVER
2
Ghost
Extra
Flossie B
Flossie A
Marshall
Ferguson A
Jones
Ferguson B
Point of Shoals
Burwell Bay
Burwell
Mulberry
Reed
Swash Hole
Boiler
Oyster Rock
Sand
Shell and Mud
Sand and Shell
Baylor Line
Former Shoreline
Meters
0
1000
Nautical Mile
0
1


JAMES RIVER
3
Oyster Rock
Shell and Mud
Shell and Sand
Sand
Buried Shell
Baylor Line
Former Shoreline
Simmons
Jail Pt.
Lands End
Deep Cr.
Bunker Hill
Blunt Pt.
Days Pt.
Meters
Nautical Mile


4
White Shoals L.H.
JAMES RIVER BRIDGE & POWER LINES (NO SURVEY)
Oyster Rock
Shell and Mud
Shell and Sand
Sand
Buried Shell
Baylor Line
Meters
Nautical Mile

JAMES RIVER


JAMES RIVER
5
Ragged Island
Ragged Island Cr.
Candy Island
Candy
Fishing
Cooper
Batten Bay
Pike Pt.
Barrel Pt.
Cypress
Pig Pt.
Oyster Rock
Shell and Mud
Shell and Sand
Sand
Buried Shell
Baylor Line
Meters
Nautical Mile

The adult hard clams have a limited amount of vertical mobility and probably will not be adversely effected by up to .5 inch of new silt.

The distribution of oysters on the Baylor Public Grounds in the Lower James River are depicted in Plates 1-5. This distribution is based on the areal extent of three different substrate types, oyster rock, mud and shell and sand and shell. These are considered productive or potentially productive oyster bottoms and are where the densest populations of oysters are found (Haven, Whitcomb and Kendall, MS in preparation).

The densities of oysters for each substrate type based on random sampling along transects across the river are presented in Table 2. In this table Area I refers to the area covered in Plates 1 and 2, Area II refers to Plate 3 and Area III refers to Plates 4 and 5 (Haven and Morales-Alamo, 1980).

The upriver limit of the distribution of the hard clam Mercenaria mercenaria in the James River is located at the level of the James River bridge. Several intensive surveys of hard clam populations in the James River have been conducted previously by VIMS (Haven and Loesch, 1972; Haven, Loesch and Whitcomb, 1973; and Haven and Kendall, 1974, 1975). The data from those studies form the basis for this report on the density of hard clams in Hampton Roads and the James River.

The region between just above the James River bridge and the mouth of the river at Old Point Comfort was divided into 31 plots (Figure 2). The acreage included in each of the plots was measured with a polar planimeter on a NOAA navigation chart. Eighteen of the plots were sampled in the surveys mentioned above and the outlines of their areas are based on those data. The other thirteen plots were not sampled and their areas were delineated following the boundaries of the areas sampled and bottom depth contours. The density of clams in plots not sampled was estimated on the basis of the

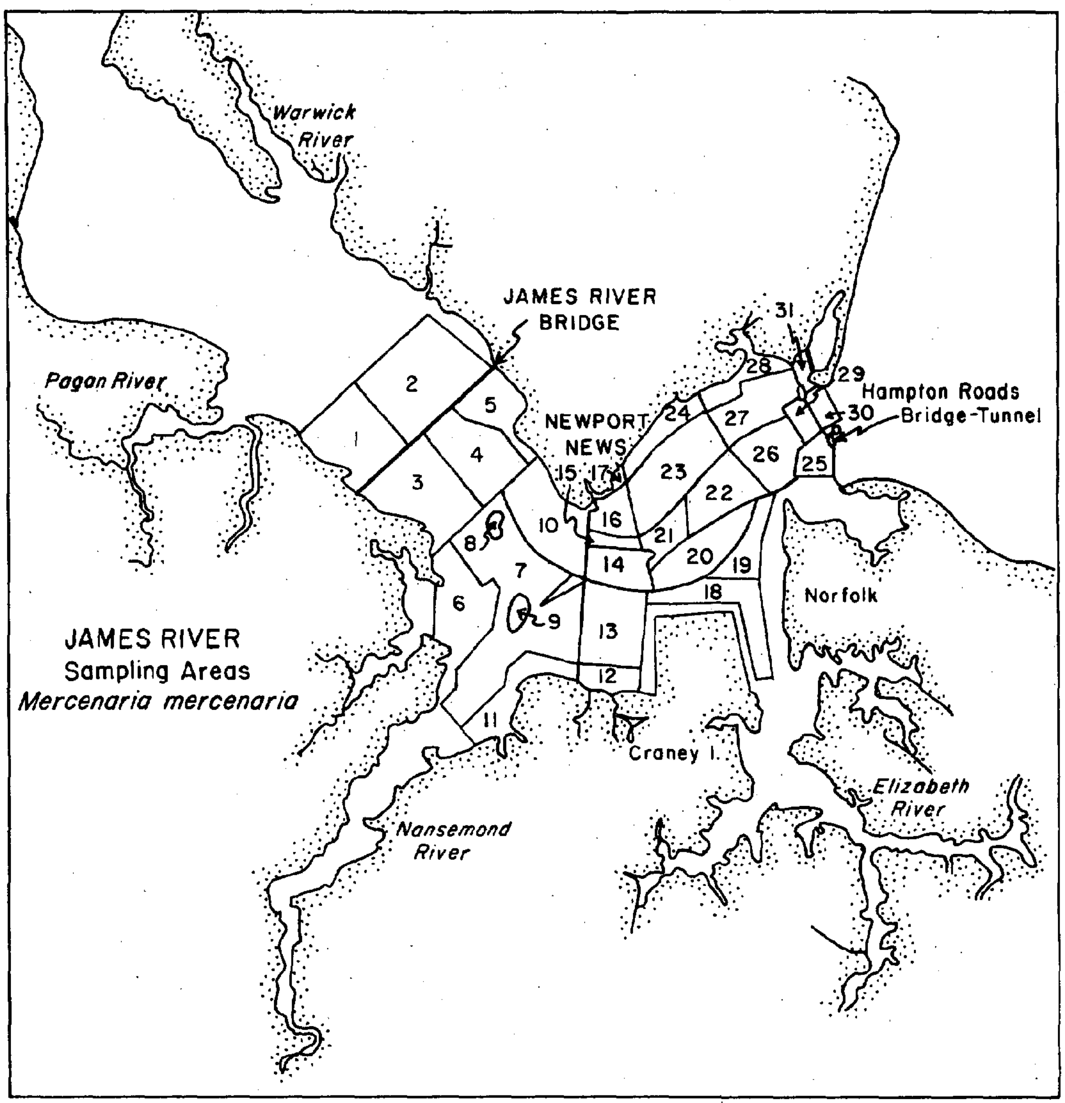


Figure 2. Division of lower James River into system of numbered plots used to estimate bottom acreage and standing crop of the hard clam Mercenaria mercenaria.

density in adjoining plots that were sampled, and our familiarity with the areas through conversations with clammers that work them and the nature of the bottom. These data are summarized in Table 3 (Haven and Morales-Alamo, 1980).

Table 3. Estimate of bottom acreage and densities of the hard clam, Mercenaria mercenaria, in plots surveyed between 1970 and 1974 in the Lower James River (Haven and Morales-Alamo, 1980).

Source of Data (Footnotes)	Plot No.	No. Acres	Clam Density (Bu/Acre)	Total No. (Bushels)
-	1	508	(0.3)[5]	152
1	2	4321	6.9	29,815
-	3	427	(0.3)[5]	128
1	4	1221	40.0	48,840
1	5	1928	36.1	69,601
-	6	528	(0.3)[5]	158
2	7	5410	1.1	5,951
2	8	71	0	0
2	9	242	5.5	1,331
2	10	2352	12.1	28,459
-	11	305	(1.0)[5]	305
3	12	610	11.0	6,710
3	13	1126	0.3	338
3	14	1323	62.0	82,026
3	15	109	6.0	654
3	16	680	65.0	44,200
3	17	183	58.0	10,614
-	18	1075	(25.0)[5]	26,875
-	19	698	(25.0)[5]	17,450
-	20	1474	(25.0)[5]	36,850
-	21	890	(5.0)[5]	4,450
-	22	1202	(5.0)[5]	6,010
-	23	2266	109.8	248,807
-	24	488	109.8	53,582
4	25	571	16.08	9,182
-	26	1486	(5.0)[5]	7,430
4	27	1473	24.12	35,529
-	28	691	(25.0)[5]	17,275
4	29	386	10.05	3,879
4	30	352	3.35	1,179
4	31	182	8.04	1,471
TOTALS		34,579		565,712

[1]Haven, D. S., J. G. Loesch and J. P. Whitcomb. 1973. An investigation into commercial aspects of the hard clam fishery and development of commercial gear for the harvest of molluscs. Final Report, Contract 3-124-R with the Virginia Marine Resources Commission, for the National Marine Fisheries Service. 119 pp. Virginia Institute of Marine Science, Gloucester Point, Virginia.

[2]Haven, D. and P. Kendall. 1975. A survey of commercial shellfish in the vicinity of Newport News Point and Pig Point in the lower James River. Final Report to McGaughy, Marshall and McMillan - Hazen and Sawyer. In: Fang, C.S. (Project Manager): Oceanographic, Water Quality and Modeling Studies

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[3]Haven, D. S. and J. G. Loesch. 1972. Hampton Roads corridor survey report for the Virginia Department of Highways. Final Report. 12 pp. + 6 tables. Virginia Institute of Marine Science, Gloucester Point, Virginia.

[4]Haven, D. and P. Kendall. 1974. A final report to the Virginia Department of Highways on hard clam (Mercenaria mercenaria) populations in the vicinity of the Hampton Roads Bridge-Tunnel (I-64). 15 pp + 6 tables + 18 figures. Virginia Institute of Marine Science, Gloucester Point, Virginia.

[5]Density given represents a guess-estimate based on familiarity with the area and data from surrounding areas.

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Spawning Activity and Nursery Utilization by Fishes in Hampton Roads and its Tributaries

by

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SPAWNING ACTIVITY AND NURSERY UTILIZATION BY FISHES IN HAMPTON ROADS AND ITS TRIBUTARIES

The information concerning the distribution of fish eggs, larvae and spawning activity in the Hampton Roads area is very limited. The available information does, however, indicate that there is considerable spawning activity, primarily forage species but with some alosine and other anadromous fish in selected areas, and heavy utilization of the area by postlarvae and juveniles as a nursery area.

The report by Hedgepeth et al. (This report) outlines nekton utilization of the study area. They state that the Hampton Roads area and the Elizabeth River are nursery grounds for juvenile spot, croaker, alewife, blueback herring, American shad, striped bass and weakfish. The most abundant spawning activity was by the resident forage species, particularly anchovies and silversides. The probability of spawning by alosine fishes and striped bass in the upper reaches of the Elizabeth River was also noted.

The presence of postlarvae of spot in the lower Elizabeth River in April was noted in the Hampton Roads Energy Company EIS (COE, 1977).

Table 1 presents data from Olney (1978) which show the numerical and temporal distribution of fish eggs and larvae in the lower Chesapeake Bay. The occurrence of most of these eggs and larvae with the exception of the shelf spawners and tropical intruders in similar numbers and at similar times of the year in Hampton Roads proper is very probable.

The most comprehensive study of the ichthyoplankton in the study area is one performed in conjunction with a study of the effects of a VEPCO power plant on the Southern Branch of the Elizabeth River by Ecological Analysts, Inc. (1979). Table 2 summarizes the species taken and the life history stages present.

Table 1. Species, total number and months of occurrence of fish eggs and larvae in the lower Chesapeake Bay. (Olney, 1978).

Species	Number		Occurrence	
	Eggs	Larvae	Eggs	Larvae
Conger oceanicus		1		May
Brevoortia tyrannus	10	28	July-August	February, April-May, August
Anchoa mitchilli	18,121	49	May-August	All months
Anchoa hepsetus*	53		May-August	
Anchoa spp.		6834		May-September
Gobiesox strumosus		10		June-September
Lophius americanus*		1		May
Urophycis regius		9		March
Rissola marginata*		3		August-September
Membras martinica		47		March, August
Atherinid larvae		132		May, August
Syngnathus fuscus		50		All seasons
Hippocampus erectus		7		March, July-August
Prionotus spp.*	1	14	August	August
Cynoscion regalis		555		June-September
Menticirrhus spp.		30		June-August
Leiostomus xanthurus		12		March
Unidentified sciaenids	1248		May-August	
Tautoga onitis	10		May	
Hypsoblennius hentzi		181		June-September
Ammodytes sp.*		4		January-March
Gobiosoma ginsburgi		358		June-September
Gobiosoma bosci		5		June-August

TABLE 1. (continued)

Species	Number Eggs	Number Larvae	Occurrence Eggs	Occurrence Larvae
Microgobius thalassinus		9		June-August
Gobiidae, 6-spined**		1		August
Gobiidae, 7-spined		46		June-September
*Scomber scombrus**		3		May
Peprilus triacanthus		1		July
Peprilus paru		13		August
Paralichthys dentatus		52		March
*Etropus microstomus**		1		August
Scophthalmus aquosus		10		May
Pseudopleuronectes americanus		3		March-April
Trinectes maculatus	682	425	June-September	June-September
Symphurus plagiusa		152		July-August
Symphurus-type	192		June-August	
Sphoeroides maculatus		5		May, July, August
Unknowns	89	53	Oct.-Nov., Mar.-Apr.	July-August
Totals	20,406	9114		

* SHELF SPAWNER
** TROPICAL INTRUDER

TABLE 2. SCIENTIFIC AND COMMON NAMES, WITH LIFE STAGES AND LIVE-DEAD EGG CATEGORIES, OF ICHTHYOPLANKTON CAPTURED IN THE SOUTHERN BRANCH STUDY AREA BETWEEN 13 FEBRUARY AND 5 SEPTEMBER 1978. (Ecological Analysts, Inc., 1979).

Scientific Name	Common Name	Live Egg	Dead Egg	Prolarvae	Postlarvae
Anguillidae	freshwater eels				
Anguilla rostrata	American eel				(elver)
Cupeidae	herrings				
Alosa spp.	--				X
Brevoortia tyrannus	Atlántic menhaden				X
Dorosoma cepedianum	gizzard shad			X	X
Engraulidae	anchovies				
Anchoa mitchilli	bay anchovy	X	X	X	X
Cyprinodontidae	killifishes				
Fundulus heteroclitus	mummichog				X
Atherinidae	silversides				
Menidia beryllina	tidewater silverside		X	X	X
Menidia menidia	Atlantic silverside		X		X
unidentified silverside					X
Percichthyidae	temperate bass				
Morone americana	white perch	X	X		X
Percidae	perches				
Etheostoma olmstedi	tessellated darter				X
Etheostoma spp.	unidentified darter				X
Perca flavescens	yellow perch			X	X
Sciaenidae	drums				
Cynoscion regalis	weakfish				X
unidentified drum	--				X
Gobiidae	gobies			X	X
Soleidae	soles				
Trinectes maculatus	hogchoker	X			X
Unidentified	--	X			X

Bay anchovy eggs were the most abundant ichthyoplankton comprising 94.1% of the total catch. The postlarvae of gobies were the most abundant larvae at 3.5% of the catch. The next most abundant segment of the ichthyoplankton was bay anchovy larvae at 1.7%. Taken together the eggs and larvae of the bay anchovy and the goby larvae represented 99.3% of the ichthyoplankton during the study (Ecological Analysts, Inc., 1979).

During February and March the only ichthyoplankton captured were American eel elvers and juvenile croakers. Postlarvae of the Atlantic menhaden began to appear in April. Silversides and gizzard shad began spawning in early April and continued through July. In mid-April white perch and yellow perch began spawning which continued through May. The bay anchovy also began spawning in mid-April but continued through September when the study ended (Ecological Analysts, Inc., 1979).

Gizzard shad and <u>Alosa</u> spp. preferred the upstream areas of the Southern Branch near the Great Bridge and Deep Creek locks for spawning. White perch preferred the upper reaches of the Southern Branch for their spawning while the yellow perch preferred the upper reaches of Deep Creek. During the periods of greatest abundance live and dead eggs and prolarvae of the bay anchovy were most numerous near the mouth of Deep Creek. The larvae of the Atlantic silverside were found only upstream of the mouth of Deep Creek and usually in low numbers. The larvae of the tidewater silverside, however, were common at all of the stations sampled. Goby postlarvae were well distributed but appeared to prefer the Elizabeth River stations over those in Deep Creek (Ecological Analysts, Inc. 1979).

The entire study area was used as a nursery area for bay anchovies, gobies, and the tidewater silverside. Yellow perch also used the entire study area as a nursery but their numbers were concentrated in Deep Creek and the upper reaches of the Southern Branch. The postlarvae of the white perch were restricted to the area near Great Bridge. The postlarvae of the gizzard shad were found throughout the summer in the upper reaches of the Southern Branch and Deep Creek (Ecological Analysts, Inc. 1979).

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MODEL AND PHYSICAL ENVIRONMENT

A MODEL FOR DREDGE-INDUCED TURBIDITY

by

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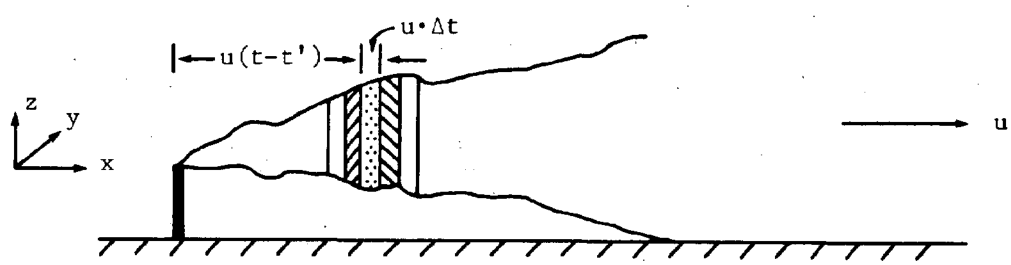
A MODEL FOR THE DREDGE-INDUCED TURBIDITY

I. Introduction

There are two major environmental concerns on the turbidity generated by a dredging operation. One is the temporary degradation of water quality by the turbidity plume. The other is the redeposition of dredge-induced turbidity in surrounding area, thus inflicting a negative impact on the habitat of benthic organisms. The model described in the following was formulated as a tool for quantitative estimate of these impacts.

II. Theoretical Derivation

The model is constructed based on the concept of 'spreading-disk' diffusion model, proposed by Frenkiel (1953) to describe a plume from a continuous point source in uniform wind field. The diffusion in the wind direction is neglected by comparison with the advection by mean wind.



As shown in the sketch, the plume is considered as a series of thin slices of disks one after the other. Each of the disksconsists of the material emitted from the source over a short duration of time from t' to t'+Δt'. The disk is convected to the position $x = u(t-t')$, and has been spread in the y and z direction by diffusion during the time interval $(t-t')$.

The diffusion of sediment particles in y and z directions may be described by the equation

$$\frac{\partial C}{\partial t} - W\frac{\partial C}{\partial z} = k_y \frac{\partial^2 C}{\partial y^2} + k_z \frac{\partial^2 C}{\partial z^2} \tag{1}$$

where

C is concentration,
t is time,
z is the coordinate in vertical direction,
y is the coordinate in transverse direction,
W is particle settling velocity,
k_y and k_z are diffusion coefficients in the y and z direction respectively.

The solution of equation (1) for an instantaneous line source along x-axis is

$$C = \frac{q}{4\pi\sqrt{k_y k_z}(t-t')} \exp\left(- \frac{(y-y')^2}{4k_y(t-t')} - \frac{\{z-z' + W(t-t')\}^2}{4k_z(t-t')} \right) \tag{2}$$

where

q is the source in mass/length/time,
y' and z' is the location of line source,
t' is the time when the material is released.

Equation (2) may be applied to the case of a continuous point source in a uniform flow field with velocity u in x-direction. In this case, the strength of line source q becomes Q/u, where Q is the source per unit time, and

$$t - t' = \frac{x}{u}$$

Equation (2) becomes

$$C(x,y,z) = \frac{Q}{4\pi\sqrt{k_y k_z}\,x} \exp\left[-\frac{(y-y')^2}{4k_y \frac{x}{u}} - \frac{(z-z' + W\frac{x}{u})^2}{4\,k_z \frac{x}{u}}\right] \tag{3}$$

III. Application to Hydraulic Dredge

A. Suspended Sediment Concentration in the Turbidity Plume

The turbidity plume induced by hydraulic dredge may be considered as the result of a point source moving back and forth on the river bottom in the y-direction. Applying equation (3), the concentration field may be described as

$$C(x,y,z) = \frac{Q}{4\pi\sqrt{k_y k_z}\,x} \exp\left[-\frac{(y-y')^2}{4\,k_y \frac{x}{u}} - \frac{(z + \frac{W}{u}x)^2}{4\,k_z \frac{x}{u}}\right] \tag{4}$$

where x is the distance from dredge head along flow direction, z is the distance above the bottom. In this application of solution for advective diffusion equation (equation (3)), the boundary effect of the water surface is assumed negligible, because the particle settling tends to keep them away from surface layer.

Since the dredge head moves back and forth in y-direction, y' is an implicit function of time, with $\frac{-B}{2} \leq y' \leq \frac{B}{2}$, where B is the sweeping range. At given distance x from dredge head and z above the bottom, the dredge-induced turbidity will have a maximum at $y = y'$,

$$C_m(x,z) = \frac{Q}{4\pi\sqrt{k_y k_z}\,x} \exp\left(-\frac{(z + \frac{W}{u}x)^2}{4\,k_z\,\frac{x}{u}}\right) \tag{5}$$

To investigate how the sediment concentration in a turbidity plume decreases with the distance from dredge head, C_m may be normalized with its value at a reference distance x_r. Dividing equation (5) by $C_m(x_r,z)$ and setting $z = z_o$, a given height above river bottom, it is obtained that

$$\frac{C_m(x,z_o)}{C_m(x_r,z_o)} = \frac{1}{X}\exp\left(-\frac{1}{4}\left\{\left(\frac{z_o^2}{k_z}\Big/\frac{x_r}{u}\right)\left(\frac{1}{X}-1\right) + \left(\frac{x_r}{u}\Big/\frac{k_z}{W^2}\right)(X-1)\right\}\right) \tag{6}$$

where $X = \frac{x}{x_r}$

Defining the dimensionless parameters

$t_d = \frac{z_o^2}{k_z}\Big/\frac{x_r}{u}$, the ratio of the time required for a particle to diffuse a distance z_o to the time of advection over a distance x_r,

$t_s = \frac{k_z}{W^2}\Big/\frac{x_r}{u} = \left(\frac{z_o}{W}\Big/\frac{x_r}{u}\right)^2\Big/t_d$, where $\left(\frac{z_o}{W}\Big/\frac{x_r}{u}\right)$ is the ratio of time required for a particle to settle a distance z_o to advection time, equation (8) may be written as

$$C_m^*(X) = \frac{1}{X} \exp\left[-\frac{1}{4}\left\{t_d\left(\frac{1}{X} - 1\right) + \frac{1}{t_s}(X-1)\right\}\right] \qquad (7)$$

For a continuous dredging in a tidal estuary, a new plume is formed with each change in current direction, while the old plume is dispersed rapidly under the combined effects of diffusion and settling. The turbidity plume will have its maximum extent near slack tide when the current has been going in the same direction for the maximum possible time period. The reference location may be taken at the plume front, and x_r equals to a tidal excursion, thus

$$x_r = uT, \text{ or } x_r/u = T$$

where T is one half of tidal period and u is the current speed averaged over flood tide or ebb tide.

Figures 1 through 5 show the function $C^*(X)$ plotted versus X for the parameter ranges encompassing typical values of coastal plain estuaries. Because the diffusion in current direction is assumed negligible, this model predicts that a turbidity plume is confined within $X \leq 1$, and the sediment concentration is zero for $X > 1$. This assumption is usually valid in a tidal estuary where the advective current is much stronger than diffusion. In coastal seas where the advective currents are weak, some refinement of the model is required.

The figures show that $C^*(X)$ becomes less sensitive to t_s as the value of t_s increases, and becomes practically

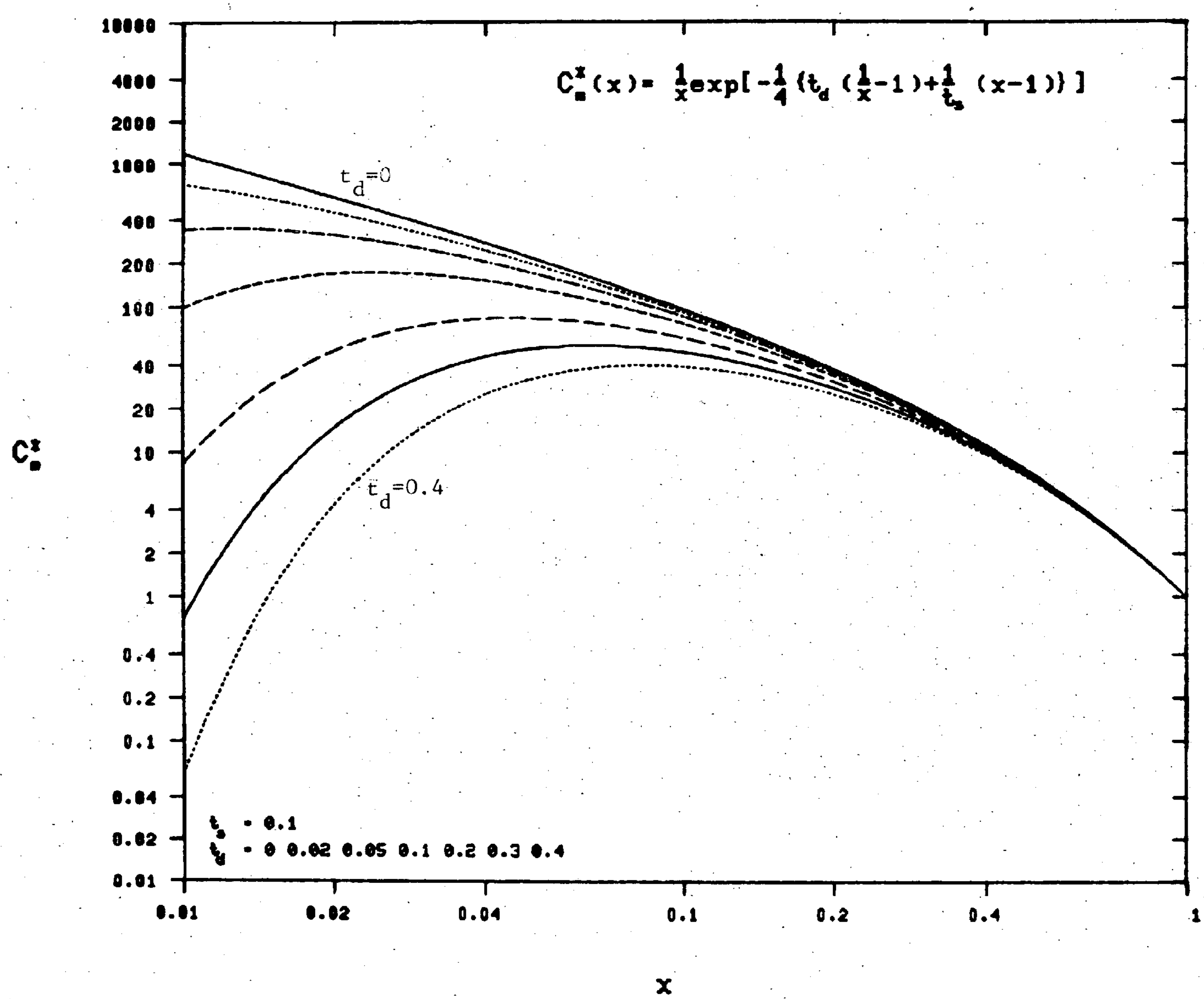


Figure 1. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, hydraulic dredge, t_s=0.1.

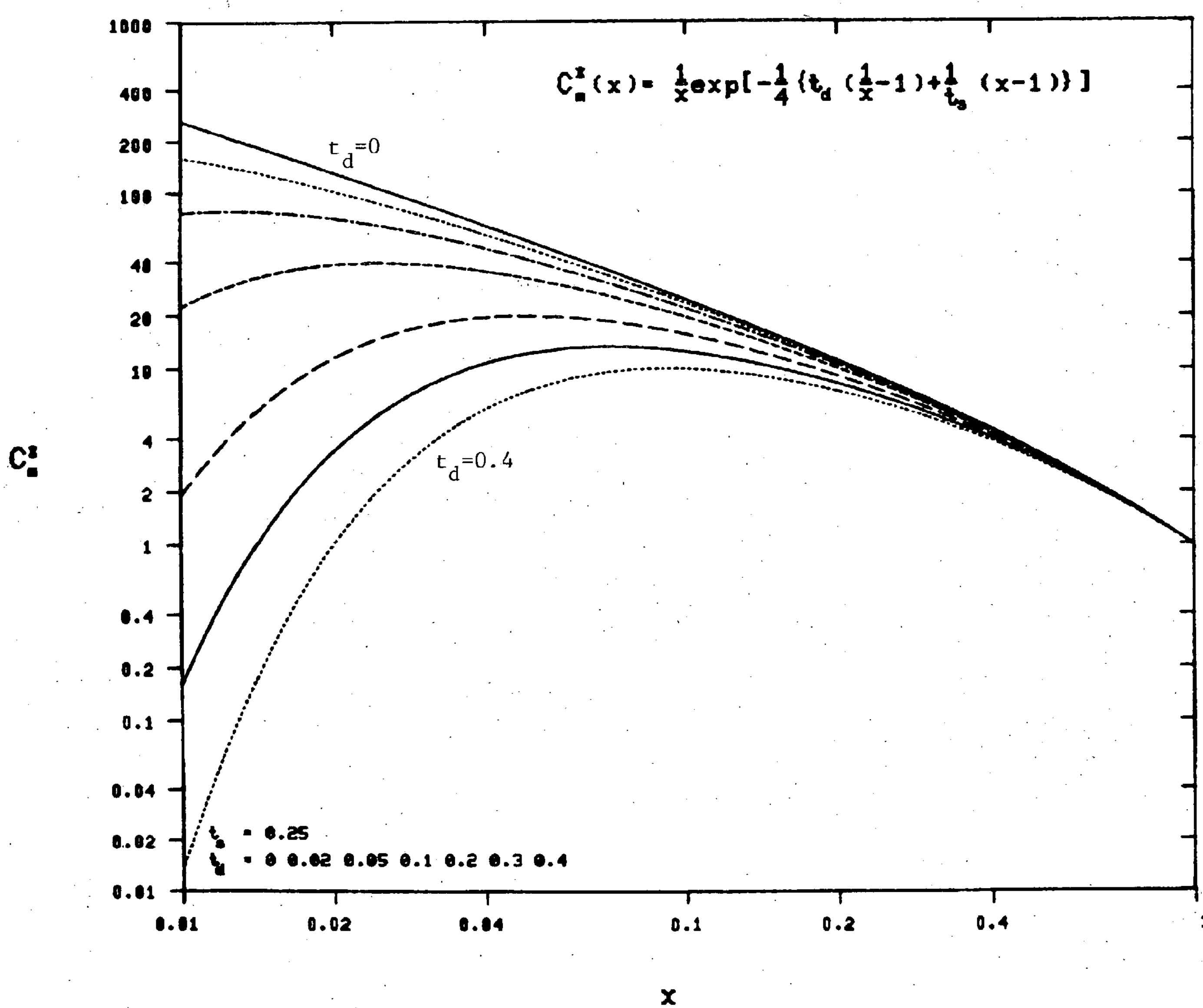


Figure 2. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, hydraulic dredge, t_s=0.25.

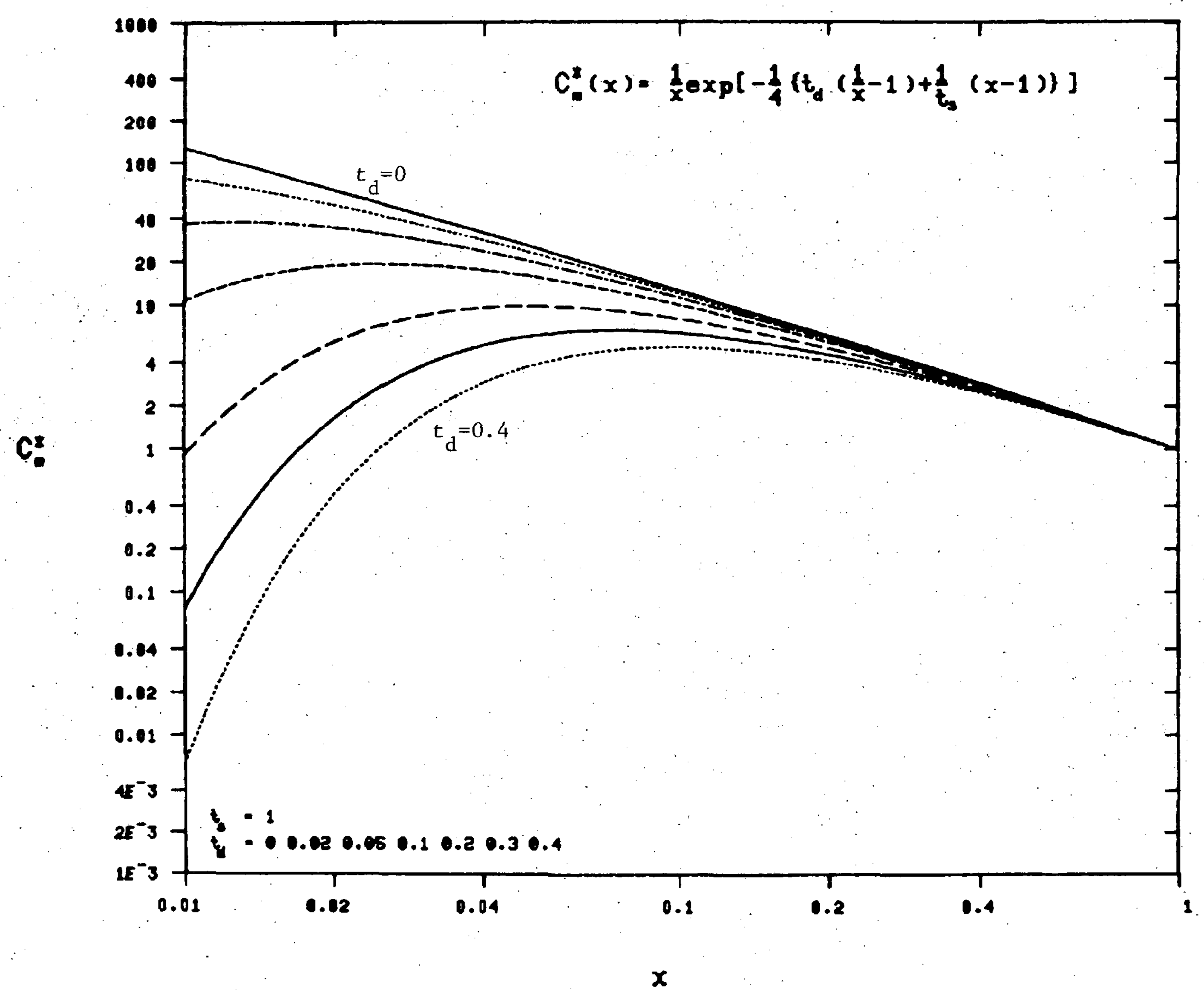


Figure 3. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, hydraulic dredge, t_s=1.0.

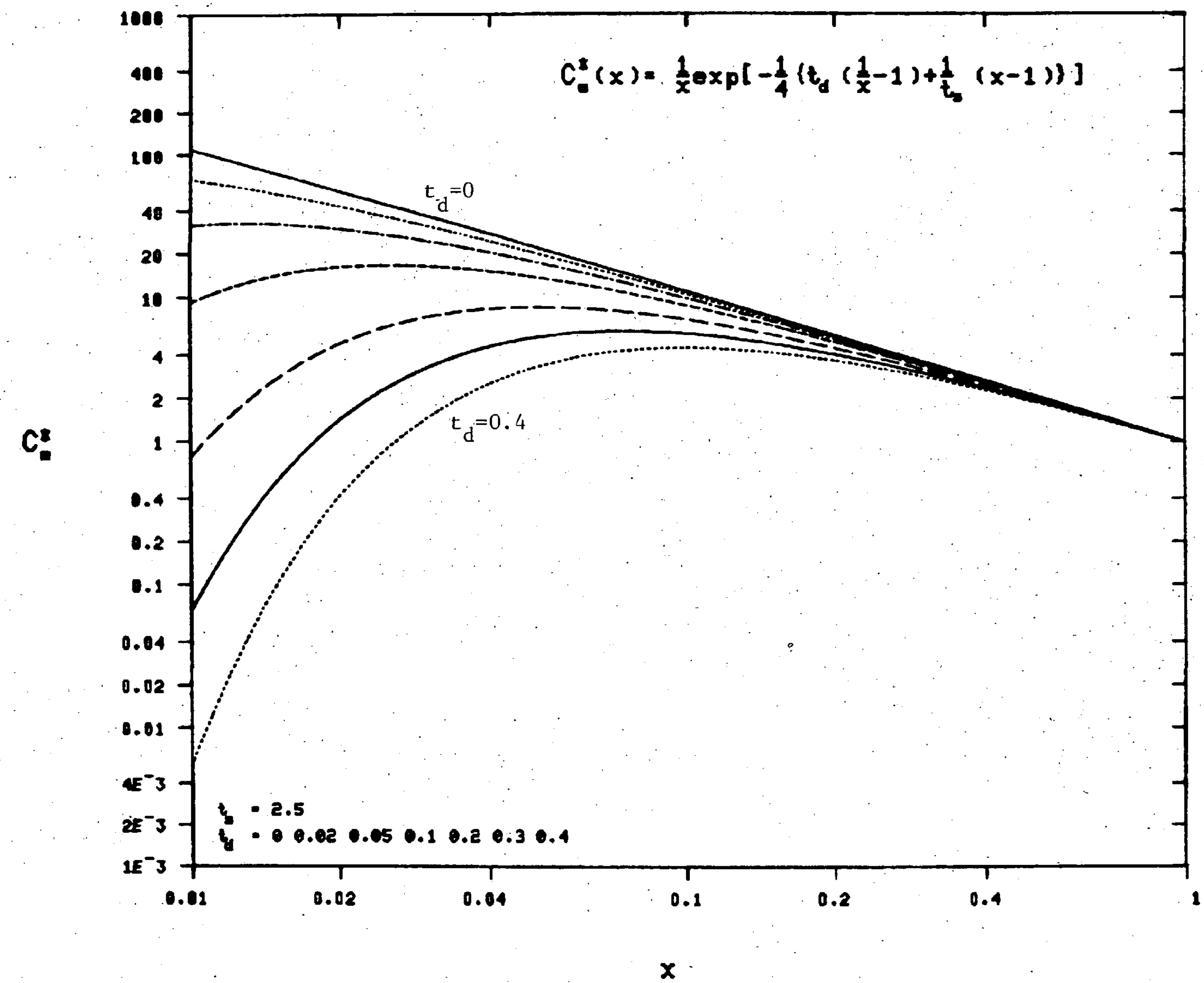


Figure 4. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, hydraulic dredge, t_s=2.5.

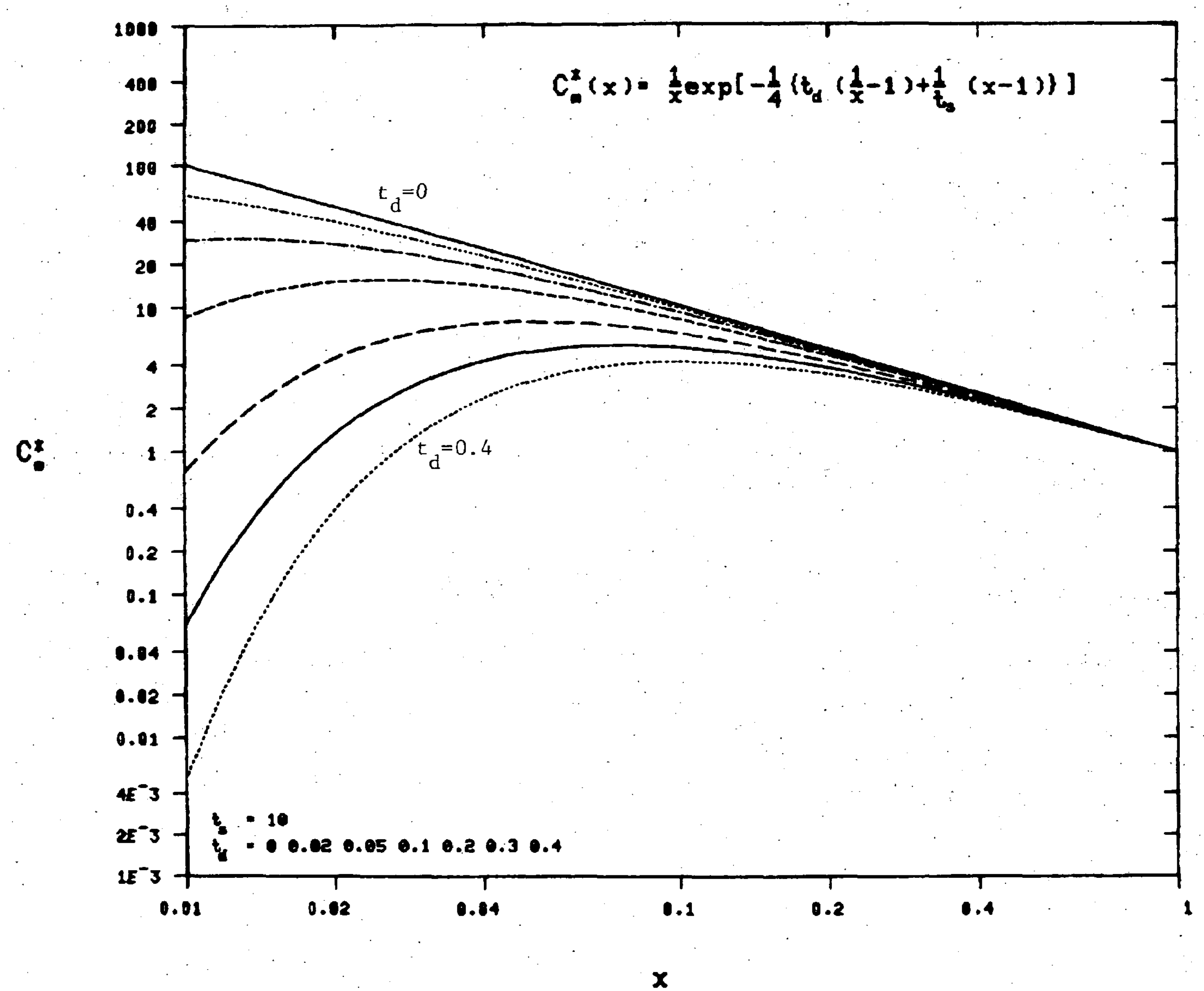


Figure 5. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, hydraulic dredge, t_s=10.0.

independent of t_s for $t_s \geq 10$. It is also seen that $C^*(X)$ varies as $1/X$ for $t_d = 0$ and large value of t_s.

B. Sediment Deposition

The suspended solids in a turbidity plume will eventually redeposit on the bottom because of particle settling. If it is assumed that all particles deposit at the location where they strike the bottom, the deposition rate may be expressed as

$$D = WC\Big|_{z=z_1} + k_z \frac{\partial C}{\partial z}\Big|_{z=z_1}$$

where D is the sediment deposition rate in mass per unit area per unit time, $C\big|_{z=z_1}$ and $\frac{\partial C}{\partial z}\big|_{z=z_1}$ are the sediment concentration and concentration gradient at bottom respectively, and z_1 is the bottom elevation. Substituting equation (4), it is obtained that

$$WC\Big|_{z=z_1} = \frac{WQ}{4\pi\sqrt{k_y k_z}\, x} \exp\left(- \frac{(y - y')^2}{4k_y \frac{x}{u}} - \frac{(z_1 + \frac{W}{u} x)^2}{4k_z \frac{x}{u}} \right)$$

for the deposition due to vertical settling, and

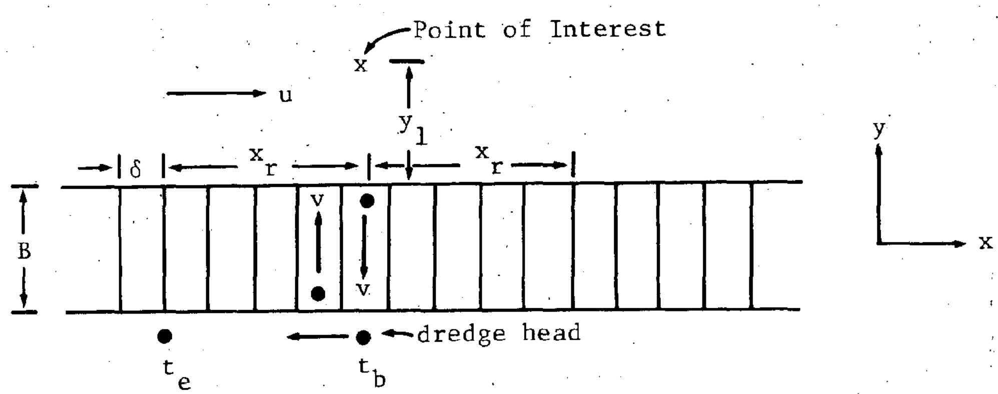
$$k_z \frac{\partial C}{\partial z}\Big|_{z=z_1} = \frac{-WQ}{4\pi\sqrt{k_y k_z}\, x} \left(\frac{1}{2} + \frac{1}{2}\frac{u}{W}\frac{z_1}{x}\right) \cdot \exp\left(- \frac{(y - y')^2}{4k_y \frac{x}{u}} - \frac{(z_1 + \frac{W}{u} x)^2}{4k_z \frac{x}{u}} \right)$$

for the deposition (or erosion) due to vertical diffusion.

The combination of the two mechanisms will give a negative deposition rate where $z_1 > \frac{W}{u} x$, which is impossible without net erosion from the bottom. For a conservative estimate of sediment deposition, the second term of upward particle diffusion is neglected and the net deposition rate is written as

$$D = \frac{WQ}{8\pi\sqrt{k_y k_z}\,x} \exp\left(-\frac{(y-y')^2}{4\,k_y\,\frac{x}{u}} - \frac{(z_1 + \frac{W}{u}x)^2}{4\,k_z\,\frac{x}{u}}\right) \qquad (8)$$

To evaluate the total amount of deposition at a given location as the result of a dredging operation, the dredging operation is characterized as follows:



The previous sketch shows that a channel of width B is to be dredged along x-direction. The dredging operation may be considered as a series of swings by dredge head in y-direction. In each swing, the dredge head will move in y-direction with a speed V and cut a slice of thickness δ in x-direction. Since the maximum extent of a dredge-induced turbidity plume is x_r, only the dredging within a stripe of length $2x_r$ centered at the point of interest will contribute deposition to this location. The dredging to the left will contribute deposition when current is positive, while the dredging to the right will contribute when current is negative. To be conservative, assuming both halves of the dredging contribute deposition to the point of interest, then the total deposition per unit area is

$$M = 2 \int_{t_b}^{t_e} D \, dt \tag{9}$$

where t_b and t_e are starting and ending time of dredging operation for the left half of the stripe. In case that it takes much more than one tidal period to complete dredging of stripe $2x_r$, the factor 2 in equation (9) may be dropped.

During each swing of dredge head, its position in y-direction may be written as

$$y' = -\frac{B}{2} + V(t - t_b - n\tau) \tag{10}$$

for $t_b + n\tau \le t \le t_b + (n+1)\tau$

where

$$\tau = \frac{B}{V}$$

is the time required to complete one swing in y-direction, and n is a positive integer. The distance along x-direction between dredge head and the point of interest is

$$x = n\delta \tag{11}$$

The time integration in equation (9) may be substituted with the sum of a series of time integration over time period τ, i.e.,

$$M = 2 \sum_{n=0}^{N-1} \int_{t_b + n\tau}^{t_b+(n+1)\tau} D \, dt \tag{12}$$

where

$$N = \frac{x_r}{\delta}$$

is the number of swings required to complete dredging a distance x_r.

Substituting equations (10) and (11) into equation (8), and substituting the results into equation (12), it is obtained that

$$M = 2 \sum_{n=0}^{N-1} \frac{WQ}{8\pi\sqrt{k_y k_z}\; n\delta} \exp\left(- \frac{(z_1 + \frac{W}{u} n\delta)^2}{4 k_z \frac{n\delta}{u}}\right) \cdot$$

$$\int_{t_b+ n\tau}^{t_b+ (n+1)\tau} \exp\left(- \frac{\{y + \frac{B}{2} - V(t-t_b-n\tau)\}^2}{4 k_y \frac{n\delta}{u}}\right) dt \tag{13}$$

To simplify the process of estimating dredge-induced turbidity, Nakai (1978) introduced a concept of 'turbidity generation unit', which relates the turbidity to the volume of dredged material. According to his definition, the suspended sediment source Q may be expressed as

$$Q = kGD\delta V \tag{14}$$

where D is the cutting depth of dredge head. The turbidity generation unit G stands for the quantity of turbidity generated when a unit volume of bed material is dredged under a standardized condition. The standardized condition was defined by the tidal current velocity at which sediment particles with diameters larger than 74μ are not resuspended. The size distribution factor is defined as

$$k = R_o/R_{74}$$

where R_{74} is the fraction of particles with a diameter smaller than 74μ and R_o is the fraction of particles with a diameter smaller than the diameter of a particle whose critical resuspension velocity equals the current velocity in the field.

Substituting equation (14) into equation (13), and carrying out the integration, it is obtained that

$$M = 2 \sum_{n=0}^{N-1} \frac{kGD\delta W}{8\sqrt{\pi k_z n\delta u}} \exp\left[- \frac{(z_1 + \frac{W}{u} n\delta)^2}{4\ k_z \frac{n\delta}{u}}\right] \left[\text{erf}\left(\frac{y + \frac{B}{2}}{\sqrt{4\ k_y \frac{n\delta}{u}}}\right) - \text{erf}\left(\frac{y - \frac{B}{2}}{\sqrt{4\ k_y \frac{n\delta}{u}}}\right)\right] \tag{15}$$

for $|y| \geq \frac{B}{2}$

where

$$\text{erf}\ (\theta) = \frac{2}{\sqrt{\pi}} \int_0^{\theta} e^{-x^2} dx$$

The equation may be written in terms of dimensionless parameters as

$$\frac{M}{kGD} = \frac{1}{4\sqrt{\pi t_s N}} \sum_{n=0}^{N-1} \frac{1}{\sqrt{n}} \exp\left[-\left(\sqrt{\frac{N}{n}\, t_B}\, Z + \frac{1}{2}\sqrt{\frac{n}{N}\frac{1}{t_s}}\right)^2\right]\left[\text{erf}\left\{\sqrt{\frac{N}{n}\, t_B}\left(y + \frac{1}{2}\right)\right\} - \text{erf}\left\{\sqrt{\frac{N}{n}\, t_B}\left(y - \frac{1}{2}\right)\right\}\right] \tag{16}$$

where

$$t_B = \frac{B^2}{4\, k_y} \Big/ \frac{x_r}{u}$$

$$Y = \frac{y}{B}$$

$$Z = \sqrt{\frac{k_y}{k_z}}\, \frac{z_1}{B}$$

and t_s is defined in previous section.

Equation (16) is a very weak function of N for the practical range of N. A numerical test indicates that M/KGD varies no more than 0.3% for N ranging from 1000 to 4000. Therefore, for the results presented hereafter, N is taken to be 1000. The non-dimensional deposition rate is presented in graphical form from Figure 6 to 12.

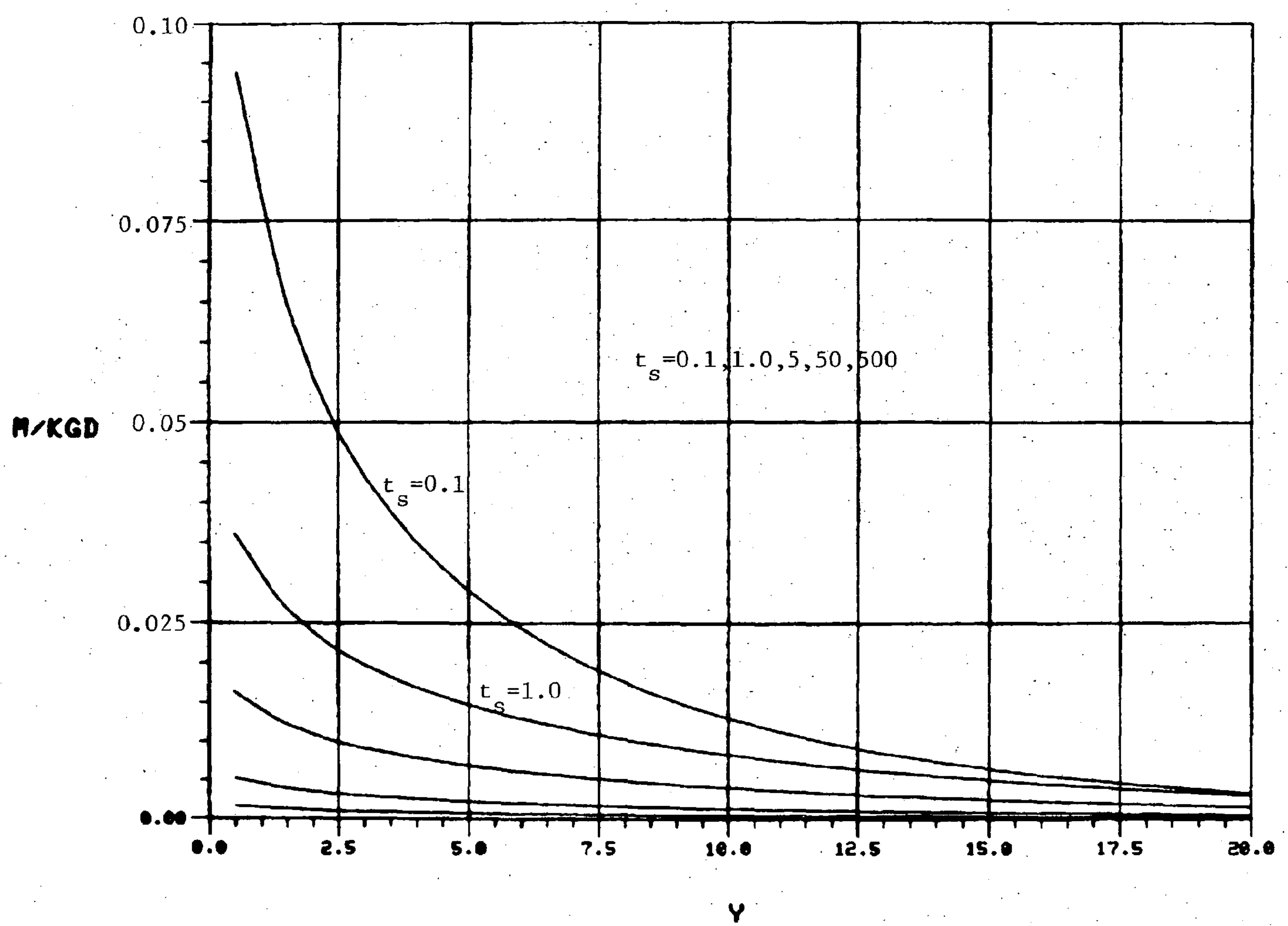


Figure 6. Dimensionless sediment deposition versus normalized lateral distance from dredge channel, hydraulic dredge, t_B=0.001, Z=0.

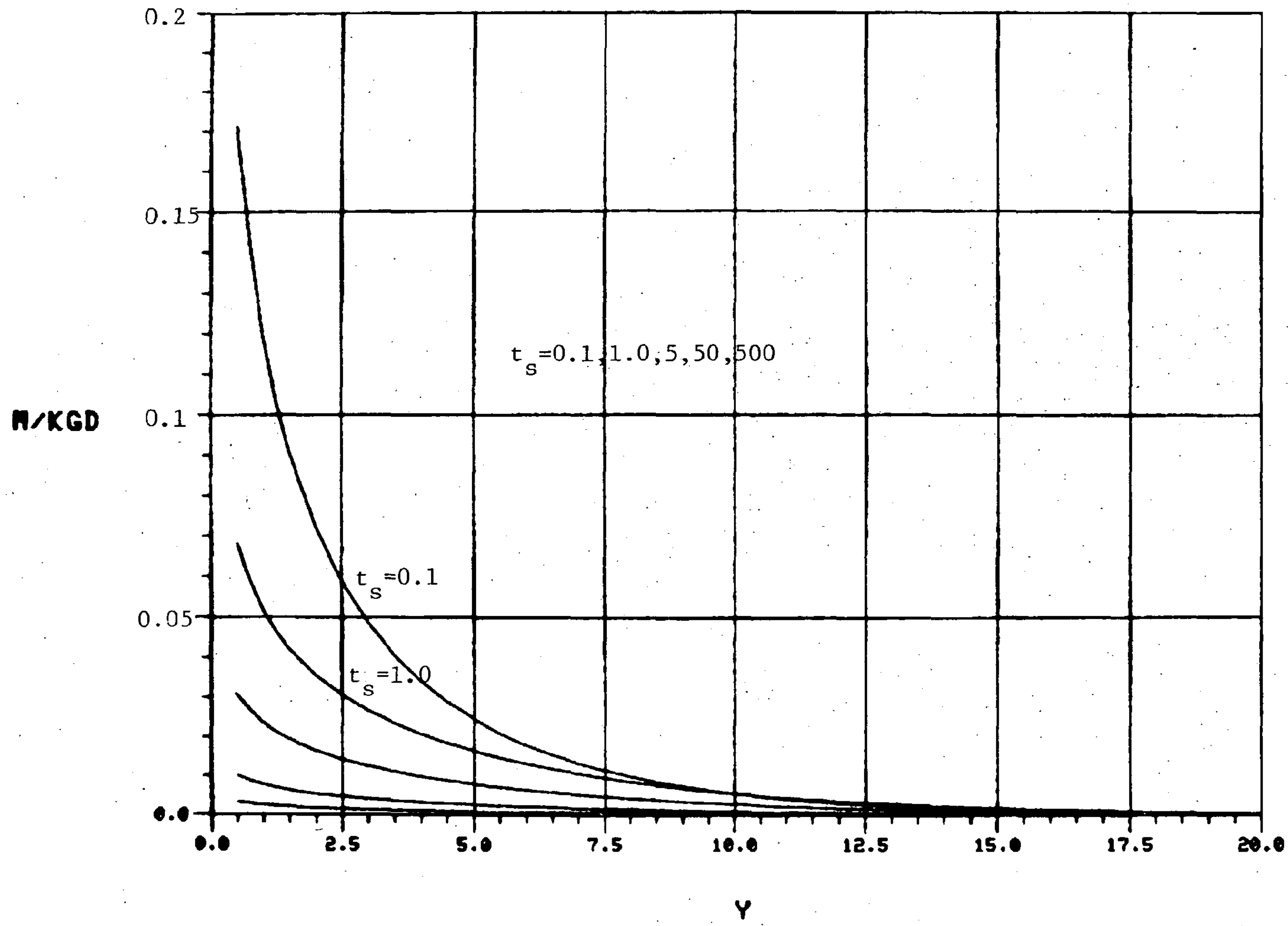


Figure 7. Dimensionless sediment deposition versus normalized lateral distance from dredge channel, hydraulic dredge, t_B=0.005, Z=0.

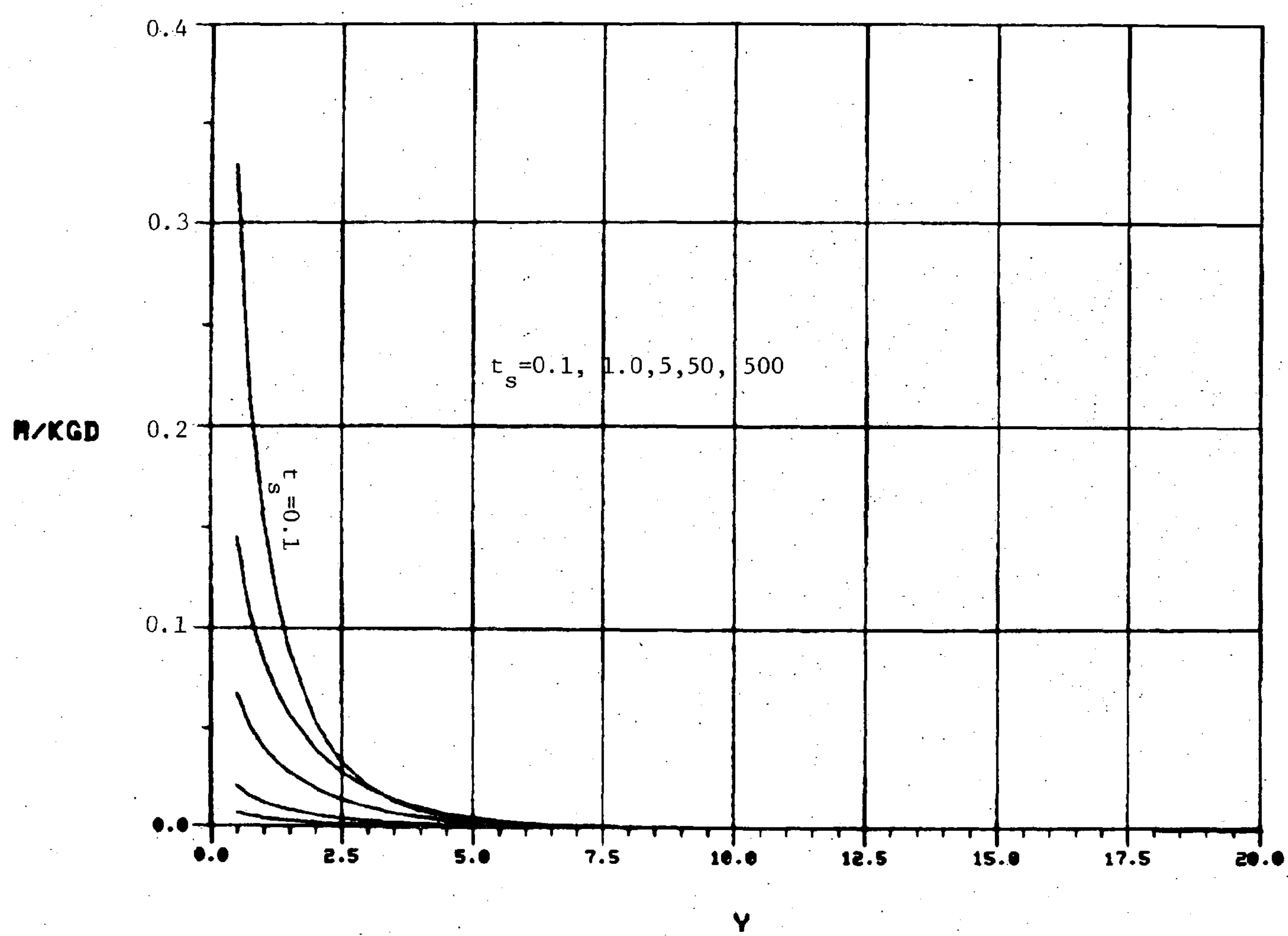


Figure 8. Dimensionless sediment deposition versus normalized lateral distance from dredge channel, hydraulic dredge, t_B=0.05, Z=0.

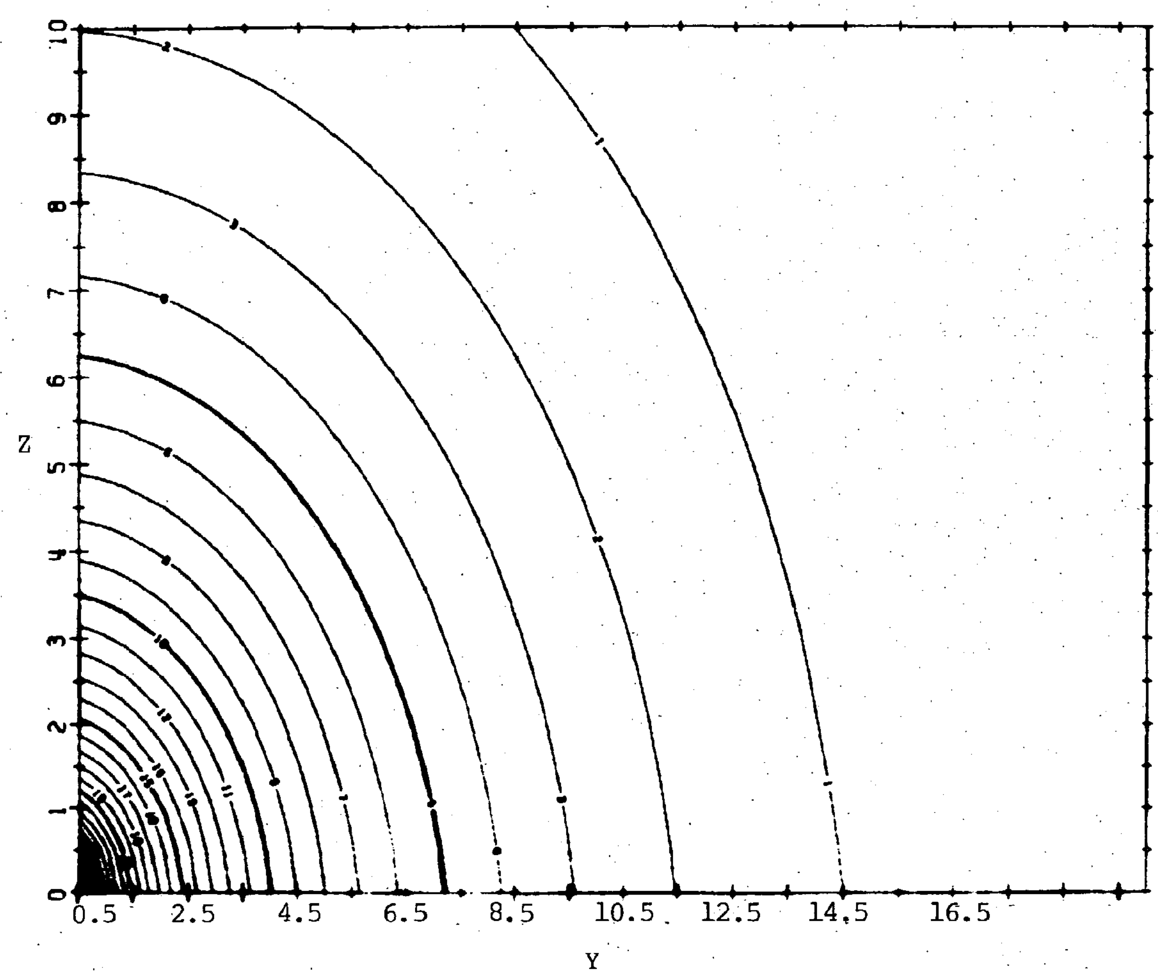


Figure 9a. Iso-deposition contours in Y-Z plane, hydraulic dredge, t_S=5, t_B=0.005. (The values of M/KGD should be multiplied by 0.001).

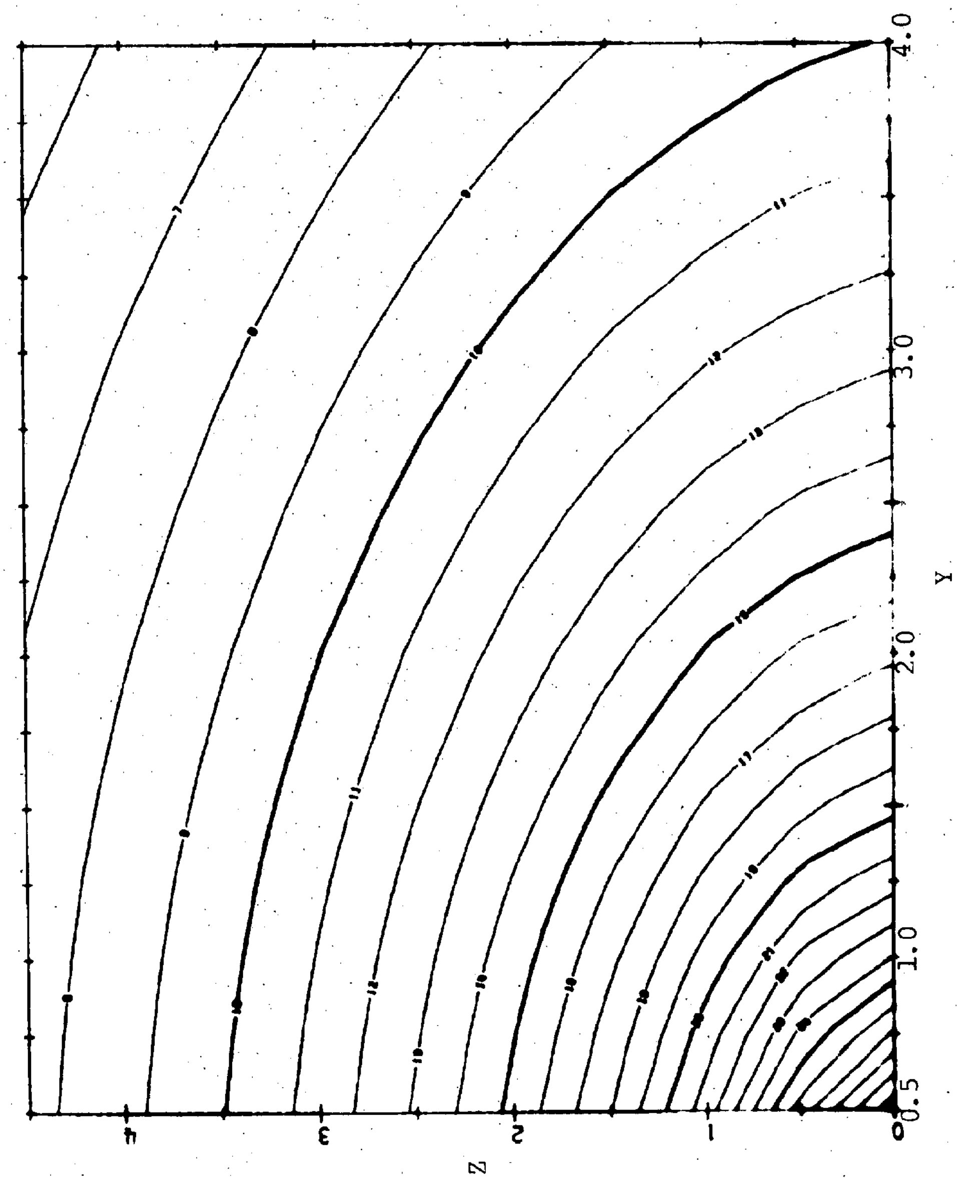


Figure 9b.

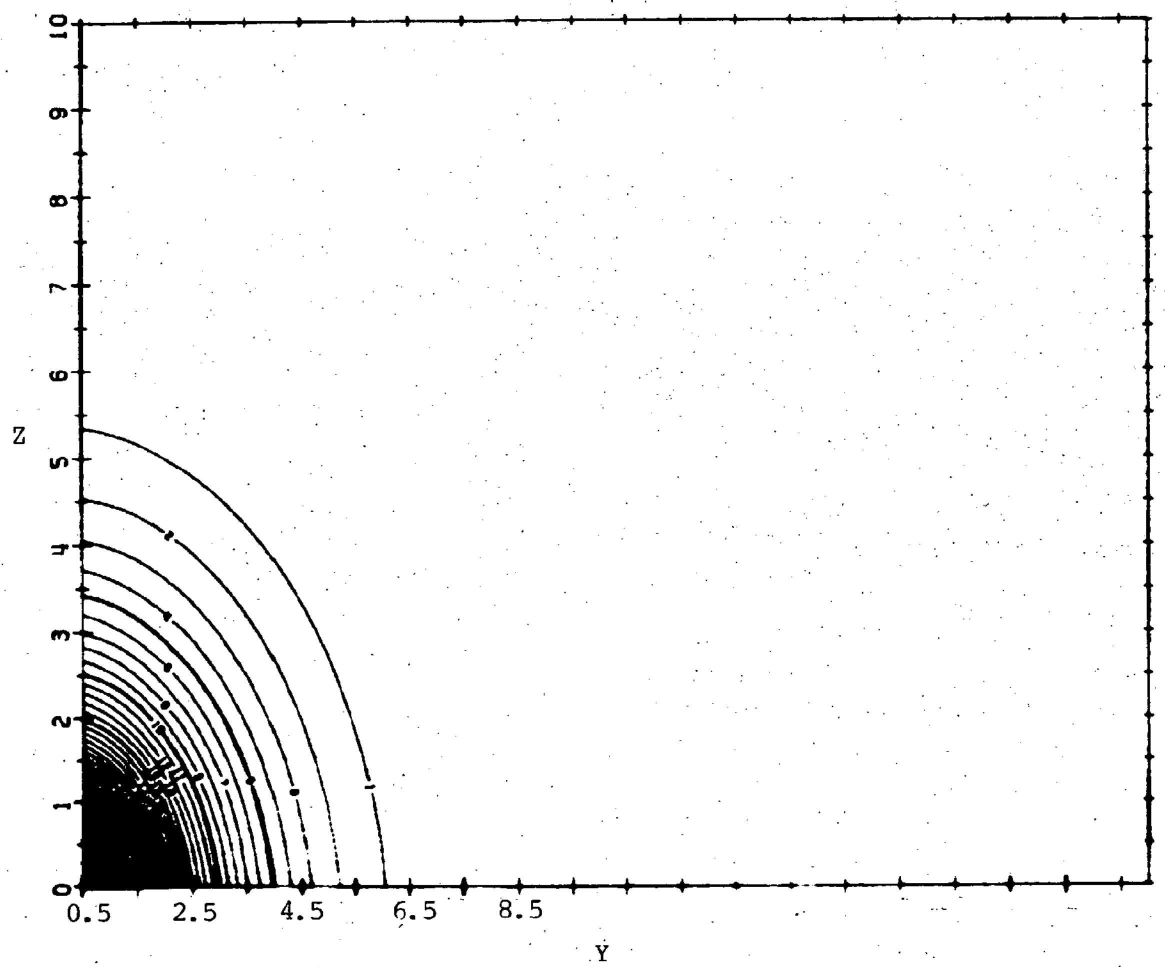


Figure 10a. Iso-deposition contours in Y-Z plane, hydraulic dredge, $t_S=5$, $t_B=0.05$. (The values of M/KGD should be multiplied by 0.001).

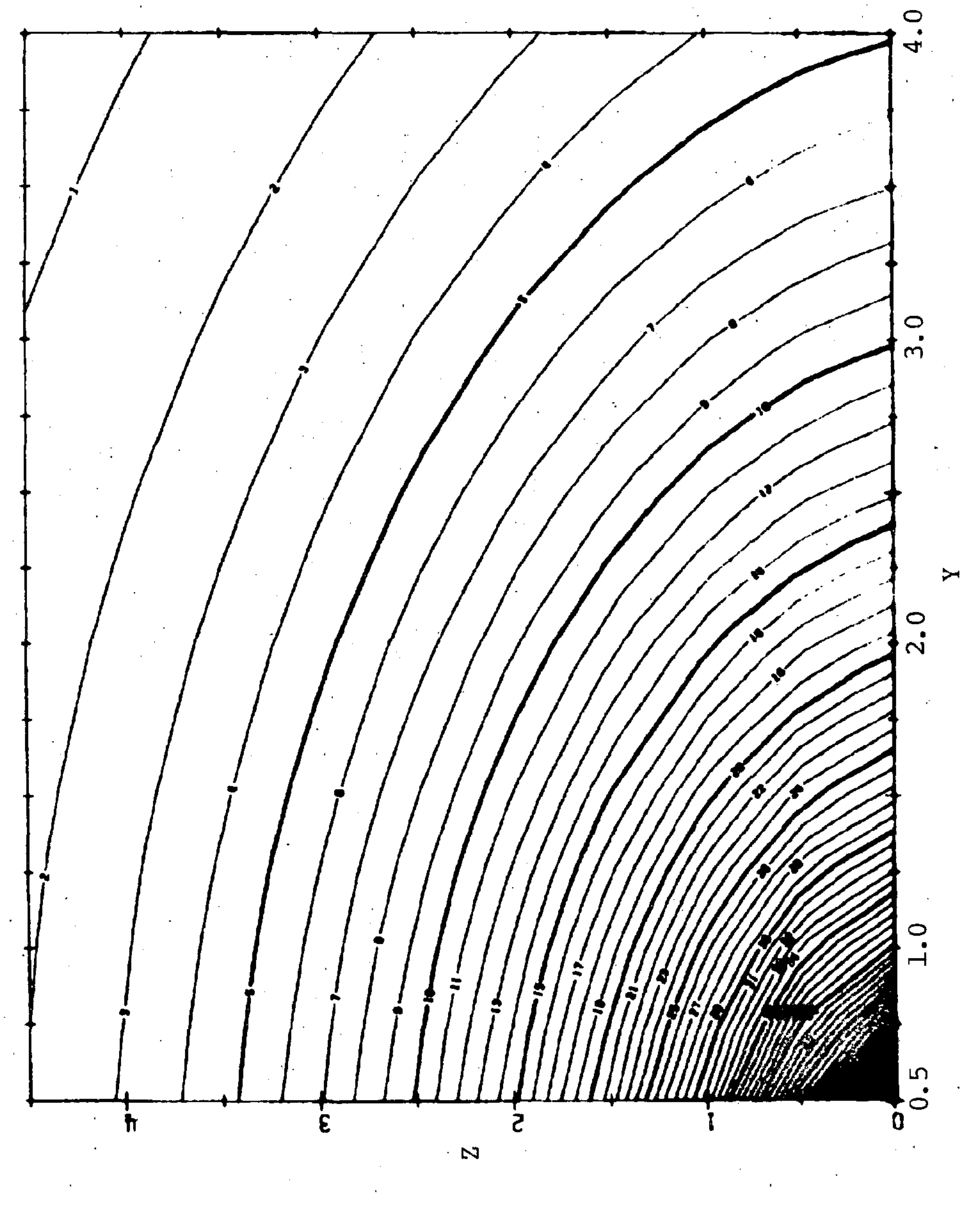


Figure 10b.

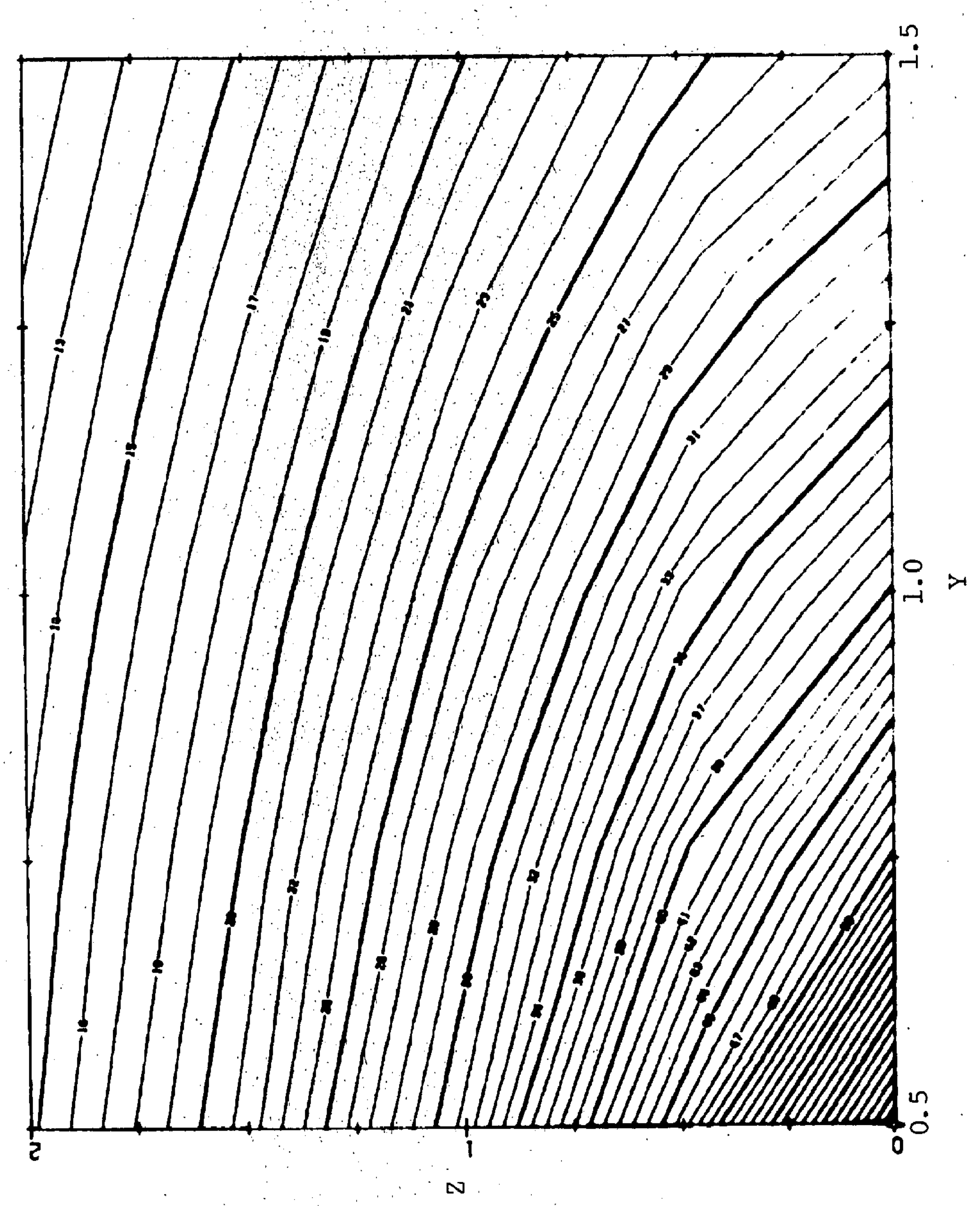


Figure 10c.

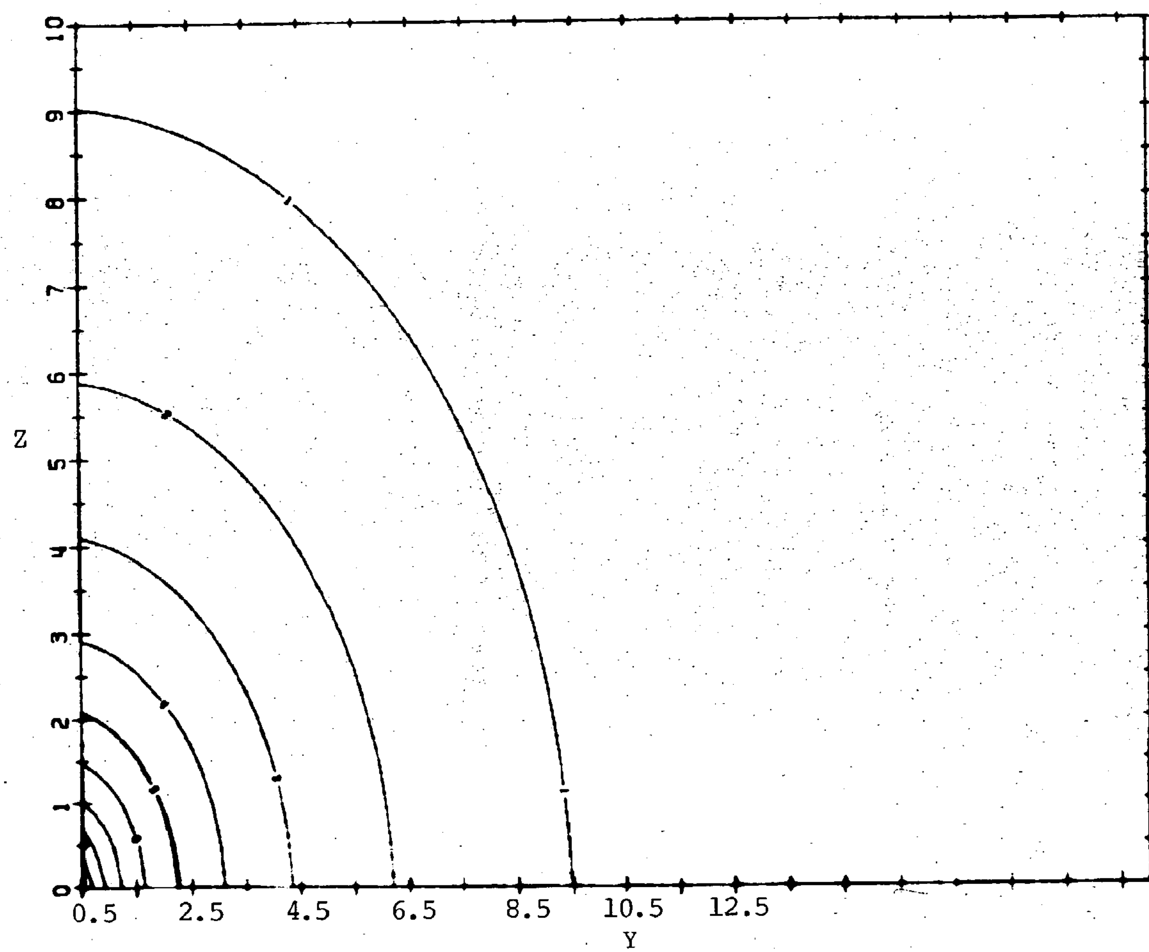


Figure 11. Iso-deposition contours in Y-Z plane, hydraulic dredge, t_S=50, t_B=0.005. (The values of M/KGD should be multiplied by 0.001).

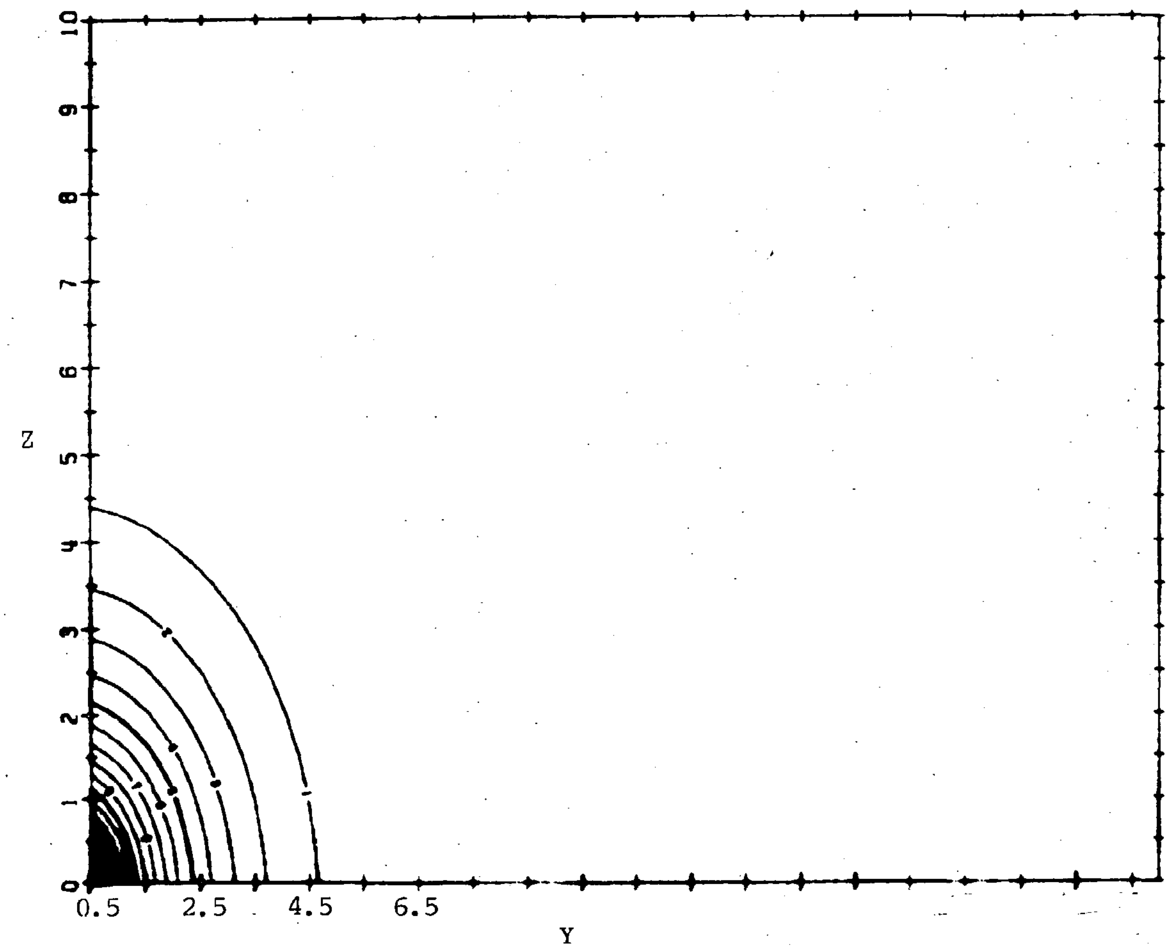


Figure 12a. Iso-deposition contours in Y-Z plane, hydraulic dredge, t_s=50, t_B=0.05. (The values of M/KGD should be multiplied by 0.001).

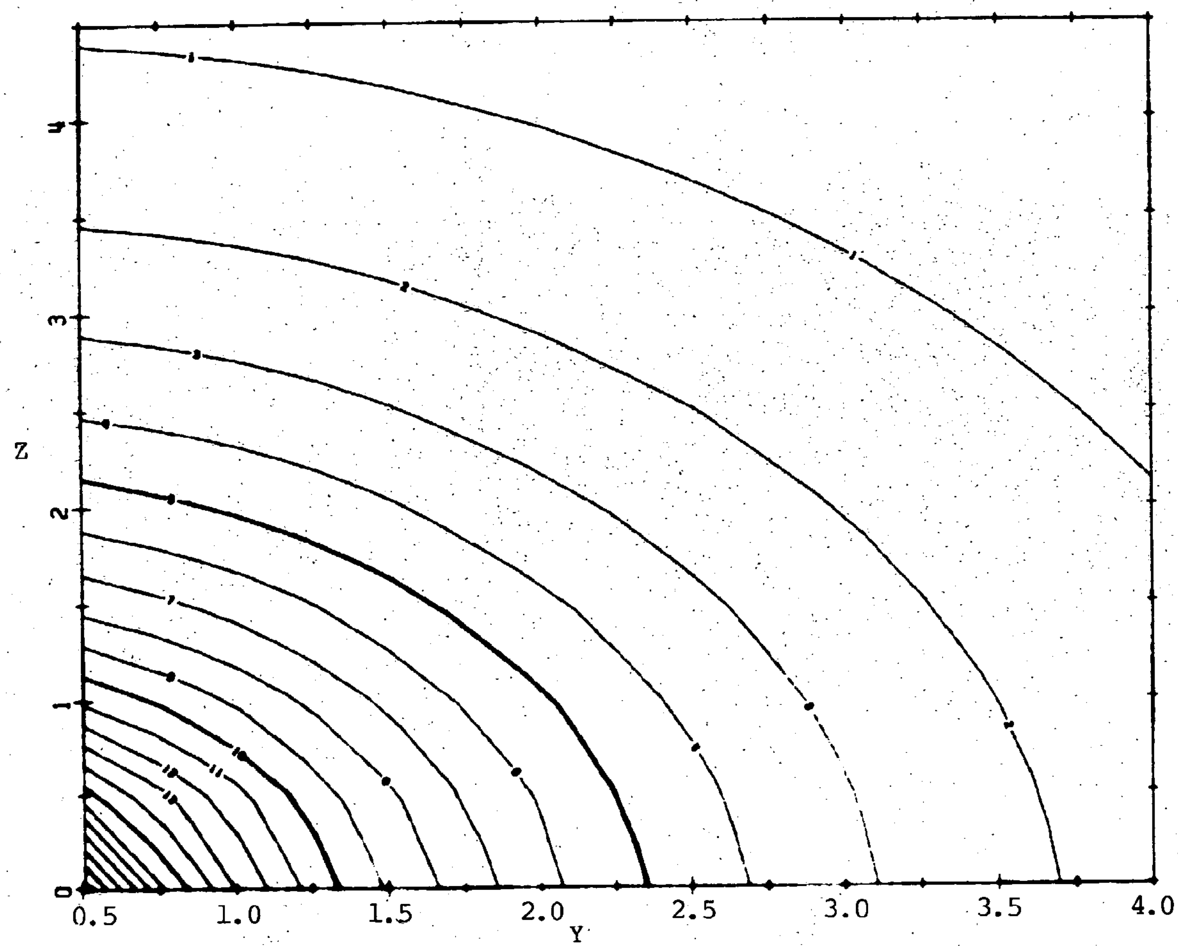


Figure 12b.

Figures 6 to 8 show the dimensionless deposition rate on the bottom of the same elevation as dredge channel (i.e. Z=0). Figures 9 to 12 present the equi-deposition contours in Y-Z plane. Some of the contour plots near the dredged channel are presented in enlarged form for clarity.

IV. Application to Bucket Dredge

A. Suspended Sediment Concentration in the Turbidity Plume

The turbidity plume induced by a bucket dredge may be considered as the result of a line source stretching from water surface to bottom. The line source will move in y-direction, and then advance in x-direction as the dredge proceeds. To arrive at the concentration field, equation (3) is integrated with respect to z' from bottom to surface,

$$C(x,y,z) = \int_o^h \frac{Q}{h \cdot 4\pi\sqrt{k_y k_z}\; x} \exp\left[- \frac{(y-y')^2}{4k_y \frac{x}{u}} - \frac{(z-z' + W\frac{x}{u})^2}{4k_z \frac{x}{u}} \right] dz'$$

$$= \frac{Q}{h\sqrt{4\pi\; k_y\; ux}} \exp\left[- \frac{(y-y')^2}{4k_y \frac{x}{u}} \right] \cdot$$

$$\frac{1}{2}\left[\mathrm{erf}\left(\frac{z + W\frac{x}{u}}{\sqrt{4k_z \frac{x}{u}}} \right) - \mathrm{erf}\left(\frac{z-h + W\frac{x}{u}}{\sqrt{4k_z \frac{x}{u}}} \right) \right] \qquad (17)^*$$

---

*The error function in equation (17) should take a negative value when its argument is negative.

where h is the depth of water. At given distances x from dredge location and z above the bottom, the maximum turbidity occurs at y=y', therefore

$$C_m(x,z) = \frac{Q}{h\sqrt{4\pi k_y ux}} \cdot \frac{1}{2}\left[\operatorname{erf}\left(\frac{z + W\frac{x}{u}}{\sqrt{4k_z\frac{x}{u}}}\right) - \operatorname{erf}\left(\frac{z-h + W\frac{x}{u}}{\sqrt{4k_z\frac{x}{u}}}\right)\right] \tag{18}$$

C_m may be normalized with respect to the concentration at a reference distance x_r. Setting $z = z_o$, a given distance above the bottom, it is obtained that

$$C_m^*(X,Z) = \frac{C_m(x,z_o)}{C_m(x_r,z_o)} =$$

$$\frac{1}{\sqrt{X}} \cdot \frac{\operatorname{erf}\left(\frac{1}{2}\sqrt{t_h}\frac{Z}{\sqrt{X}} + \frac{1}{2}\sqrt{\frac{X}{t_s}}\right) - \operatorname{erf}\left(\frac{1}{2}\sqrt{t_h}\frac{Z-1}{\sqrt{X}} + \frac{1}{2}\sqrt{\frac{X}{t_s}}\right)}{\operatorname{erf}\left(\frac{1}{2}\sqrt{t_h}\,Z + \frac{1}{2}\sqrt{\frac{1}{t_s}}\right) - \operatorname{erf}\left(\frac{1}{2}\sqrt{t_h}\,(Z-1) + \frac{1}{2}\sqrt{\frac{1}{t_s}}\right)} \tag{19}$$

where

$$X = \frac{x}{x_r}, \quad Z = \frac{z_o}{h}$$

$$t_h = \frac{h^2}{k_z} \bigg/ \frac{x_r}{u}$$

Equation (19) is presented in graphical form in Figures 13 through 21 for the non-dimensional concentration

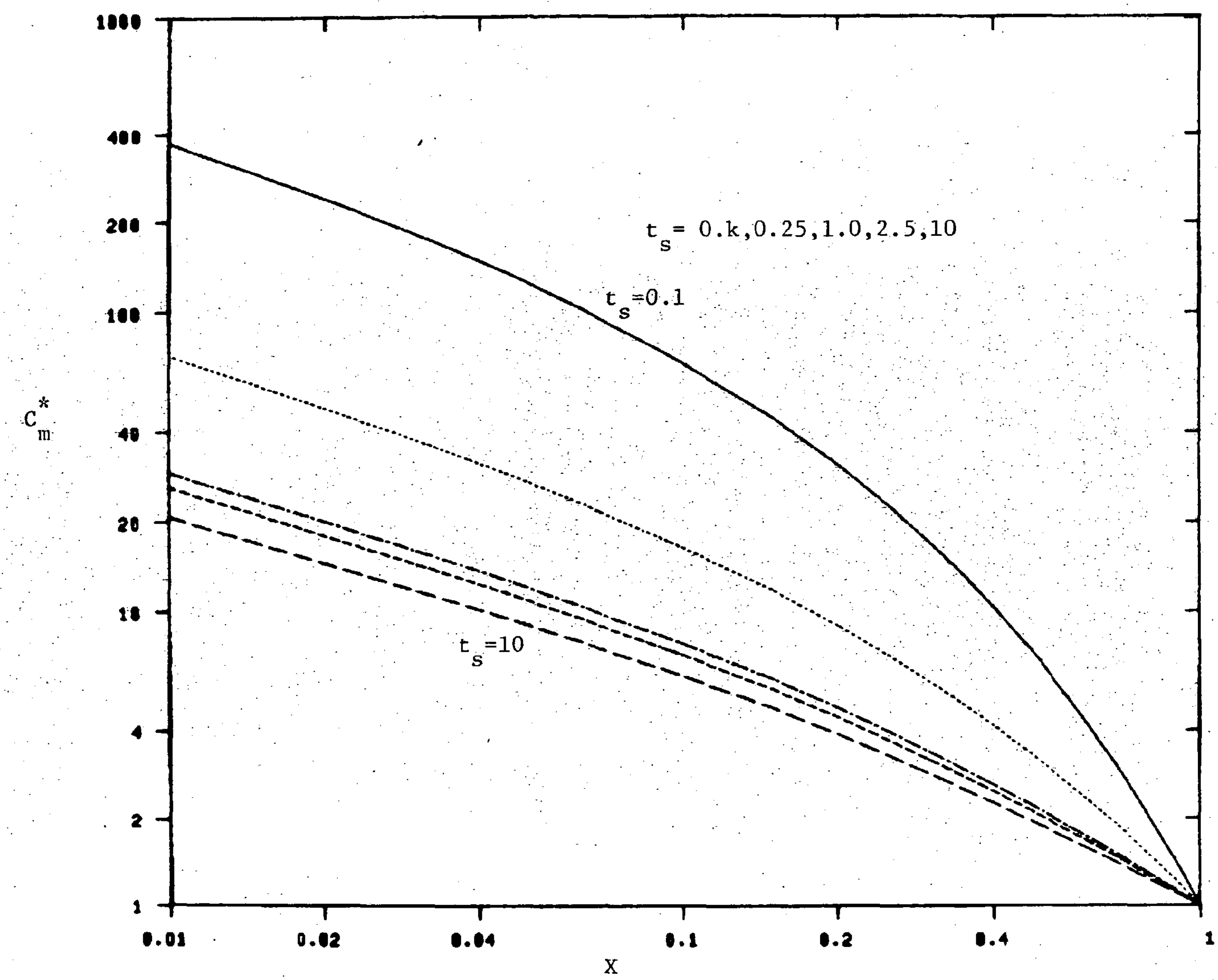


Figure 13. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, $Z=1.0, t_h=1.0$.

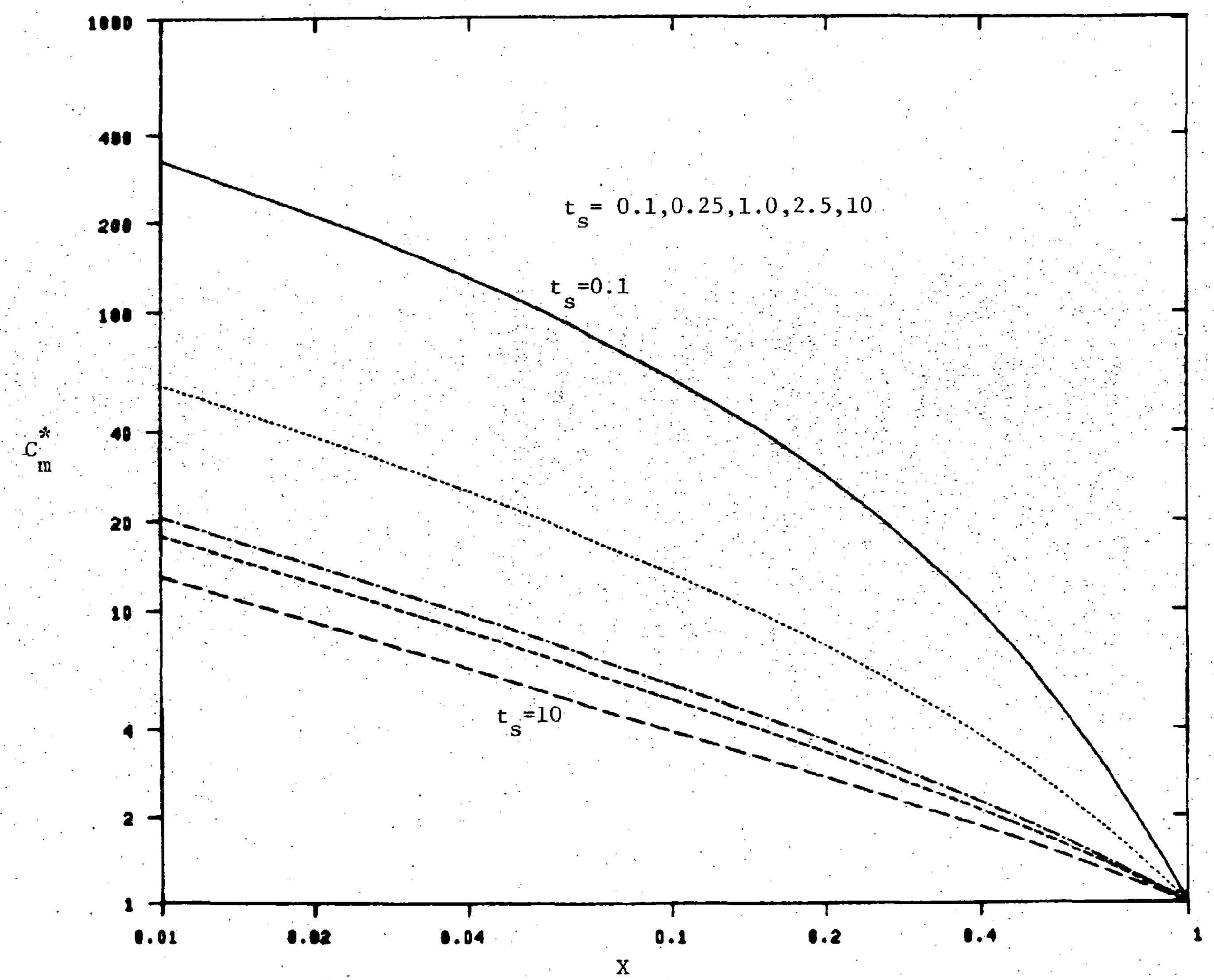


Figure 14. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, Z=1.0,t_h=5.0.

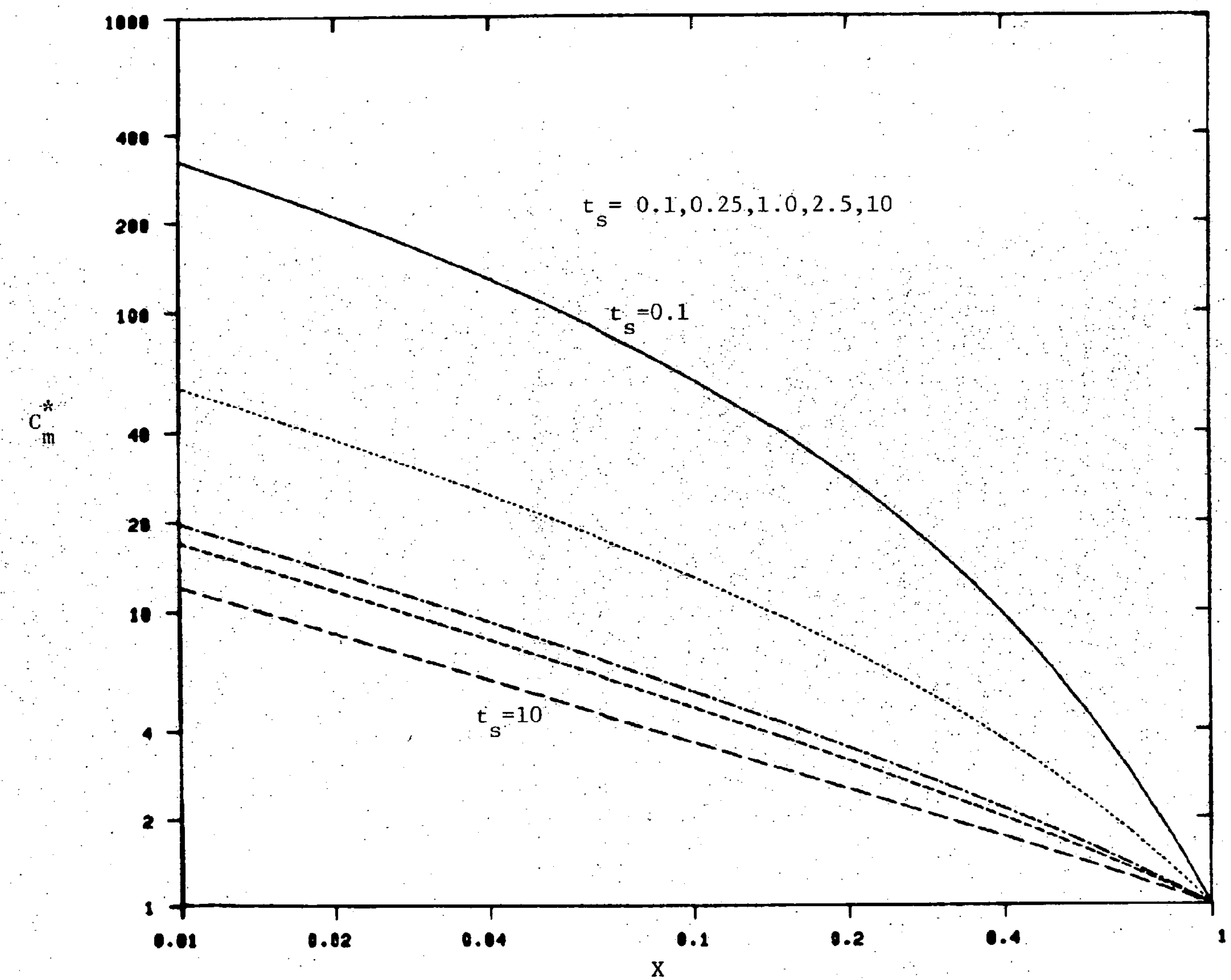


Figure 15. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, Z=1.0, t_h=10.

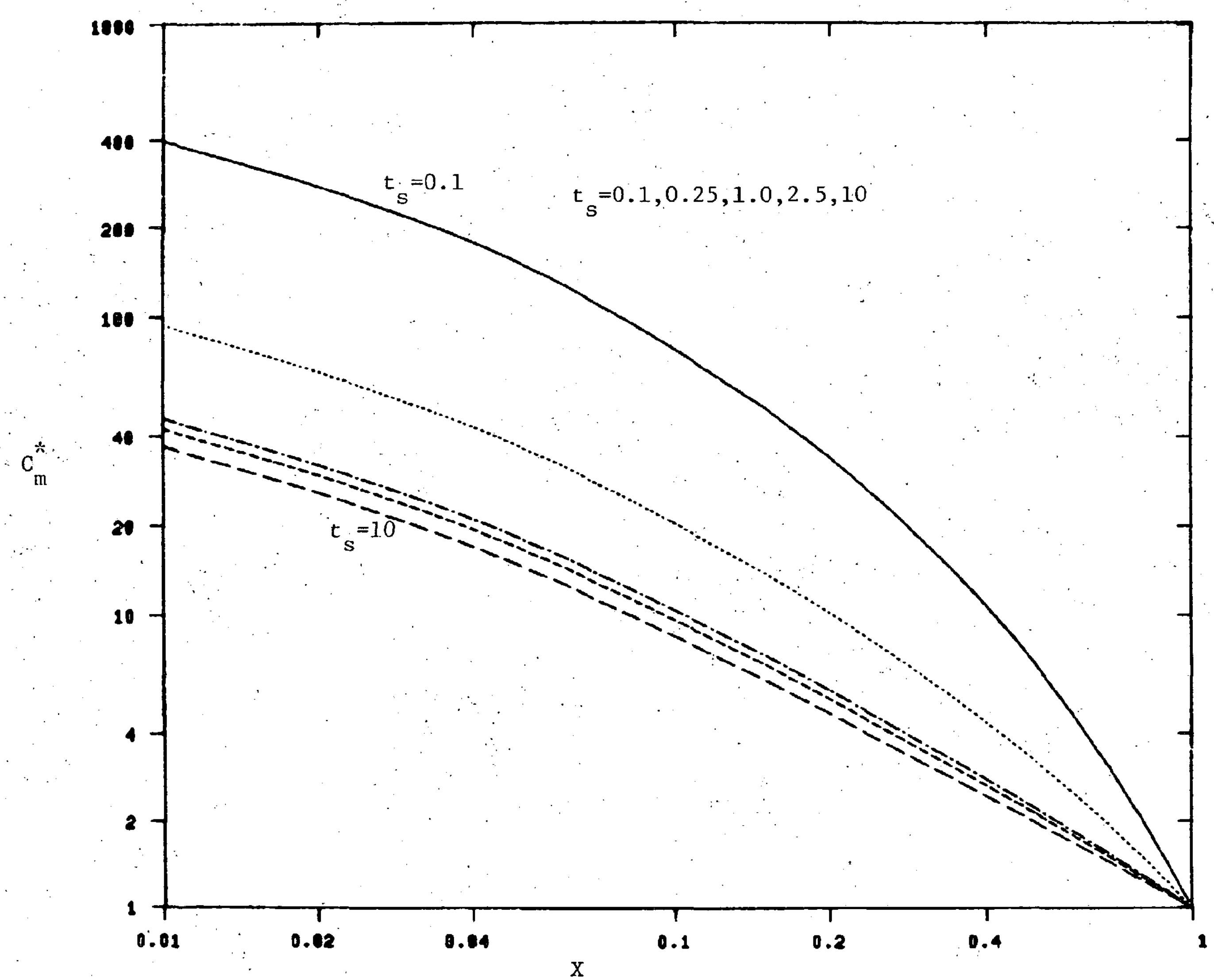


Figure 16. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, Z=0.5,t_h=1.0.

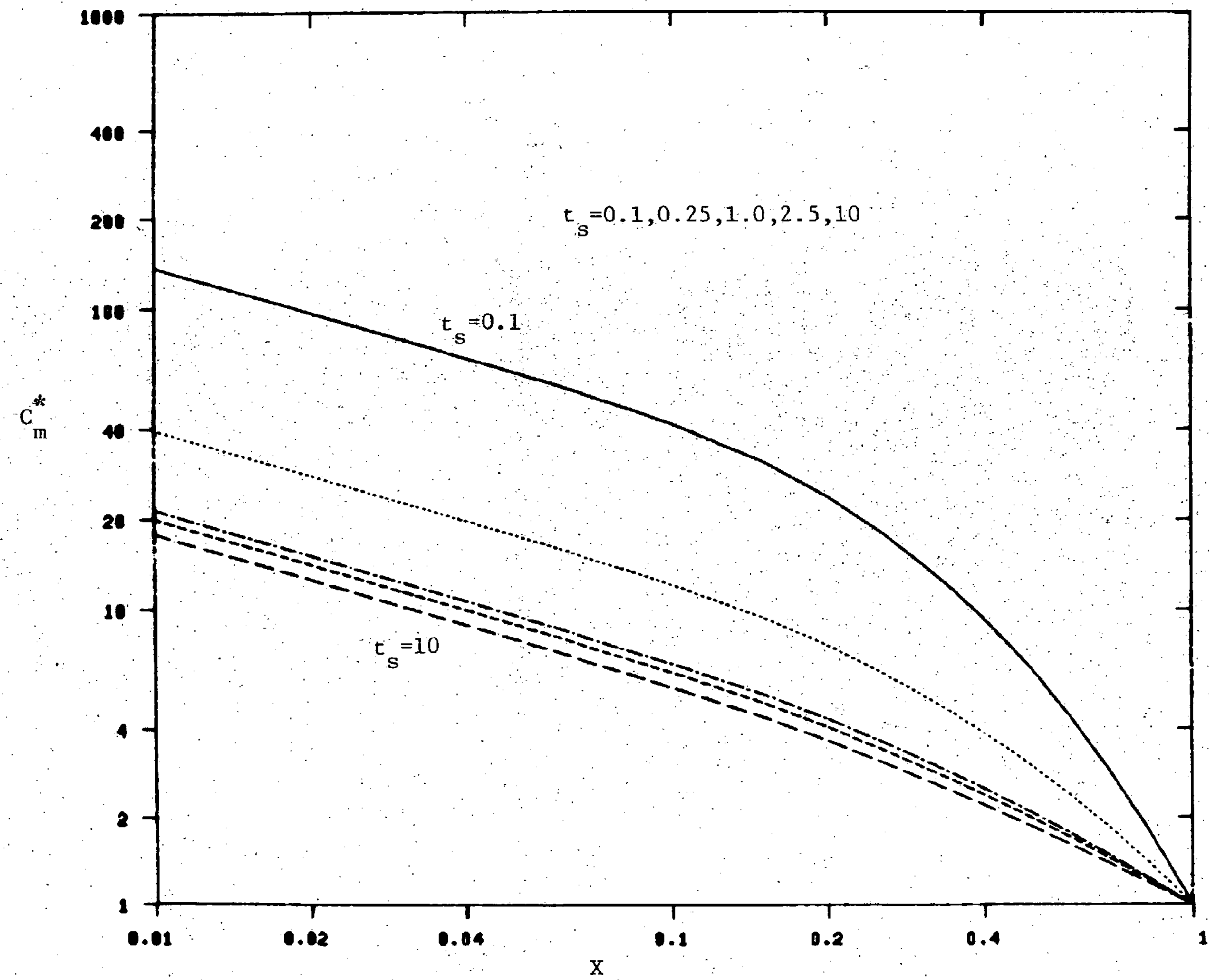


Figure 17. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, $Z=0.5, t_h=5.0$.

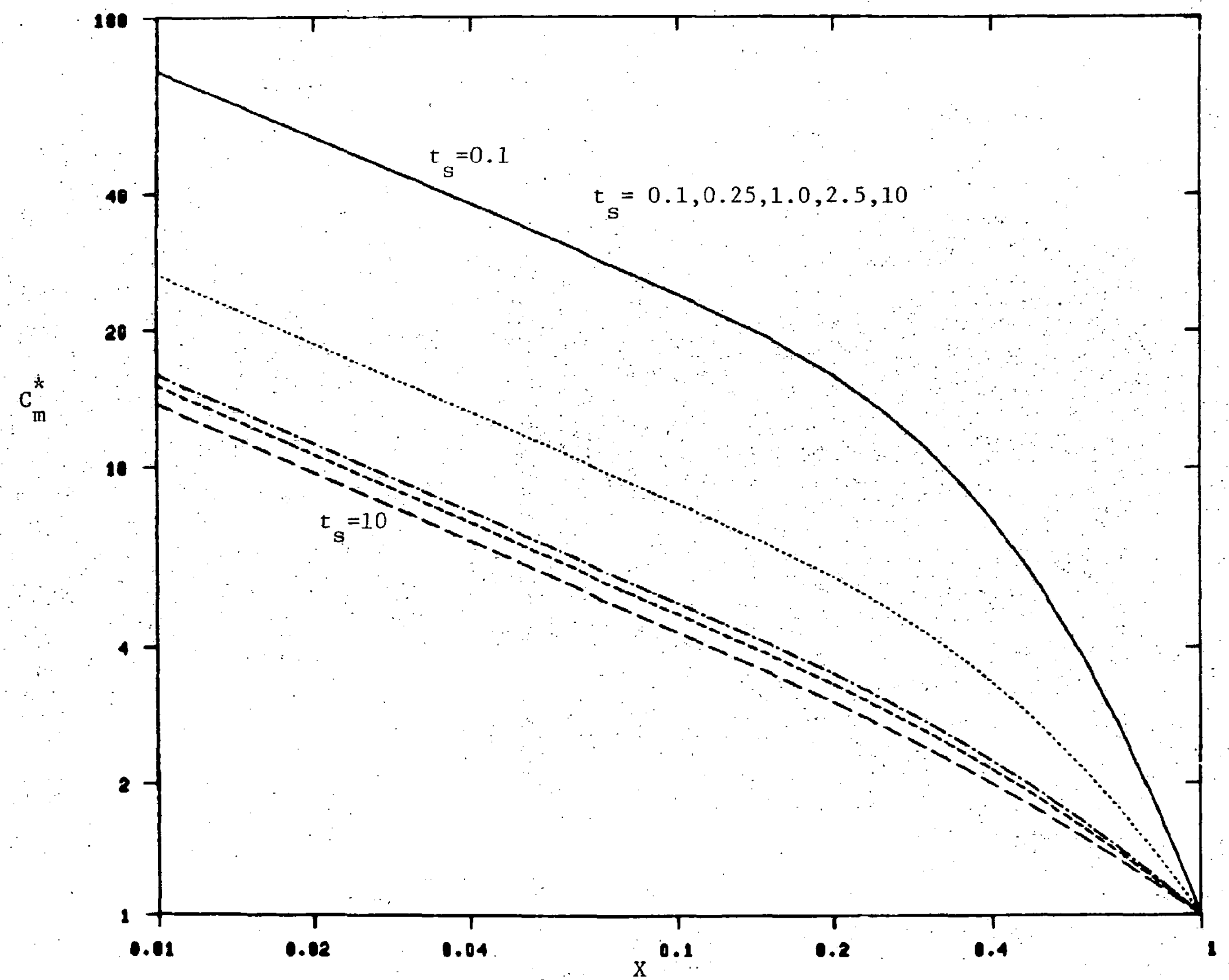


Figure 18. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, $Z=1.0, t_h=10$.

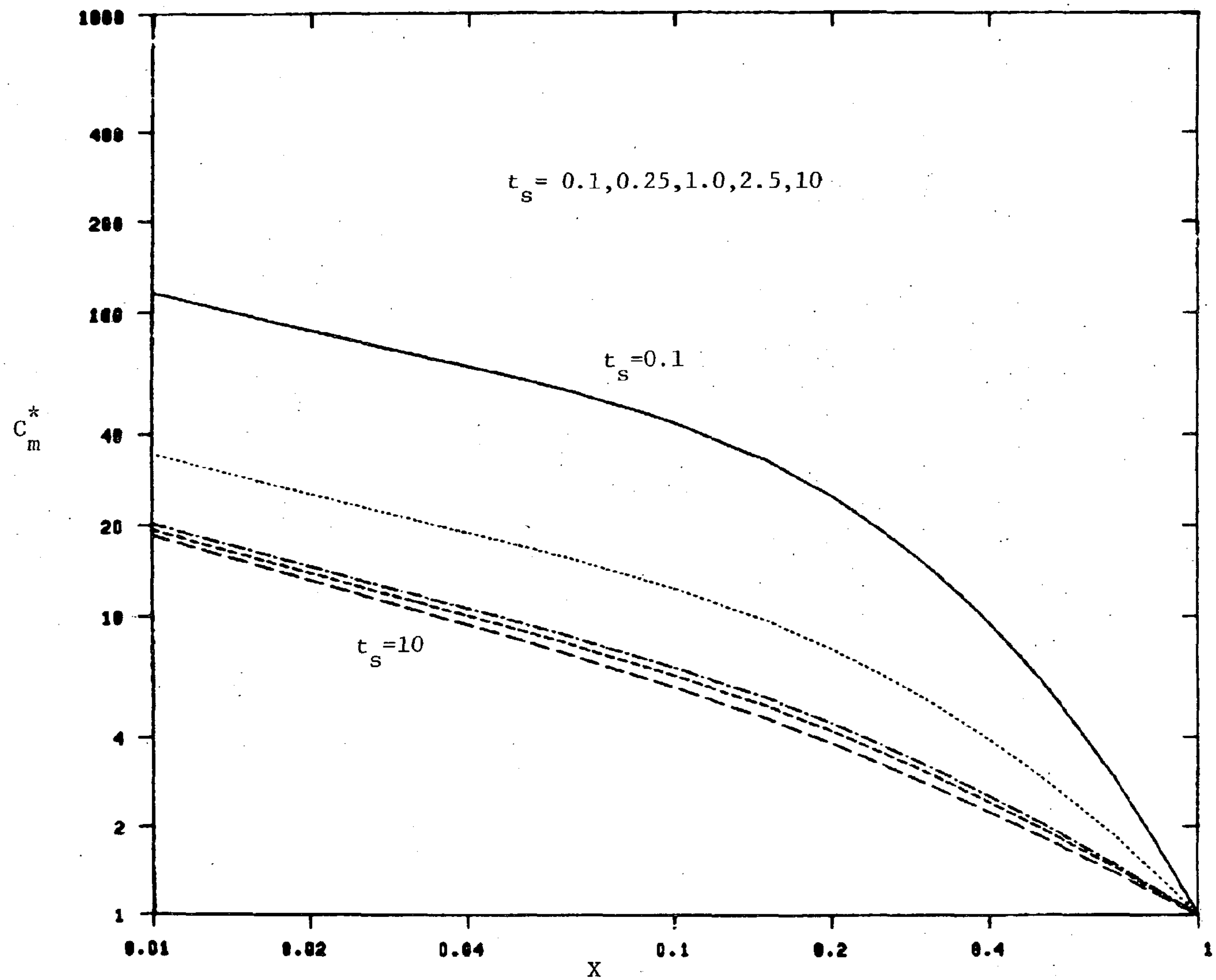


Figure 19. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, $Z=0, t_h=1.0$.

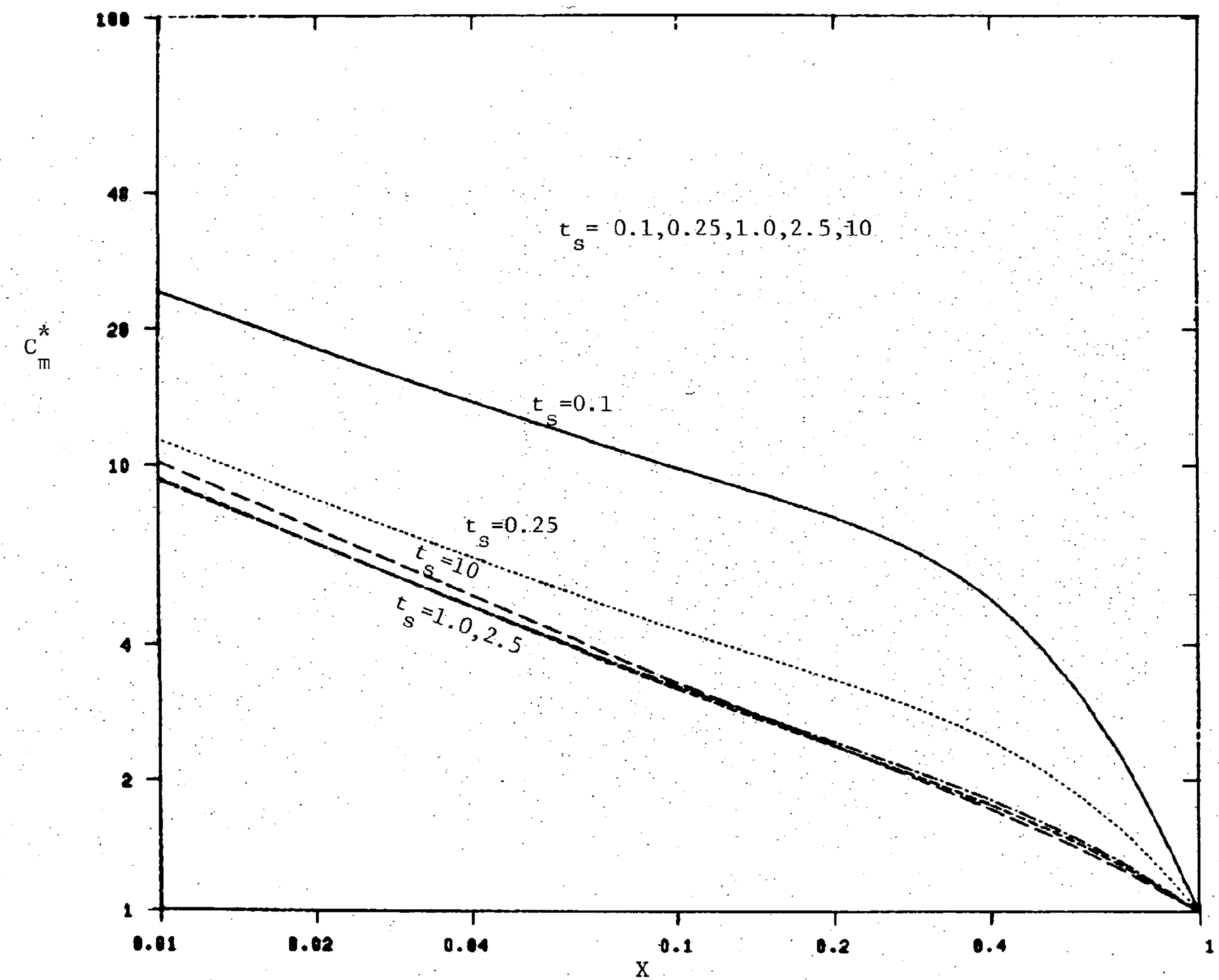


Figure 20. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, $Z=0$, $t_h=5.0$.

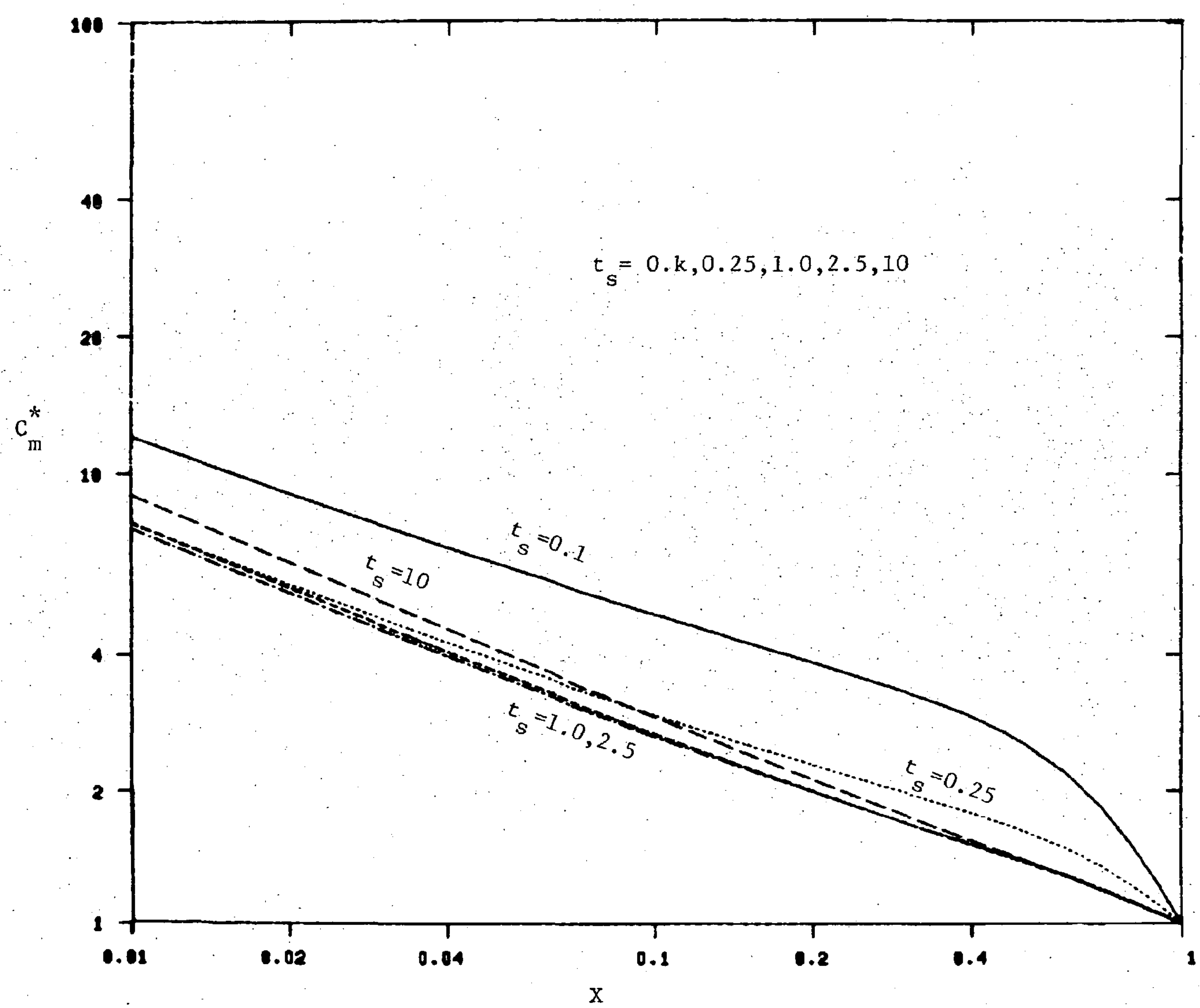


Figure 21. Normalized suspended sediment distribution versus normalized longitudinal distance from dredge head, bucket dredge, $Z=0,t_h=10$.

distributions at surface ($Z = 1.0$), mid-depth ($Z = 0.5$) and bottom ($Z = 0$). It is to be noted that the sediment concentration is normalized with the concentration at the plume front at the corresponding depth. Therefore the distribution curves decrease more rapidly for the surface concentration.

B. Sediment Deposition

As the case of hydraulic dredge, the sediment deposition rate may be expressed as

$$D = WC\Big|_{z=z_1} + k_z \frac{\partial C}{\partial z}\Big|_{z=z_1}$$

where z_1 is the bottom elevation. Substituting equation (17) and neglecting the upward diffusion, it is obtained that

$$D = \frac{WQ}{h\sqrt{4\pi k_y\ ux}} \exp\left(-\frac{(y-y')^2}{4k_y \frac{x}{u}}\right)$$

$$\cdot \frac{1}{2}\left[\operatorname{erf}\left(\frac{z_1 + W\frac{x}{u}}{\sqrt{4k_z \frac{x}{u}}}\right) - \operatorname{erf}\left(\frac{z_1 - h + W\frac{x}{u}}{\sqrt{4k_z \frac{x}{u}}}\right)\right] \qquad (20)$$

Unlike the hydraulic dredge in which the point source moves continuously across the channel in y-direction, the bucket dredge generates a line source which moves discretely in y-direction. To facilitate mathematical derivation, the discrete motion is approximated by a continuous motion with velocity V. Then, similar to the hydraulic dredge, the total sediment deposition at a given point may be written as

$$M = 2 \sum_{n=0}^{N-1} \frac{WQ}{h\sqrt{4\pi k_y \cdot u \cdot n\delta}} \cdot \int_{t_b + n\tau}^{t_b+(n+1)\tau} \exp\left[-\frac{\{y + \frac{B}{2} - V(t-t_b-n\tau)\}^2}{4k_y \frac{n\delta}{u}}\right] dt \cdot \frac{1}{2}\left[\operatorname{erf}\left(\frac{z_1 + W\frac{n\delta}{u}}{\sqrt{4k_z \frac{n\delta}{u}}}\right) - \operatorname{erf}\left(\frac{z_1 - h + W\frac{n\delta}{u}}{\sqrt{4k_z \frac{n\delta}{u}}}\right)\right] \tag{21}$$

Substituting turbidity generation unit and carrying out the integration, it is obtained that

$$M = \frac{1}{2} \sum_{n=0}^{N-1} \frac{kGD\delta W}{hu} \cdot \left[\operatorname{erf}\left(\frac{y + \frac{B}{2}}{\sqrt{4k_y \frac{n\delta}{u}}}\right) - \operatorname{erf}\left(\frac{y - \frac{B}{2}}{\sqrt{4k_y \frac{n\delta}{u}}}\right)\right] \cdot \left[\operatorname{erf}\left(\frac{z_1 + W\frac{n\delta}{u}}{\sqrt{4k_z \frac{n\delta}{u}}}\right) - \operatorname{erf}\left(\frac{z_1 - h + W\frac{n\delta}{u}}{\sqrt{4k_z \frac{n\delta}{u}}}\right)\right] \tag{22}$$

or, in terms of dimensionless parameters,

$$\frac{M}{kGD} = \frac{1}{2N} \cdot \frac{1}{\sqrt{t_h t_s}} \sum_{n=0}^{N-1} \left[\operatorname{erf}\left\{\sqrt{\frac{N}{n}\, t_B}\,(Y + \tfrac{1}{2})\right\} - \operatorname{erf}\left\{\sqrt{\frac{N}{n} t_B}\,(Y - \tfrac{1}{2})\right\}\right] \cdot \left[\operatorname{erf}\left\{\frac{1}{2}\sqrt{\frac{N}{n} t_h}\, Z + \frac{1}{2}\sqrt{\frac{n}{N}\frac{1}{t_s}}\right\} - \operatorname{erf}\left\{\frac{1}{2}\sqrt{\frac{N}{n} t_h}\,(Z-1) + \frac{1}{2}\sqrt{\frac{n}{N}\frac{1}{t_s}}\right\}\right] \tag{23}$$

where

$$Z = \frac{z_1}{h}$$

$$Y = \frac{y}{B}$$

Equation (23) involves three independent parameters, t_s, t_h and t_B. Using typical values of t_B and t_h for the dredging operation in the Elizabeth River, equation (23) is presented graphically in Figures 22 to 28. Equation (23) is a very weak function of N, and a numerical test shows that the value of M/kGD changes no more than 1.2% for N varies from 200 to 2000. For the results presented in Figures 22 to 28, the value of N is taken as 200. Figures 22, 23 and 24 show the amount of sediment deposition as function of distance from dredged channel, assuming the bottom is of the same elevation as the channel. Figures 25 to 28 present the equi-deposition contours on the Y-Z plane.

It is to be noted that the vertical diffusive flux of sediment particles is neglected in deriving equation (23). Therefore, the amount of sediment deposition as predicted by the equation is a conservative estimate.

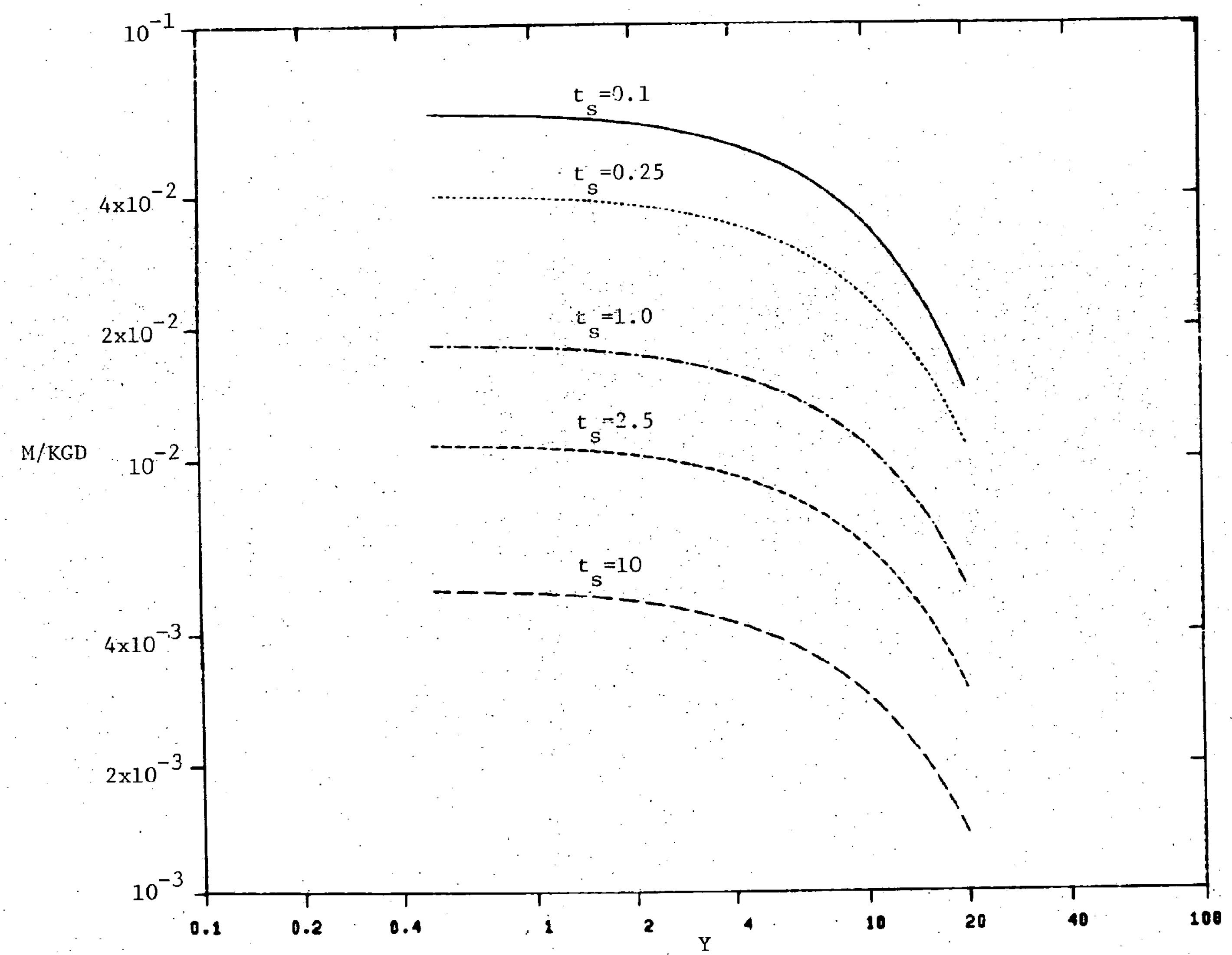


Figure 22. Dimensionless sediment deposition versus normalized lateral distance from dredge channel, bucket dredge, t_h=5.0, t_B=0.001, Z=0.

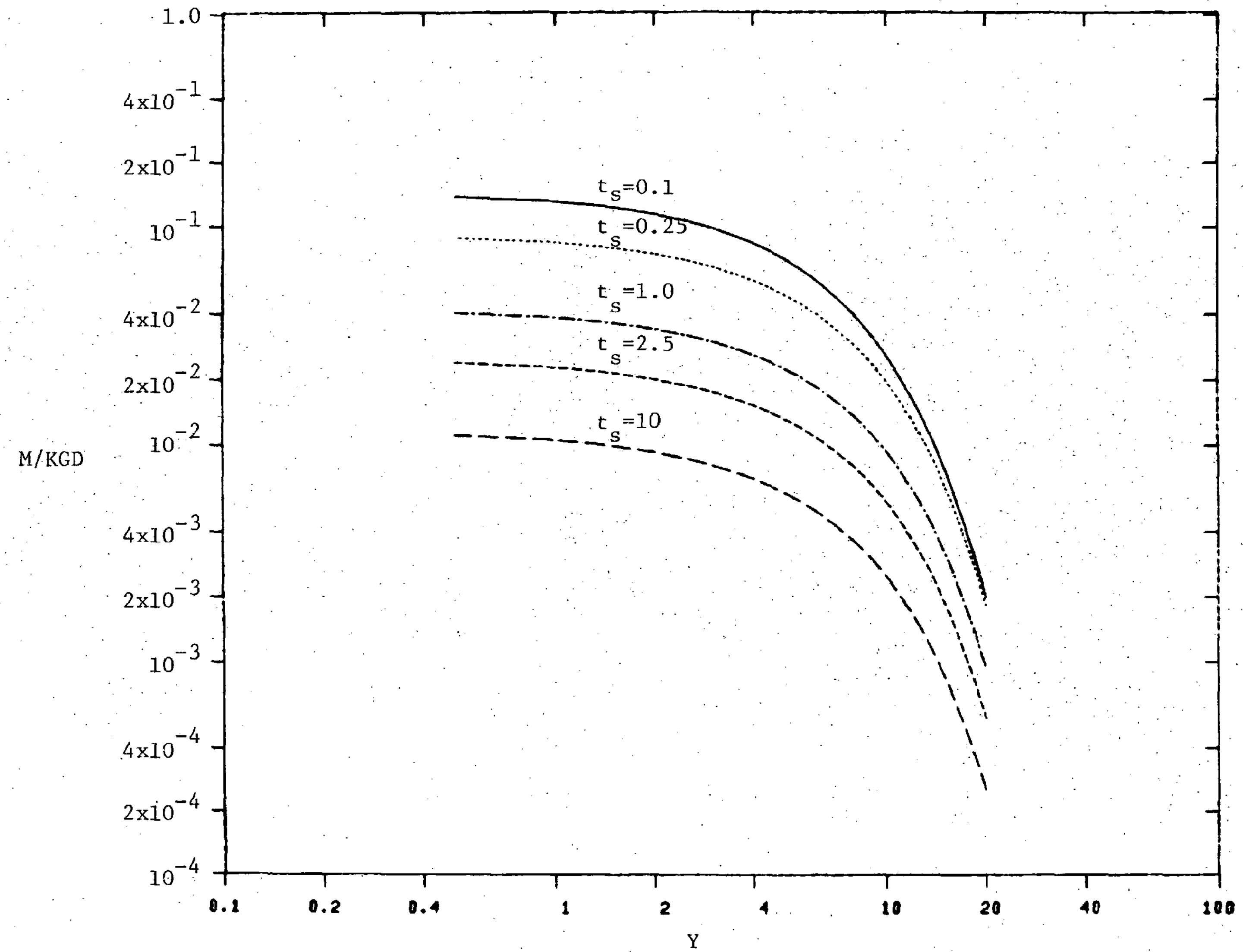


Figure 23. Dimensionless sediment deposition versus normalized lateral distance from dredge channel, bucket dredge, t_h=5.0, t_B=0.005, Z=0.

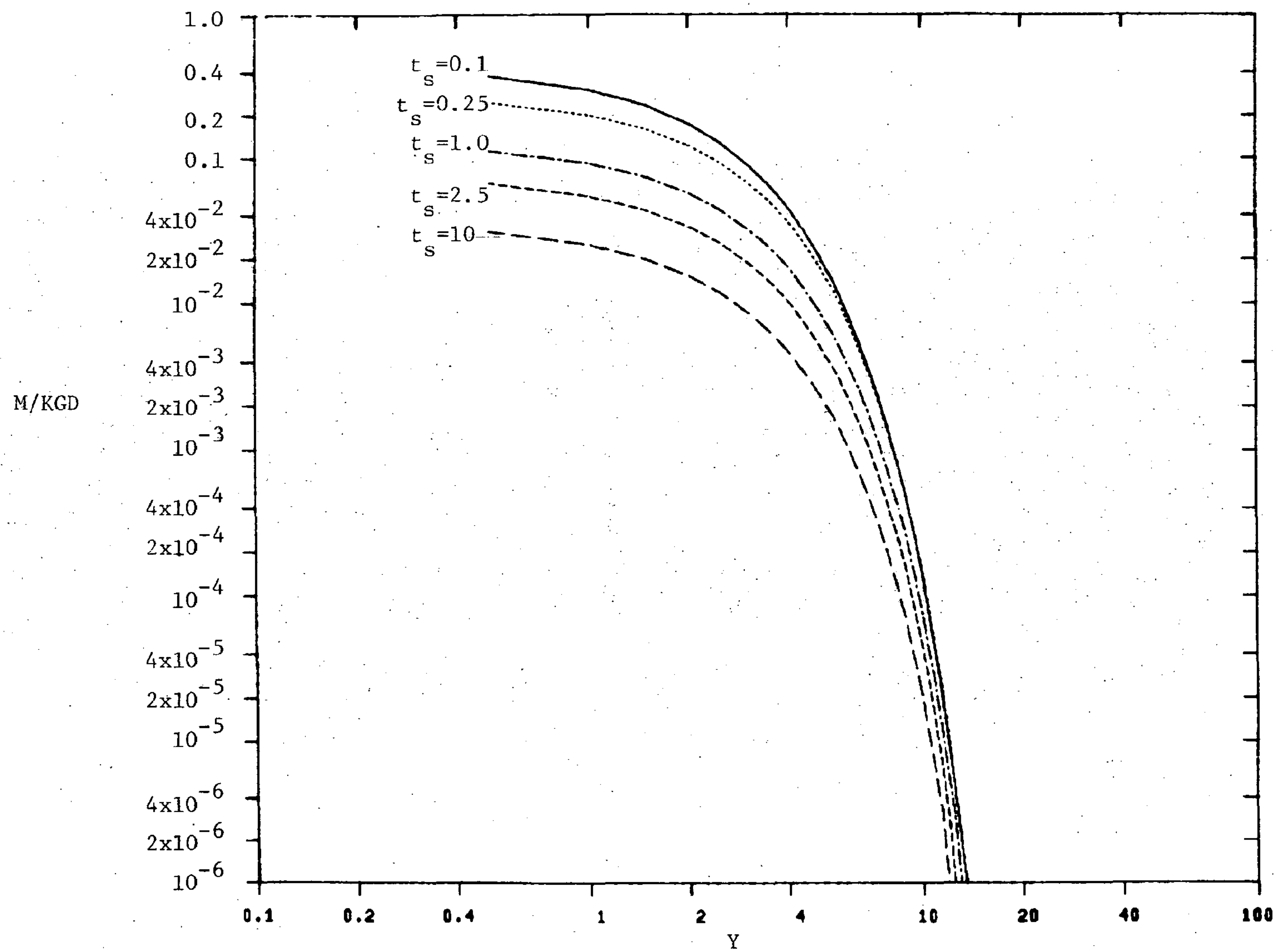


Figure 24. Dimensionless sediment deposition versus normalized lateral distance from dredge channel, bucket dredge, $t_h=5.0$, $t_B=0.05$, $Z=0$.

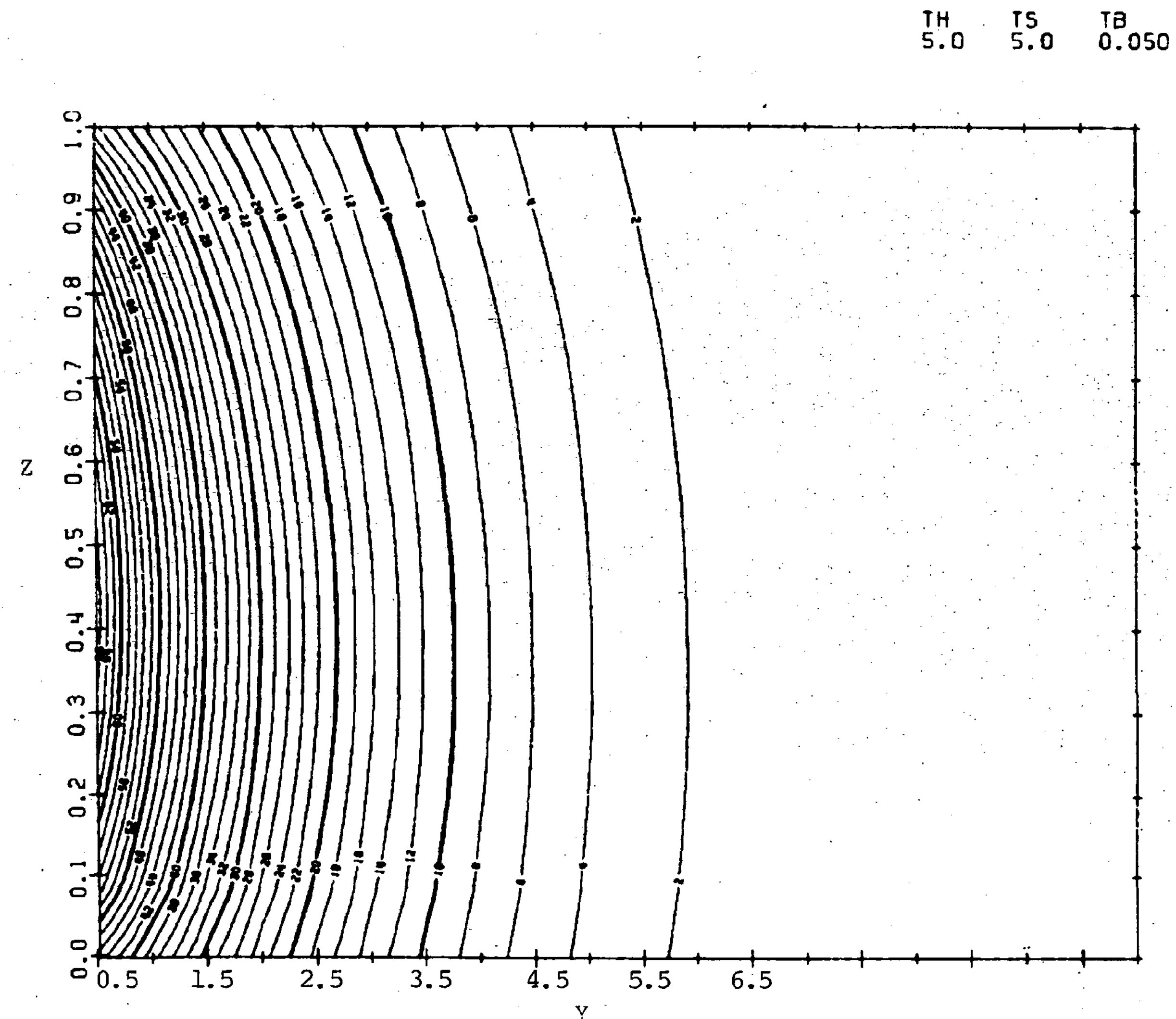


Figure 25a. Iso-deposition contours in Y=Z plane, bucket dredge, t_h=5.0, t_s=5.0, t_B= 0.05. (The values of M/KGD should be multiplied by 0.001).

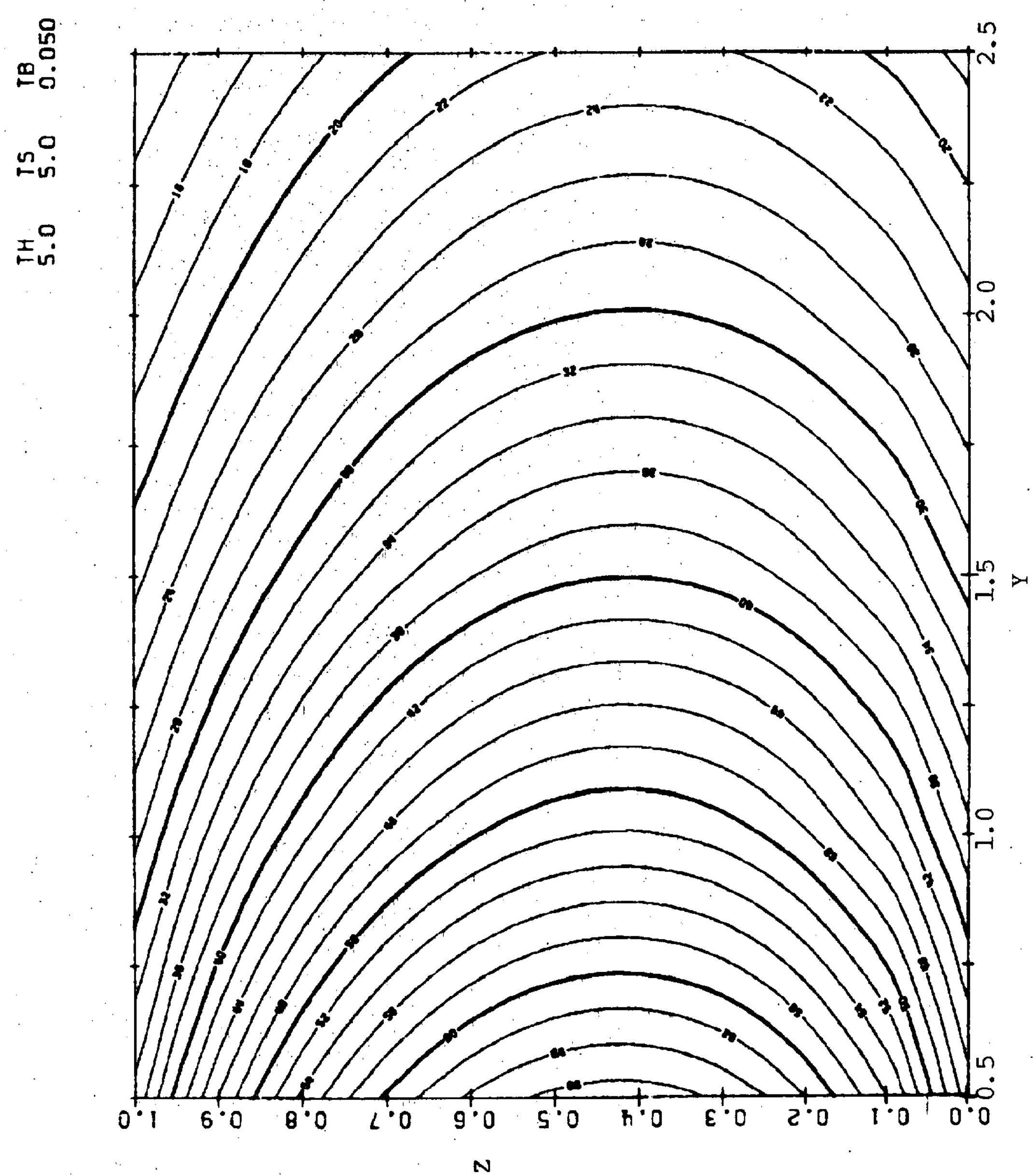


Figure 25b.

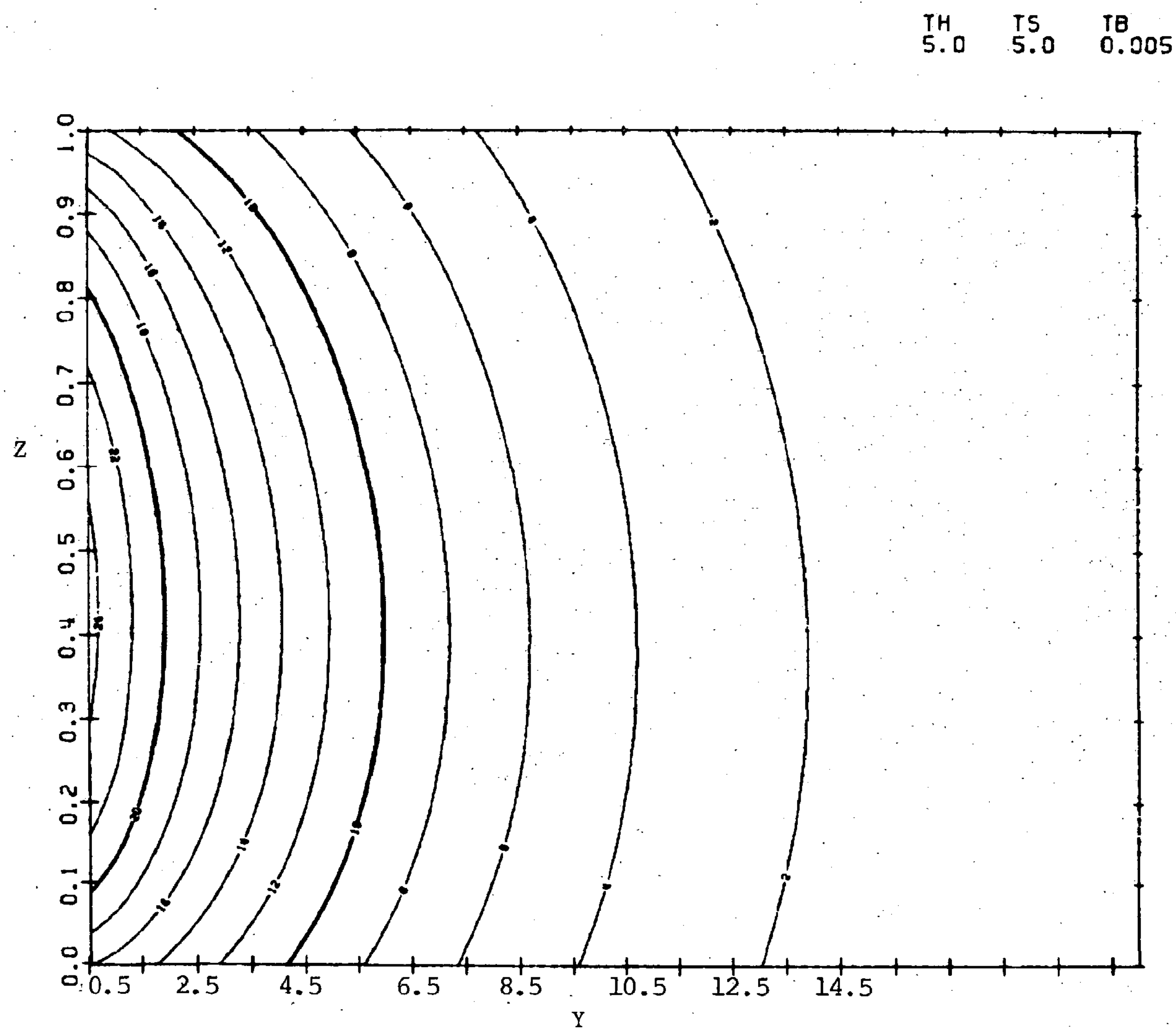


Figure 26a. Iso-deposition contours in Y-Z plane, bucket dredge, t_h=5.0, t_s=5.0, t_B= 0.005. (The values of M/KGD should be multiplied by 0.001).

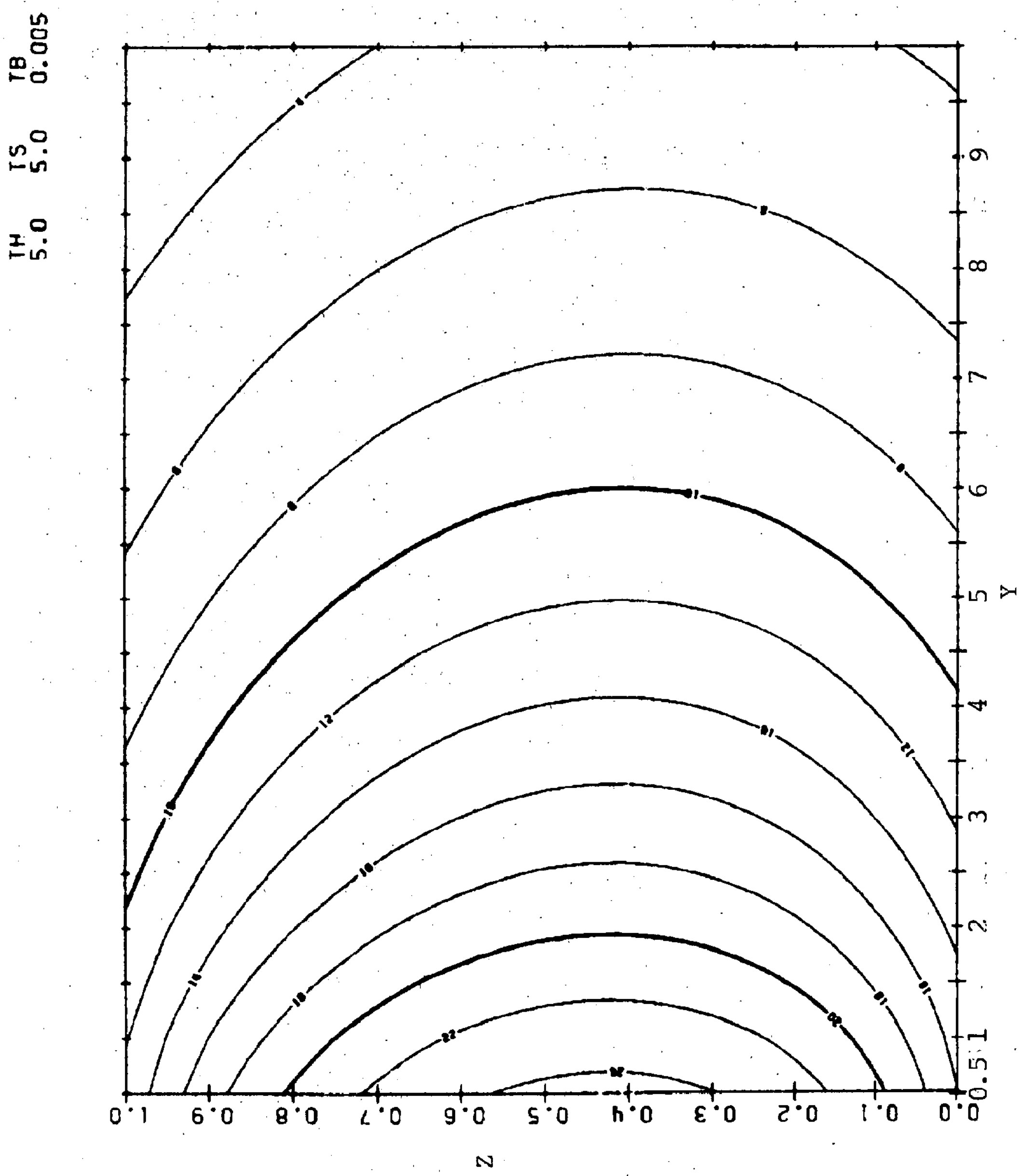


Figure 26b.

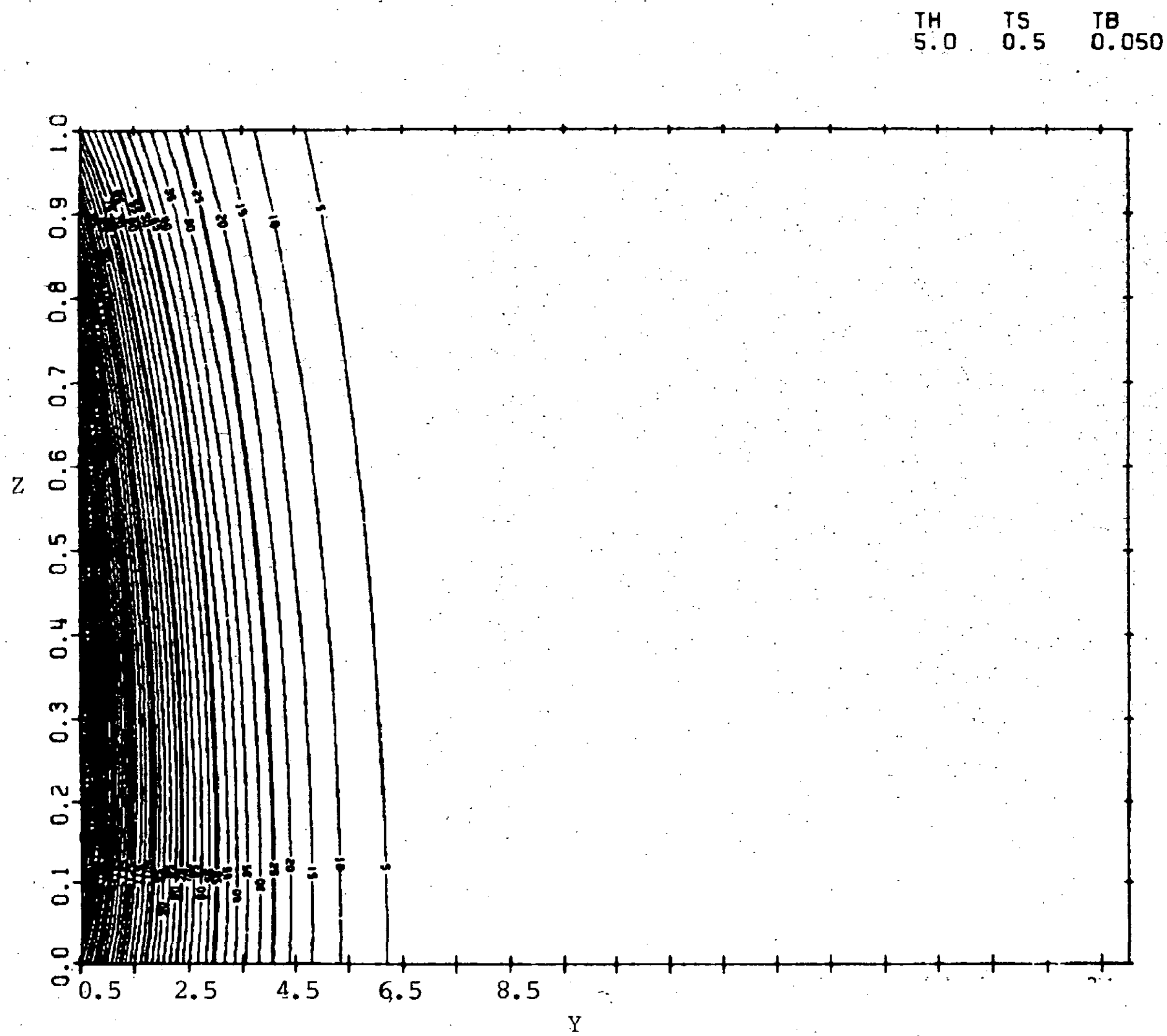


Figure 27a. Iso-deposition contours in Y-Z plane, bucket dredge, $t_h=5.0$, $t_s= 0.5$, $t_B= 0.05$. (The value of M/KGD should be multiplied by 0.001).

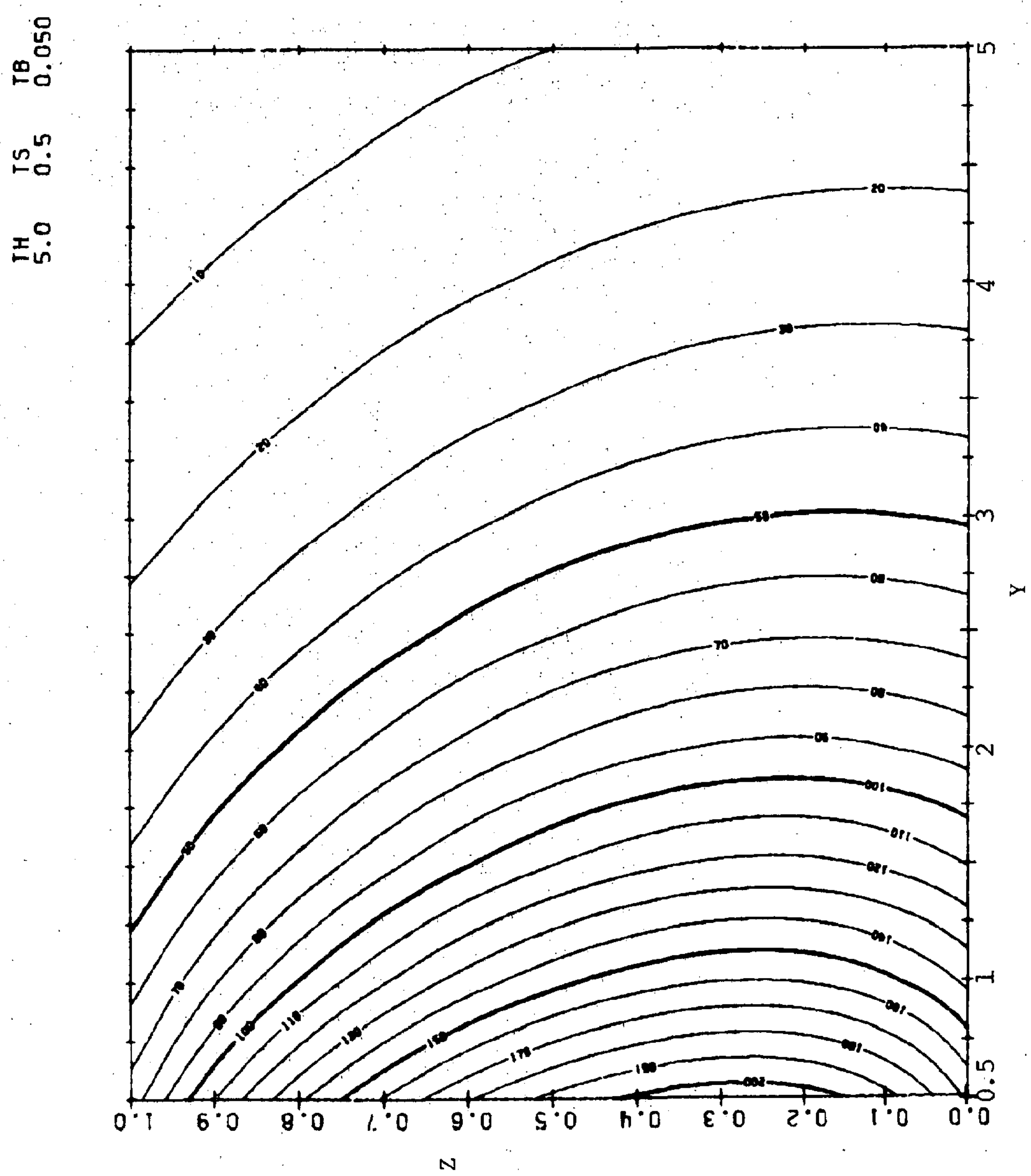


Figure 27b.

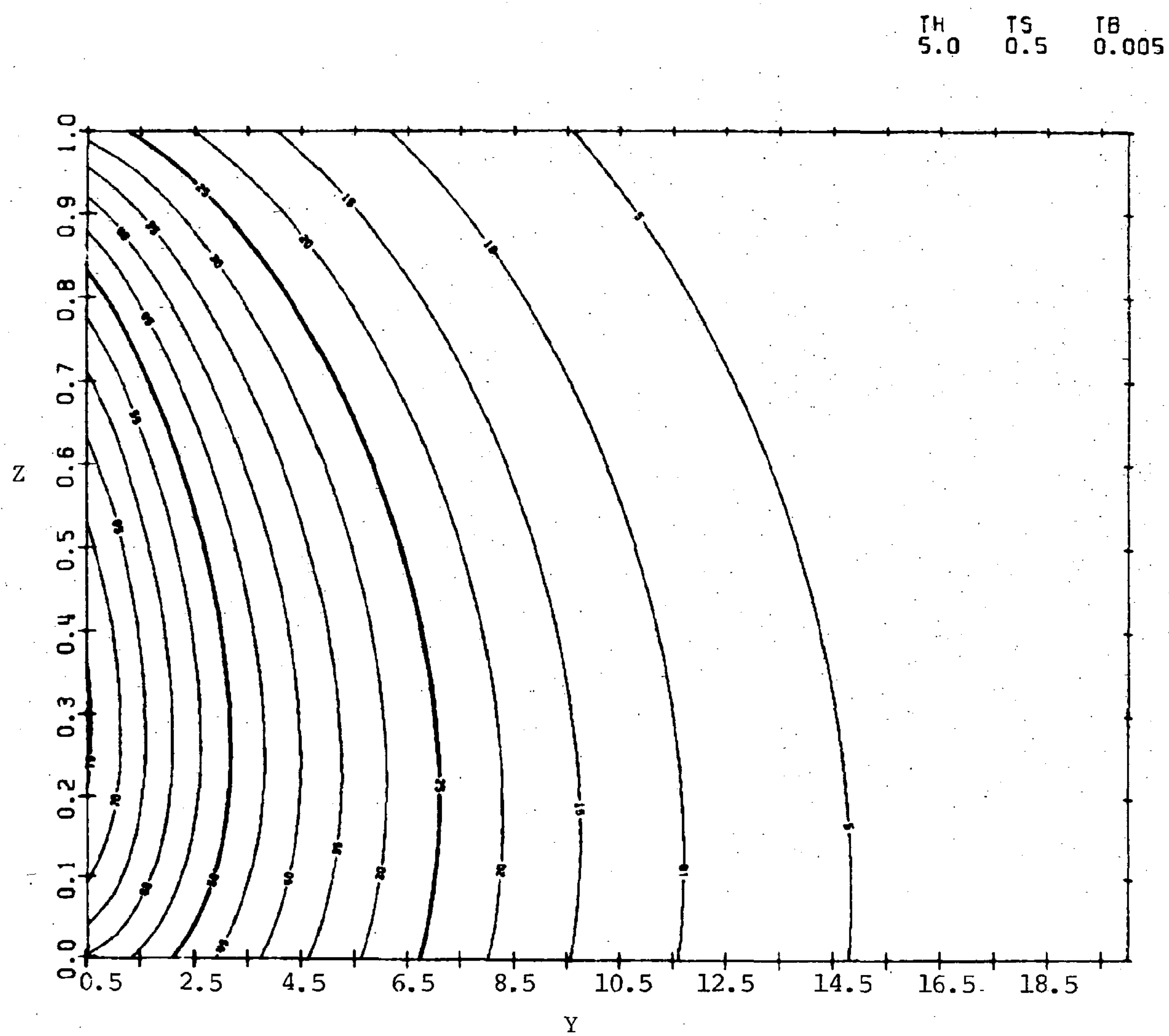


Figure 28. Iso-deposition contours in Y-Z plane, bucket dredge, t_h=5.0, t_s= 0.5, t_B=0.005. (The values of M/KGD should be multiplied by 0.001).

References

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Kuo, A. Y. and J. P. Jacobson. 1976. "Prediction of Pollutant Distribution in Estuaries". Proceedings of the 15th Coastal Engineering Conference, pp. 3276-3293.

Nakai, O. 1978. "Turbidity Generated by Dredging Projects." Proceedings of the 3rd U.S.-Japan Experts' Meeting on Management of Bottom Sediments Containing Toxic Substances.

Appendix 1. Suspended Solid Concentrations at the Plume Front

In figures 1 to 5 and 13 to 21, the longitudinal distributions of suspended solid concentration are presented in dimensionless form normalized with the concentration at plume front. For practical application, the numerical values obtained from these figures need to be multiplied by the solid concentration at the plume front to arrive at the absolute concentrations. The concentrations at plume front may be evaluated with equations (5) and (18) for hydraulic dredge and bucket dredge respectively. Setting $x = x_r$ and $z = z_o$, equation (5) becomes

$$C_m(x_r, z_o) \Big/ \frac{Q}{4\pi\sqrt{k_y k_z}\; x_r} = \exp\left[-\frac{1}{4}\left(\sqrt{t_d} + \sqrt{\frac{1}{t_s}}\right)^2\right] \qquad \text{(A1)}$$

and equation (18) becomes

$$C_m(x_r, z_o) \Big/ \frac{Q}{4h\sqrt{\pi k_y u\; x_r}} = \text{erf}\left(\frac{1}{2}\sqrt{t_h}\; Z + \frac{1}{2}\sqrt{\frac{1}{t_s}}\right) - \text{erf}\left[\frac{1}{2}\sqrt{t_h}\;(Z-1) + \frac{1}{2}\sqrt{\frac{1}{t_s}}\right] \qquad \text{(A2)}$$

Equations (A1) and (A2) are presented graphically in figures A1(a) to A4(a) with linear scales, and in figures A1(b) to A4(b) with logarithmic scales. Figures A1 are for hydraulic dredge, they show the variation of non-dimensional plume front concentration versus t_d, with t_s as a parameter. Figures A2 to A4 show the plume front concentrations at surface (Z=1), mid depth (Z=0.5) and bottom (Z=0) respectively for a plume induced by bucket dredge. They show the non-dimensional concentrations versus t_h with t_s as a parameter.

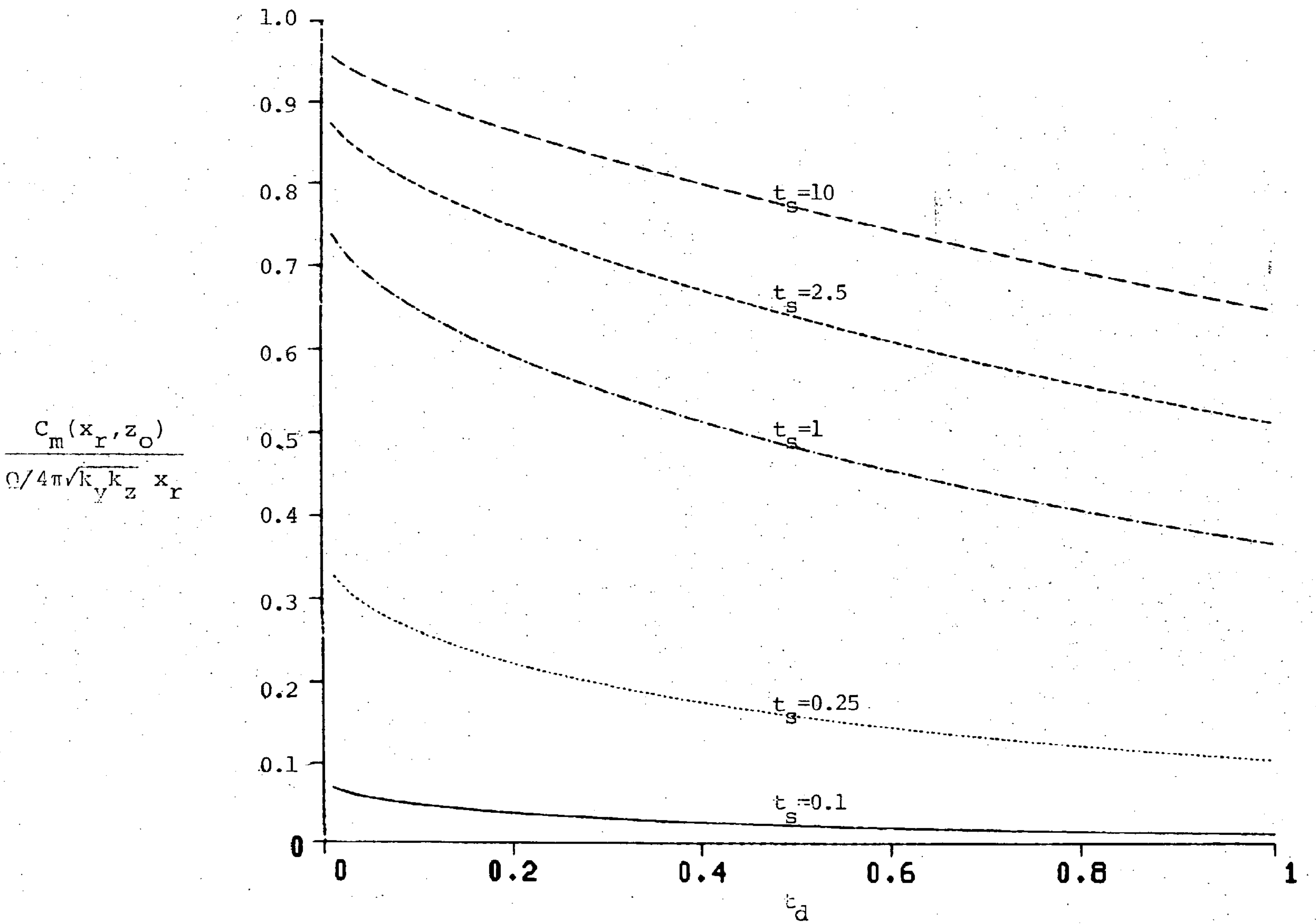

Figure A1(a). Normalized suspended solid concentration at the front of a turbidity plume induced by hydraulic dredge, linear scale.

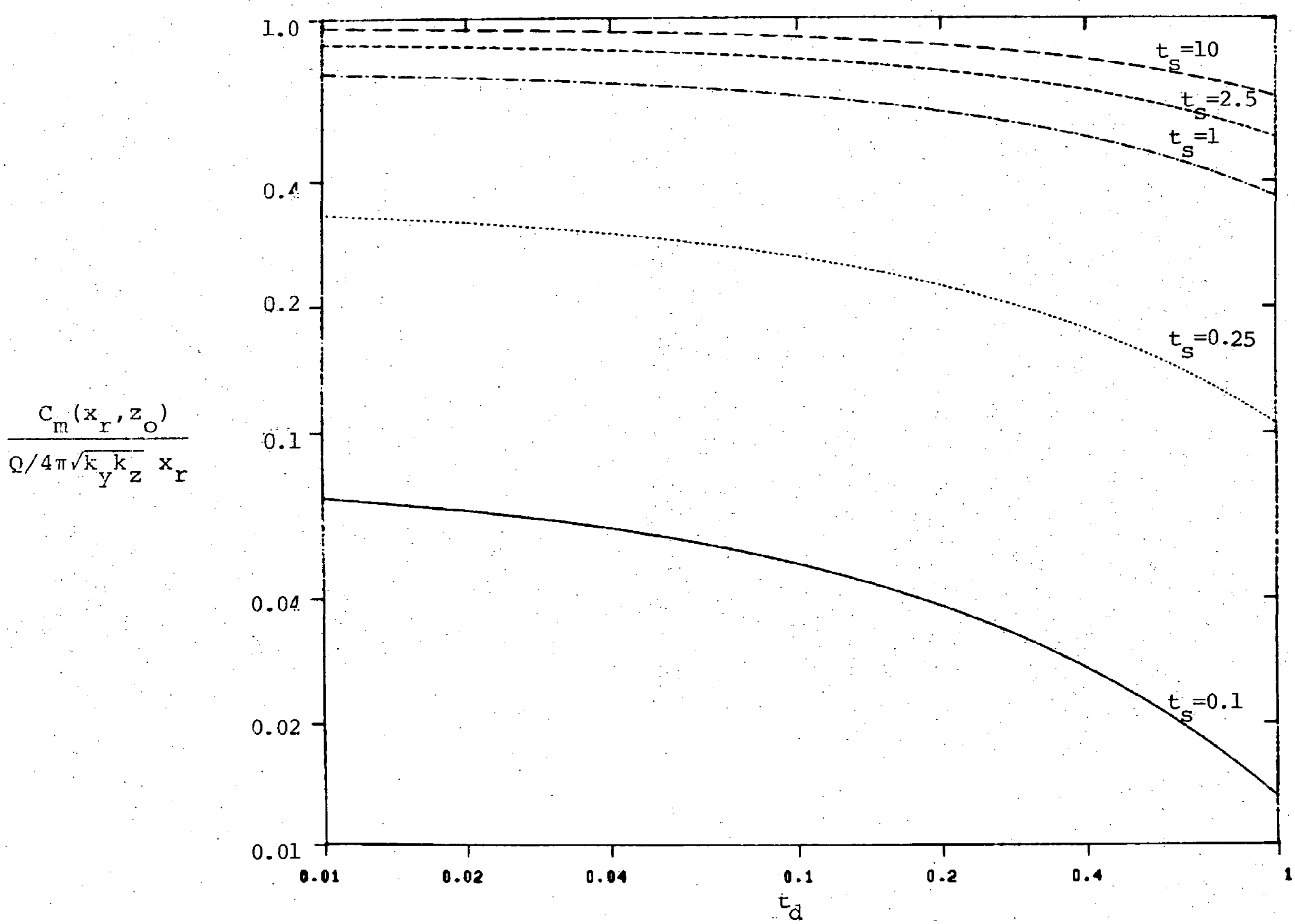

Figure A1(b). Normalized suspended solid concentration at the front of a turbidity plume induced by hydraulic dredge, logarithmic scale.

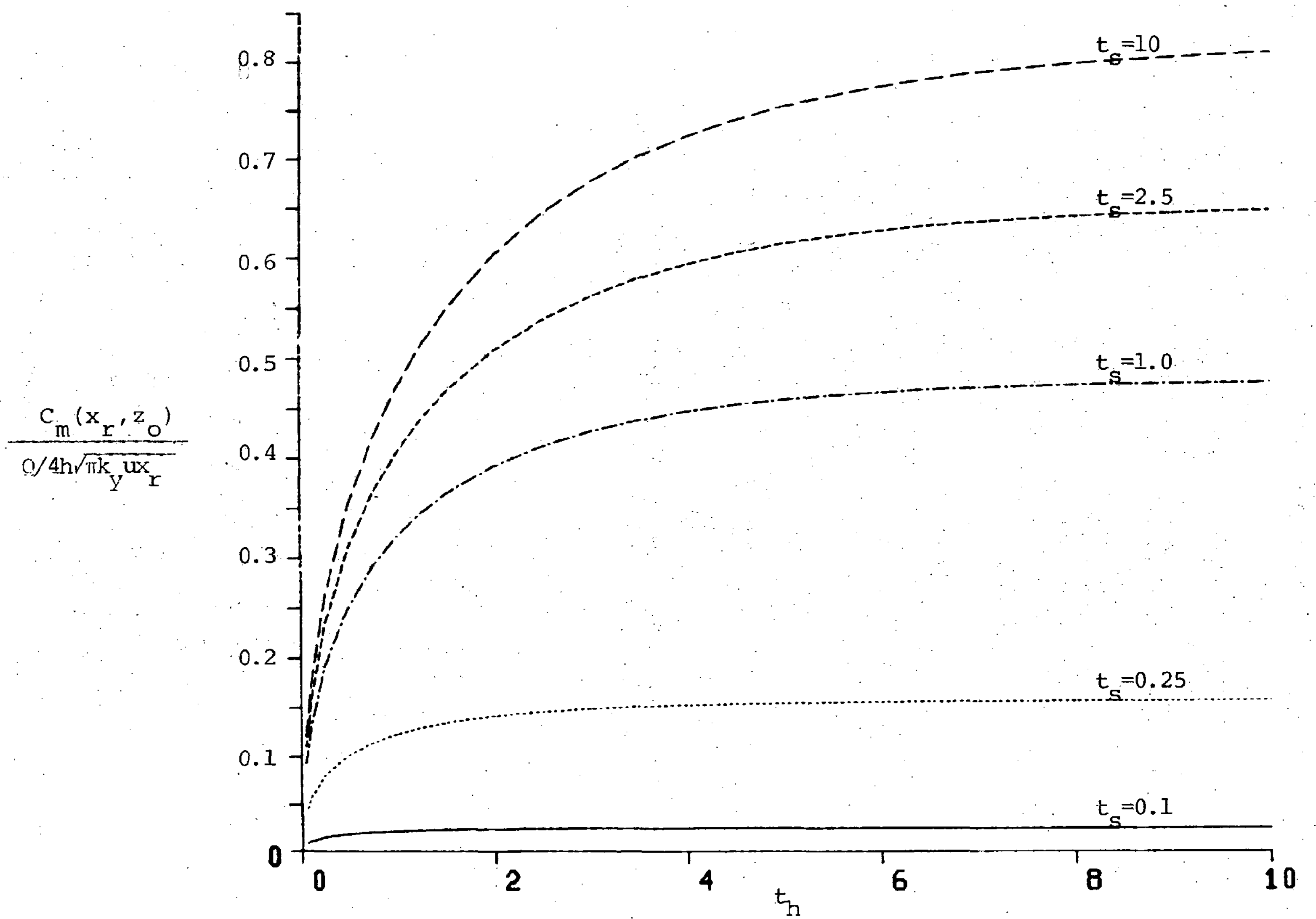

Figure A2(a). Normalized suspended solid concentration at the front of a turbidity plume induced by bucket dredge, Z=1.0, linear scale.

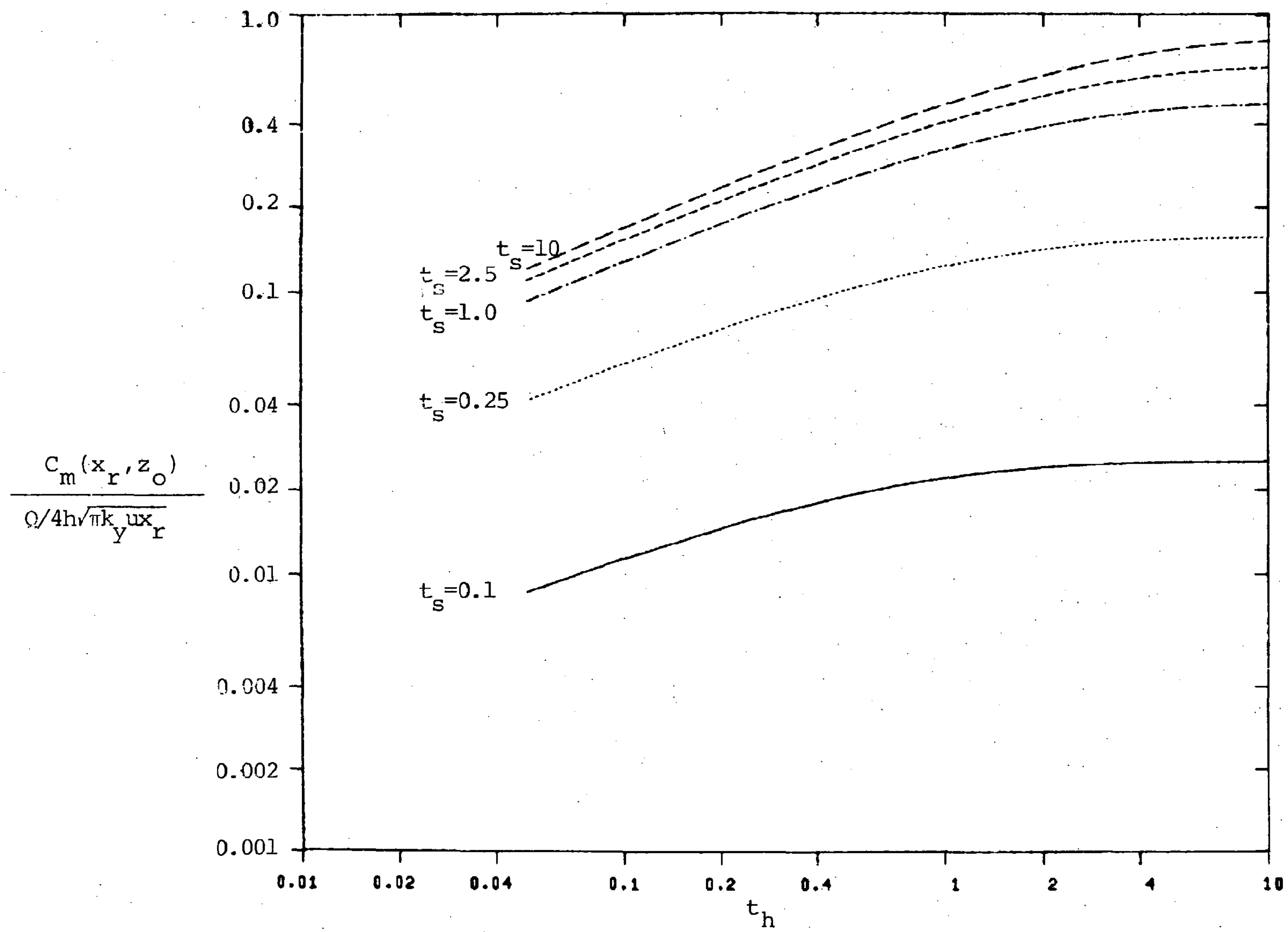

Figure A2(b). Normalized suspended solid concentration at the front of a turbidity plume induced by bucket dredge, Z=1.0, logarithmic scale.

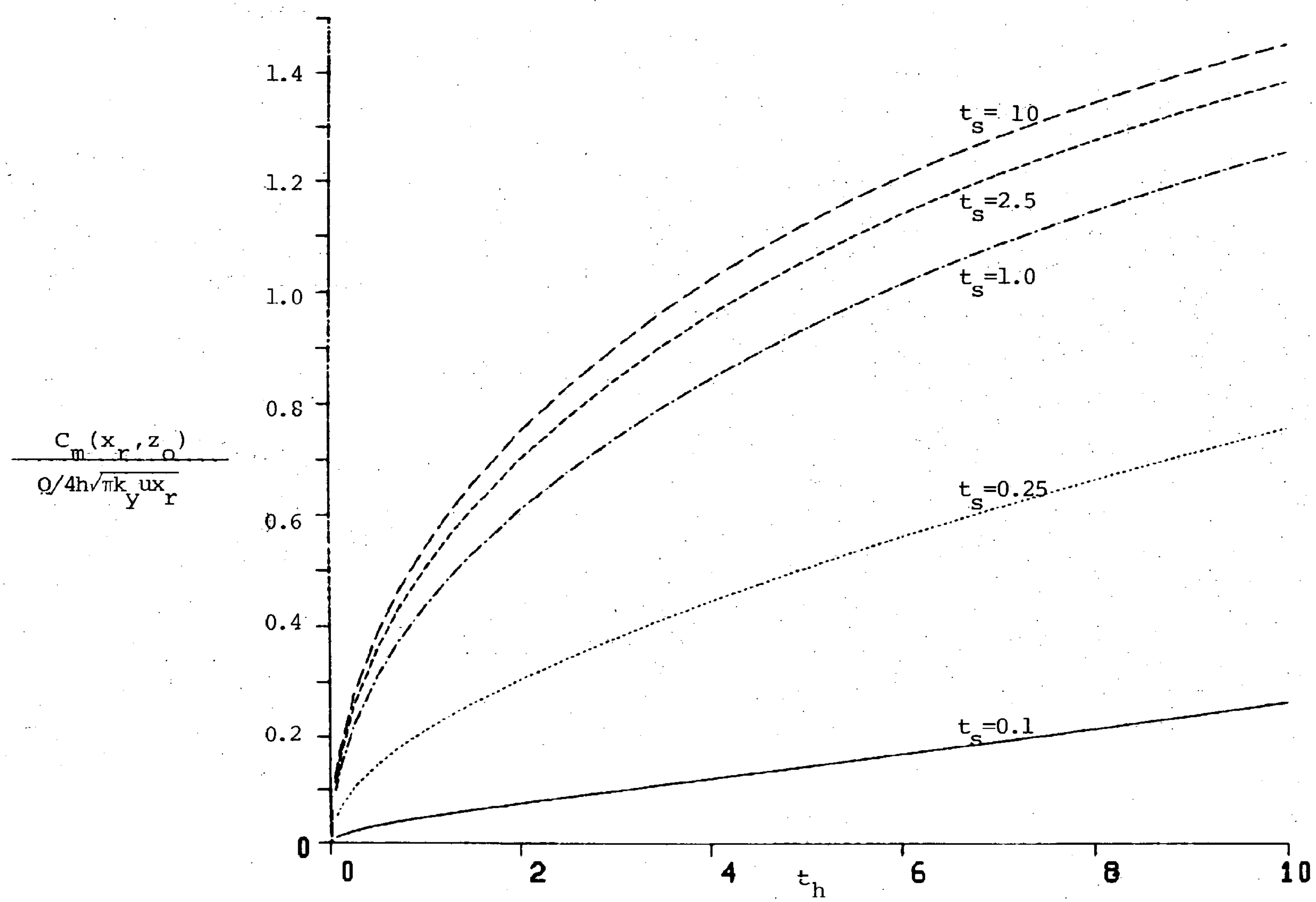

Figure A3(a). Normalized suspended solid concentration at the front of a turbidity plume induced by bucket dredge, Z=0.5, linear scale.

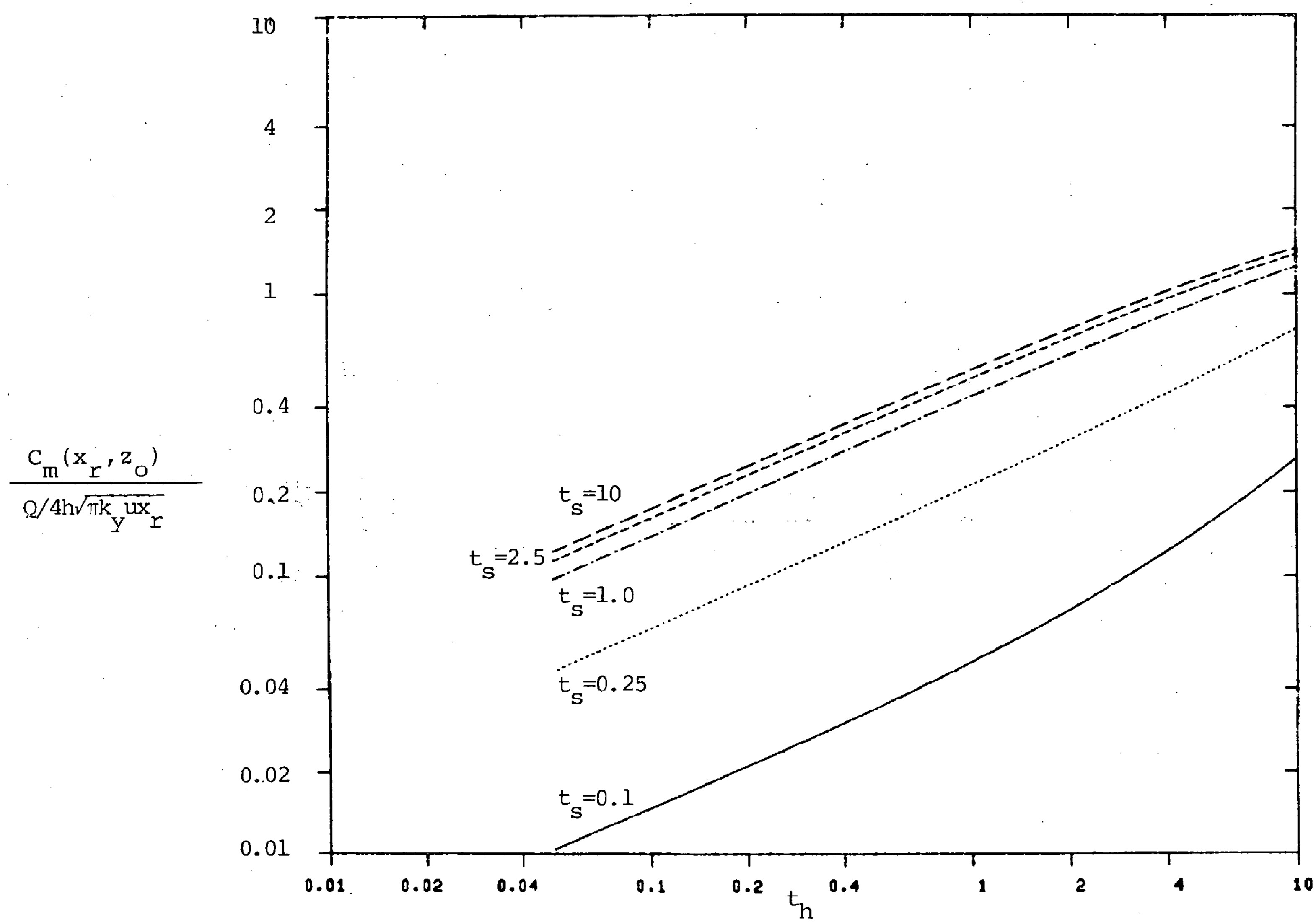

Figure A3(b). Normalized suspended solid concentration at the front of a turbidity plume induced by bucket dredge, Z =0.5, logarithmic scale.

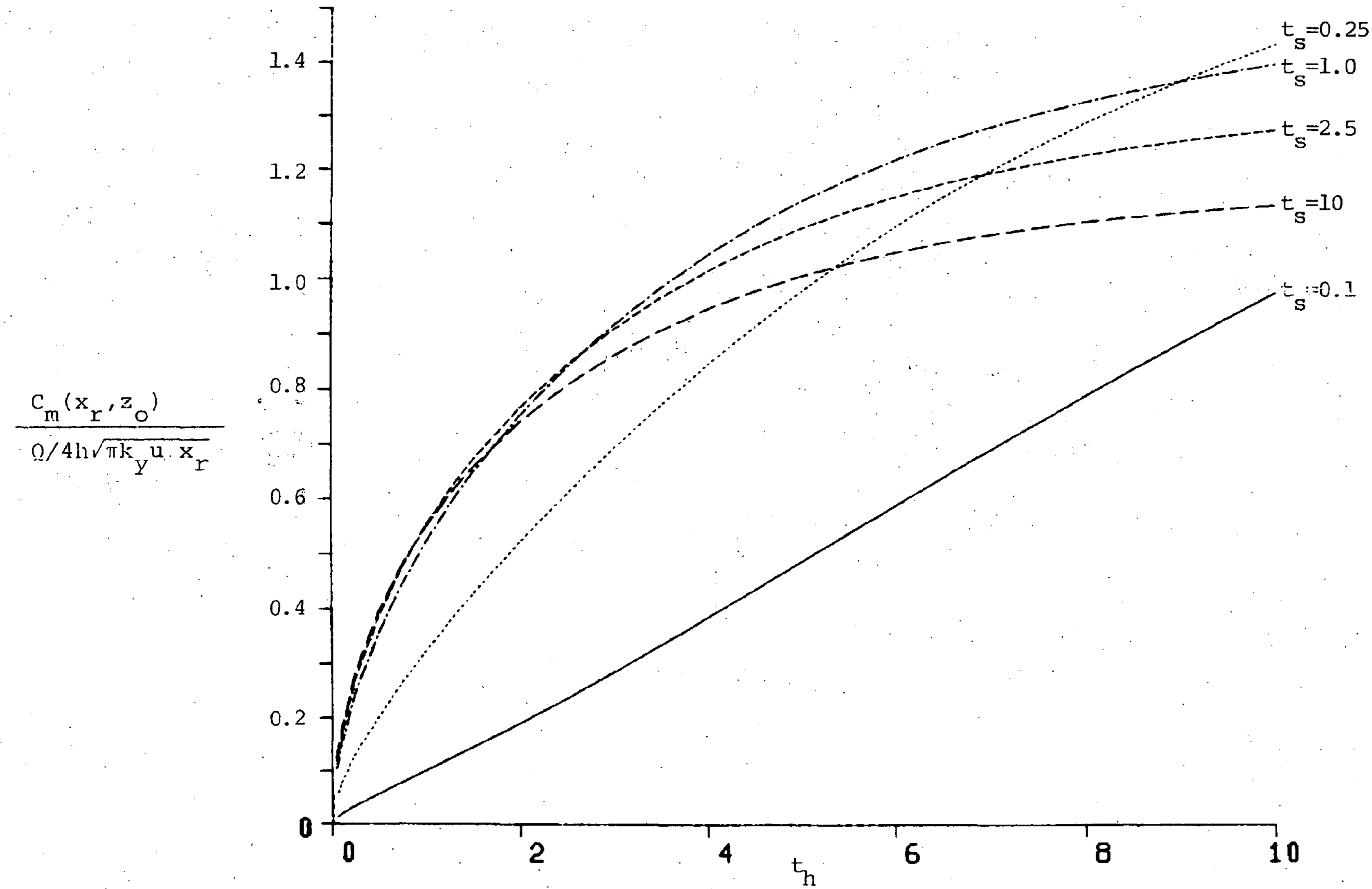

Figure A4(a). Normalized suspended solid concentration at the front of a turbidity plume induced by bucket dredge, Z=0, linear scale.

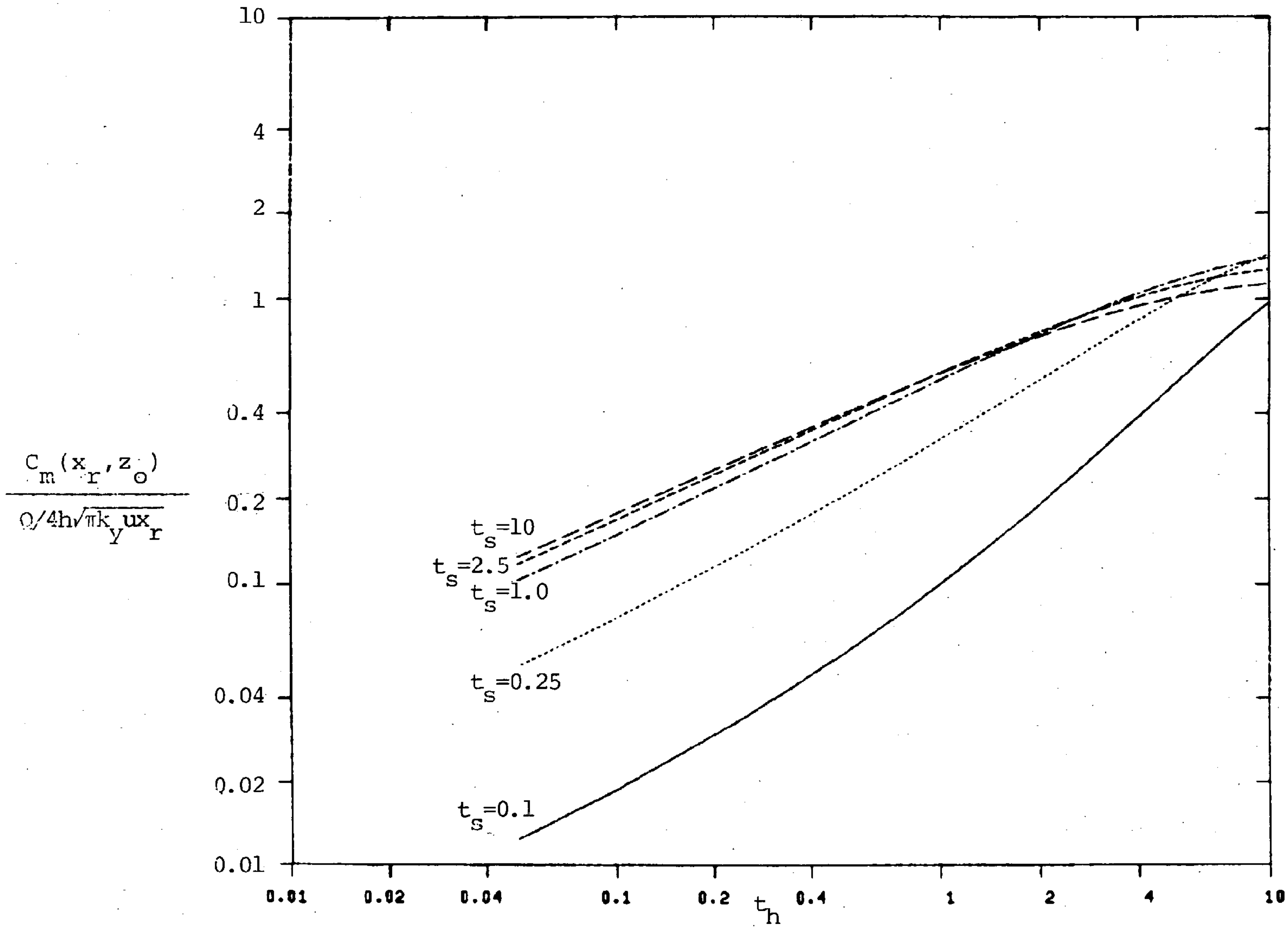

Figure A4(b). Normalized suspended solid concentration at the front of a turbidity plume induced by bucket dredge, Z=0, logarithmic scale.

Appendix 2. Applications to Example Problems

Taking some typical dredging operations in the Virginia estuaries as examples, the following demonstrates how the model may be used to predict the dredge-induced turbidity and subsequent sediment deposition.

I. Hydraulic Dredge in the Elizabeth River

A. Input Information

(1) Specifications of dredging operation

channel width

$B = 200$ ft $= 61$ m. $= 6.1 \times 10^3$ cm

dredging thickness

10 ft, to be completed in two steps, each step dredges 5 ft.

$D = 5$ ft $= 1.52$ m

swing speed of cutter head

$V = 0.67$ ft/sec $= 0.20$ m/s

$\tau = 5$ minutes

cutter head cuts 6 ft in x-direction in each swing

$\delta = 6$ ft $= 1.83$ m

(2) Characteristics of sediments at the channel bottom

mean particle size

$d = 6\mu = 6 \times 10^{-4}$ cm

variance

$s^2 = 70\mu^2 = 70 \times 10^{-8}$ cm^2

the fraction of particles with diameter smaller than 74 μ

$R_{74} > 99.99\%$

(3) Characteristics of ambient flow field

mean velocity

$u = 13$ cm/sec

period of flood or ebb

$T = 2.24 \times 10^4$ sec

vertical turbulent diffusion coefficient

$k_z = 10$ cm^2/sec

lateral turbulent diffusion coefficient

$k_y = 10^5 cm^2/sec$

B. Information Sought

(1) The longitudinal distribution of suspended solid concentration in the turbidity plume at 1 meter above bottom.

(2) The amount of sediment deposition in the surrounding area.

C. Calculation of Model Parameters

(1) settling velocity of sediment particles

$$W = 9 \times 10^3 \ (d^2 + s^2) \text{ in cgs unit}$$
$$= 9 \times 10^3 \ (36 \times 10^{-8} + 70 \times 10^{-8})$$
$$= 10^{-2} \text{ cm/sec}$$

(2) particle size with critical resuspension velocity equals ambient velocity, 13 cm/sec

$d_c = 276\ \mu$ (equation of Ingersol and equation of Camp *et al*.)*

(3) the fraction of particles with diameter smaller than d_c

$R_o = 100\%$

(4) the particle size distribution factor

$k = R_o/R_{74} = 1.0$

(5) the turbidity generation unit

$G = 5.3 \sim 36.4\ kg/m^3$ for hydraulic dredge of silty clay material (Nakai, 1978)

use $G = 15\ kg/m^3$

(6) source strength of suspended solid

$$Q = kGD\,\delta V$$
$$= 1.0 \times 15 \times 1.52 \times 1.83 \times 0.2$$
$$= 8.34 \text{ kg/sec}$$

*From the data provided by Nakai (1978), the equations may be written as:

$V_c = 0.00128\ d_c^2$. . . . .Ingersol for $V_c \leq 7$ cm/sec

$V_c = 0.783\ \sqrt{d_c}$ . . . . .Camp, et al. for $V_c > 7$ cm/sec

where V_c and d_c are in the units of cm/s and microns respectively.

(7) the maximum longitudinal extent of the dredge-induced plume

$$x_r = uT$$
$$= 0.13 \times 2.24 \times 10^4$$
$$= 2.91 \times 10^3 \text{ m}$$

(8) $$t_d = \frac{z_o^2}{k_z} \Big/ \frac{x_r}{u} = \frac{z_o^2}{k_z} \Big/ T$$

$$= \frac{100^2}{10} \Big/ 2.24 \times 10^4$$

$$= 0.045$$

(9) $$t_s = \frac{k_z}{W^2} \Big/ \frac{x_r}{u} = \frac{k_z}{W^2} \Big/ T$$

$$= \frac{10}{0.01^2} \Big/ 2.24 \times 10^4$$

$$= 4.5$$

(10) $$t_B = \frac{B^2}{4k_y} \Big/ \frac{x_r}{u} = \frac{B^2}{4k_y} \Big/ T$$

$$= \frac{(6.1 \times 10^3)^2}{4 \times 10^5} \Big/ 2.24 \times 10^4 = 4.15 \times 10^{-3}$$

D. Application of the Model

(1) from figure A1(a) (or equation A1), with $t_s = 4.5$, $t_d = 0.045$

$$\frac{C_m}{Q/4\pi\sqrt{k_y k_z}\ x_r} = 0.9$$

$$\therefore\ C_m\ (x_r, z_o) = 0.9 \cdot \frac{Q}{4\pi\sqrt{k_y k_z} \cdot x_r}$$

$$Q = 8.34 \times 10^3 \text{ gm/sec}$$

$$k_y = 10^5 \text{ cm}^2\text{/sec}$$

$k_z = 10\ cm^2/sec$

$x_r = 2.91 \times 10^5\ cm$

$C_m(x_r, z_o) = 2.05\ z\ 10^{-6}\ gm/cm^3$

$= 2.05\ mg/l$

(2) Since $C_m(x,z_o)/C_m(x_r,z_o)$ is nearly independent of t_s for $t_s \geq 2.5$, use figure 4 (or equation (7)) for evaluating

$C_m^* = C_m(x,z_o)/C_m(x_r,z_o)$

$C_m(x,z_o) = 2.05 \cdot C_m^*\ mg/l$

e.g.

X	x(m)	C_m^*	C_m(mg/l)
0.01	29.1	30	61.5
0.1	291	10	20.5

(3) With $t_B = 0.0042$ and $t_s = 4.5$, use figure 9 (or equation (16)) to calculate M/kGD.

$kG \cdot (2D)^* = 1.0 \times 15 \times 305 = 4.58 \times 10^3\ mg/cm^2$

$= 4.58\ gm/cm^2$

e.g. Z = 0

Y	y(m)	M/kGD	M(gm/cm^2)
1.0	61 m	30×10^{-3}	0.137
5	305	9×10^{-3}	0.041
10	610 m	3×10^{-3}	0.014

*The factor 2 is introduced because the dredging operation required two cuts each with dredging thickness of 1.52 m.

II. Maintenance Dredge in the Hampton Roads

A. Input Information

(1) Specification of dredging operations

channel width

$B = 800 \text{ ft} = 244 \text{ m} = 2.44 \times 10^4 \text{cm}$

dredging depth

$D = 5 \text{ ft} = 1.52 \text{ m} = 152 \text{ cm}$

(a) hydraulic dredge

swing speed of cutter head

$V = 0.67 \text{ ft/sec} = 0.2 \text{ m/sec}$

cutter head advance in each swing

$\delta = 6 \text{ ft} = 1.83 \text{ m}$

(b) bucket dredge

bucket volume

$\nabla = 3 \text{ m}^3$

dredging frequency

$f = 1/120 \text{ sec.}$

(2) Characteristics of sediments at channel bottom

mean particle size

$d = 6\mu = 6 \times 10^{-4} \text{ cm}$

variance

$s^2 = 70 \mu^2 = 70 \times 10^{-8} \text{ cm}^2$

the fraction of particles with diameter smaller than 74μ

$R_{74} > 0.999$

(3) Characteristics of ambient flow field

mean velocity

$u = 40 \text{ cm/sec}$

period of flood or ebb

$T = 2.24 \times 10^4 \text{ sec}$

vertical turbulent diffusion coefficient

$k_z = 10 \text{ cm}^2\text{/sec}$

lateral turbulent diffusion coefficient

$k_y = 10^5 \text{ cm}^2\text{/sec}$

water depth

$$h = 45 \text{ ft} = 13.7 \text{ m} = 1.37 \times 10^3 \text{ cm}$$

B. Calculation of Model Parameters

(1) Settling velocity of sediment particles

$$W = 9 \times 10^3 \ (d^2 + S^2) \text{ in cgs unit.}$$
$$= 9 \times 10^3 \ (36 \times 10^{-8} + 70 \times 10^{-8})$$
$$= 10^{-2} \text{ cm/sec}$$

(2) Particle size with critical resuspension velocity equals ambient velocity, 40 cm/sec

$$d_c = V_c{}^2/0.783^2 \text{ (eqn. of Camp et al.)}$$
$$= 40^2/0.783^2 = 2.6 \times 10^3 \ \mu$$

(3) The fraction of particles with diameter smaller than d_c.

$$R_o = 1.0$$

(4) The particle size distribution factor

$$k = R_o/R_{74} = 1.0$$

(5) The turbidity generation unit

(a) hydraulic dredge

$$G = 30 \text{ kg/m}^3$$

(b) bucket dredge

$$G = 100 \text{ kg/m}^3$$

Note: the high values reported by Nakai (1979) are used for the sake of conservative assumption

(6) Source strength of suspended solids

(a) hydraulic dredge

$$Q = kGD\delta V$$
$$= 1.0 \times 30 \times 1.52 \times 1.83 \times 0.2$$
$$= 16.7 \text{ kg/sec} = 1.67 \times 10^4 \text{ gm/sec}$$

(b) bucket dredge

$$Q = kG\nabla f = 1.0 \times 100 \times 3/120 = 2.5 \text{ kg/sec}$$

(7) The maximum longitudinal extent of the dredge-induced plume

$$x_r = uT$$
$$= 0.4 \times 2.24 \times 10^4$$
$$= 8.96 \times 10^3 \text{ m}$$

(8)

(a) hydraulic dredge

$$t_d = \frac{z_o^{\;2}}{k_z} \Big/ T$$
$$= \frac{100^2}{10} \Big/ 2.24 \times 10^4 \quad \text{if } z_o = 1 \text{ m}$$
$$= 0.045$$

(b) bucket dredge

$$t_h = \frac{h^2}{k_z} \Big/ T$$
$$= \frac{(1.37 \times 100)^2}{10} \Big/ 2.24 \times 10^4$$
$$= 8.45$$

(9) $t_s = \frac{k_z}{W^2} \Big/ T$

$$= \frac{10}{0.01^2} \Big/ 2.24 \times 10^4$$
$$= 4.5$$

(10) $t_B = \frac{B^2}{4k_y} \Big/ T$

$$= \frac{(2.44 \times 10^4)^2}{4 \times 10^5} \Big/ 2.24 \times 10^4$$
$$= 6.65 \times 10^{-2}$$

C. Application of the Model for Hydraulic Dredge

(1) Calculate concentration at plume front. From figure A1(b) (or equation A1), with $t_s = 4.5$, $t_d = 0.045$ (i.e. 1 meter above bottom, $z_o = 1$ m)

$$\frac{C_m}{Q/4\pi\sqrt{k_y k_z}\; x_r} = 0.9$$

$$\therefore\; C_m(x_r, z_o) = 0.9 \cdot \frac{Q}{4\pi\sqrt{k_y k_z}\; x_r}$$

$Q = 1.67 \times 10^4$ gm/sec

$k_y = 10^5$ cm^2/sec

$k_z = 10$ cm^2/sec

$x_r = 8.96 \times 10^5$ cm

$$C_m(x_r, z_o) = 1.33 \times 10^{-6}\ \text{gm/cm}^3 = 1.33\ \text{mg/l}$$

(2) Calculate near bottom ($z_o = 1$m) concentration along plume axis as function of distance from the dredge. Since $C_m(x,z_o)/C_m(x_r,z_o)$ is nearly independent of t_s for $t_s \geq 2.5$, use figure 4 (or equation (7)) for evaluating C_m^*

$$C_m^* = C_m(x,z_o)/C_m(x_r,z_o)$$

$$\therefore\; C_m(x,z_o) = C_m^* \cdot C_m(x_r,z_o) = 1.33\ C_m^*$$

e.g.

X	x(m)	C_m^*	C_m(mg/l)
0.01	89.6	30	40
0.1	896	10	13.3

(3) With $t_B = 0.0665$ and $t_s = 4.5$, use figure 10 (or equation (16)) to calculate M/kGD

$$kGD = 1.0 \times 30 \times 152 = 4.56 \times 10^3 \text{ mg/cm}^2$$
$$= 4.56 \text{ gm/cm}^2$$

e.g.

Y	y(m)	M/kGD	M(gm/cm^2)
0.5	122	67×10^{-3}	0.31
1.0	244	40×10^{-3}	0.18
5.0	1220	3×10^{-3}	0.014

D. Application of the Model for Bucket Dredge

(1) Calculate surface concentration at the plume front

$z_o = 13.7$ m

$Z = 1.0$

from figure A2 (or equation A2), with

$t_s = 4.5$, $t_h = 8.45$

$$\frac{C_m(x_r, z_o)}{Q/4h\sqrt{\pi k_y u x_r}} = 0.75$$

with

$Q = 2.5 \times 10^3$ gm/sec

$h = 1.37 \times 10^3$ cm

$k_y = 10^5$ cm^2/sec

$u = 40$ cm/sec

$x_r = 8.96 \times 10^5$ cm

$C_m(x_r, z_o) = 1.02 \times 10^{-7}$ gm/cm^3 = 0.102 mg/l

(2) Calculate surface concentration along plume axis as function of distance from the dredge. With $t_s = 4.5$, $t_h = 8.45$, $Z = 1.0$, figure 17 (or eqn. (19)) is used to evaluate C_m^*.

$$C_m^* = C_m(x,z_o)/C_m(x_r,z_o)$$

$$\therefore C_m(x,z_o) = C_m^* \cdot C_m(x_r,z_o)$$
$$= 0.102\ C_m^*$$

e.g.

X	x(m)	C_m^*	C_m(mg/l)
0.01	89.6	15	1.52
0.1	896	5	0.51
0.5	4480	1.3	0.13

(3) With $t_B = 0.0665$, $t_s = 4.5$, $t_h = 8.45$, use figures 26,27 (or eqn. (23)) to calculate M/kGD.

$$kGD = 1.0 \times 100 \times 152 = 1.52 \times 10^4 \text{ mg/cm}^2$$
$$= 15.2 \text{ gm/cm}^2$$

e.g. Z = 0

Y	y(m)	M/kGD	M(gm/cm^2)
0.5	122	0.045	0.68
1.0	244	0.037	0.56
5.0	1220	0.004	0.061

III. Bucket Dredge in Small Creek

A. Input Information

(1) Specification of dredging operations

channel width

$B = 50 \text{ ft} = 15.2 \text{ m}$

dredging depth

$D = 1 \text{ m}$

bucket volume

$\nabla = 1 \text{ m}^3$

dredging frequency

$f = 1/60 \text{ sec.}$

(2) Characteristics of sediments at channel bottom

mean particle size

$d = 6\mu = 6 \times 10^{-4} \text{ cm}$

variance

$s^2 = 70\mu^2 = 70 \times 10^{-8} \text{ cm}^2$

the fraction of particles with diameter smaller than 74μ

$R_{74} > 0.999$

(3) Characteristics of ambient flow field

mean velocity

$u = 5 \text{ cm/sec}$

period of flood or ebb

$T = 2.24 \times 10^4 \text{ sec}$

vertical turbulent diffusion coefficient

$k_z = 2 \text{ cm}^2/\text{sec}$

lateral turbulent diffusion coefficient

$k_y = 10^4 \text{cm}^2/\text{sec}$

water depth

$h = 1 \text{ m} = 100 \text{ cm}$

B. Calculation of Model Parameters

(1) Settling velocity of sediment particles

$$W = 9 \times 10^3 \, (d^2 + s^2) \text{ in cgs unit}$$
$$= 9 \times 10^3 \, (36 \times 10^{-8} + 70 \times 10^{-8})$$
$$= 0.01 \text{ cm/sec}$$

(2) Particle size with critical resuspension velocity equals ambient velocity, V_c = 5 cm/sec

$$d_c = (V_c/0.00128)^{\frac{1}{2}} \quad \text{(eqn. of Ingersol)}$$
$$= (5/0.00128)^{\frac{1}{2}}$$
$$= 62.5\mu$$

(3) The fraction of particles with diameter smaller than d_c

$$R_o = 0.90$$

determined from particle size analysis of bottom

(4) The particle size distribution factor

$$k = R_o/R_{74}$$
$$= 0.90$$

(5) The turbidity generation unit

$$G = 100 \text{ km/m}^3$$

Note: The high value reported by Nakai (1979) is used for the sake of conservative assumption

(6) Source strength of suspended solids

$$Q = kG\nabla f$$
$$= 0.90 \times 100 \times 1 \times 1/60 = 1.5 \text{ kg/sec}$$

(7) The maximum longitudinal extent of the dredge-induced plume

$$x_r = uT$$
$$= 5 \times 2.24 \times 10^4$$
$$= 1.12 \times 10^5 \text{ cm} = 1120 \text{ m}$$

(8)

$$t_h = \frac{h^2}{k_z} \Big/ T$$

$$= \frac{100^2}{2} \Big/ 2.24 \times 10^4$$

$$= 0.22$$

(9)

$$t_s = \frac{k_z}{W^2} \Big/ T$$

$$= \frac{2}{(0.01)^2} \Big/ 2.24 \times 10^4$$

$$= 0.9$$

(10)

$$t_B = \frac{B^2}{4k_y} \Big/ T$$

$$= \frac{(1520)^2}{4 \times 10^4} \Big/ 2.24 \times 10^4$$

$$= 0.0026$$

C. Application of the Model

(1) Calculate surface concentration at the plume front

$z_o = 100$ cm

$Z = 1.0$

from figure A2(b) (or equation A2), with

$t_s = 0.9$, $t_h = 0.22$

$$\frac{C_m(x_r, z_o)}{Q/4h\sqrt{\pi k_y u x_r}} = 0.15$$

$$C_m(x_r, z_o) = 0.15 \cdot \frac{Q}{4h\sqrt{\pi k_y u x_r}}$$

with

$Q = 1.5 \times 10^3$ gm/sec

$h = 100$ cm

$k_y = 10^4$ cm^2/sec

$u = 5$ cm/sec

$x_r = 1.12 \times 10^5$ cm

$C_m(x_r, z_o) = 4.25 \times 10^{-6}$ gm/cm^3 = 4.25 mg/l

(2) Calculate surface concentration along plume axis as function of distance from the dredge. With $t_s = 0.9$, $t_h = 0.22$, $Z = 1.0$, eqn. (19) is used to evaluate C_m^*

$$C_m^* = C_m(x, z_o)/C_m(x_r, z_o)$$

$$\therefore C_m(x, z_o) = C_m^* \cdot C_m(x_r, z_o)$$
$$= 4.25\, C_m^*$$

e.g.

X	x(m)	C_m^*	C_m(mg/l)
0.01	11.2	35	149
0.1	112	10	42.5

(3) With $t_B = 0.0026$, $t_s = 0.9$, $t_h = 0.22$, equation (23) is used to calculate M/kGD

$$kGD = 0.90 \times 100 \times 100$$
$$= 9 \times 10^3 \text{ mg/cm}^2$$
$$= 9 \text{ gm/cm}^2$$

e.g. $Z = 0$

Y	y(m)	M/kGD	M(gm/cm^2)
0.5	7.6	3×10^{-2}	0.27
5	76	1.8×10^{-2}	0.16

Suspended Sediment Experiment and Model Calibration

by

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Suspended Sediment Experiment and Model Calibration

In order to examine the plume from a dredging operation both to calibrate the model and to characterize the plume from field data, an experiment was conducted in September 1978 in the Elizabeth River to measure the extent of the plume resulting from hydraulic maintenance dredging of a ship channel. This experiment used a fluorometer operated as a nephelometer sampling continuously at a depth of about 1 meter from the bottom, or at mid-depth. The channel is maintained at 50 ft., with the surrounding bottom about 20 feet. The fluorometer was towed through the plume in various patterns in order to obtain the plume shape. The tracks of the tows are shown in Appendix 1 as are the associated suspended sediment data. In all cases, the tidal flow in the Elizabeth River was towards the north or the south. Also, the positions of the plume are all relative to the observed central position of the cutter head for the dredge, the source for the sediment plume. During the tests, the dredge was operating in the main channel of the reach opposite the Craney Island landfill area. The values of suspended sediment concentration are calculated from the measured light transmission by an empirical calibration from samples obtained during the data runs. These values are also shown in the appendix for the tracks. The set of runs encompasses most of the tidal cycle, from late flood through high slack, ebb, and low slack water. The early and full flood phases are not sampled, but in the Elizabeth River, they may be plausibly expected to be similar to their ebb counterparts.

The model of the plume presented elsewhere in this report (Kuo and Lukens, 1981) describes a nearly steady plume from a constant point source which is generated at the bottom of the channel and never reaches the surface. In actuality, the plume is generated by an oscillating and moving source, the cutter head of the dredge incising a notch with a cross-section of 30 ft^2 for a length of 200 feet in a period of 5 minutes. The non-random currents and finite size of the cutter head are not well modeled by a point source model in some near field region, but this discrepancy is expected to be reduced rapidly outside of the immediate vicinity of the cutter head. The sweep produces a series of diagonal intermittent plumes rather than a steady state plume. The angle of the diagonal plume axis relative to the stream lines in the case studied was less than 45^o except near slack tides, so the axial model is applicable except near the source at slack water. Because the model does not consider longitudinal dispersion, the intermittent nature of the actual plume is not a serious drawback to model application, although experimental data showing an absence or great reduction of the plume may be expected. Finally, the along-axis section made at mid-depth (25 feet, track 2 on 9/28/78) failed to detect any suspended sediment above the ambient level (20 mg/l). Thus from a qualitative standpoint, the model is generally applicable to the generated plumes provided that the intermittent nature near the endpoints of the swings are considered in the analyses of observations. The qualitative data which do not support the model description are particularly high values of sediment found near the dredge head near slack tide (9/19/80 track 3) and isolated peaks within 400 feet of the source during high currents (9/7/78 track 7). These occurrences may serve to define a near field region of about 400 feet from the dredge head, particularly near slack water, where anomalously high values of sediment may be found within the sediment plume. Apart from these exceptions, the model seems qualitatively applicable to the data.

The calibration of the model starts from equation 7, repeated here for reference

$$C_m^* \ (X) = \frac{1}{X} \exp \left[- \frac{1}{4} \left\{ t_d \left(\frac{1}{X} - 1 \right) + \frac{1}{t_s} \ (X-1) \right\} \right] \tag{7}$$

A new time scale, t_w, is introduced as the ratio of the settling time to the horizontal advection time for the purpose of calibration.

$$t_w = \frac{z_o}{w} \cdot \frac{u}{x_r}$$

With this definition, we have

$t_s = t_w^2 / t_d$, and equation (7) becomes

$$C_m^* \ (X) = \frac{1}{X} \exp \left[- \frac{1}{4} \ t_d \left\{ \left(\frac{1}{X} - 1 \right) + \frac{1}{t_w^2} \ (X-1) \right\} \right] \tag{1}$$

In this form, the calibration task is seen to be the determination of estimates for t_w and t_d from measurements of concentration and distance from the source (X). To this end, it is convenient to transform equation (X.1) to the form

$$\frac{X}{(1-X)} \ \ln \ (X \ C_m^*) = \frac{1}{4} \ \frac{t_d}{t_w^2} \left(X - t_w^2 \right) \tag{2}$$

In this form, the left hand side consists entirely of values which can be calculated from observations, and the right hand side has the form of a straight line with X intercept at $X = t_w^2$. The slope of the line is related to t_w and t_d in the same way that t_s is, and can be expressed as 1/4 t_s. A calibration procedure which is suggested by this form is to transform the data into the left hand side, fit a straight line by regression to the points, and evaluate the parameters on the right hand side from the equation for the line.

Before this procedure can be followed, a further scaling is required because C_m^* is a ratio of observed excess sediment concentration to a reference value, chosen in the theory to be the value at the full extent of the plume. In practice, such a value can be observed only at slack tide, for the plume is fully developed only then. In addition, the excess value of sediment concentration at that location may be below the detection threshold. These two difficulties may be overcome by defining, for the purpose of calibration, a new advective distance scale $x_B = \alpha x_r$ such that the level of suspended sediment at x_B is easily detectable. The corresponding non-dimensional scale of distance is $X' = x/x_B$, and the corresponding derived parameters become t_d' and t_w'. After these are determined, the unprimed values are evaluated as $t_w = \alpha t_d'$. The equations used in evaluating the calibration data are presented in table 1.

For the particular calibration calculations, the tracks listed in the appendix were plotted on a common distance scale,

Table 1. Equations Used in Model Calibration and Interpretation for the Sediment Plume Study

Symbol	Units	General Formula	Formula Applied to Elizabeth River
$\bar{u}$	ft/min	$\frac{\Delta H/\Delta t}{\overline{\Delta H/\Delta t}} \times \bar{u}_m \times 60$	$5.57 \times 10^3 \times \Delta H/\Delta t \times u_p$
x_r	ft	$x_r = \bar{u}\,T$	$x_r = 5903 \times R$
x_B	ft	chosen from data	chosen from data
C_B	mg/liter	chosen from data	chosen from data
α	1	x_B/x_r	x_B/x_r
t_w'	1	$t_w' = \sqrt{X_o}$	$t_w' = \sqrt{X_o'}$
t_w	1	$t_w = \alpha t_w'$	$t_w = \alpha t_w'$
t_d'	1	$t_d' = 4mX_o'$	$t_d = 4mX_o'$
t_d	1	$t_d = \alpha t_d'$	$t_d = \alpha t_d'$
t_s	1	$t_s = \frac{1}{4m}$	$t_s = \frac{1}{4m}$
W	cm/sec	$W = \frac{z_o}{t_w} \frac{1}{60\,T}$	$W = \frac{1.67}{t_w\,T}$
C_m^*	1	$C_m^{*'} = \frac{C_m}{C_B}$	$C_m^{*'} = C_m/C_B$
k_z	cm^2/sec	$k_z = \frac{1}{60\,T} \frac{z_o^2}{t_d}$	$k_z = \frac{166.7}{t_d\,T}$
X'	1	x/x_B	x/x_B
a	microns	$a = 111\,W^{1/2}$ @ $20^{o}C$ for a sediment particle of specific gravity 2.5	$a = 111\,W^{1/2}$

Table 1 (Cont'd)

Symbol	Definitions
T	Period, in minutes, of rising or falling tide during observations from tide gauge or tables.
R	Range, in feet, of tide rise or fall for tidal half cycle during which observations were taken from tide gauge or tables.
x	Distance of a given observation, in feet, from the source in the downstream direction.
u_p	Peak speed in a given locality for mean tide as given by Cerco and Kuo (unpublished ms.).
$\bar{u}$	Mean speed over tidal phase during which observations were obtained.
$\bar{u}_m$	Mean speed over a mean tidal phase.
C_m	A maximum measured value of sediment concentration in an approximately transverse section of the plume.
X'_o	The horizontal intercept of the line fitted to the data.
m	The slope of the straight line fitted to the data.
x_B	The base distance, in feet, chosen from the data to represent the advective extent of the easily detectable part of the plume.
C_B	The sediment concentration, in mg/liter, inferred or measured at x_B.
z_o	Height, in meters, of the observations over the bottom.
a	Diameter of a representative sediment grain.
ΔH	Difference in height from high to low (or low to high) tide in feet.
Δt	Time span, in minutes, between successive tidal height extrema.

Table 2. Plume Axis Estimates for Calibration

Day	Track	Maximum Concentration	Background Value	Distance from Source	X'	C_m	$\frac{X'}{1-X'} \ln (X' C_m^*)$	C_m^*
9/7/78	1	54	27	260		27		
9/7/78	2	46	26	200		20		
9/7/78	3	103	(27)	50		76		
9/7/78	4	51	30	200		21		
9/7/78	5	30	25	200		5		
9/7/78	6	73	35	220	.22	38	-.246	1.90
9/7/78	7	90	27	320	.32	63	+.004	3.15
9/7/78	8	80	24	440	.44	56	+.164	2.80
9/7/78	8	69	24	460	.46	45	+.029	2.25
9/7/78	9	60	33	870	.87	27	+1.076	1.35
9/7/78	10	44	34	1130	1.13	10	+4.963	0.50
9/7/78	11	44	34	1230	1.23	10	+2.600	0.50
9/19/78	1	86	17	115	.575	69	1.41	4.93
9/19/78	1	73	17	160	.800	56	4.65	4.00
9/19/78	1	31	17	220	1.100	14	-1.05	1.00
9/19/78	2	114	38	110	.22	76	-.309	1.52
9/19/78	2	114	38	160	.32	76	-.339	1.52
9/19/78	2	121	38	360	.72	83	+.459	1.66
9/19/78	2	46	38	680	1.36	8	+5.76	0.16

Table 2 (Cont'd)

Day	Track	Maximum Concentration	Background Value	Distance from Source	X'	C_m	$\frac{X'}{1-X'}$, $\ln(X'C_m^*)$	C_m^*
9/19/78	3	181	24	60	.300	157	+0.520	11.21
no	3	49	24	130	.650	25	-3.50	1.79
parabola	3	38	24	200	1.00	14	-0.189	1.00
9/19/78	5	65	22	60	-	43		-
9/26/78	2(I)	40	9	230	.575	31	1.209	4.25
9/26/78	2(I)	22	9	360	.90	13	3.449	1.63
9/26/78	2(I)	18	9	390	.975	9	3.779	1.13
9/26/78	2(II)	40	9	230	.288	31	-0.417	1.24
9/26/78	2(II)	37	9	700	.875	26	-0.660	1.04
9/26/78	2(II)	32	9	880	1.100	23	-0.131	0.92
9/28/78	No clear interpretation							

Table 3. Calibration Calculated Values

						I	II
Date	9/7/78	9/7/78	9/19/78	9/19/78	9/19/78	9/26/78	9/26/78
Plume	1	2	1	2	3	1	1
Tidal Phase	late flood	full ebb	early ebb	late ebb	late ebb	low slack	low slack
T	384	375	379	379	379	365	365
R	2.8	-2.6	3.3	3.3	3.3	-2.0	-2.0
$\frac{\Delta H}{\Delta t}$	7.3×10^{-3}	-6.9×10^{-3}	-8.7×10^{-3}	-8.7×10^{-3}	-8.7×10^{-3}	-5.5×10^{-3}	-5.5×10^{-3}
x_r	16549	-15276	-19480	-19480	-19480	-11806	-11806
x_B	Failed	-1000	200	500	200	-400	-800
C_B		20	14	50	14	8	25
α		.065	.0103	.0257	.0103	.0339	.0678
X'_o		.340	Failed	.355	Failed	.383	Failed
m		2.6-4.7		4.15		6.6	
t_w'		.583		.596		.619	
t_w		.038		.015		.021	
t_d'		3.5-6.4		5.89		10.11	
t_d		.230-.415		.151		.343	
t_s		.0035-.0063		.0015		.0013	
W		.117		.293		.217	
a		38		60		52	
k_z		1.08-1.95		2.90		1.36	

based on linear interpolation between listed positions. Values of sediment concentrations for plume peaks and background were then obtained from these graphs. These values are given in table 2. The peak concentration values were plotted versus distance and an "eyeball" line was used to estimate the general shape of the plume. A value for the reference distance (x_B) and concentration (C_B) were then read from the line. These values were used to compute the relevant model parameters with results shown in table 3. In this table, the notation "failed" indicates those cases for which the correlation of the points from the data was clearly low or the line sloped downwards instead of upwards.

Interpretation of the calibration results consists of examining the reasons for the "failed" data and comparing particle sizes and vertical diffusivities corresponding to the model parameters chosen to other published values. The earliest data set for which the calibration failed was the first plume on 9/7/78. In this instance, the three estimates of C_m at a single distance, 200 feet, prevented the analysis from being stable, so the failure can be assigned to sampling strategy rather than properties of the plume. The data for plumes 1 and 3 on 9/19/78 also failed. In the first case, the correlation was low. As in all but one of the failed cases, the plume was not found further than 250 feet from the source, because it had already dispersed, because the survey did not happen to cross it, or because the dredge operation was not producing a detectable plume at the time of sampling or during the preceeding 20 minutes. Plume numbers of 9/19/78 also failed, and this is of particular interest because it produced the highest measured suspended sediment concentrations (>180 mg/liter) for the entire study. Such large maxima were never found far from the dredge head, and near the head the operation must appear as a distributed source rather than the point source assumed in the model formulation. Thus, we can estimate that the near field region, for which the point source theory is not expected to describe the plume extends about 300 feet from the dredge head. The final failure concerns the second interpretation of the data from 9/26/78. If we choose the first interpretation, which fits the data, there are two unexplained peaks of sediment concentration downstream from the dredge head, at distances of 700 and 880 feet from the head. These peaks could be attributed to earlier dredging at a different source strength or to extraneous sources, such as the passage of vessels down the channel.

Particle diameter (a) and coefficient of vertical diffusivity (k_z) are related to the non-dimensional times used in the analysis, t_w and t_d, respectively through formulas listed in Table 1. Some insight into the effectiveness of the model and its calibration can be gained by comparing the calibration-derived values of particle diameter and vertical diffusivity to other estimates from other studies.

The particle diameters obtained from the calibration analyses ranged between 38 and 60 microns. These sizes are in accordance with the "type B" sediments of Nichols (1972), who noted that sediments in the James River of type B were found in the lower estuary both on the shoals and on the channel floor, where tidal current peaks reached 30 cm/sec. Because the tidal currents in the lower Elizabeth River near the bottom reach 30 cm/sec and because the Elizabeth River is directly connected to the main channel of the lower James River, the model results appear to be consistent with the previous work. On the other hand, samples taken from the general area subsequent to the dredging have a mean diameter of only 6 microns, with a variance of 70 microns^2. The discrepancy between these numbers could be ascribed to any or a combination of several sources, including a substantial variability of the sediments within that reach of the river, differences in laboratory techniques used in the various size measurements and the response of the model calibration procedure to a heterogeneous mix of sediment sizes.

Values of the coefficient of vertical diffusivity, where such a formulation is used to depict vertical transfer of material in a fluid with turbulent fluctuations, range over a wide range of values. Kullenberg (1971), measuring the vertical and horizontal growth of dye patches in a shallow part of the Kategat, reported values of k_z ranging from .05 to 110 cm^2/sec. The values were strongly related to the degree of vertical stratification in the water column, higher stratifications inhibiting the vertical mixing. In the James River, Pritchard (1967) estimated values of k_z which ranged from 0 at the surface and bottom, due to the analysis method, to a pair of peak values of 5 and 9 cm^2/sec. At a distance of 1 meter from the bottom, the value is slightly greater than 1 cm^2/sec. In view of the wide range of values found in the Kategat, the range of values found in the calibration study, 1.08 to 2.90 cm^2/sec, appears to agree well with the available previous data.

With these results, the model, which before had been shown to be in accord with the field data in a qualitative sense outside of a near field region of about 300 feet, seems to give results in the process of calibration which are quantitatively consistent with other studies in the study area. This agreement serves as a verification of the model formulation.

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Appendix 1

SUSPENDED SEDIMENT DATA

Position Data

Date-Track	Time	Location(ft) N/S	E/W	Time Relative to High(H) or Low(L) Water	Tidal Phase
9/7/78-1	1032.40	-95S	0	L + 4:53	Late
	1034.81	-150S	0	H - 1:29	Flood
	1039.31	-200S	0		
	1042.60	-250S	0		
	1045.52	-300S	0		
	1047.67	-350S	0		
9/7/78-2	1202.50	-200S	400E	H - 0:00	High
	1211.00	-200S	-450W		Slack
9/7/78-3	1215.70	-50S	260E	H + 0:12	High
	1217.11	-50S	0		Slack
	1219.21	-50S	-250W		
9/7/78-4	1233.67	-80S	0	H + 0:30	High
	1240.18	-1000S	0		Slack
9/7/78-5	1306.70	-40S	0	H + 1:04	High
	1308.83	-400S	0	L - 5:11	Slack
9/7/78-6	1607.16	220N	-80W	H + 4:04	
	1607.90	220N	0	L - 2:11	Full
	1608.62	220N	200E		Ebb
9/7/78-7	1608.62	220N	200E		
	1611.51	400N	-300W		
9/7/78-8	1611.51	400N	-300W		
	1613.71	420N	-80W		
	1615.22	500N	300E		
9/7/78-9	1615.22	500N	300E		
	1618.70	1100N	-100W		
9/7/78-10	1618.70	1100N	-100W	H + 4:16	
	1620.90	1300N	300E	L - 1:59	
9/19/78-1	1303.87	0	0	H + 2:14	
	1304.20	100N	0	L - 4:03	Early
	1305.96	300N	0		Ebb
	1306.52	500N	0		
	1307.20	700N	0		
	1307.78	900N	0		

Appendix 1 - Position Data (Cont'd)

Date-Track	Time	Location(ft) N/S	Location(ft) E/W	Time Relative to High(H) or Low(L) Water	Tidal Phase
9/19/78-2	1540.35	0	0	H + 4:51	
	1541.22	200N	0	L - 1:26	Late
	1542.11	400N	0		Ebb
	1543.00	600N	0		
	1543.83	800N	0		
	1545.01	990N	0		
9/19/78-3	1552.01	1000N	0	H + 5:03	Late
	1553.79	800N	0	L - 1:15	Ebb
	1554.82	600N	0		
	1555.97	400N	0		
	1556.92	200N	0		
	1558.81	50N	0		
	1559.02	0	0		
9/19/78-4	1607.20	-200S	0	H + 6:17	Late
	1608.14	0	0	L - 1:00	Ebb
	1608.89	200N	0		
9/19/78-5	1609.60	200N	0	H + 6:20	Late
	1611.22	0	0	L - 0:58	Ebb
	1612.34	-200S	0		
9/26/78-1	1042.01	1000N	0	L + 0:13	Low
	1044:21	800N	0	H - 6:03	Slack
	1046.40	600N	0		
	1047.90	400N	0		
	1050.17	200N	0		
	1050.93	0	0		
	1052.05	-200S	0		
9/28/78-1	1144.60	800N	0	H + 5:33	Low
	1148.21	600N	0	L - 0:29	Slack
	1152.10	400N	0		
	1155.25	200N	0		
	1158.01	0	0		
	1200.81	-200S	0		
	1203.52	-400S	0		
9/26/78-2	1104.02	0	0	L + 0:35	Low
	1104.72	200N	0	H - 5:47	Slack
	1106.82	400N	0		
	1108.01	600N	0		
	1109.60	800N	0		
	1111.24	1000N	0		

Appendix 1 - Position Data (Cont'd)

Date-Track	Time	Location(ft) N/S	E/W	Time Relative to High(H) or Low(L) Water	Tidal Phase
9/26/78-3	1749.11	1000N	0	H + 0:58	High
	1750.30	800N	0	L - 5:27	Slack
	1751.82	600N	0		
	1753.11	400N	0		
	1755.13	200N	0		
	1756.40	0	0		
	1757.80	-200S	0		
	1758.90	-400S	0		
	1800.00	-600S	0		
	1801.63	-800S	0		
9/28/78-2	1210.80	-400S	0	H + 5:59	Low
25 ft.	1212.29	-200S	0	L - 0:06	Slack
	1213.86	0	0		
	1215.68	200N	0		
	1217.05	400N	0		
	1218.69	600N	0		
	1219.97	800N	0		
9/28/78-3	1226.60	800N	-200W		
	1229.01	800N	+200E		
9/28/78-4	1231.13	600N	200E		
	1238.31	600N	-200W		
9/28/78-5	1303.10	400N	-200W		
	1305.13	400N	200E		
9/28/78-6	1306.66	200N	300E		
	1316.00	200N	-300W		
9/28/78-7	1320.80	200N	-300W		
25 ft.	1324.11	200N	300E		
9/28/78-8	1327.57	600N	300E	L + 1:11	
25 ft.	1335.40	600N	-300W	H - 5:02	
9/28/78-9	1736.50	200N	0	L + 5:20	Late
	1739.55	-200S	0	H - 0:53	Flood
	1740.75	-400S	0		

Suspended Sediment Data
9/7/78 Track 1
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1032.40	32	-95 S	0	1033.42	36			1034.46	31		
1032.42	32			1033.45	37			1034.49	31		
1032.45	31			1033.49	37			1034.52	30		
1032.48	30			1033.51	38			1034.54	30		
1032.51	30			1033.54	38			1034.57	30		
1032.54	30			1033.56	38			1034.61	30		
1032.56	30			1033.59	38			1034.64	30		
1032.59	29			1033.61	38			1034.67	30		
1032.62	29			1033.64	38			1034.69	30		
1032.64	29			1033.67	39			1034.72	30		
1032.67	29			1033.69	39			1034.74	30		
1032.69	28			1033.72	39			1034.77	31		
1032.72	28			1033.75	40			1034.81	31	-150 S	0
1032.75	28			1033.77	40			1034.83	31		
1032.77	27			1033.81	40			1034.86	32		
1032.81	27			1033.83	40			1034.89	32		
1032.84	28			1033.86	38			1034.91	32		
1032.86	28			1033.89	38			1034.94	32		
1032.89	30			1033.91	36			1034.96	33		
1032.91	31			1033.94	36			1034.99	33		
1032.94	32			1033.96	35			1035.02	33		
1032.96	34			1033.99	34			1035.04	33		
1032.99	35			1034.01	33			1035.07	33		
1033.01	36			1034.04	32			1035.10	33		
1033.04	38			1034.07	32			1035.14	33		
1033.06	38			1034.09	32			1035.17	32		
1033.09	39			1034.12	32			1035.19	32		
1033.11	40			1034.14	32			1035.22	31		
1033.14	40			1034.17	32			1035.24	31		
1033.17	40			1034.19	32			1035.27	30		
1033.21	39			1034.23	32			1035.29	29		
1033.24	38			1034.26	32			1035.32	28		
1033.27	38			1034.29	32			1035.34	28		
1033.29	37			1034.31	31			1035.37	28		
1033.32	37			1034.34	31			1035.41	27		
1033.34	36			1034.38	31			1035.44	27		
1033.37	36			1034.41	31			1035.46	27		
1033.39	36			1034.43	31			1035.49	26		

Suspended Sediment Data
9/7/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1035.51	26			1036.49	35			1037.47	47		
1035.54	26			1036.52	36			1037.51	47		
1035.56	26			1036.54	37			1037.53	47		
1035.59	25			1036.57	37			1037.56	47		
1035.61	25			1036.60	38			1037.61	47		
1035.64	24			1036.63	38			1037.64	47		
1035.66	24			1036.66	37			1037.66	47		
1035.69	24			1036.68	37			1037.69	47		
1035.72	24			1036.71	37			1037.71	47		
1035.74	23			1036.74	37			1037.74	47		
1035.77	23			1036.77	38			1037.76	46		
1035.79	23			1036.79	39			1037.79	46		
1035.82	23			1036.82	41			1037.82	46		
1035.84	23			1036.84	43			1037.86	46		
1035.87	23			1036.87	45			1037.89	45		
1035.89	23			1036.89	46			1037.91	45		
1035.92	24			1036.92	46			1037.94	44		
1035.94	25			1036.94	46			1037.97	43		
1035.97	26			1036.97	46			1037.99	42		
1035.99	27			1036.99	45			1038.02	41		
1036.02	28			1037.02	44			1038.04	40		
1036.04	31			1037.04	43			1038.07	38		
1036.07	33			1037.07	43			1038.09	37		
1036.09	34			1037.09	43			1038.12	36		
1036.12	36			1037.12	43			1038.14	35		
1036.14	38			1037.14	44			1038.17	34		
1036.17	39			1037.17	45			1038.19	33		
1036.19	39			1037.19	46			1038.22	32		
1036.22	39			1037.22	46			1038.24	32		
1036.25	38			1037.24	47			1038.29	32		
1036.27	38			1037.27	47			1038.31	33		
1036.30	37			1037.29	47			1038.34	34		
1036.32	36			1037.32	47			1038.36	35		
1036.35	35			1037.34	47			1038.39	36		
1036.37	34			1037.37	46			1038.41	37		
1036.40	34			1037.39	46			1038.44	38		
1036.44	34			1037.42	46			1038.46	39		
1036.46	34			1037.45	47			1038.49	39		

Suspended Sediment Data
9/7/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1038.51	40			1039.61	44			1040.79	51		
1038.54	40			1039.63	45			1040.81	51		
1038.56	40			1039.66	45			1040.84	51		
1038.59	40			1039.69	45			1040.86	51		
1038.61	40			1039.73	45			1040.89	51		
1038.64	40			1039.76	45			1040.92	51		
1038.67	40			1039.79	45			1040.94	51		
1038.69	40			1039.82	45			1040.97	52		
1038.72	41			1039.86	44			1040.99	52		
1038.76	41			1039.89	44			1041.06	52		
1038.78	41			1039.92	43			1041.09	51		
1038.81	41			1039.96	42			1041.12	51		
1038.84	41			1039.99	42			1041.15	51		
1038.87	41			1040.01	41			1041.18	51		
1038.90	41			1040.04	41			1041.21	51		
1038.92	41			1040.07	41			1041.24	51		
1038.95	41			1040.10	40			1041.26	51		
1038.99	41			1040.14	40			1041.29	51		
1039.01	41			1040.18	40			1041.33	51		
1039.05	40			1040.21	40			1041.37	52		
1039.08	40			1040.23	41			1041.39	52		
1039.11	40			1040.26	41			1041.42	52		
1039.13	41			1040.28	41			1041.45	52		
1039.16	41			1040.31	41			1041.47	52		
1039.19	41			1040.33	42			1041.50	52		
1039.22	42			1040.37	42			1041.52	52		
1039.25	42			1040.40	43			1041.56	51		
1039.29	42			1040.43	44			1041.58	51		
1039.31	42	-200 S	0	1040.46	46			1041.61	51		
1039.34	42			1040.49	47			1041.63	51		
1039.37	42			1040.52	48			1041.67	51		
1039.39	43			1040.54	49			1041.70	51		
1039.42	43			1040.57	50			1041.73	51		
1039.45	43			1040.60	50			1041.76	52		
1039.49	44			1040.66	50			1041.78	52		
1039.52	44			1040.69	50			1041.81	53		
1039.56	44			1040.73	50			1041.84	53		
1039.58	44			1040.76	50			1041.87	52		

Suspended Sediment Data
9/7/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1041.90	51		
1041.92	50		
1041.95	48		
1041.97	47		
1042.00	46		
1042.03	44		
1042.06	43		
1042.08	42		
1042.11	41		
1042.13	40		
1042.17	40		
1042.19	41		
1042.22	41		
1042.24	42		
1042.27	43		
1042.29	43		
1042.33	44		
1042.36	44		
1042.39	43		
1042.41	43		
1042.44	43		
1042.47	43		
1042.49	43		
1042.52	44		
1042.55	45		
1042.57	46		
1042.60	49	-250 S	0
1042.62	50		
1042.65	53		
1042.68	54		
1042.71	55		
1042.73	55		
1042.76	55		
1042.79	55		
1042.82	54		
1042.84	54		
1042.87	53		
1042.89	53		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1042.92	52		
1042.94	52		
1042.99	51		
1043.01	51		
1043.04	51		
1043.07	51		
1043.14	50		
1043.17	51		
1043.20	51		
1043.23	52		
1043.27	52		
1043.31	53		
1043.34	53		
1043.37	53		
1043.41	52		
1043.44	51		
1043.46	51		
1043.49	50		
1043.51	50		
1043.54	49		
1043.57	48		
1043.61	48		
1043.64	48		
1043.67	47		
1043.71	47		
1043.74	47		
1043.79	47		
1043.82	47		
1043.84	47		
1043.87	47		
1043.89	47		
1043.92	47		
1043.95	47		
1043.98	47		
1044.01	46		
1044.04	46		
1044.06	46		
1044.09	46		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1044.11	46		
1044.14	46		
1044.17	46		
1044.19	46		
1044.22	45		
1044.25	45		
1044.27	45		
1044.32	45		
1044.34	45		
1044.37	44		
1044.39	44		
1044.42	44		
1044.44	43		
1044.51	42		
1044.54	41		
1044.56	40		
1044.59	40		
1044.62	39		
1044.64	38		
1044.67	37		
1044.70	37		
1044.74	36		
1044.77	35		
1044.84	34		
1044.87	34		
1044.89	34		
1044.92	34		
1044.95	33		
1044.99	33		
1045.02	33		
1045.04	33		
1045.07	33		
1045.11	33		
1045.13	33		
1045.17	33		
1045.21	33		
1045.24	33		
1045.30	33		

Suspended Sediment Data
9/7/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1045.36	33		
1045.39	33		
1045.42	33		
1045.46	33		
1045.49	33		
1045.52	33	-300 S	0
1045.55	33		
1045.57	33		
1045.61	34		
1045.64	34		
1045.67	35		
1045.71	36		
1045.73	37		
1045.78	38		
1045.81	38		
1045.83	39		
1045.88	39		
1045.91	40		
1045.94	40		
1045.97	40		
1046.00	40		
1046.02	40		
1046.06	41		
1046.09	41		
1046.12	42		
1046.15	42		
1046.19	43		
1046.23	44		
1046.26	44		
1046.28	45		
1046.31	45		
1046.34	45		
1046.37	44		
1046.39	43		
1046.42	43		
1046.44	42		
1046.47	41		
1046.49	41		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1046.52	40		
1046.56	40		
1046.59	39		
1046.62	39		
1046.66	39		
1046.69	39		
1046.72	39		
1046.75	39		
1046.79	39		
1046.82	38		
1046.86	38		
1046.89	38		
1046.92	39		
1046.95	39		
1046.99	39		
1047.01	39		
1047.04	39		
1047.07	40		
1047.10	40		
1047.12	40		
1047.17	39		
1047.22	39		
1047.25	39		
1047.31	39		
1047.34	39		
1047.37	39		
1047.41	38		
1047.43	38		
1047.51	38		
1047.53	39		
1047.56	39		
1047.59	39		
1047.62	39		
1047.64	39		
1047.67	39	-350 S	0

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W

Suspended Sediment Data
9/7/78 Track 2
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1202.50	29	-200 S	400 E	1203.49	30			1204.52	29		
1202.50	29			1203.52	29			1204.55	29		
1202.53	28			1203.55	28			1204.57	29		
1202.57	28			1203.57	28			1204.60	29		
1202.57	28			1203.60	27			1204.62	29		
1202.59	28			1203.63	27			1204.67	29		
1202.62	28			1203.65	27			1204.70	29		
1202.65	28			1203.68	27			1204.73	29		
1202.68	28			1203.72	27			1204.76	29		
1202.69	28			1203.75	27			1204.80	29		
1202.71	28			1203.78	27			1204.82	29		
1202.75	28			1203.82	28			1204.85	28		
1202.77	28			1203.85	29			1204.87	28		
1202.80	28			1203.88	29			1204.88	28		
1202.82	28			1203.91	28			1204.91	29		
1202.85	27			1203.93	28			1204.93	29		
1202.87	27			1203.95	27			1204.95	29		
1202.90	27			1203.98	27			1204.97	29		
1202.93	27			1204.02	27			1205.00	29		
1202.96	27			1204.02	27			1205.02	29		
1203.00	28			1204.05	27			1205.05	29		
1203.03	27			1204.08	28			1205.07	29		
1203.06	27			1204.12	29			1205.07	29		
1203.08	27			1204.15	30			1205.10	28		
1203.12	28			1204.16	30			1205.12	28		
1203.15	28			1204.17	30			1205.16	28		
1203.18	28			1204.20	30			1205.18	28		
1203.22	29			1204.22	29			1205.20	28		
1203.25	29			1204.23	29			1205.22	28		
1203.27	29			1204.25	29			1205.24	28		
1203.30	29			1204.27	29			1205.25	28		
1203.34	29			1204.30	29			1205.27	28		
1203.37	28			1204.35	29			1205.30	28		
1203.38	28			1204.37	29			1205.33	28		
1203.39	28			1204.40	29			1205.36	28		
1203.42	29			1204.42	29			1205.40	29		
1203.45	30			1204.46	29			1205.43	29		
1203.47	30			1204.48	29			1205.48	29		

Suspended Sediment Data
9/7/78 Track 2 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1205.52	29		
1205.56	30		
1205.58	30		
1205.62	30		
1205.64	30		
1205.67	30		
1205.70	30		
1205.74	30		
1205.77	30		
1205.80	30		
1205.84	30		
1205.85	30		
1205.87	30		
1205.87	30		
1205.90	30		
1205.93	30		
1205.97	30		
1206.02	31		
1206.05	31		
1206.10	31		
1206.13	31		
1206.17	31		
1206.20	31		
1206.22	31		
1206.25	31		
1206.28	31		
1206.30	31		
1206.34	32		
1206.37	31		
1206.39	31		
1206.43	30		
1206.47	31		
1206.51	32		
1206.55	33		
1206.59	36		
1206.62	37		
1206.66	37		
1206.70	38		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1206.73	39		
1206.76	39		
1206.78	39		
1206.82	38		
1206.85	37		
1206.87	35		
1206.89	34		
1206.92	35		
1206.96	36		
1206.99	34		
1207.02	31		
1207.04	30		
1207.07	30		
1207.08	29		
1207.10	29		
1207.13	30		
1207.16	29		
1207.20	29		
1207.22	30		
1207.23	30		
1207.26	30		
1207.27	30		
1207.29	30		
1207.32	31		
1207.33	31		
1207.35	32		
1207.37	32		
1207.38	32		
1207.40	32		
1207.45	33		
1207.50	35		
1207.54	36		
1207.57	38		
1207.60	39		
1207.62	40		
1207.64	40		
1207.67	41		
1207.68	41		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1207.71	41		
1207.75	40		
1207.78	40		
1207.80	40		
1207.83	39		
1207.85	37		
1207.85	37		
1207.86	37		
1207.88	38		
1207.92	40		
1207.92	40		
1207.94	39		
1207.97	37		
1207.99	35		
1208.00	35		
1208.02	35		
1208.05	35		
1208.05	35		
1208.07	35		
1208.09	36		
1208.12	37		
1208.12	37		
1208.13	37		
1208.15	37		
1208.16	35		
1208.17	35		
1208.17	35		
1208.21	39		
1208.24	44		
1208.27	46		
1208.30	46		
1208.30	46		
1208.33	43		
1208.35	39		
1208.37	39		
1208.38	39		
1208.39	39		
1208.42	40		

Suspended Sediment Data
9/7/78 Track 2 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1208.44	38		
1208.47	38		
1208.48	38		
1208.51	38		
1208.54	40		
1208.57	45		
1208.60	46		
1208.60	46		
1208.63	44		
1208.65	44		
1208.66	44		
1208.69	44		
1208.72	42		
1208.74	40		
1208.77	36		
1208.79	34		
1208.82	32		
1208.84	30		
1208.85	29		
1208.87	29		
1208.90	29		
1208.93	29		
1208.97	30		
1208.97	30		
1209.00	30		
1209.02	30		
1209.07	30		
1209.09	31		
1209.10	31		
1209.11	32		
1209.13	32		
1209.15	31		
1209.16	31		
1209.18	31		
1209.20	31		
1209.21	31		
1209.22	31		
1209.25	32		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1209.28	33		
1209.32	34		
1209.33	34		
1209.35	34		
1209.37	33		
1209.40	32		
1209.42	32		
1209.42	32		
1209.46	33		
1209.48	34		
1209.50	34		
1209.51	34		
1209.52	34		
1209.55	34		
1209.57	34		
1209.58	35		
1209.60	35		
1209.62	34		
1209.62	34		
1209.65	34		
1209.67	34		
1209.68	34		
1209.71	32		
1209.73	29		
1209.77	26		
1209.79	26		
1209.82	27		
1209.85	29		
1209.88	30		
1209.92	32		
1209.95	33		
1209.97	34		
1209.98	34		
1210.02	35		
1210.05	37		
1210.06	36		
1210.08	33		
1210.11	32		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1210.13	31		
1210.14	31		
1210.17	31		
1210.20	31		
1210.22	30		
1210.23	30		
1210.25	30		
1210.27	30		
1210.28	30		
1210.30	29		
1210.32	27		
1210.35	26		
1210.37	25		
1210.40	26		
1210.42	27		
1210.43	27		
1210.47	27		
1210.49	27		
1210.50	27		
1210.53	27		
1210.57	30		
1210.60	35		
1210.63	37		
1210.63	37		
1210.65	36		
1210.68	34		
1210.69	34		
1210.71	34		
1210.74	35		
1210.76	35		
1210.77	35		
1210.80	34		
1210.82	33		
1210.85	32		
1210.87	31		
1210.90	32		
1210.92	32		
1210.93	32		

Suspended Sediment Data
9/7/78 Track 2 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1210.95	31										
1210.95	30										
1210.98	28										
1211.00	26	-200 S	-450 W								

Suspended Sediment Data
9/7/78 Track 3
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1215.70	83	-50 S	260 E
1215.74	99		
1215.76	100		
1215.77	100		
1215.78	100		
1215.82	102		
1215.82	103		
1215.84	103		
1215.85	102		
1215.88	99		
1215.90	90		
1215.93	87		
1215.94	84		
1215.95	84		
1215.98	88		
1216.02	90		
1216.05	89		
1216.07	84		
1216.10	76		
1216.12	69		
1216.14	67		
1216.15	66		
1216.18	63		
1216.20	60		
1216.22	58		
1216.23	59		
1216.26	63		
1216.27	63		
1216.29	62		
1216.32	61		
1216.35	64		
1216.38	66		
1216.40	67		
1216.41	66		
1216.44	66		
1216.44	66		
1216.47	67		
1216.50	70		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1216.53	72		
1216.57	74		
1216.58	74		
1216.60	75		
1216.62	81		
1216.63	81		
1216.65	82		
1216.67	81		
1216.70	78		
1216.73	77		
1216.75	76		
1216.77	76		
1216.78	77		
1216.82	81		
1216.83	83		
1216.85	83		
1216.88	84		
1216.88	83		
1216.92	80		
1216.94	75		
1216.97	73		
1216.98	72		
1217.00	73		
1217.02	73		
1217.03	72		
1217.05	68		
1217.07	65		
1217.08	68		
1217.11	90	-50 S	0
1217.12	93		
1217.14	95		
1217.18	98		
1217.21	101		
1217.23	97		
1217.23	96		
1217.26	90		
1217.28	82		
1217.31	70		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1217.32	68		
1217.34	71		
1217.36	74		
1217.37	74		
1217.40	72		
1217.40	68		
1217.42	63		
1217.44	61		
1217.45	61		
1217.49	63		
1217.51	64		
1217.52	63		
1217.55	60		
1217.57	58		
1217.58	58		
1217.61	60		
1217.63	60		
1217.64	60		
1217.67	59		
1217.70	57		
1217.73	53		
1217.74	53		
1217.76	56		
1217.80	62		
1217.83	67		
1217.87	68		
1217.90	68		
1217.90	68		
1217.93	69		
1217.97	72		
1217.98	73		
1218.00	73		
1218.02	69		
1218.05	68		
1218.07	61		
1218.10	56		
1218.12	54		
1218.13	53		

Suspended Sediment Data
9/7/78 Track 3 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1218.15	53			1219.08	31						
1218.18	53			1219.10	31						
1218.20	52			1219.13	30						
1218.23	52			1219.14	30						
1218.26	53			1219.16	30						
1218.29	53			1219.18	30						
1218.32	53			1219.21	30	-50 S	-250 W				
1218.34	52										
1218.37	53										
1218.40	53										
1218.42	52										
1218.43	51										
1218.47	21										
1218.50	37										
1218.53	37										
1218.55	36										
1218.58	36										
1218.62	37										
1218.65	38										
1218.68	40										
1218.70	41										
1218.71	39										
1218.73	37										
1218.77	35										
1218.79	34										
1218.81	34										
1218.83	34										
1218.85	33										
1218.88	33										
1218.90	33										
1218.93	32										
1218.95	32										
1218.98	32										
1219.00	32										
1219.02	32										
1219.03	32										
1219.05	32										
1219.06	32										

Suspended Sediment Data
9/7/78 Track 4
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1233.67	36	-80 S	0	1234.75	44			1235.84	35		
1233.70	36			1234.75	44			1235.87	35		
1233.74	35			1234.79	42			1235.91	35		
1233.77	35			1234.82	41			1235.95	35		
1233.82	35			1234.85	40			1235.98	34		
1233.85	36			1234.89	39			1236.02	34		
1233.87	37			1234.92	39			1236.05	34		
1233.90	38			1234.95	38			1236.08	34		
1233.93	39			1234.97	38			1236.12	34		
1233.96	40			1234.98	38			1236.15	34		
1233.99	41			1235.01	38			1236.19	34		
1234.01	41			1235.02	38			1236.22	34		
1234.04	43			1235.04	38			1236.25	35		
1234.08	44			1235.07	36			1236.27	35		
1234.10	44			1235.10	35			1236.30	35		
1234.13	45			1235.13	34			1236.32	35		
1234.16	47			1235.17	34			1236.34	35		
1234.18	48			1235.19	34			1236.37	35		
1234.19	48			1235.22	36			1236.40	35		
1234.21	47			1235.24	37			1236.45	34		
1234.25	46			1235.25	37			1236.48	34		
1234.28	47			1235.27	37			1236.52	33		
1234.30	48			1235.30	37			1236.56	33		
1234.33	49			1235.34	37			1236.60	33		
1234.35	50			1235.37	37			1236.63	33		
1234.38	51			1235.42	37			1236.65	32		
1234.41	51			1235.45	37			1236.68	32		
1234.43	51			1235.49	36			1236.70	33		
1234.44	51			1235.52	36			1236.75	33		
1234.47	50			1235.55	36			1236.78	33		
1234.50	50			1235.60	36			1236.81	33		
1234.53	49			1235.62	36			1236.84	33		
1234.56	49			1235.67	36			1236.86	33		
1234.59	48			1235.70	36			1236.88	33		
1234.63	47			1235.74	35			1236.90	33		
1234.67	45			1235.77	35			1236.94	34		
1234.70	44			1235.80	35			1236.95	34		
1234.72	44			1235.82	35			1236.98	33		

Suspended Sediment Data
9/7/78 Track 4 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1237.01	33		
1237.05	34		
1237.06	34		
1237.10	33		
1237.13	33		
1237.16	33		
1237.19	33		
1237.21	33		
1237.23	33		
1237.26	32		
1237.30	32		
1237.33	32		
1237.36	32		
1237.39	31		
1237.41	31		
1237.43	31		
1237.46	31		
1237.51	31		
1237.55	31		
1237.59	31		
1237.63	31		
1237.66	31		
1237.69	31		
1237.73	31		
1237.77	31		
1237.80	31		
1237.83	30		
1237.87	30		
1237.91	31		
1237.96	31		
1237.99	30		
1238.02	30		
1238.04	30		
1238.08	31		
1238.11	31		
1238.15	30		
1238.19	30		
1238.24	31		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1238.28	31		
1238.31	31		
1238.35	31		
1238.38	31		
1238.41	31		
1238.46	31		
1238.49	31		
1238.52	31		
1238.55	31		
1238.59	31		
1238.62	31		
1238.66	31		
1238.69	31		
1238.71	31		
1238.74	31		
1238.77	31		
1238.80	30		
1238.83	30		
1238.87	30		
1238.90	30		
1238.94	30		
1238.98	30		
1239.02	30		
1239.05	29		
1239.09	29		
1239.14	29		
1239.17	29		
1239.19	30		
1239.22	30		
1239.24	31		
1239.28	31		
1239.31	31		
1239.34	31		
1239.35	31		
1239.38	31		
1239.41	31		
1239.45	31		
1239.50	31		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1239.50	32		
1239.52	32		
1239.55	33		
1239.55	33		
1239.58	33		
1239.62	33		
1239.65	33		
1239.69	33		
1239.73	33		
1239.77	33		
1239.78	33		
1239.82	33		
1239.85	33		
1239.88	33		
1239.92	32		
1239.96	32		
1239.99	32		
1240.02	32		
1240.05	32		
1240.08	32		
1240.11	32		
1240.15	32		
1240.18	32		

Suspended Sediment Data
9/7/78 Track 5
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1306.70	25	-40 S	0	1307.83	26						
1306.73	25			1307.86	26						
1306.76	25			1307.89	26						
1306.79	26			1307.92	26						
1306.82	26			1307.96	26						
1306.86	26			1307.99	26						
1306.89	26			1308.03	26						
1306.93	26			1308.05	26						
1306.96	26			1308.06	26						
1306.99	26			1308.09	26						
1307.02	26			1308.12	26						
1307.06	26			1308.15	26						
1307.10	26			1308.18	25						
1307.13	26			1308.21	25						
1307.17	26			1308.24	25						
1307.21	26			1308.25	25						
1307.24	26			1308.27	25						
1307.27	25			1308.30	25						
1307.30	25			1308.33	24						
1307.33	25			1308.37	24						
1307.36	26			1308.41	25						
1307.36	26			1308.44	24						
1307.40	26			1308.46	24						
1307.45	26			1308.47	24						
1307.48	26			1308.50	23						
1307.51	26			1308.53	23						
1307.55	26			1308.58	23						
1307.56	26			1308.62	23						
1307.58	26			1308.65	23						
1307.61	27			1308.70	24						
1307.64	28			1308.73	24						
1307.67	29			1308.75	25						
1307.69	29			1308.76	25						
1307.71	29			1308.80	25						
1307.74	28			1308.83	25	-400 S	0				
1307.76	28										
1307.79	27										
1307.80	27										

Suspended Sediment Data
9/7/78 Track 6
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1607.16	64	220 N	-80 W	1607.87	62						
1607.19	73			1607.88	64						
1607.19	73			1607.90	54	220 N	0				
1607.22	54			1607.93	42						
1607.26	46			1607.95	38						
1607.27	45			1607.96	39						
1607.28	46			1607.99	37						
1607.30	46			1608.01	36						
1607.32	49			1608.03	37						
1607.34	53			1608.03	37						
1607.35	52			1608.06	41						
1607.35	51			1608.07	42						
1607.37	53			1608.08	42						
1607.38	51			1608.10	40						
1607.40	49			1608.11	39						
1607.43	45			1608.13	39						
1607.46	53			1608.15	38						
1607.47	55			1608.19	34						
1607.49	48			1608.20	34						
1607.51	42			1608.22	34						
1607.52	43			1608.25	37						
1607.55	43			1608.25	38						
1607.58	40			1608.27	37						
1607.58	39			1608.30	37						
1607.60	42			1608.30	37						
1607.63	48			1608.33	36						
1607.63	48			1608.34	35						
1607.66	47			1608.36	40						
1607.67	45			1608.39	41						
1607.70	38			1608.41	41						
1607.73	47			1608.42	41						
1607.75	51			1608.45	51						
1607.75	52			1608.47	65						
1607.77	52			1608.51	65						
1607.78	51			1608.54	61						
1607.81	48			1608.57	52						
1607.82	48			1608.59	47						
1607.84	55			1608.62	46	220 N	200 E				

Suspended Sediment Data
9/7/78 Track 7
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1608.62	46	220 N	200 E	1609.30	53			1609.96	78		
1608.62	46			1609.33	51			1609.98	77		
1608.64	44			1609.36	47			1610.01	78		
1608.65	46			1609.37	47			1610.03	80		
1608.67	50			1609.39	48			1610.04	82		
1608.67	53			1609.40	49			1610.05	85		
1608.70	55			1609.42	50			1610.06	87		
1608.70	56			1609.44	54			1610.08	86		
1608.72	56			1609.47	57			1610.10	84		
1608.75	52			1609.47	57			1610.11	84		
1608.75	47			1609.49	59			1610.12	85		
1608.77	44			1609.49	59			1610.15	87		
1608.78	42			1609.52	51			1610.17	90		
1608.80	42			1609.55	47			1610.18	84		
1608.82	44			1609.55	47			1610.19	77		
1608.83	44			1609.57	53			1610.20	70		
1608.87	40			1609.58	54			1610.22	63		
1608.88	40			1609.59	60			1610.24	64		
1608.90	44			1609.60	64			1610.26	65		
1608.92	45			1609.61	66			1610.27	65		
1608.92	45			1609.64	67			1610.30	62		
1608.95	46			1609.67	66			1610.31	62		
1608.96	46			1609.69	63			1610.33	63		
1608.98	45			1609.70	66			1610.34	64		
1609.00	43			1609.72	71			1610.37	58		
1609.02	43			1609.75	77			1610.40	52		
1609.04	49			1609.77	79			1610.41	54		
1609.05	51			1609.80	76			1610.42	64		
1609.07	49			1609.81	76			1610.44	68		
1609.10	47			1609.83	80			1610.45	72		
1609.12	48			1609.85	81			1610.47	66		
1609.14	51			1609.86	82			1610.49	61		
1609.17	51			1609.88	82			1610.50	60		
1609.20	52			1609.89	79			1610.53	52		
1609.23	51			1609.90	76			1610.53	50		
1609.25	52			1609.93	76			1610.56	45		
1609.27	52			1609.94	78			1610.58	42		
1609.28	52			1609.95	78			1610.60	40		

Suspended Sediment Data
9/7/78 Track 7 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1610.60	40			1611.28	36						
1610.60	41			1611.31	32						
1610.61	39			1611.34	27						
1610.63	39			1611.36	26						
1610.64	39			1611.38	26						
1610.66	41			1611.39	28						
1610.66	41			1611.42	28						
1610.69	42			1611.45	28						
1610.71	43			1611.48	28						
1610.72	43			1611.49	27						
1610.74	45			1611.51	26	400 N	-300 W				
1610.76	141										
1610.77	112										
1610.78	81										
1610.79	125										
1610.80	136										
1610.82	104										
1610.85	58										
1610.88	30										
1610.89	28										
1610.91	28										
1610.93	43										
1610.94	44										
1610.96	44										
1610.98	43										
1610.99	42										
1611.00	41										
1611.02	41										
1611.05	40										
1611.06	39										
1611.10	36										
1611.13	31										
1611.14	30										
1611.16	29										
1611.18	29										
1611.21	28										
1611.25	32										
1611.28	35										

Suspended Sediment Data
9/7/78 Track 8 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1614.11	65		
1614.11	64		
1614.14	69		
1614.14	69		
1614.17	65		
1614.18	59		
1614.20	57		
1614.24	53		
1614.24	50		
1614.27	50		
1614.27	50		
1614.30	46		
1614.30	45		
1614.33	43		
1614.34	43		
1614.37	42		
1614.38	43		
1614.40	43		
1614.42	40		
1614.43	40		
1614.47	41		
1614.51	40		
1614.54	37		
1614.57	38		
1614.58	38		
1614.61	37		
1614.65	38		
1614.66	38		
1614.68	38		
1614.72	37		
1614.75	36		
1614.76	37		
1614.78	40		
1614.79	40		
1614.82	41		
1614.85	40		
1614.88	39		
1614.91	36		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1614.94	37		
1614.95	37		
1614.96	39		
1614.99	40		
1615.02	40		
1615.04	41		
1615.05	41		
1615.08	40		
1615.11	38		
1615.15	35		
1615.18	38		
1615.22	42	500 N	300 E

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W

Suspended Sediment Data
9/7/78 Track 8
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1611.51	26	400 N	-300 W	1612.46	29			1613.35	47		
1611.54	26			1612.48	30			1613.36	45		
1611.56	31			1612.50	28			1613.38	46		
1611.58	31			1612.53	25			1613.40	48		
1611.60	28			1612.57	24			1613.40	48		
1611.61	27			1612.59	25			1613.42	46		
1611.63	29			1612.62	26			1613.44	49		
1611.68	27			1612.64	28			1613.46	51		
1611.69	26			1612.67	30			1613.47	48		
1611.70	28			1612.69	28			1613.49	48		
1611.73	31			1612.71	32			1613.52	49		
1611.77	28			1612.73	38			1613.53	51		
1611.80	25			1612.76	36			1613.54	54		
1611.83	25			1612.79	40			1613.57	57		
1611.85	27			1612.82	36			1613.57	57		
1611.88	29			1612.85	37			1613.60	53		
1611.90	31			1612.88	35			1613.60	53		
1611.93	31			1612.88	34			1613.63	56		
1611.97	29			1612.92	36			1613.65	55		
1611.98	29			1612.95	40			1613.67	56		
1612.01	31			1612.95	41			1613.71	67	420 N	-80 W
1612.05	32			1612.98	37			1613.74	75		
1612.06	33			1613.00	36			1613.76	81		
1612.09	29			1613.02	38			1613.77	80		
1612.12	25			1613.04	41			1613.80	76		
1612.16	25			1613.05	48			1613.83	70		
1612.18	25			1613.07	50			1613.86	64		
1612.20	27			1613.10	41			1613.90	54		
1612.23	28			1613.12	41			1613.92	52		
1612.27	26			1613.13	44			1613.94	53		
1612.28	25			1613.14	49			1613.97	55		
1612.31	28			1613.18	51			1613.97	55		
1612.33	28			1613.21	51			1614.00	53		
1612.33	29			1613.24	47			1614.01	52		
1612.37	26			1613.25	48			1614.02	54		
1612.39	27			1613.27	50			1614.05	65		
1612.42	30			1613.30	50			1614.06	67		
1612.44	29			1613.32	47			1614.07	68		

Suspended Sediment Data
9/7/78 Track 9
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1615.22	42	500 N	300 E	1616.19	40			1617.01	47		
1615.22	43			1616.23	39			1617.02	47		
1615.26	41			1616.26	37			1617.04	51		
1615.27	40			1616.29	36			1617.07	55		
1615.29	39			1616.31	36			1617.09	58		
1615.33	37			1616.32	36			1617.11	59		
1615.33	36			1616.35	37			1617.13	57		
1615.37	36			1616.35	38			1617.15	58		
1615.40	38			1616.39	41			1617.17	58		
1615.40	38			1616.42	42			1617.20	59		
1615.42	38			1616.42	41			1617.22	59		
1615.45	38			1616.45	40			1617.22	60		
1615.46	37			1616.46	40			1617.25	54		
1615.50	37			1616.48	41			1617.28	48		
1615.53	35			1616.49	41			1617.31	45		
1615.55	34			1616.54	42			1617.32	46		
1615.57	34			1616.57	40			1617.35	47		
1615.59	34			1616.57	41			1617.36	50		
1615.60	34			1616.60	40			1617.41	45		
1615.62	35			1616.60	41			1617.45	42		
1615.65	37			1616.63	46			1617.48	39		
1615.67	37			1616.63	47			1617.49	38		
1615.68	38			1616.65	46			1617.52	39		
1615.70	38			1616.70	45			1617.55	41		
1615.73	38			1616.72	45			1617.57	45		
1615.77	38			1616.74	45			1617.58	46		
1615.81	37			1616.77	44			1617.60	46		
1615.85	37			1616.78	43			1617.63	43		
1615.88	36			1616.80	44			1617.65	44		
1615.91	35			1616.83	45			1617.67	46		
1615.95	35			1616.87	48			1617.70	44		
1616.01	35			1616.87	50			1617.73	40		
1616.01	36			1616.89	48			1617.75	39		
1616.05	36			1616.93	49			1617.77	41		
1616.10	35			1616.94	49			1617.80	43		
1616.11	35			1616.96	47			1617.82	46		
1616.13	36			1616.98	47			1617.85	48		
1616.16	38			1617.00	47			1617.89	50		

Suspended Sediment Data
9/7/78 Track 9 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1617.94	54										
1617.97	51										
1618.00	47										
1618.04	43										
1618.08	43										
1618.11	45										
1618.11	45										
1618.13	46										
1618.18	45										
1618.22	45										
1618.24	45										
1618.25	45										
1618.27	44										
1618.30	46										
1618.33	46										
1618.37	44										
1618.41	44										
1618.45	46										
1618.50	46										
1618.53	45										
1618.53	44										
1618.55	45										
1618.57	46										
1618.60	45										
1618.63	43										
1618.63	42										
1618.67	42										
1618.70	43	1100 N	-100 W								

Suspended Sediment Data
9/7/78 Track 10
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1618.70	43	1100 N	-100 W
1618.74	40		
1618.75	40		
1618.78	40		
1618.82	40		
1618.86	41		
1618.87	41		
1618.89	39		
1618.92	37		
1618.94	35		
1618.97	35		
1618.99	35		
1619.00	39		
1619.02	41		
1619.03	43		
1619.05	44		
1619.08	45		
1619.12	41		
1619.14	41		
1619.15	41		
1619.19	42		
1619.22	42		
1619.25	41		
1619.28	40		
1619.33	41		
1619.37	43		
1619.40	42		
1619.45	40		
1619.48	39		
1619.48	39		
1619.52	42		
1619.52	42		
1619.55	41		
1619.58	41		
1619.62	40		
1619.63	39		
1619.65	40		
1619.67	41		
1619.70	41		
1619.75	41		
1619.78	42		
1619.80	43		
1619.85	41		
1619.87	39		
1619.90	39		
1619.93	40		
1619.95	40		
1619.98	39		
1620.00	37		
1620.02	37		
1620.05	37		
1620.08	38		
1620.10	39		
1620.11	39		
1620.13	39		
1620.17	42		
1620.17	43		
1620.19	43		
1620.22	43		
1620.22	43		
1620.25	44		
1620.27	44		
1620.28	45		
1620.32	44		
1620.33	44		
1620.37	42		
1620.40	42		
1620.43	39		
1620.47	37		
1620.50	37		
1620.55	36		
1620.57	36		
1620.60	36		
1620.63	36		
1620.66	38		
1620.68	39		
1620.73	41		
1620.75	42		
1620.77	42		
1620.80	39		
1620.82	41		
1620.84	42		
1620.87	43		
1620.88	44		
1620.90	40	1300 N	300 E

Suspended Sediment Data
9/19/78 Track 1
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1303.87	27	0	0	1305.16	18						
1304.02	29			1305.20	18						
1304.05	31			1305.24	17						
1304.08	36			1305.96	16	300 N	0				
1304.10	41			1306.52	17	500 N	0				
1304.14	45			1307.20	16	700 N	0				
1304.16	49			1307.78	14	900 N	0				
1304.20	48	100 N	0								
1304.23	59										
1304.26	82										
1304.28	86										
1304.31	78										
1304.34	61										
1304.37	47										
1304.40	48										
1304.43	55										
1304.45	65										
1304.49	73										
1304.52	67										
1304.54	49										
1304.57	37										
1304.60	30										
1304.63	25										
1304.66	25										
1304.70	26										
1304.74	27										
1304.77	28										
1304.80	29										
1304.84	31										
1304.87	30										
1304.90	26										
1304.93	23										
1304.96	23										
1304.99	23										
1305.03	22										
1305.06	21										
1305.09	21										
1305.13	20										

Suspended Sediment Data
9/19/78 Track 2
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1540.35	54	0	0
1540.39	54		
1540.43	54		
1540.47	55		
1540.51	55		
1540.55	54		
1540.58	54		
1540.62	54		
1540.65	54		
1540.69	57		
1540.73	58		
1540.77	59		
1540.80	61		
1540.83	69		
1540.86	78		
1540.89	99		
1540.92	111		
1540.93	114		
1540.95	111		
1540.98	89		
1541.01	70		
1541.01	69		
1541.04	85		
1541.07	104		
1541.09	115		
1541.11	112		
1541.14	94		
1541.16	72		
1541.19	62		
1541.22	57	200 N	0
1541.24	52		
1541.25	52		
1541.27	56		
1541.30	65		
1541.33	59		
1541.36	53		
1541.38	50		
1541.41	50		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1541.44	50		
1541.47	49		
1541.50	49		
1541.53	49		
1541.56	48		
1541.59	49		
1541.62	48		
1541.64	48		
1541.69	48		
1541.73	48		
1541.75	47		
1541.76	47		
1541.79	63		
1541.82	79		
1541.83	86		
1541.84	86		
1541.85	86		
1541.88	99		
1541.90	110		
1541.93	110		
1541.96	119		
1541.97	121		
1542.00	119		
1542.02	117		
1542.04	114		
1542.05	113		
1542.09	111		
1542.11	106	400 N	0
1542.14	112		
1542.14	112		
1542.17	108		
1542.20	101		
1542.24	95		
1542.26	88		
1542.29	75		
1542.31	70		
1542.34	69		
1542.38	71		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1542.41	69		
1542.44	66		
1542.46	63		
1542.49	60		
1542.53	57		
1542.55	56		
1542.58	56		
1542.63	56		
1542.65	54		
1542.70	50		
1542.73	46		
1542.78	46		
1542.82	45		
1542.84	45		
1542.87	43		
1542.89	42		
1542.93	41		
1542.95	41		
1542.98	40		
1543.00	39	600 N	0
1543.04	39		
1543.07	39		
1543.11	41		
1543.14	41		
1543.17	39		
1543.22	39		
1543.28	43		
1543.31	44		
1543.35	44		
1543.39	45		
1543.42	44		
1543.44	43		
1543.47	40		
1543.49	40		
1543.52	40		
1543.55	38		
1543.62	38		
1543.64	37		

Suspended Sediment Data
9/19/78 Track 2 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1543.69	38		
1543.73	38		
1543.76	39		
1543.79	39		
1543.83	39	800 N	0
1543.86	40		
1543.89	39		
1543.92	38		
1543.95	38		
1543.97	38		
1544.01	38		
1544.04	38		
1544.09	38		
1544.12	38		
1544.15	38		
1544.18	38		
1544.22	38		
1544.27	39		
1544.32	42		
1544.35	42		
1544.38	42		
1544.40	40		
1544.44	38		
1544.47	35		
1544.50	35		
1544.53	35		
1544.58	33		
1544.61	33		
1544.64	32		
1544.67	32		
1544.70	30		
1544.72	30		
1544.75	28		
1544.78	28		
1544.82	28		
1544.84	28		
1544.88	28		
1544.92	27		
1544.96	28		
1545.01	29	990 N	0

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W

Suspended Sediment Data
9/19/78 Track 3
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1552.01	27	1000 N	0
1552.89	29		
1553.37	31		
1553.79	33	800 N	0
1554.15	32		
1554.32	27		
1554.44	30		
1554.57	24		
1554.66	28		
1554.70	25		
1554.77	31		
1554.82	31	600 N	0
1554.86	26		
1554.97	33		
1555.02	27		
1555.09	28		
1555.15	22		
1555.29	23		
1555.35	28		
1555.50	29		
1555.67	31		
1555.84	30		
1555.90	28		
1555.97	30	400 N	0
1556.02	31		
1556.09	21		
1556.13	21		
1556.16	26		
1556.19	31		
1556.22	35		
1556.25	37		
1556.28	33		
1556.31	27		
1556.34	22		
1556.37	21		
1556.40	20		
1556.43	20		
1556.47	20		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1556.52	21		
1556.56	21		
1556.59	22		
1556.62	22		
1556.65	28		
1556.69	29		
1556.73	29		
1556.76	28		
1556.79	29		
1556.85	30		
1556.89	31		
1556.92	32	200 N	0
1556.95	36		
1556.98	38		
1557.01	33		
1557.04	28		
1557.07	26		
1557.10	25		
1557.13	26		
1557.16	27		
1557.19	28		
1557.22	27		
1557.24	25		
1557.27	22		
1557.31	24		
1557.34	31		
1557.37	32		
1557.40	29		
1557.43	26		
1557.47	24		
1557.50	28		
1557.54	33		
1557.57	35		
1557.59	34		
1557.62	33		
1557.64	32		
1557.67	32		
1557.71	34		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1557.74	35		
1557.77	37		
1557.80	43		
1557.83	49		
1557.86	49		
1557.89	40		
1557.92	34		
1557.94	30		
1557.97	28		
1557.99	26		
1558.02	26		
1558.04	26		
1558.07	24		
1558.10	24		
1558.14	24		
1558.18	24		
1558.22	24		
1558.26	24		
1558.30	24		
1558.33	24		
1558.36	24		
1558.40	24		
1558.44	24		
1558.48	27		
1558.52	33		
1558.55	36		
1558.58	34		
1558.60	32		
1558.63	32		
1558.66	40		
1558.69	68		
1558.72	87		
1558.74	162		
1558.77	181		
1558.78	181		
1558.80	179		
1558.81	179	50 N	0
1558.82	179		

Suspended Sediment Data
9/19/78 Track 3 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1558.83	170										
1558.86	142										
1558.89	82										
1558.92	45										
1558.94	36										
1558.97	29										
1558.98	27										
1558.99	26										
1559.02	24	0	0								

Suspended Sediment Data
9/19/78 Track 4
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1607.20	25	-200 S	0								
1608.14	26	0	0								
1608.89	24	200 N	0								

Suspended Sediment Data
9/19/78 Track 5
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1609.60	24	200 N	0	1611.34	21						
1609.63	22			1611.38	27						
1609.66	22			1611.41	30						
1609.67	22			1611.44	27						
1609.69	22			1611.47	26						
1609.72	23			1611.50	27						
1609.75	22			1611.53	34						
1609.78	22			1611.56	46						
1609.83	22			1611.59	56						
1609.87	22			1611.61	58						
1609.91	28			1611.62	56						
1609.94	31			1611.65	52						
1609.98	34			1611.67	47						
1610.02	37			1611.70	45						
1610.05	37			1611.72	37						
1610.09	42			1611.75	30						
1610.13	46			1611.78	26						
1610.17	50			1611.81	23						
1610.20	54			1611.84	22						
1610.26	60			1611.88	22						
1610.30	60			1611.91	22						
1610.31	60			1611.95	22						
1610.33	57			1612.00	24						
1610.35	54			1612.03	24						
1610.37	51			1612.05	24						
1610.38	51			1612.08	24						
1610.41	58			1612.12	24						
1610.45	65			1612.15	24						
1610.47	62			1612.18	24						
1610.50	50			1612.20	23						
1610.52	38			1612.24	23						
1610.55	30			1612.27	23						
1610.57	25			1612.30	23						
1610.58	25			1612.34	22	-200 S	0				
1610.60	24										
1610.63	23										
1610.65	22										
1611.22	21	0	0								

Suspended Sediment Data
9/26/78 Track 1
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1042.01	20	1000 N	0	1043.17	17			1044.44	15		
1042.05	21			1043.20	18			1044.47	13		
1042.07	21			1043.23	17			1044.50	16		
1042.11	24			1043.26	16			1044.53	16		
1042.13	24			1043.29	17			1044.56	15		
1042.16	23			1043.32	17			1044.59	15		
1042.19	20			1043.36	16			1044.62	16		
1042.22	16			1043.39	15			1044.65	16		
1042.25	15			1043.42	16			1044.69	16		
1042.28	18			1043.45	15			1044.72	16		
1042.31	22			1043.49	15			1044.74	16		
1042.33	23			1043.52	14			1044.78	14		
1042.37	21			1043.55	13			1044.80	14		
1042.40	23			1043.58	14			1044.85	14		
1042.43	20			1043.62	14			1044.89	14		
1042.48	21			1043.65	11			1044.92	13		
1042.51	21			1043.69	11			1044.96	13		
1042.53	23			1043.72	12			1045.00	12		
1042.56	21			1043.75	12			1045.03	14		
1042.59	21			1043.78	12			1045.08	13		
1042.62	20			1043.83	12			1045.11	13		
1042.66	22			1043.85	14			1045.16	12		
1042.69	20			1043.89	13			1045.20	12		
1042.72	22			1043.91	15			1045.23	13		
1042.75	19			1043.94	15			1045.27	13		
1042.79	18			1043.98	14			1045.30	13		
1042.82	16			1044.02	13			1045.34	13		
1042.85	15			1044.05	12			1045.37	14		
1042.88	24			1044.09	13			1045.40	14		
1042.91	17			1044.12	12			1045.45	14		
1042.95	14			1044.15	15			1045.48	14		
1042.97	15			1044.18	17			1045.70	14		
1043.00	15			1044.21	14	800 N	0	1045.80	17		
1043.03	16			1044.24	15			1045.87	14		
1043.06	16			1044.27	15			1045.92	16		
1043.09	15			1044.32	15			1045.97	13		
1043.12	14			1044.35	13			1046.05	13		
1043.15	16			1044.39	15			1046.19	15		

Suspended Sediment Data
9/26/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1046.30	13		
1046.32	18		
1046.37	10		
1046.40	12	600 N	0
1046.49	13		
1046.55	13		
1046.62	13		
1046.70	13		
1046.76	16		
1046.82	16		
1046.84	18		
1046.84	21		
1046.88	18		
1046.92	16		
1046.96	16		
1046.97	18		
1047.00	16		
1047.03	16		
1047.09	14		
1047.13	16		
1047.15	16		
1047.20	13		
1047.25	12		
1047.30	11		
1047.34	11		
1047.37	10		
1047.56	9		
1047.65	13		
1047.69	11		
1047.74	10		
1047.77	14		
1047.80	11		
1047.83	12		
1047.85	10		
1047.90	12	400 N	0
1047.95	10		
1047.95	12		
1048.00	10		
1048.03	15		
1048.05	12		
1048.06	21		
1048.09	13		
1048.17	12		
1048.21	10		
1048.27	11		
1048.33	12		
1048.38	11		
1048.42	9		
1048.45	15		
1048.46	9		
1048.50	9		
1048.53	12		
1048.57	11		
1048.65	12		
1048.71	13		
1048.78	10		
1048.86	11		
1048.90	12		
1048.95	10		
1049.18	9		
1049.38	10		
1049.52	10		
1049.68	10		
1049.78	12		
1049.87	11		
1050.02	11		
1050.17	11	200 N	0
1050.35	10		
1050.55	10		
1050.65	8		
1050.80	10		
1050.93	10	0	0
1051.05	11		
1051.15	13		
1051.20	9		
1051.20	11		
1051.30	9		
1051.47	9		
1051.60	11		
1051.65	12		
1051.70	10		
1051.80	11		
1051.87	8		
1051.90	15		
1051.95	10		
1052.05	9	-200 S	0

Suspended Sediment Data
9/28/78 Track 1
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1144.60	51	800 N	0	1145.18	43			1145.81	45		
1144.63	39			1145.18	42			1145.83	44		
1144.65	37			1145.20	44			1145.83	43		
1144.66	37			1145.21	45			1145.84	44		
1144.69	37			1145.23	44			1145.86	43		
1144.69	38			1145.24	43			1145.87	47		
1144.72	36			1145.26	44			1145.88	44		
1144.73	39			1145.28	43			1145.89	42		
1144.74	38			1145.29	42			1145.91	42		
1144.74	40			1145.32	43			1145.91	42		
1144.76	39			1145.35	42			1145.93	41		
1144.76	41			1145.38	43			1145.95	42		
1144.77	40			1145.41	42			1145.97	41		
1144.79	39			1145.41	44			1145.98	43		
1144.79	41			1145.44	40			1145.98	44		
1144.83	38			1145.47	43			1146.00	43		
1144.84	36			1145.48	43			1146.02	44		
1144.86	37			1145.50	40			1146.03	45		
1144.88	40			1145.52	38			1146.03	48		
1144.91	41			1145.53	39			1146.04	45		
1144.93	42			1145.55	42			1146.05	47		
1144.94	42			1145.56	41			1146.05	49		
1144.94	44			1145.58	40			1146.09	44		
1144.95	49			1145.59	40			1146.11	41		
1144.98	46			1145.60	46			1146.13	43		
1144.98	45			1145.61	46			1146.13	46		
1144.99	44			1145.62	46			1146.15	44		
1145.01	47			1145.63	43			1146.16	45		
1145.01	47			1145.64	44			1146.18	45		
1145.04	42			1145.65	43			1146.19	47		
1145.05	41			1145.67	46			1146.21	48		
1145.06	43			1145.68	47			1146.23	48		
1145.06	43			1145.70	44			1146.24	45		
1145.09	44			1145.73	40			1146.24	45		
1145.11	44			1145.74	44			1146.28	42		
1145.14	42			1145.78	42			1146.30	43		
1145.15	43			1145.78	41			1146.33	46		
1145.16	43			1145.80	44			1146.37	41		

Suspended Sediment Data
9/28/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1146.38	41		
1146.39	42		
1146.39	43		
1146.43	41		
1146.46	41		
1146.48	40		
1146.49	42		
1146.49	42		
1146.53	39		
1146.54	38		
1146.55	39		
1146.58	40		
1146.60	40		
1146.61	40		
1146.62	45		
1146.63	44		
1146.65	40		
1146.66	40		
1146.67	41		
1146.69	40		
1146.71	39		
1146.72	40		
1146.74	42		
1146.75	40		
1146.78	37		
1146.78	39		
1146.79	40		
1146.80	39		
1146.81	40		
1146.83	41		
1146.84	39		
1146.85	38		
1146.85	50		
1146.87	44		
1146.89	39		
1146.90	37		
1146.93	38		
1146.95	40		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1146.96	40		
1146.99	36		
1146.99	37		
1146.99	41		
1147.02	38		
1147.05	38		
1147.08	36		
1147.10	36		
1147.11	36		
1147.14	36		
1147.17	37		
1147.19	37		
1147.23	37		
1147.26	37		
1147.26	37		
1147.29	37		
1147.31	37		
1147.35	38		
1147.38	35		
1147.41	36		
1147.42	40		
1147.44	37		
1147.44	42		
1147.46	39		
1147.48	36		
1147.48	40		
1147.49	40		
1147.53	37		
1147.56	36		
1147.56	37		
1147.59	37		
1147.62	36		
1147.65	35		
1147.68	36		
1147.68	37		
1147.70	35		
1147.71	36		
1147.72	37		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1147.75	37		
1147.78	35		
1147.80	42		
1147.81	40		
1147.83	36		
1147.84	36		
1147.86	36		
1147.88	35		
1147.88	38		
1147.89	37		
1147.91	34		
1147.92	36		
1147.93	37		
1147.94	37		
1147.96	36		
1147.98	36		
1148.00	38		
1148.00	39		
1148.03	37		
1148.04	37		
1148.08	37		
1148.10	37		
1148.13	38		
1148.15	39		
1148.15	40		
1148.18	36		
1148.18	38		
1148.18	39		
1148.21	37	600 N	0
1148.24	37		
1148.28	36		
1148.30	39		
1148.33	40		
1148.35	41		
1148.38	40		
1148.41	40		
1148.43	42		
1148.46	42		

Suspended Sediment Data
9/28/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1148.48	41			1149.16	44			1150.00	37		
1148.49	41			1149.16	44			1150.03	36		
1148.53	41			1149.19	42			1150.06	36		
1148.56	41			1149.21	44			1150.09	40		
1148.58	41			1149.24	45			1150.10	37		
1148.59	41			1149.27	44			1150.11	40		
1148.59	47			1149.29	44			1150.12	40		
1148.61	44			1149.33	44			1150.15	37		
1148.64	41			1149.35	44			1150.19	34		
1148.66	41			1149.39	44			1150.23	34		
1148.66	43			1149.43	43			1150.25	34		
1148.68	40			1149.44	43			1150.27	35		
1148.70	41			1149.46	45			1150.28	38		
1148.73	41			1149.47	46			1150.29	41		
1148.74	41			1149.49	45			1150.31	36		
1148.75	41			1149.51	46			1150.34	32		
1148.76	45			1149.54	43			1150.35	32		
1148.78	44			1149.54	44			1150.38	32		
1148.79	42			1149.57	46			1150.39	31		
1148.81	41			1149.58	44			1150.40	33		
1148.84	41			1149.60	43			1150.43	34		
1148.87	44			1149.64	42			1150.45	36		
1148.88	44			1149.67	41			1150.46	38		
1148.90	41			1149.68	41			1150.48	38		
1148.91	40			1149.69	42			1150.50	40		
1148.93	41			1149.70	44			1150.53	39		
1148.95	40			1149.72	43			1150.56	41		
1148.95	41			1149.74	41			1150.60	40		
1148.96	44			1149.74	43			1150.63	41		
1148.98	43			1149.74	43			1150.65	42		
1149.00	44			1149.78	38			1150.68	43		
1149.03	44			1149.83	37			1150.71	39		
1149.04	44			1149.83	43			1150.74	42		
1149.06	54			1149.86	37			1150.78	41		
1149.06	55			1149.87	37			1150.79	40		
1149.09	46			1149.90	37			1150.81	37		
1149.12	44			1149.93	38			1150.84	35		
1149.13	43			1149.96	37			1150.88	35		

Suspended Sediment Data
9/28/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1150.90	34			1151.77	37			1152.73	44		
1150.91	34			1151.79	39			1152.75	38		
1150.93	36			1151.83	37			1152.78	31		
1150.97	38			1151.86	36			1152.81	32		
1151.00	43			1151.88	38			1152.83	34		
1151.03	43			1151.91	41			1152.87	31		
1151.05	44			1151.94	39			1152.88	31		
1151.08	44			1151.97	40			1152.90	31		
1151.10	45			1152.00	39			1152.93	33		
1151.12	46			1152.03	39			1152.96	31		
1151.13	43			1152.07	37			1152.98	39		
1151.16	43			1152.10	36	400 N	0	1153.02	33		
1151.17	47			1152.13	37			1153.03	37		
1151.18	46			1152.15	38			1153.05	32		
1151.19	44			1152.18	37			1153.08	32		
1151.21	43			1152.18	34			1153.11	36		
1151.24	42			1152.19	34			1153.11	37		
1151.28	41			1152.20	37			1153.14	33		
1151.31	41			1152.21	35			1153.14	37		
1151.34	41			1152.24	34			1153.17	33		
1151.37	40			1152.25	35			1153.20	31		
1151.39	39			1152.28	34			1153.22	31		
1151.43	40			1152.31	34			1153.25	31		
1151.43	42			1152.33	36			1153.28	33		
1151.46	42			1152.34	35			1153.31	34		
1151.48	38			1152.37	31			1153.32	36		
1151.49	40			1152.40	33			1153.32	36		
1151.52	40			1152.42	32			1153.35	35		
1151.56	40			1152.43	34			1153.38	34		
1151.59	37			1152.45	36			1153.41	34		
1151.59	35			1152.49	33			1153.44	34		
1151.61	37			1152.53	34			1153.47	33		
1151.61	38			1152.55	34			1153.50	32		
1151.64	36			1152.58	35			1153.54	31		
1151.68	35			1152.60	35			1153.57	31		
1151.70	35			1152.63	35			1153.60	31		
1151.73	35			1152.68	33			1153.63	31		
1151.75	36			1152.72	31			1153.66	31		

Suspended Sediment Data
9/28/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1153.69	30			1154.57	30			1156.89	29		
1153.72	29			1154.58	31			1156.94	28		
1153.74	30			1154.59	38			1156.97	28		
1153.78	31			1154.60	36			1156.98	34		
1153.80	30			1154.63	31			1157.03	29		
1153.81	30			1154.64	31			1157.05	31		
1153.83	33			1154.68	31			1157.13	29		
1153.84	31			1154.70	31			1157.16	29		
1153.88	30			1154.73	32			1157.19	27		
1153.89	30			1154.77	32			1157.21	31		
1153.92	34			1154.80	30			1157.24	28		
1153.94	36			1155.07	28			1157.28	30		
1153.96	31			1155.25	29	200 N	0	1157.29	29		
1153.98	31			1155.25	31			1157.30	31		
1153.99	31			1155.40	30			1157.31	29		
1154.02	33			1155.56	28			1157.34	28		
1154.04	33			1155.60	30			1157.36	31		
1154.08	30			1155.68	29			1157.40	29		
1154.12	31			1155.84	30			1157.42	30		
1154.15	30			1155.94	29			1157.46	28		
1154.17	30			1155.99	31			1157.49	29		
1154.20	30			1156.03	29			1157.52	30		
1154.22	30			1156.08	30			1157.54	28		
1154.24	30			1156.17	29			1157.55	28		
1154.25	33			1156.24	28			1157.58	29		
1154.26	35			1156.32	30			1157.61	29		
1154.28	30			1156.33	28			1157.63	31		
1154.28	30			1156.38	31			1157.65	33		
1154.31	30			1156.43	29			1157.66	33		
1154.34	30			1156.44	31			1157.68	33		
1154.38	29			1156.47	29			1157.70	33		
1154.41	31			1156.49	31			1157.74	39		
1154.44	30			1156.50	29			1157.74	40		
1154.46	30			1156.65	29			1157.76	39		
1154.46	32			1156.74	29			1157.79	36		
1154.47	37			1156.80	29			1157.83	31		
1154.50	31			1156.81	31			1157.85	34		
1154.55	29			1156.83	30			1157.88	36		

Suspended Sediment Data
9/28/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1157.90	34			1158.83	29			1159.52	32		
1157.91	35			1158.84	33			1159.54	30		
1157.93	42			1158.84	37			1159.57	29		
1157.94	40			1158.88	34			1159.59	29		
1157.98	37			1158.93	31			1159.61	28		
1158.01	35	0	0	1158.95	29			1159.62	30		
1158.04	33			1158.96	30			1159.63	30		
1158.05	32			1158.97	31			1159.64	29		
1158.08	33			1159.00	31			1159.67	30		
1158.11	33			1159.02	29			1159.68	31		
1158.14	32			1159.03	32			1159.68	35		
1158.17	31			1159.04	37			1159.70	30		
1158.18	31			1159.06	28			1159.72	30		
1158.21	31			1159.09	28			1159.74	31		
1158.23	32			1159.10	27			1159.74	31		
1158.27	35			1159.12	30			1159.76	30		
1158.28	36			1159.13	31			1159.78	30		
1158.32	36			1159.15	30			1159.81	28		
1158.35	35			1159.16	30			1159.84	29		
1158.38	34			1159.18	26			1159.86	29		
1158.38	33			1159.21	27			1159.87	30		
1158.43	33			1159.24	27			1159.89	28		
1158.45	34			1159.27	29			1159.91	28		
1158.48	34			1159.29	29			1159.93	30		
1158.52	35			1159.33	29			1159.93	29		
1158.55	36			1159.34	32			1159.96	28		
1158.58	34			1159.36	31			1159.98	29		
1158.61	32			1159.36	29			1200.00	28		
1158.64	35			1159.38	35			1200.03	28		
1158.66	37			1159.38	33			1200.14	27		
1158.67	38			1159.41	29			1200.17	27		
1158.68	38			1159.42	28			1200.19	28		
1158.71	34			1159.45	28			1200.22	28		
1158.73	33			1159.48	29			1200.24	28		
1158.74	32			1159.49	30			1200.27	29		
1158.75	31			1159.50	30			1200.31	30		
1158.78	33			1159.51	30			1200.34	27		
1158.81	30			1159.52	29			1200.37	28		

Suspended Sediment Data
9/28/78 Track 1 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1200.39	29		
1200.42	29		
1200.45	27		
1200.48	28		
1200.52	27		
1200.54	30		
1200.57	30		
1200.60	29		
1200.64	28		
1200.67	29		
1200.69	29		
1200.72	29		
1200.75	27		
1200.77	28		
1200.79	31		
1200.81	30	-200 S	0
1200.82	28		
1200.84	29		
1200.87	29		
1200.89	29		
1200.95	29		
1200.99	28		
1201.02	29		
1201.08	28		
1201.12	28		
1201.21	28		
1201.28	27		
1201.35	29		
1201.38	28		
1201.41	29		
1201.42	27		
1201.44	32		
1201.49	28		
1201.59	27		
1201.67	27		
1201.75	27		
1201.78	26		
1201.81	28		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1201.85	27		
1201.86	29		
1201.92	27		
1201.96	28		
1201.97	27		
1202.01	30		
1202.04	28		
1202.06	28		
1202.07	33		
1202.10	31		
1202.13	31		
1202.16	30		
1202.19	29		
1202.23	28		
1202.28	28		
1202.31	28		
1202.36	28		
1202.39	29		
1202.41	34		
1202.42	33		
1202.44	31		
1202.46	29		
1202.49	29		
1202.51	30		
1202.54	28		
1202.56	30		
1202.60	29		
1202.64	28		
1202.66	28		
1202.66	32		
1202.69	29		
1202.69	30		
1202.76	29		
1202.80	29		
1202.83	28		
1202.84	31		
1202.87	30		
1202.89	28		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1202.93	27		
1202.96	27		
1203.04	27		
1203.06	29		
1203.07	27		
1203.09	29		
1203.14	27		
1203.19	27		
1203.22	27		
1203.23	30		
1203.28	28		
1203.33	28		
1203.39	27		
1203.41	27		
1203.43	30		
1203.47	28		
1203.52	27	-400 S	0

Suspended Sediment Data
9/26/78 Track 2
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1104.02	8	0	0	1105.28	24			1106.54	14		
1104.05	9			1105.31	23			1106.57	15		
1104.08	9			1105.34	22			1106.60	18		
1104.11	9			1105.37	20			1106.63	19		
1104.13	9			1105.40	19			1106.67	18		
1104.16	9			1105.44	16			1106.71	17		
1104.19	8			1105.47	14			1106.74	17		
1104.22	9			1105.51	12			1106.79	17		
1104.24	9			1105.54	12			1106.82	17	400 N	0
1104.28	9			1105.59	14			1106.86	16		
1104.31	9			1105.62	15			1106.89	15		
1104.34	9			1105.66	12			1106.92	12		
1104.39	9			1105.69	11			1106.96	11		
1104.42	10			1105.74	11			1106.99	10		
1104.47	10			1105.77	10			1107.03	9		
1104.50	9			1105.80	10			1107.06	10		
1104.53	10			1105.82	11			1107.08	13		
1104.57	10			1105.86	9			1107.11	16		
1104.61	10			1105.89	9			1107.13	18		
1104.65	10			1105.92	12			1107.16	20		
1104.69	10			1105.96	12			1107.21	21		
1104.72	10	200 N	0	1105.99	10			1107.26	22		
1104.75	10			1106.02	11			1107.29	20		
1104.77	10			1106.07	10			1107.31	21		
1104.81	12			1106.11	12			1107.35	21		
1104.83	17			1106.14	11			1107.38	20		
1104.86	20			1106.17	11			1107.42	18		
1104.89	28			1106.22	12			1107.46	18		
1104.91	37			1106.24	13			1107.51	15		
1104.94	40			1106.27	17			1107.54	15		
1104.99	38			1106.29	19			1107.58	15		
1105.03	36			1106.32	21			1107.61	16		
1105.06	34			1106.35	22			1107.65	18		
1105.09	32			1106.38	22			1107.68	15		
1105.13	30			1106.41	20			1107.71	15		
1105.16	29			1106.44	17			1107.73	17		
1105.19	28			1106.47	16			1107.76	19		
1105.23	29			1106.52	13			1107.79	18		

Suspended Sediment Data
9/26/78 Track 2 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1107.84	17		
1107.87	16		
1107.91	19		
1107.93	22		
1107.96	26		
1107.98	29		
1108.01	31	600 N	0
1108.04	28		
1108.08	28		
1108.12	28		
1108.14	29		
1108.17	32		
1108.20	29		
1108.23	29		
1108.28	28		
1108.31	27		
1108.34	27		
1108.39	29		
1108.42	32		
1108.44	32		
1108.47	33		
1108.51	32		
1108.53	33		
1108.57	30		
1108.60	26		
1108.63	27		
1108.66	31		
1108.69	38		
1108.72	37		
1108.76	37		
1108.79	34		
1108.83	28		
1108.86	24		
1108.88	27		
1108.92	26		
1108.98	25		
1109.01	25		
1109.04	23		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1109.07	21		
1109.11	19		
1109.15	18		
1109.18	18		
1109.23	17		
1109.26	18		
1109.29	17		
1109.32	17		
1109.36	14		
1109.39	14		
1109.43	14		
1109.46	13		
1109.51	15		
1109.56	15		
1109.60	15	800 N	0
1109.63	15		
1109.66	15		
1109.71	16		
1109.74	14		
1109.77	13		
1109.79	13		
1109.82	16		
1109.86	13		
1109.88	13		
1109.92	17		
1109.95	23		
1109.98	28		
1110.01	30		
1110.03	30		
1110.07	31		
1110.09	31		
1110.14	30		
1110.17	29		
1110.19	30		
1110.22	32		
1110.25	27		
1110.30	26		
1110.33	29		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1110.36	26		
1110.40	22		
1110.44	18		
1110.48	16		
1110.53	13		
1110.57	12		
1110.61	12		
1110.64	12		
1110.68	12		
1110.72	11		
1110.76	10		
1110.79	10		
1110.82	10		
1110.86	10		
1110.88	10		
1110.91	12		
1110.93	12		
1110.97	10		
1110.99	10		
1111.03	10		
1111.06	10		
1111.08	10		
1111.11	10		
1111.14	10		
1111.18	10		
1111.24	10	1000 N	0

Suspended Sediment Data
9/26/78 Track 3
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1749.11	7	1000 N	0
1749.14	4		
1749.17	8		
1749.19	11		
1749.23	5		
1749.26	10		
1749.29	8		
1749.32	12		
1749.35	11		
1749.38	7		
1749.41	12		
1749.44	8		
1749.47	13		
1749.50	13		
1749.53	16		
1749.57	13		
1749.60	14		
1749.63	8		
1749.65	9		
1749.68	10		
1749.71	5		
1749.74	5		
1749.78	5		
1749.80	8		
1749.83	11		
1749.86	10		
1749.89	5		
1749.93	21		
1749.96	9		
1749.98	11		
1750.01	12		
1750.05	16		
1750.08	9		
1750.10	13		
1750.13	11		
1750.18	6		
1750.21	6		
1750.24	7		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1750.28	5		
1750.30	16	800 N	0
1750.34	9		
1750.37	7		
1750.39	10		
1750.43	8		
1750.45	11		
1750.49	10		
1750.52	9		
1750.57	6		
1750.60	6		
1750.64	12		
1750.68	8		
1750.71	6		
1750.74	5		
1750.79	6		
1750.83	4		
1750.86	2		
1750.88	5		
1750.91	11		
1750.93	17		
1750.97	10		
1751.00	10		
1751.04	7		
1751.08	10		
1751.13	14		
1751.16	12		
1751.19	9		
1751.22	9		
1751.25	9		
1751.29	6		
1751.34	10		
1751.39	7		
1751.43	6		
1751.46	10		
1751.49	11		
1751.52	10		
1751.55	6		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1751.59	10		
1751.61	16		
1751.65	7		
1751.68	7		
1751.72	8		
1751.75	16		
1751.78	10		
1751.82	7	600 N	0
1751.84	9		
1751.88	8		
1751.90	11		
1751.94	11		
1751.97	10		
1752.01	8		
1752.04	10		
1752.08	4		
1752.11	3		
1752.14	7		
1752.19	10		
1752.23	5		
1752.25	5		
1752.28	7		
1752.31	11		
1752.34	7		
1752.37	13		
1752.40	5		
1752.44	5		
1752.49	16		
1752.52	7		
1752.54	10		
1752.58	7		
1752.60	8		
1752.63	11		
1752.66	8		
1752.70	5		
1752.73	7		
1752.76	6		
1752.78	9		

Suspended Sediment Data
9/26/78 Track 3 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1752.83	5		
1752.86	6		
1752.89	13		
1752.92	9		
1752.95	20		
1752.99	10		
1753.03	6		
1753.05	8		
1753.08	14		
1753.11	7	400 N	0
1753.13	17		
1753.18	8		
1753.20	10		
1753.23	9		
1753.27	7		
1753.29	9		
1753.33	11		
1753.35	27		
1753.38	6		
1753.41	11		
1753.47	9		
1753.50	7		
1753.53	6		
1753.56	7		
1753.59	8		
1753.62	9		
1753.64	10		
1753.68	11		
1753.71	8		
1753.75	9		
1753.79	4		
1753.81	8		
1753.84	4		
1753.88	4		
1753.91	4		
1753.94	7		
1753.98	6		
1754.02	6		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1754.04	9		
1754.08	10		
1754.10	10		
1754.13	10		
1754.16	8		
1754.20	8		
1754.23	12		
1754.28	10		
1754.33	8		
1754.36	16		
1754.40	7		
1754.43	8		
1754.46	9		
1754.49	5		
1754.52	13		
1754.55	11		
1754.58	11		
1754.61	9		
1754.65	3		
1754.68	6		
1754.70	6		
1754.73	8		
1754.76	7		
1754.79	9		
1754.81	15		
1754.84	9		
1754.85	26		
1754.88	10		
1754.89	16		
1754.91	13		
1754.94	11		
1754.97	7		
1754.99	10		
1755.03	8		
1755.06	5		
1755.09	8		
1755.13	10	200 N	0
1755.19	9		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1755.22	11		
1755.26	12		
1755.29	11		
1755.32	6		
1755.35	5		
1755.38	6		
1755.42	7		
1755.44	8		
1755.47	10		
1755.50	9		
1755.53	23		
1755.56	12		
1755.59	8		
1755.61	9		
1755.64	9		
1755.67	8		
1755.70	10		
1755.73	10		
1755.76	8		
1755.78	8		
1755.81	9		
1755.84	7		
1755.87	12		
1755.91	7		
1755.93	11		
1755.97	9		
1755.99	11		
1756.03	9		
1756.06	9		
1756.10	14		
1756.13	6		
1756.17	6		
1756.19	11		
1756.23	9		
1756.26	9		
1756.30	10		
1756.35	11		
1756.38	12		

Suspended Sediment Data
9/26/78 Track 3 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1756.40	20	0	0
1756.44	10		
1756.48	7		
1756.50	8		
1756.53	10		
1756.55	15		
1756.59	12		
1756.62	8		
1756.65	14		
1756.68	9		
1756.72	5		
1756.75	6		
1756.78	7		
1756.80	15		
1756.83	15		
1756.85	22		
1756.89	9		
1756.91	10		
1756.94	13		
1756.98	9		
1757.00	20		
1757.03	11		
1757.06	13		
1757.09	9		
1757.13	8		
1757.17	8		
1757.20	9		
1757.23	13		
1757.26	14		
1757.30	14		
1757.33	8		
1757.37	9		
1757.40	14		
1757.42	15		
1757.44	72		
1757.47	36		
1757.48	30		
1757.49	67		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1757.49	49		
1757.53	38		
1757.57	18		
1757.59	7		
1757.60	11		
1757.63	15		
1757.66	13		
1757.69	10		
1757.73	10		
1757.75	13		
1757.80	17	-200 S	0
1757.84	8		
1757.88	10		
1757.90	10		
1757.95	8		
1757.98	14		
1758.03	8		
1758.05	10		
1758.08	11		
1758.10	11		
1758.13	12		
1758.16	8		
1758.19	18		
1758.22	13		
1758.25	10		
1758.28	10		
1758.33	8		
1758.37	7		
1758.39	8		
1758.43	11		
1758.45	13		
1758.48	13		
1758.51	11		
1758.55	14		
1758.59	9		
1758.63	4		
1758.67	6		
1758.72	4		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1758.75	6		
1758.78	6		
1758.80	8		
1758.84	7		
1758.88	12		
1758.90	14	-400 S	0
1758.94	7		
1758.99	6		
1759.01	10		
1759.05	9		
1759.09	15		
1759.13	12		
1759.16	11		
1759.19	9		
1759.23	8		
1759.26	8		
1759.30	10		
1759.32	12		
1759.35	14		
1759.38	9		
1759.42	9		
1759.46	9		
1759.49	10		
1759.51	12		
1759.54	7		
1759.57	10		
1759.60	7		
1759.63	9		
1759.65	10		
1759.71	5		
1759.73	17		
1759.74	11		
1759.78	7		
1759.78	17		
1759.80	10		
1759.83	5		
1759.88	5		
1759.90	7		

Suspended Sediment Data
9/26/78 Track 3 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1759.93	5		
1759.94	5		
1759.95	22		
1759.97	9		
1759.98	9		
1800.00	12	-600 S	0
1800.03	9		
1800.06	6		
1800.08	5		
1800.10	7		
1800.12	16		
1800.13	18		
1800.16	10		
1800.20	9		
1800.23	11		
1800.25	12		
1800.30	7		
1800.33	10		
1800.37	10		
1800.40	8		
1800.43	4		
1800.46	4		
1800.48	11		
1800.52	12		
1800.57	5		
1800.60	10		
1800.66	4		
1800.68	10		
1800.73	5		
1800.75	5		
1800.80	6		
1800.83	8		
1800.85	8		
1800.88	9		
1800.92	12		
1800.96	7		
1801.00	8		
1801.03	7		
1801.03	9		
1801.06	13		
1801.08	21		
1801.10	18		
1801.11	13		
1801.11	21		
1801.13	17		
1801.16	14		
1801.19	14		
1801.22	16		
1801.25	18		
1801.29	14		
1801.31	17		
1801.35	18		
1801.38	20		
1801.41	14		
1801.45	17		
1801.48	22		
1801.53	19		
1801.56	8		
1801.59	4		
1801.63	9	-800 S	0

Suspended Sediment Data
9/28/78 Track 2
Depth is 25 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1210.80	22	-400 S	0
1210.91	21		
1211.03	22		
1211.04	22		
1211.14	21		
1211.32	21		
1211.54	20		
1211.77	20		
1212.04	20		
1212.29	20	-200 S	0
1212.42	21		
1212.54	21		
1212.76	20		
1212.87	20		
1213.00	21		
1213.17	21		
1213.34	21		
1213.51	21		
1213.67	21		
1213.86	21	0	0
1214.09	21		
1214.33	21		
1214.56	20		
1214.85	20		
1215.15	21		
1215.42	21		
1215.68	21	200 N	0
1215.91	21		
1216.14	21		
1216.23	20		
1216.29	22		
1216.34	22		
1216.40	21		
1216.50	21		
1216.58	21		
1216.64	20		
1216.68	21		
1216.75	23		

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W
1216.80	21		
1216.87	21		
1216.94	22		
1217.05	23	400 N	0
1217.29	22		
1217.52	23		
1217.66	22		
1217.89	21		
1218.04	22		
1218.17	23		
1218.30	22		
1218.48	23		
1218.69	24	600 N	0
1218.86	25		
1218.94	24		
1219.10	23		
1219.33	24		
1219.49	24		
1219.61	24		
1219.76	24		
1219.97	24	800 N	0

Time EST	Sed.Conc mg/l	Location (ft) N/S	E/W

Suspended Sediment Data
9/28/78 Track 3
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1226.60	24	800 N	-200 W								
1226.70	23										
1226.85	21										
1227.03	21										
1227.14	19										
1227.35	19										
1227.60	18										
1227.87	18										
1228.03	17										
1228.26	17										
1228.57	16										
1228.79	16										
1229.01	16	800 N	200 E								

Suspended Sediment Data
9/28/78 Track 4
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1231.13	18	600 N	200 E
1231.47	18		
1231.76	17		
1231.98	17		
1232.19	19		
1232.40	19		
1232.62	19		
1232.81	19		
1233.05	18		
1233.28	18		
1233.52	19		
1233.86	19		
1234.10	19		
1234.38	19		
1234.58	18		
1234.80	20		
1234.97	20		
1235.17	20		
1235.50	19		
1235.79	19		
1236.10	19		
1236.40	20		
1236.55	22		
1236.70	23		
1236.87	23		
1236.96	23		
1237.05	23		
1237.15	23		
1237.20	21		
1237.25	18		
1237.36	18		
1237.42	19		
1237.57	18		
1237.75	19		
1237.95	19		
1238.14	19		
1238.31	19	600 N	-200 W

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W

Suspended Sediment Data
9/28/78 Track 5
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1303.10	32	400 N	-200 W	1304.50	28						
1303.13	30			1304.55	27						
1303.17	31			1304.61	27						
1303.20	29			1304.65	28						
1303.24	31			1304.69	27						
1303.30	31			1304.80	27						
1303.33	32			1304.86	27						
1303.36	31			1304.92	26						
1303.38	29			1304.95	25						
1303.43	30			1304.96	28						
1303.46	32			1305.00	27						
1303.50	32			1305.06	26						
1303.55	32			1305.08	27						
1303.60	29			1305.13	25	400 N	200 E				
1303.61	32										
1303.64	29										
1303.66	30										
1303.71	29										
1303.75	31										
1303.80	29										
1303.85	29										
1303.90	26										
1303.93	27										
1303.98	29										
1304.01	27										
1304.03	26										
1304.08	26										
1304.11	26										
1304.11	28										
1304.16	26										
1304.23	26										
1304.26	29										
1304.29	29										
1304.30	27										
1304.35	28										
1304.39	29										
1304.43	27										
1304.45	28										

Suspended Sediment Data
9/28/78 Track 6
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1306.66	28	200 N	300 E
1306.68	27		
1306.71	28		
1306.81	27		
1306.88	28		
1306.92	29		
1306.93	28		
1306.93	30		
1306.96	28		
1307.02	29		
1307.03	28		
1307.07	28		
1307.11	28		
1307.16	27		
1307.19	30		
1307.28	29		
1307.39	28		
1307.48	28		
1307.55	29		
1307.68	28		
1307.75	27		
1307.83	27		
1307.84	28		
1307.88	27		
1308.04	28		
1308.17	27		
1308.27	29		
1308.29	27		
1308.34	27		
1308.36	30		
1308.36	28		
1308.39	30		
1308.42	27		
1308.48	28		
1308.53	29		
1308.58	28		
1308.64	28		
1308.65	30		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1308.68	29		
1308.68	30		
1308.71	27		
1308.79	28		
1308.86	28		
1308.93	29		
1308.95	30		
1308.96	28		
1309.01	28		
1309.08	28		
1309.13	28		
1309.19	29		
1309.25	28		
1309.31	28		
1309.36	29		
1309.37	32		
1309.41	28		
1309.47	28		
1309.49	30		
1309.49	31		
1309.53	29		
1309.58	28		
1309.62	28		
1309.64	29		
1309.68	29		
1309.69	28		
1309.72	28		
1309.74	29		
1309.77	27		
1309.78	31		
1309.82	27		
1309.84	29		
1309.86	27		
1309.93	29		
1309.93	28		
1309.98	29		
1309.99	28		
1310.00	29		

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1310.08	30		
1310.08	28		
1310.14	29		
1310.17	29		
1310.19	29		
1310.23	29		
1310.25	29		
1310.29	29		
1310.33	29		
1310.37	30		
1310.41	33		
1310.43	35		
1310.48	39		
1310.50	42		
1310.51	42		
1310.54	45		
1310.57	46		
1310.60	46		
1310.62	46		
1310.63	45		
1310.64	44		
1310.66	44		
1310.67	43		
1310.69	41		
1310.71	36		
1310.71	34		
1310.73	31		
1310.74	31		
1310.77	29		
1310.77	29		
1310.80	39		
1310.81	42		
1310.83	47		
1310.84	51		
1310.87	55		
1310.88	58		
1310.90	57		
1310.92	56		

Suspended Sediment Data
9/28/78 Track 6 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1310.94	56			1311.79	32			1312.69	44		
1310.95	55			1311.80	31			1312.72	43		
1310.97	54			1311.84	30			1312.73	44		
1310.98	53			1311.86	30			1312.79	44		
1310.99	55			1311.87	31			1312.83	42		
1311.00	56			1311.89	30			1312.84	41		
1311.04	52			1311.90	30			1312.87	41		
1311.05	52			1311.93	30			1312.89	42		
1311.08	57			1311.95	30			1312.90	42		
1311.11	60			1311.98	31			1312.92	39		
1311.14	62			1312.00	31			1312.97	41		
1311.17	64			1312.01	31			1312.99	37		
1311.19	69			1312.04	30			1313.02	36		
1311.22	69			1312.07	32			1313.04	34		
1311.24	62			1312.09	35			1313.07	34		
1311.24	59			1312.11	36			1313.09	33		
1311.27	51			1312.14	39			1313.12	32		
1311.30	46			1312.17	46			1313.15	31		
1311.32	44			1312.22	43			1313.18	32		
1311.33	44			1312.22	41			1313.21	31		
1311.34	45			1312.24	38			1313.25	32		
1311.37	45			1312.25	35			1313.28	32		
1311.41	42			1312.28	33			1313.31	31		
1311.43	39			1312.30	29			1313.33	32		
1311.46	36			1312.33	28			1313.35	32		
1311.46	35			1312.35	28			1313.39	33		
1311.49	31			1312.38	28			1313.42	33		
1311.50	30			1312.43	28			1313.43	33		
1311.53	29			1312.46	30			1313.45	34		
1311.55	29			1312.49	31			1313.49	35		
1311.58	29			1312.50	31			1313.53	36		
1311.59	30			1312.53	32			1313.56	37		
1311.63	30			1312.55	34			1313.59	36		
1311.65	29			1312.56	38			1313.62	35		
1311.69	29			1312.59	41			1313.65	37		
1311.72	30			1312.60	41			1313.71	38		
1311.73	30			1312.62	44			1313.75	39		
1311.76	29			1312.66	44			1313.80	41		

Suspended Sediment Data
9/28/78 Track 6 (continued)
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1313.84	39			1315.03	51			1315.96	41		
1313.86	40			1315.06	50			1315.98	39		
1313.88	38			1315.12	49			1316.00	39	200 N	-300 W
1313.90	37			1315.14	48						
1313.93	39			1315.17	50						
1313.96	40			1315.19	51						
1313.99	42			1315.21	50						
1314.04	44			1315.24	47						
1314.05	44			1315.27	48						
1314.09	46			1315.31	52						
1314.12	46			1315.33	53						
1314.14	45			1315.35	52						
1314.17	46			1315.36	52						
1314.22	46			1315.39	53						
1314.25	45			1315.42	56						
1314.27	44			1315.46	58						
1314.30	46			1315.49	62						
1314.32	45			1315.52	64						
1314.36	44			1315.55	67						
1314.40	46			1315.57	68						
1314.43	48			1315.59	68						
1314.45	48			1315.62	66						
1314.50	50			1315.65	64						
1314.56	49			1315.65	63						
1314.60	44			1315.67	60						
1314.63	47			1315.70	58						
1314.67	47			1315.70	57						
1314.71	48			1315.72	55						
1314.72	49			1315.76	55						
1314.74	48			1315.77	56						
1314.77	47			1315.79	55						
1314.79	46			1315.80	54						
1314.82	45			1315.84	54						
1314.83	45			1315.87	53						
1314.87	46			1315.87	52						
1314.92	47			1315.91	49						
1314.96	47			1315.92	45						
1315.00	50			1315.94	42						

Suspended Sediment Data
9/28/78 Track 7
Depth is 25 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1320.80	24	200 N	-300 W	1322.03	29						
1320.84	24			1322.07	26						
1320.87	25			1322.12	24						
1320.91	24			1322.15	24						
1320.97	24			1322.17	24						
1320.99	24			1322.22	24						
1321.03	23			1322.25	23						
1321.05	27			1322.29	21						
1321.08	24			1322.32	21						
1321.12	22			1322.34	23						
1321.16	21			1322.37	21						
1321.19	21			1322.40	21						
1321.22	21			1322.44	21						
1321.25	21			1322.47	22						
1321.28	21			1322.51	22						
1321.32	21			1322.56	22						
1321.34	21			1322.59	21						
1321.37	21			1322.63	21						
1321.40	21			1322.66	20						
1321.45	21			1322.68	20						
1321.48	21			1322.71	20						
1321.51	21			1322.74	20						
1321.54	21			1322.77	21						
1321.58	21			1322.82	21						
1321.61	21			1322.86	21						
1321.65	21			1322.89	20						
1321.68	21			1323.10	21						
1321.72	21			1323.28	20						
1321.76	21			1323.34	20						
1321.78	22			1323.46	20						
1321.82	25			1323.54	21						
1321.84	27			1323.68	20						
1321.87	25			1323.84	19						
1321.90	25			1323.92	19						
1321.93	24			1323.97	21						
1321.96	25			1324.05	21						
1321.98	26			1324.11	19	200 N	300 E				
1322.01	28										

Suspended Sediment Data
9/28/78 Track 8
Depth is 25 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1327.57	18	600 N	300 E								
1327.78	19										
1327.90	18										
1328.07	19										
1328.25	19										
1328.57	18										
1328.91	20										
1329.10	20										
1329.47	20										
1329.78	20										
1330.09	20										
1330.50	21										
1330.97	21										
1331.32	21										
1331.78	21										
1332.03	20										
1332.37	20										
1332.70	20										
1332.95	20										
1333.37	20										
1333.64	20										
1334.05	19										
1334.41	19										
1334.69	19										
1334.99	18										
1335.21	19										
1335.40	18	600 N	-300 W								

Suspended Sediment Data
9/28/78 Track 9
Depth is 50 feet

Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W	Time EST	Sed.Conc mg/l	Location (ft) N/S	Location (ft) E/W
1736.50	12	200 N	0								
1736.84	12										
1737.26	12										
1737.68	11										
1738.81	12	0	0								
1738.96	16										
1739.12	19										
1739.15	16										
1739.18	17										
1739.24	18										
1739.27	15										
1739.32	16										
1739.36	15										
1739.39	13										
1739.55	13	-200 S	0								
1739.61	15										
1739.67	15										
1739.69	14										
1739.85	16										
1739.99	17										
1740.08	15										
1740.29	13										
1740.47	12										
1740.62	11										
1740.75	11	-400 S	0								

Near Bottom Currents in the Lower James and Elizabeth Rivers

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Near Bottom Currents in the Lower James and Elizabeth Rivers

A knowledge of currents in the Lower James and Elizabeth Rivers has been of interest for the longest time to the commercial and military shipping interests. This may be illustrated by the events which led to the historic naval engagement between the USS Monitor and the CSS Virginia in Hampton Roads.

A systematic survey of the currents in this region, undertaken as part of a comprehensive regional survey by the US Coast and Geodetic Survey, was reported by Haight, et al. (1930). While comprehensive in areal extent, this survey, responsive to the needs of port operation, dealt primarily with surface currents in the region of interest for the present study. The 1930 results are further compromised, for the present study, by the substantial alteration of the dredged channels since that time.

After the channel was dredged, the Coast and Geodetic Survey again measured the currents, this time at several depths, in 1951. Between then and now, the construction of the Craney Island Disposal Area again changed the current patterns in the study area. These changes are noted by Neilson and Boulé (1975).

The significance (and difficulty) of current measurements in the study region is illustrated by noting that, in 1951, the first technical report produced by the newly formed Chesapeake Bay Institute (Pritchard and Burt, 1951) was titled

"An inexpensive and rapid technique for obtaining current profiles in estuarine waters". This report, an indication of the agenda of the new institution, introduced a biplane current drag, subsequently called the Pritchard drag. In operation, the drag is manually deployed over the side of an anchored vessel, the current being related to the angle from the vertical caused by the current pulling the drag to the side while a weight tends to return it to the vertical. It is of interest, from the perspective of nearly thirty years, that the qualities of low cost and rapidity of operation were emphasized in the title while those of accuracy and precision were not so emphasized.

A study, named Operation Oyster Spat, was quickly initiated using the new device, and the data from station J-17, located in the main channel just to the south of Burwell Bay, have become famous as the prototype mean flow pattern for partially mixed estuaries. Another station from Operation Oyster Spat was located upriver of J-17, at Deep Water Shoal, the upper limit of oyster production in the James.

A subsequent study, Operation James River (Shidler and MacIntyre), was performed 13 years later by VIMS and other cooperating organizations. This study was conducted after the Craney Island Disposal Area had been built, and the currents in the lower part of the study area were shown (Neilson and Boulé, 1975) to have been shifted to the north by the construction. In contrast to the earlier study by Chesapeake

Bay Institute, Operation James River concentrated on obtaining a wide spatial coverage of the lower James River with short time series rather than long series at a few locations.

A further study using current meters in the James River part of the study area was undertaken by the U.S. Army Corps of Engineers in the support of the calibration for the Chesapeake Bay Model. For this study (Ruzecki and Markle, 1974) current meters were placed at several depths at four river transects in the study area: at the mouth of the James, at the upper limit of the Newport News Shipyard, near the downstream part of Burwell Bay and off Hog Point. Ten stations were occupied in these transects, the ones at the mouth for a period of 19 days and the others for periods of about four days each. In total thirty-three current meters were deployed at these stations. Some of the data have been analyzed (Lewis, 1975) at the downriver transects to obtain tidal constituents.

In June of 1972, the entire Chesapeake Bay watershed, including the James River, was inundated with rains from tropical storm "Agnes". As part of a massive study to examine the effects of this flooding, current meters were again set in the study area, occupying the transect off of the Shipyard (Jacobson and Fang, 1977) for a period of eight days.

From the standpoint of maintenance dredging, the Elizabeth River is much more important relative to the James River than its areal extent would suggest, for the majority of the Elizabeth has been dredged to a substantial depth. One result of the channel depth and the short length of the Elizabeth is that the gravitational flow, which results in estuarine circulation in longer estuaries with greater fresh water inflow, becomes a rapid adjustment of the stratification in the Elizabeth to that of the James and to rainfall events (Neilson, 1975). Thus, circulation in the Elizabeth River is expected to be primarily tidal, augmented with events of two layer circulation consisting generally as an intrusion of salty water from the James upriver in the Elizabeth along the bottom. As the two layer circulation occurs in distinct events it may or may not be evident in any particular set of current records obtained in the Elizabeth River.

Several sets of current data have been obtained in the Elizabeth River over the years. A set of four stations was occupied in 1974 for a period of two and a half days, the stations located in the main stem and each of the three branches of the river. The 12 current meters used in this study were deployed at depth increments of about six feet with the uppermost instrument at a depth of six feet (Cerco and Kuo, unpublished ms.). The U.S. Navy has obtained several sets of current meter records in the part of the Elizabeth adjacent to the Norfolk Navy Base. One of these sets (S. Jenkins, Scripps Institute of Oceanography) resides at the Scripps Institution of Oceanography. Another (Ruzecki and Ayres, 1974) had current meters located near the bottom on both sides of the ship channel of the Elizabeth River close to its junction with the James

River for a period of about 20 hours under conditions of low river flow and spring tides. A third set of current meters was deployed in conjunction with the present investigation near the Craney Island landfill site for a period of 28 days with meters at depths of 3, 6, 12 and 15 meters during September and early October of 1978. As these last data have not yet been finally analyzed, they are not included in the interpretation.

One of the experimental constraints with current meter measurements is that strings of current meters cannot be placed in shipping channels, because they will be destroyed by the shipping traffic. The string of meters placed in the Elizabeth for the present study was placed at the edge of the shipping channel, and it was still damaged by shipping. As a result of this constraint, there are few direct measurements of currents in the middle of shipping channels. The writer knows of only one current transect obtained in the Newport News Channel. That transect has never been published, as it was ancillary to a larger experiment, and the current meters were not ever calibrated. The data do show, however, that the current in the transect reached a local maximum speed (during both flood and ebb) within the dredged channel just below the level of the surrounding river bottom. In both instances, the current speed at this maximum was about the same as that at the surface.

Another method of measuring currents, drogued buoys, has also been employed in the study region with some success. This method does not produce long time series, but it can be applied in the channel areas where current meters are in jeopardy. It is also compatible with a simultaneous description of currents over a wide area, such as the entrance channel of the Elizabeth River or the breadth of Hampton Roads. Using drogued buoys, surface current data have been obtained within the Elizabeth River and Hampton Roads in several projects associated with sewage effluents, (Neilson and Boulé, 1975; Welch and Neilson, 1976); bridge tunnel construction, (Fang, et al., 1972; Fang, 1979); and port facility siting efforts, (Fang, 1975). In the Elizabeth River, the surface data gathered from these various efforts have been compiled into a single Elizabeth River Circulation Atlas, (Munday et al., this report) which segregates surface current patterns by tidal phase and wind velocity classes. Another use of drogued buoys was made in the Elizabeth River directly in support of the present effort. A cross-sectional velocity estimate was constructed from drogued buoy data in a region crossing and including the main ship channel of the Elizabeth River. This estimate is of significance beyond this project because it is the first synoptic cross sectional current velocity determination which has been made entirely using drogued buoys located by remote sensing in a concurrently occupied shipping channel. It has been reported as such by Munday, et al (1980) in its context as a new technique which is applicable to current determination in busy port areas.

A number of current studies have been performed in the region of interest. Even with these studies, little direct evidence exists for formulating estimates of currents near the bottom of dredged channels, the focus of interest for the present study. For this reason, the formulation of the estimate for current speeds at the bottom of dredged channels in the study area will be based partly on indirect measurements and inferences. The remainder of this report is concerned with these estimates for the Elizabeth River, the Newport News Channel, and the Rocklanding Shoals Channel, the major dredged channels in the study area.

Elizabeth River Current Calculation

The Elizabeth River is complex in its geometry, but it also is relatively short. The National Ocean Survey Tide and Tidal Current Tables show time differences between tidal height and tidal currents as they propagate down the 24 kilometer length of the deep channel. The time of high tide, according to these tables, is within 15 minutes of being simultaneous at all stations, while tidal currents reach slack water about 30 minutes or less after slack water at the river mouth, near Craney Island. In addition, the typical tidal ranges at all stations are within 10% of those at Sewell's Point, at the mouth of the Elizabeth River. As all of these time differences are small with respect to the 12.42 hour (745 minute) semi-diurnal tidal period, an estimate of the tidal currents can be made using tidal prism calculations, which are based on the assumption that the water surface in the Elizabeth River is at all times a level surface, implying that slack currents occur simultaneously with extreme tidal heights and that extreme tidal heights are simultaneous and equal throughout the basin. Because of this assumption, the current estimates will be made only in the enclosed part of the Elizabeth River, that portion south of the outer levee of the Craney Island Disposal Area ($36^{o}55'27"N$).

Under this assumption, the volume of water which passes through any cross-section of the river equals the product of the surface area upriver from that section and the change in water level. If the water levels considered are successive tidal height extremes, the volume is called the intertidal volume. If the intertidal volume of water above a chosen cross section is assumed to be supplied by water moving through the section during the rising and falling tide, a cross-sectional average flow speed can be calculated for the tidal phase (rising or falling tide). The peak speed averaged over the cross section during a tidal cycle is $\pi/2$ times this average flow speed under the assumption that the speed describes a half-sinusoid between successive times of slack water (or height extremes). Thus, a volumetric calculation is available which permits calculation of cross-sectional average flow speeds (and peak speeds) from a consideration of surface areas and cross-sectional areas in a short estuary of complex geometry. This calculation has been used to estimate currents in the Elizabeth River.

If a distance scale (x) is defined extending from the head of each tributary and the main course of the river, an incremental surface area dA(x) can be defined so that the total area upriver of a given point, x_o, is $A(x_o) = \int_o^{x_o} dA(x) + \sum_i T_i$, where T_i is the total surface area of the i^{th} tributary entering the river above x_o. If $A(x_o)$ is relatively independent of water level, corresponding to nearly vertical banks, the total volume of water entering the river above a cross-section at x_o is $A(x_o)\Delta H$, where ΔH is the change in water level. With the river cross-sectional area at x_o denoted as $C(x_o)$ and the time difference between the two water levels denoted as Δt, the flow velocity averaged over the cross section and the time interval becomes $\overline{v}(x_o) = \frac{A(x_o)}{C(x_o)} \frac{\Delta H}{\Delta t}$. In our flow calculations, the quantity $\frac{A(x)}{C(x)}$ is evaluated for a set of chosen cross sections, and $\frac{\Delta H}{\Delta t}$ is evaluated for each of the intervals between tide height extremes during the year 1975, an arbitrary year presumed to be typical, the values being grouped and presented as a cumulative frequency curve.

The Elizabeth and its tributaries were subdivided into 26 segments according to the scheme used by Cerco and Kuo (unpublished ms.), and the mean low water areas were measured for each segment. The measurements were made from National Ocean Survey charts 12245 and 12253, which together cover the entire tidal extent of the Elizabeth and its tributaries at a scale of 1:20,000. Because the basin does not possess extensive marsh areas, indeed is substantially bordered by vertical bulkheads, the areas measured were applied to the entire tidal range for current computations. The areas are shown in table 1, and the segmentation scheme is shown in figure 1. To calculate tidal heights, tidal predictions from Sewell's Point were gathered for the year 1975, and values of $\Delta H/\Delta t$ were calculated for each tidal cycle, segregated into rising and falling tides. As the two cumulative frequency curves are nearly identical for Sewell's Point, we present only a single curve in figure 2. Selected percentile values are presented in table 2. The mean value is 3.48×10^{-3} cm/sec, while the median is 3.40×10^{-3} cm/sec. Mean current speeds for each cross-section are also shown in table 1. The calculated mean cross-sectional values are shown, with other information, on figure 3 as a set of line segments connecting calculated points.

Verification of the data can be done with comparison to other work. The areal measurements are compared with previous work by Cronin (1972). The mean current speeds are verified by comparison with a drogued buoy cross-sectional current determination done specifically for the present effort.

In comparing areal measurements of the rivers, allowance must be made for the difference in river mouth locations between Cronin (1972) and Cerco and Kuo (unpublished ms.). If this is done by using Appendix A in Cronin (1972), and the value for the Lafayette River is added to that of the Elizabeth

Table 1. Measured Segment Areas and Mean Speed Calculation for the Elizabeth River

Segment	Area ($x10^5 m^2$)	Cumulative Area ($x10^5 m^2$)	Downriver Bounding Cross-Section Area ($x\ 10^3 m^2$)	Multiplier ($x\ 10^2$)	Mean Current Speed (cm/sec)
2	5.84	5.84	0.53	11.01	3.8
3	5.73	11.57	0.43	26.91	9.4
4	5.91	17.48	0.57	30.67	10.7
5	14.02	31.50	0.69	45.65	15.9
6	8.80	40.30	1.79	22.51	7.8
7	8.52	48.82	3.25	15.02	5.2
8	8.18	57.00	3.08	18.51	6.5
9	10.82	67.82	2.52	26.91	9.4
10	9.99	77.81	2.78	27.99	9.8
11	4.96	82.77	4.78	17.32	6.0
12	11.24	141.13*	6.28	22.47	7.8
13	29.03	170.16	11.78	14.44	5.0
14	42.30	271.18*	9.13	29.70	10.4
15	46.54	317.72	10.20	31.15	10.9
16	39.19	415.42*	11.52	36.06	12.6
17	46.88	462.30	14.56	31.75	11.0
E2	19.64	19.64	1.46	13.45	4.7
E3	16.38	36.02	2.00	18.01	6.3
E4	11.10	47.12	3.52	13.39	4.7
W2	15.93	15.93	0.84	18.96	6.6
W3	23.06	38.99	1.36	28.67	10.0
W4	19.73	58.72	2.09	28.10	9.8
L1	17.73	17.73	0.99	17.91	6.2
L2	18.33	36.06	0.69	52.26	18.2
L3	22.45	58.51	0.86	68.03	23.7

*Includes tributary contribution

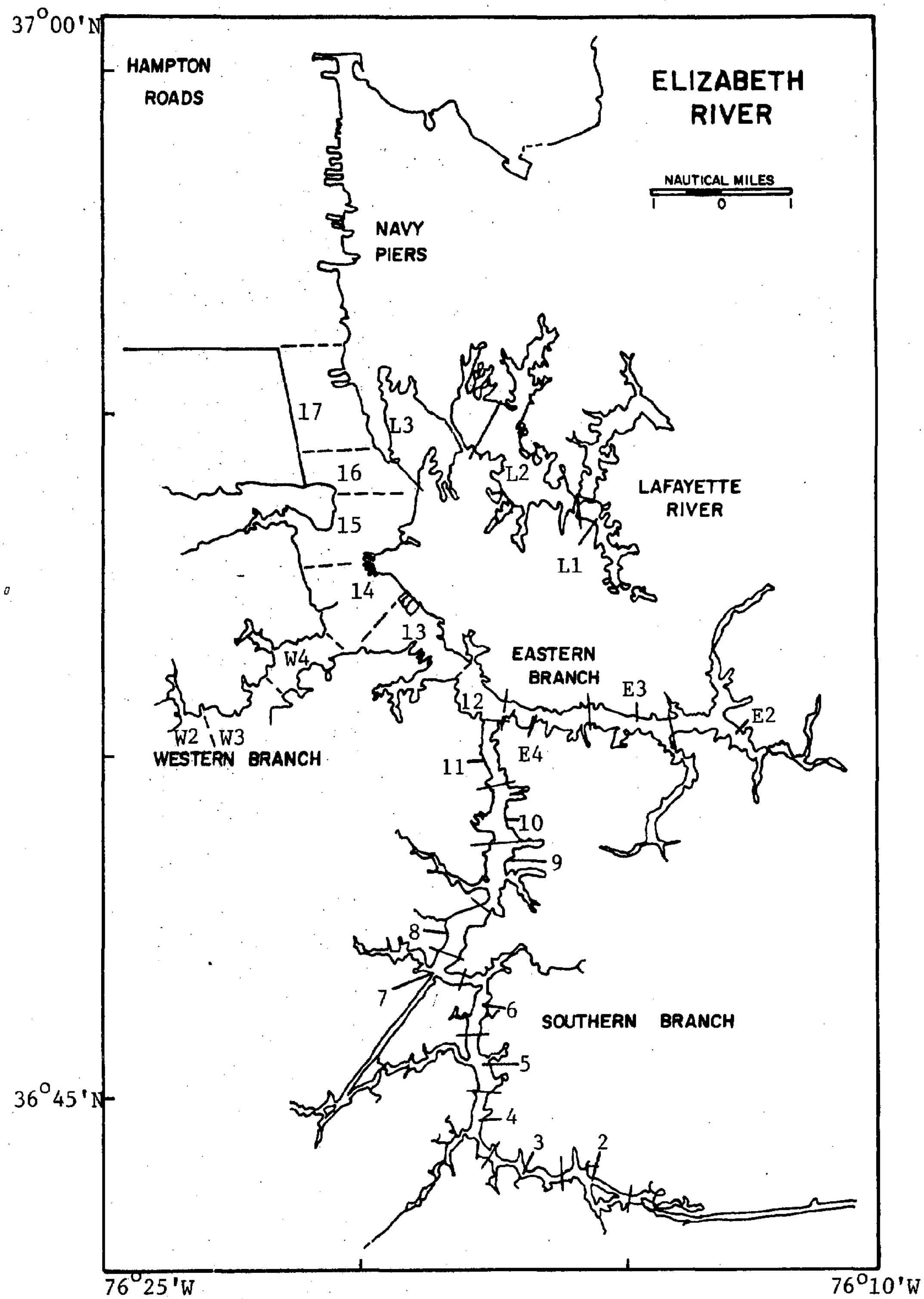


Figure 1. Segmentation of the Elizabeth River basin for tidal prism calculations (after Cerco and Kuo, unpublished ms.).

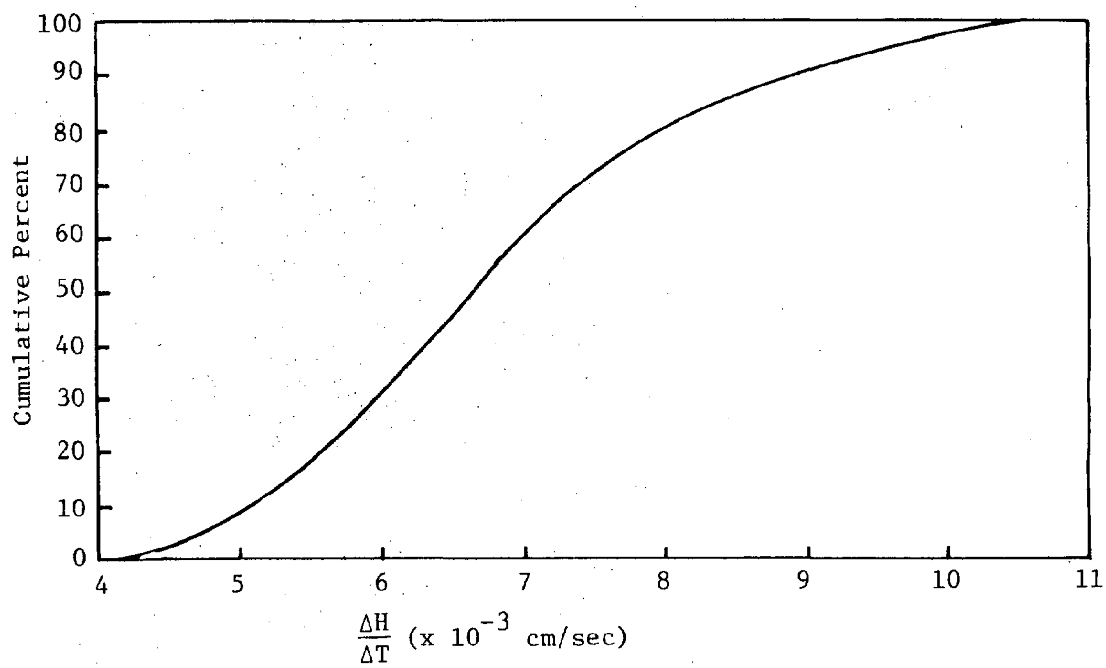
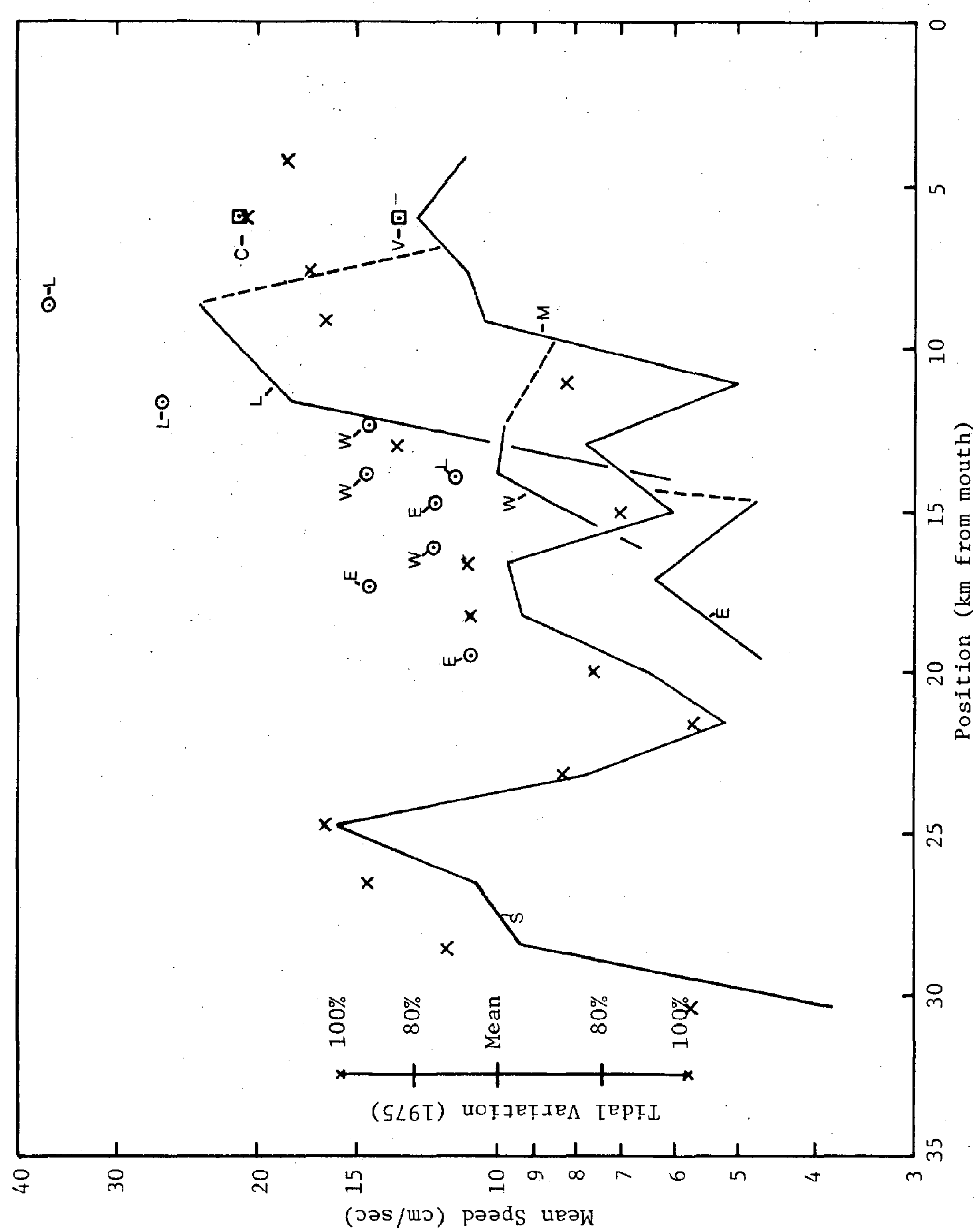


Figure 2. Cumulative rates of average predicted height change over a half tidal cycle at Sewell's Point, Hampton Roads, Virginia.

Table 2. Percentage Points for Predicted Average Height Change Over a Half Tidal Cycle at Sewell's Point, Hampton Roads, Virginia. Sample Period is 1975.

Percentage of Occurrences Less Than	Level
.1	4.0
.5	4.3
1	4.5
2	4.6
5	4.9
10	5.2
15	5.4
20	5.6
25	5.8
30	6.0
35	6.2
40	6.4
45	6.6
50	6.7
55	6.8
60	7.0
65	7.2
70	7.4
75	7.7
80	8.0
85	8.5
90	8.9
95	9.5
98	9.8
99	10.2
99.9	10.8

Figure 3. Mean current speeds for the Elizabeth River and its tributaries. M: Main Stem, S: Southern Branch, E: Eastern Branch, L: Lafayette River. Dashed lines show connections between tributaries and the main stem. X's and ⊖'s are corresponding values for model study (Cerco and Kuo, unpublished ms.). The X's are the values for the main stem, while the O's are labeled by tributary. The point V-⊡ is the mean value calculated from the drogued buoy study, while C-⊡ is the estimated time mean value of cross-sectional peak speed used for model comparison. Variation bars show extent of variability due to tidal variability around time mean values.


Mean Speed (cm/sec)
Position (km from mouth)
Tidal Variation (1975)
100%
80%
Mean
80%
100%

River, the total area for the river from our measurements becomes 566.08 x $10^5 m^2$ while that from Cronin (1972) is 518.8 x $10^5 m^2$. The resulting difference amounts to 8% of our measured value. The estimated accuracy of the present area measurements is 1%, so a real discrepancy exists between the two sets of measurements.

A further comparison was made between the transport predicted by the tidal prism measurements and that measured (Munday, et al., 1980) for that purpose on September 19, 1978. The verification measurements were made near the outer boundary of section 16 as defined by Cerco and Kuo just north of Tanner Point. The resulting interpolated velocity section (fig. 4) was planimetered for areas between each 5 cm/sec isotach neglecting the deep area towards the right of the section, which is part of a berthing area surrounded by piers, and plausibly has little transport. The areas measured are bounded by the dashed line with the dotted extension, the solid line where there is no dashed line, and the free surface. This measured cross-sectional mean speed was 22.5 cm/sec. To compare with mean speeds shown in figure 3, this value was multiplied by the ratio of mean $\Delta H/\Delta t$ to that calculated for the time of the measurements using Sewell's Point tide station observations. It was again corrected for the time within the tidal cycle (estimated as 105 minutes before high slack water) of the measurements under the assumption of a sinusoidal height variation with time. The resulting mean speed value, 13.3 cm/sec, is shown in figure 3 and is comparable to the value of

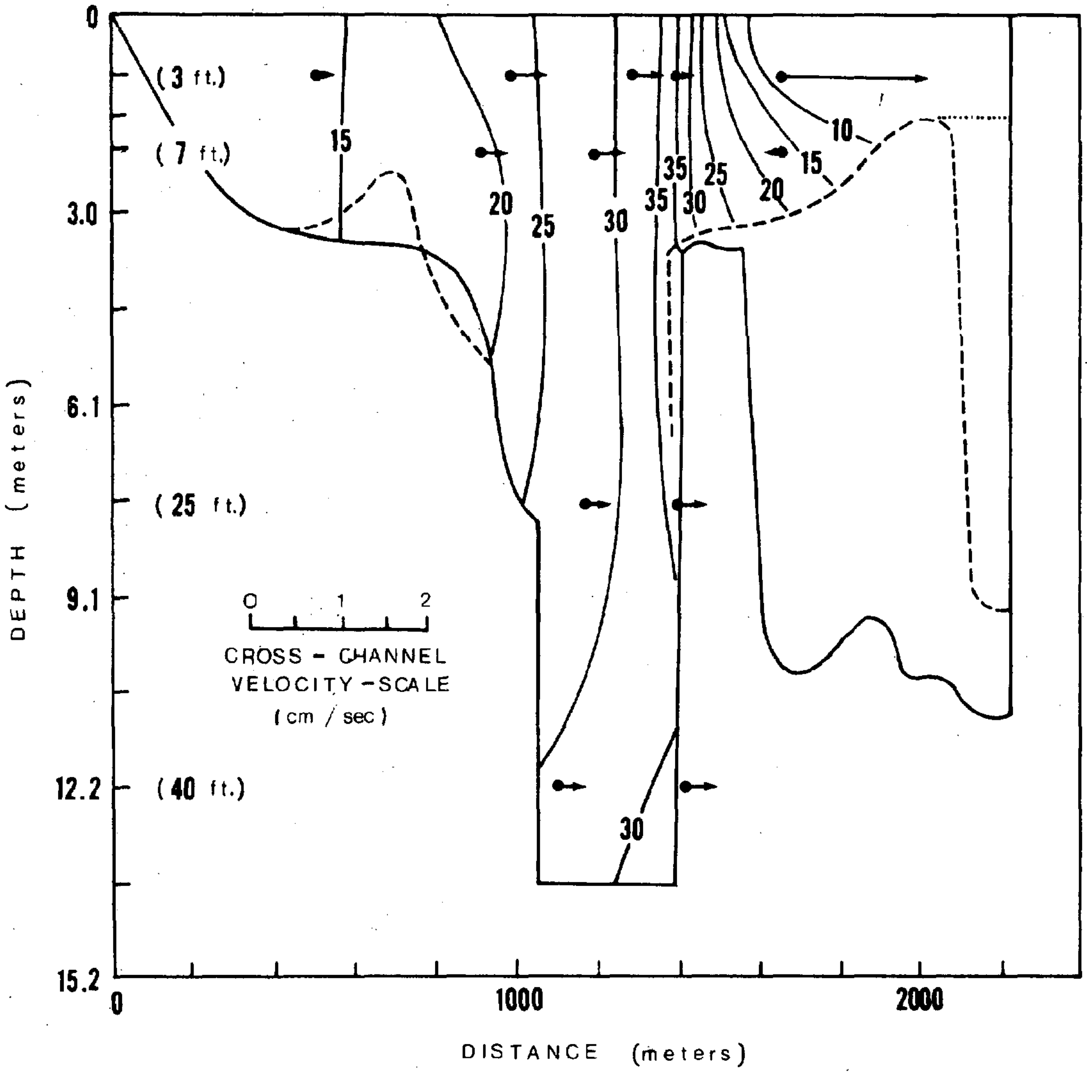


Figure 4. Synoptic flood tidal velocity cross section using drogued buoys and photogrammetry on September 19, 1978. Section is located within segment 17 looking towards the river mouth. Isotachs have units of cm/sec.

12.6 cm/sec obtained from tidal prism calculations. The two average cross section currents agree to within 6% for this verification. This agreement is well within the limits of experimental accuracy.

A final comparison is shown in figure 3 between mean current speeds from the tidal prism calculations and speeds calculated from amplitude values derived from the current meter measurements of Cerco and Kuo. These latter are shown as x's on figure 3 for the main stem and southern branch of the Elizabeth River, and as circled points for the other tributaries. Comparing the two sets of values, agreement is relatively close (<15%) in the middle part of the main and southern branch segment, but it is reduced towards the mouth and in the smaller tributaries, the Cerco and Kuo values being systematically higher than the tidal prism calculations by from 20 to 100%. Because these values were obtained by current meters located in or near the central channel, the hypothesis was formulated that the current meter data were obtained in a rapidly flowing part of the river and that the average speed was smaller than the measured speed in places where the channel occupied a relatively small part of the cross section. To test this hypothesis, the mean speed from the prism measurements for section 16 was multiplied by the peak-to-mean speed ratio from the cross section in figure 4, (37.5 cm-sec^{-1}/22.5 cm-sec^{-1} = 1.67). The resulting value, 20.8 cm/sec, was within 2% of the mean value of 20.4 obtained from Cerco and Kuo's results.

This supports the hypothesis that the current meter values were associated with high velocity cores in the cross-sectional flow. If the flow pattern in figure 4 is typical, it is the high speed core value which is most appropriate to the near-bottom part of the channels, where maintenance dredging is needed. This finding is similar to that obtained from the current profile from the Newport News Channel disclosed earlier.

For the Elizabeth River, then, the speed values associated with the Cerco and Kuo current meter results, denoted by X's in figure 3, are our best estimate for values of currents in deep channels for which maintenance dredging is required. These values are mean values, and the variability due to varying astronomical tides is given by the range bars in figure 3.

Newport News Ship Channel Current Calculation

The method used for estimating currents in the Elizabeth River, while applicable to small enclosed basins with little freshwater flow, is not suitable for calculations in the main stem channels of the James River. The major reasons are that the tidal propagation in the main stem of the James has to a large extent the character of a propagating wave, and so the tidal prism estimating technique must be modified. Also, the James has current associated with river flow and an estuarine circulation which is not accounted for in the tidal prism method. On the other hand, the Newport News Ship channel has a relatively uniform width and project depth along its length, so currents can be plausibly supposed more nearly uniform along its length than in a confined port area. Accordingly, it seems reasonable to apply data from a small number of current meters to the entire length of the Newport News Ship Channel, while such generalization is not supported in the Elizabeth. The basis for the estimate in Newport News Ship Channel is current meter data.

Current meters are sensitive to the vector sum of currents from all causes. If we have available time as an independent variable, a current record can be decomposed into a mean value, representing river flow, estuarine circulation and the mean of weather events during the period of record, an oscillatory tidal signal, representing the major current component in the region of interest, and a time-varying flow due to storm surges, local wind response and other weather related events as Kiley (1980) has done in the York River. Under these conditions, the best estimate of mean currents is the mean non-tidal value for the record. Also, the best estimate of variability from non-tidal currents is the non-tidal variability of the record. The tidal variability is obtainable from the predictions or an astronomical tidal forcing function, and measured tidal variability can be biased to provide an improvement over the record data itself by taking the regularity of the tides into account. Currents from short term VIMS moorings have been treated this way by Lewis (1974), and Boon and Kiley (1978) report another method using least squares fits for longer period data. Both of these methods are useful for segregating the total time series into tidal and non-tidal parts, with determinations of astronomical tidal constituents as at least part of their result. Both of these approaches require computers to be practically implemented, although one (Boon and Kiley, 1978) can be performed with a calculator and a special set of auxiliary tables. Both of these methods also require a regularly spaced time series of current measurements as input.

Another analysis method to estimate mean currents variability has been developed for the present estimate for which a hand calculator and tidal height tables are sufficient, particularly if the estimate to be made is near a primary tidal station, such as that at Sewell's Point. For this method, the times and speeds of current maxima are obtained from the record, and corresponding values for $\Delta H/\Delta t$ are calculated from the tide tables. The current values are then linearly regressed on the $\Delta H/\Delta t$ values, and the mean value of peak current is obtained from the long term mean value of $\Delta H/\Delta t$, already developed for Sewell's Point in the Elizabeth River calculation.

In the present instance, only one of the previously noted current studies, that of the Coast and Geodetic Survey in 1969 (DeRycke, unpublished data), actually deployed current meters within the deep channel of the Newport News Ship Channel. Two of these stations were located in the channel itself, one (station 2) at the eastern end and one (station 3) at the channel edge in mid channel. These were both occupied for about 15 days with Roberts Radio current meters, with occasional comparison readings made using drogued buoys. The times, speeds and directions for the flood and ebb current peaks obtained from this data are shown in Appendix 1 along with corresponding values of $\Delta H/\Delta t$ (in feet/minute, most easily obtained from the Tide Tables). These data, segregated into ebb and flood directions, were then analyzed for a regression relation of the form

$$\text{Speed (knots)} = B_o + B_1 \times \Delta H/\Delta t \text{ (feet/minute)}.$$

The standard errors from the relation (table 3) were calculated as estimates of random variability with tidal variability being obtainable from the variation bars of figure 3. The mean value of speed was obtained by evaluating the regression equation for $\Delta H/\Delta t = 6.86 \times 10^{-3}$ ft/min, the mean value for Sewell's Point. Finally, these data are increased by a factor of 1.53, to correct a systematic bias in C&GS data reported in Fang (1979) and converted to cm/sec for consistency with the Elizabeth River estimates. The mean current estimates for use in the sediment plume model are obtained by dividing by $\pi/2$ to produce mean values throughout the tidal phase (ebb or flood). The mean values of peak speeds during a tidal cycle are shown in table 3 as "corrected mean" and "corrected standard error", with the estimates for mean value for use in the sediment plume model listed as "Tidal Phase Mean".

Table 3. Results of Current Calculations in Newport News Ship Channel

Station	Phase	B_o (knots)	B_1 $\left[\frac{\text{knots}}{\text{ft/min} \times 10^{-3}}\right]$	Standard Error (knots)	Corrected Mean (cm/sec)	Corrected Standard Error (cm/sec)	Tidal Phase Mean (cm/sec)
2	Flood	.01	.10	.14	55	11	35
2	Ebb	.09	.10	.15	61	12	39
3	Flood	.09	.11	.17	66	13	42
3	Ebb	-.32	.15	.13	56	10	36

In interpretation, the values from station 3 are probably more representative of the dredged channel than those from station 2. The former have their directions oriented parallel to the dredged channel while the latter are oriented in the direction of the natural entrance channel to Hampton Roads, 45° from the dredged channel.

Rocklanding Shoal Channel

The third and final channel in the area under consideration, Rocklanding Shoal Channel, has the shape of a dog-leg on a chart. The channel is about 6 nautical miles long, with the dog-leg section comprising the southern 25% of the length. Passing the oyster grounds of Burwell Bay, it is maintained at a depth of 21½ feet below mean low water. Rocklanding Shoal Channel shares the tidal flow of the

James with another natural channel in Burwell Bay having a controlling depth of 11 feet. According to Nichols (1972), more tidal flow passes through Rocklanding Shoal Channel during flood tide than during ebb, classifying it as a flood channel. Along its length, Rocklanding Shoal Channel passes by numerous indentations and side channels with nearly the project depth, in contrast to the other channels described in this study, which are well defined cuts through shallow reaches.

In estimating the currents in Rocklanding Shoals Channel, current meter data obtained during Operation James River (Shidler and MacIntyre, 1967) are used. Current stations with measurements obtained each half hour for a period of more than three days were obtained at three locations within the channel during this study. The locations are near the northern and southern ends of the primary section and in the center of the dog-leg. Currents at the two stations in the main part of the channel were measured with a Roberts Radio current meter, with a Hydro Products meter used for surface currents. At the dog-leg station, a current pole was used for surface currents, and a Pritchard drag was used for subsurface currents with direction being determined with the ship's compass or a hand-held Weems magnetic compass.

The currents at these stations each have a distinct character, so it is likely that no single value of current can accurately describe the entire channel. Because the available stations span the length of the channel, it is plausible that they represent the extreme conditions and that appropriate values for the intermediate points can be obtained through linear interpolation from the available data.

In the dog-leg section, the direction for ebb currents has a bimodal distribution, the bottom current frequently following the channel at $90^{\circ}T$ and the upper currents following the trend of the river at $130^{\circ}T$, but the pattern of occurrence is not regular. At the southern end of the major leg, the record shows ebb currents slightly dominating over flood currents. Perhaps more important, the flood currents have little relation to the corresponding $\Delta H/\Delta t$'s, the correlation coefficient being only .16 with 8 samples. In contrast, ebb currents, after deletion of a weather-associated outlier, have a correlation of .70 with $\Delta H/\Delta t$. It may be that the division of flood currents between Rocklanding Shoals Channel and the alternate channel through Burwell Bay is highly variable and responsive to other factors, such as transverse wind stress. From the available data, the ebb currents in the southern part of the channel tend, with marginal significance, to predominate over flood currents. At the northern end of the channel, the opposite condition is found with flood currents predominating over ebb currents substantially. Both flood and ebb currents are correlated (at the 90% significance level) with $\Delta H/\Delta t$'s at the northern end. Thus, the northern end of Rocklanding Shoals Channel is a definite flood channel, and the southern end is a slight ebb channel. This is consistent with the data of Nichols (1972) who characterized the channel as a whole as a flood channel from data taken slightly north of its center. The change in measured predominance may be due to the sharp bend which must be taken by entering water to pass by the current stations at both ends of the channel on the appropriate tidal phase.

For five of the six possibilities, estimates can be made for the average current speeds to be found in the channel for average $\Delta H/\Delta t$. These are shown in table 4. For the sixth case, the estimate is simply of the available observations, with the standard deviation of the observations reported instead of the standard error of the regression. These values are shown in parentheses to emphasize the difference in derivation between them and the rest of the values.

In general, an increase in current speeds is found in the bottom of the dredged channels as one progresses up the James River within the study area. This increase is partly due to a decrease in cross-section area progressing upstream along with a smaller decrease in tidal flux. This interpretation is a contrast to that of Nichols (1972), who indicates that bottom currents at Rocklanding Shoal are substantially smaller than those near Newport News. The difference may be related to the difference between field data used in the present estimate and hydraulic model data used in the estimate of Nichols (1972).

Table 4

Results of Current Calculations in Rocklanding Shoals Channel

Station	Phase	B_o (cm/sec)	B_1 $\frac{\text{cm/sec}}{\text{ft/minx}10^{-3}}$	Standard Error (cm/sec)	Mean (cm/sec)	Tidal Phase Mean (cm/sec)	Corrected Tidal Phase Mean (cm/sec)
Dog-Leg	Flood	-44.76	16.10	12	66	42	42
Dog-Leg	Ebb	-90.18	23.75	8	72	46	46
South End	Flood	-	-	(10)	(33)	(21)	(32)
South End	Ebb	-35.28	11.72	8	45	29	44
North End	Flood	23.09	4.55	7	54	35	53
North End	Ebb	-16.20	8.14	5	40	25	39

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Appendix 1. Times and Speeds of Maximum Currents in Newport News Channel During U.S. Coast and Geodetic Survey Observations, 1969.

Station: 2
Latitude: 36°57'28"N
Longitude: 76°21'22"W
Depth: 40'

Time Meridian: 75°W
Observer: R. J. DeRycke
USC&GSS Ferrel (ASV-92)

Date	Time (EST)	Speed (Kt)	Direction (°T Towards)	$\Delta H/\Delta T$ ($x10^{-3}$ ft/min)
1/13/69	2055	-0.4	055	-5.7
1/14/69	0300	+0.7	205	+7.0
1/14/69	1000	-0.8	035	-6.7
1/14/69	1550	+0.6	215	+5.5
1/14/69	2245	-0.7	025	-6.0
1/15/69	0355	+0.8	220	+9.2
1/15/69	1015	-0.9	030	-7.4
1/15/69	1705	+0.6	220	+5.9
1/15/69	2220	-0.7	050	-6.7
1/16/69	0505	+0.8	220	+8.3
1/16/69	1215	-0.8	030	-8.2
1/16/69	1820	+0.8	235	+7.1
1/16/69	2355	-0.7	040	-7.8
1/17/69	0635	+0.9	210	+9.1
1/17/69	1255	-0.9	030	-8.9
1/17/69	1845	+0.7	225	+7.6
1/18/69	0055	-0.7	050	-7.9
1/18/69	0740	+1.1	220	+9.4
1/18/69	1335	-0.7	040	-9.1
1/18/69	1935	+0.5	230	+8.1
1/19/69	0155	-0.8	050	-8.5
1/19/69	0815	+1.1	220	+9.6
1/19/69	1425	-0.8	050	-9.3
1/19/69	2055	+1.0	240	+8.2
1/20/69	0235	-0.9	045	-8.5
1/20/69	0930	+1.1	240	+9.3
1/20/69	1535	-1.0	050	-9.0
1/20/69	2210	+1.0	210	+8.2
1/21/69	0330	-1.0	035	-8.2
1/21/69	1055	+1.0	215	+8.5
1/21/69	1610	-1.1	045	-8.2
1/21/69	2315	+0.6	220	+7.9
1/22/69	0425	-1.0	035	-7.5
1/22/69	1125	+0.8	220	+7.7
1/22/69	1635	-1.1	035	-7.4
1/22/69	2335	+0.6	215	+7.1
1/23/69	0520	-0.8	050	-6.7
1/23/69	1145	+0.9	215	+6.4
1/23/69	1720	-0.9	040	-6.5
1/24/69	0020	+1.0	225	+6.8

Appendix 1 (Cont'd)
Station 2

Date	Time (EST)	Speed (Kt)	Direction (^{o}T Towards)	$\Delta H/\Delta T$ ($x10^{-3}$ft/min)
1/24/69	0605	-0.9	040	-6.1
1/24/69	1240	+0.7	230	+5.4
1/24/69	1855	-0.8	045	-5.6
1/25/69	0005	+0.8	240	+6.2
1/25/69	0655	-0.6	060	-5.6
1/25/69	1305	+0.4	260	+4.5
1/25/69	1920	-0.7	050	-4.8
1/26/69	0110	+0.5	245	+5.6
1/26/69	1000	-0.3	040	-4.9
1/26/69	1435	+0.3	210	+4.0
1/26/69	2115	-0.5	060	-4.4
1/27/69	0205	+0.5	250	+5.2
1/27/69	0745	-0.5	045	-4.9
1/27/69	1455	+0.5	220	+4.0
1/27/69	2130	-0.4	040	-4.4
1/28/69	0250	+0.6	220	+5.2
1/28/69	1055	-0.5	030[1]	-4.9
1/28/69	1655	+0.4	255	+4.0
1/28/69	2155	-0.5	060	-4.5
1/29/69	0455	+0.5	245	+5.8
1/29/69	1150	-0.7	060	-5.4
1/29/69	1645	+0.6	215	+4.4
1/29/69	2225	-0.4	035	-4.7
1/30/69	0405	+0.5	230	+6.1

End of Data

[1]Speed from drogued buoy. Roberts Radio current meter readings are erratic and low.

Appendix 1 (Cont'd)

Station: 3
Latitude: 36°57.3'N
Longitude: 76°22.9'W
Depth: 40'

Time Meridian: 75°W
Observer: R. J. DeRycke
USC&GSS Ferrel (ASV-92)
Roberts Radio Current Meter

Date	Time (EST)	Speed (Kt)	Direction (°T Towards)	$\Delta H/\Delta T$ ($x10^{-3}$ft/min)
1/14/69	1600	+0.7	250	+5.5
1/14/69	2130	-0.6	090	-6.0
1/15/69	0435	+1.1	260	+9.2
1/15/69	1115	-0.7	070	-7.4
1/15/69	1705	+0.8	110[2]	+5.9
1/15/69	2245	-0.8	295[2]	-6.7
1/16/69	0520	+1.1	120[2]	+8.3
1/16/69	1245	-1.0	80	-8.2
1/16/69	1745	+0.9	260	+7.1
1/17/69	0010	-0.9	075	-7.8
1/17/69	0615	+1.4	275	+9.1
1/17/69	1305	-1.1	080	-8.9
1/17/69	1845	+0.9	260	+7.6
1/18/69	0045	-0.9	080	-7.9
1/18/69	0710	+1.3	270	+9.4
1/18/69	1400	-1.0	075	-9.1
1/18/69	1925	+0.9	270	+8.1
1/19/69	0140	-0.9	075	-8.5
1/19/69	0750	+1.2	265	+9.6
1/19/69	1415	-1.0	080	-9.3
1/19/69	2030	+0.7	270	+8.2
1/20/69	0255	-0.7	080	-8.5
1/20/69	0905	+1.1	270	+9.3
1/20/69	1600	-0.9	065	-9.0
1/20/69	2130	+1.0	295	+8.2
1/21/69	0330	-1.0	065	-8.2
1/21/69	1020	+0.9	290	+8.5
1/21/69	1645	-0.9	80	-8.2
1/21/69	2240	+0.7	270	+7.9
1/22/69	0410	-0.8	070	-7.5
1/22/69	1045	+0.9	280	+7.7
1/22/69	1620	-0.9	080	-7.4
1/22/69	2315	+0.7	275	+7.1
1/23/69	0540	-0.8	070	-6.7
1/23/69	1100	+0.8	270[1]	+6.4
1/23/69	1710	-0.9	070	-6.5

[2] Readings are in wrong direction-suspect instrument malfunction.

[1] Raw data indication switches from 040 to 270 with little change in speed. Instrument malfunction is plausible.

Appendix 1 (Cont'd)
Station 3

Date	Time (EST)	Speed (Kt)	Direction (^{o}T Towards)	$\Delta H/\Delta T$ ($x10^{-3}$ft/min)
1/23/69	2400	+0.7	060	+6.8
1/24/69	0615	-0.8	065	-6.1
1/24/69	1230	+0.9	240	+5.4
1/24/69	1740	-0.7	270[2]	-5.6
1/25/69	0035	+1.0	270	+6.2
1/25/69	0605	-0.6	270[2]	-5.6
1/25/69	1255	+0.6	085[2]	+4.5
1/25/69	1935	-0.4	080	-4.8
1/26/69	0110	+0.8	080[2]	+5.6
1/26/69	0815	-0.2	085	-4.9
1/26/69	1335	+0.2	085[2]	+4.0
1/27/69	1505	+0.5	260	+4.0
1/27/69	2130	-0.2	090	-4.4
1/28/69	0305	+0.9	265	+5.2
1/28/69	1020	-0.5	080	-4.9
1/28/69	1625	+0.5	270	+4.0
1/28/69	2200	-0.2	90	-4.5
1/29/69	0430	+1.0	255	+5.8
1/29/69	0935	-0.3	080	-5.4

End of Data

[2]Readings are in wrong direction-suspect instrument malfunction.

ELIZABETH RIVER SURFACE CIRCULATION ATLAS

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ELIZABETH RIVER SURFACE CIRCULATION ATLAS

Description

The Elizabeth River Surface Circulation Atlas is a compendium of maps which detail the surface circulation throughout the main branch of the Elizabeth River, in the port of Hampton Roads, Virginia. Data for the Atlas maps were obtained directly from field experiments using Remote Sensing and dye-emitting low-windage surface drogues. The maps show surface Lagrangian trajectories under various combinations of wind and tide. The Atlas is not intended to duplicate NOAA tidal current tables, but rather to supplement the tables with empirical trajectory data at increased spatial resolution. Knowledge of surface currents under different tide and wind conditions enables a user to predict the movement of floating debris, such as oil spills, within the Elizabeth River Basin.

The Atlas is based on the fact that motion of surface water is a product of tidal flow and local winds, and is repeatable under similar conditions. The user obtains readily-available local wind and predicted tidal data, and finds within the Atlas the maps referring to the same conditions. With the trajectories on the maps, the user may move along a trajectory forward in time to find possible future positions, or backward to identify possible earlier positions.

The Atlas was designed to be used by planners and managers charged with decision-making and regulation in the Hampton Roads port region. Within this region, the Elizabeth River Basin was chosen for development of a circulation atlas, because of the Basin's large volume of ship traffic, industrial and waste treatment plants, oil and coal handling facilities, and military and civilian port activities. Immediate applications include: prediction of oil slick movement, to permit containment of a spill before serious environmental damage occurs; 'hindsight' prediction, to identify a possible source for a spill; and sewage and industrial outfall siting, with consideration for all the various wind and tide combinations.

The Atlas is arranged in leaves to allow future revisions in response to specific user needs. Future generations of the Atlas will include data from new field studies, filling in data gaps in the Condition Matrix.

One possible modification would be the addition of a grid coordinate system superimposed on the Atlas maps for orientation. As the data base becomes more complete, circulation information could be referenced to individual grid squares for tide and wind combinations, extending the usefulness of the Atlas to all locations in the Basin. A second possibility is to include circulation anomalies such as foam lines and convergence zones on the maps. These, of course, significantly modify the surface circulation by trapping and concentrating surface material under certain tidal phases. A third possibility is the addition of maps showing subsurface trajectories. Such data can be obtained using Remote Sensing techniques developed by Munday, Welch, and Gordon (1980, Ports 80 Conference, ASCE, p. 417-428).

Revisions will be contingent upon user experience with the Atlas and upon future needs. Due to the flexibility of the Atlas design, accommodations to user needs could be undertaken with a minimum of expense, effort, and time. New current data can be obtained and incorporated easily because the Atlas is prepared using semi-automated photogrammetric and computer plotting techniques.

Instructions

The surface circulation maps are keyed to wind data from the National Weather Service Office at Norfolk Regional Airport, and to NOAA Tide Tables for predicted high and low water at Sewells Point (Hampton Roads). The following steps are taken to locate the proper map:

1. Using the NOAA Tide Tables, find the times of predicted low and high tide at Sewells Point (Hampton Roads) which bracket the time of interest,

2. Call the National Weather Service Office in Norfolk (853-0553) and request the current and previous (2 to 3 hours) wind velocities,

3. Using the Condition Matrix, locate one of the sixteen bins appropriate for the tide phase and wind direction from Steps 1 and 2. Within the bin locate the wind speed rectangle corresponding to the actual speed from Step 2, and

4. The number(s) indicate the map number(s) which contain the specific circulation data of interest.

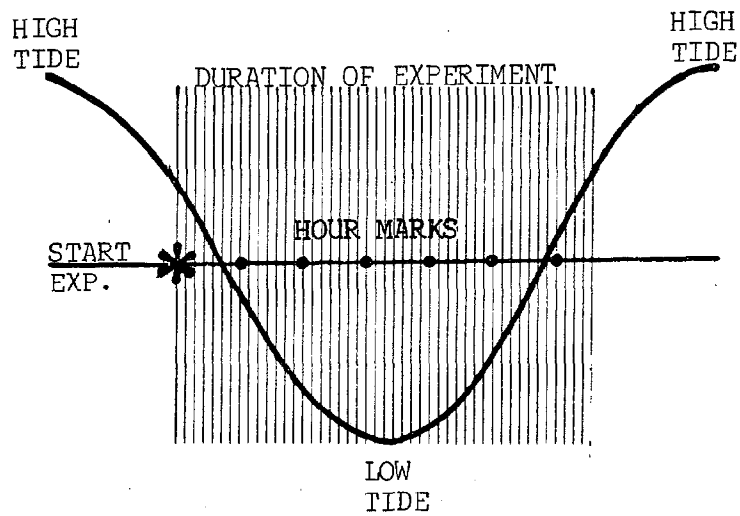
On each map are surface drogue positions plotted every 15 minutes, with the initial release position depicted by a * symbol. On the lower right corner is a tide curve (high tide above the horizontal line, low tide below) showing the span of the experiment within a tide cycle. Dots along the horizontal line indicate hours after drogue release. Wind speed and direction are illustrated on each map with an arrow referenced to the north arrow (0 to 5 knots, short arrow; 6 to 15 knots, medium arrow; greater than 15 knots, wind arrow same length as north arrow).

CONDITION MATRIX

TIDE PHASE	WIND SPEED (KTS)	NE	SE	SW	NW
H	> 15			10	
H	6–15				5,8
H	0–5				
FALLING	> 15				
FALLING	6–15	2,3		4,7	5,6,8
FALLING	0–5				
L	> 15				
L	6–15	2,3,11		9	6
L	0–5				
RISING	> 15				
RISING	6–15	12		9	
RISING	0–5				

WIND DIRECTION

Sample Tide Curve

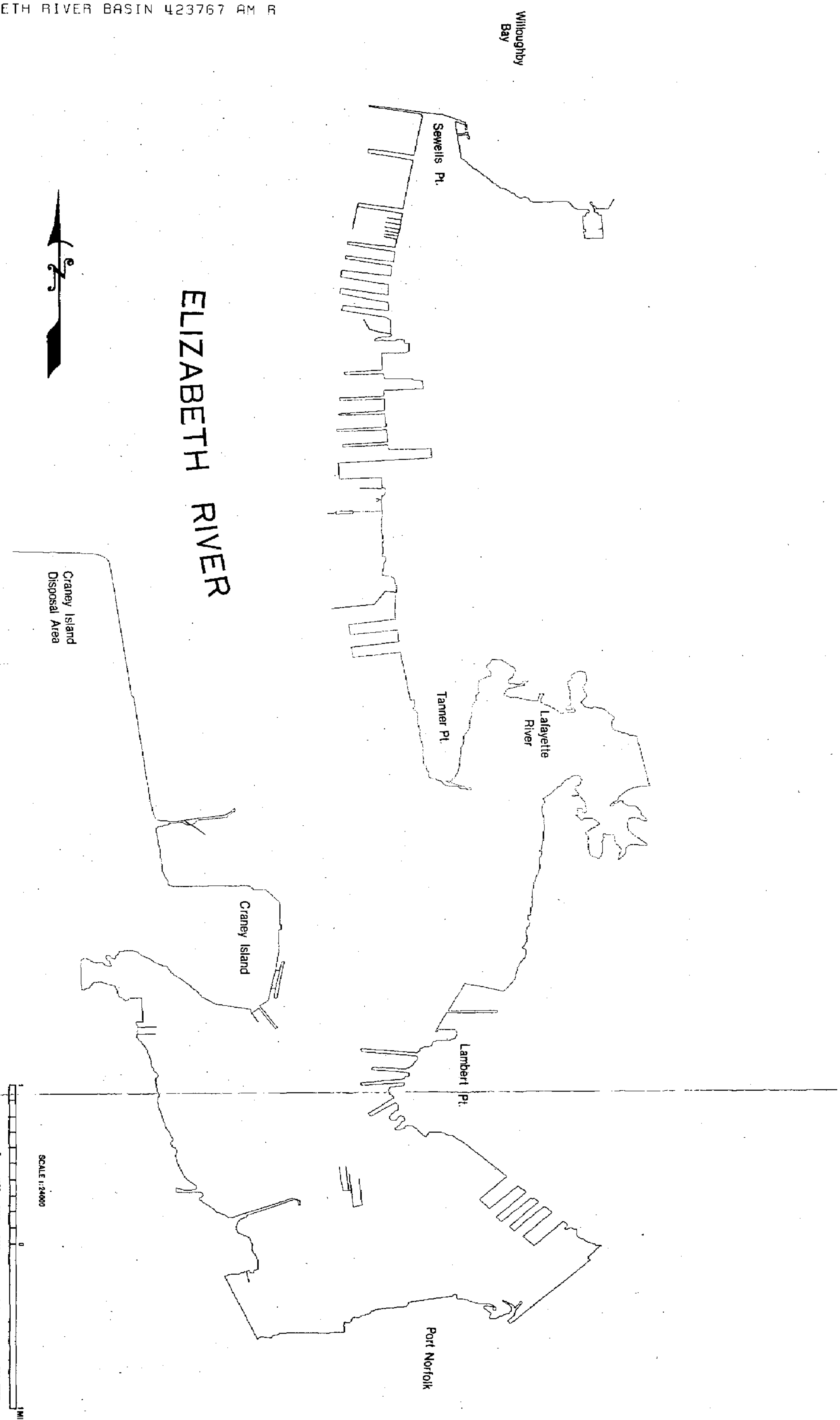


Example (Hypothetical)

Suppose one wishes to know surface circulation west of Tanner Point in the Elizabeth River at 1200 on a particular day. By consulting the NOAA Tide Tables, time of high tide is found to be 0930 and low tide 1500. A call to the Norfolk Weather Bureau shows winds to be 200° at 10 gusting to 15 knots. Checking the Condition Matrix for a tide phase between high (H) and low (L), wind direction SW, and speed 6 to 15 knots reveals maps number 4 and 7 are appropriate. A brief review of the wind and tide information on both maps tends to favor map 4 which begins earlier in the tide cycle and has winds nearer 200°. Drogue tracks show a well-defined ebb flow.

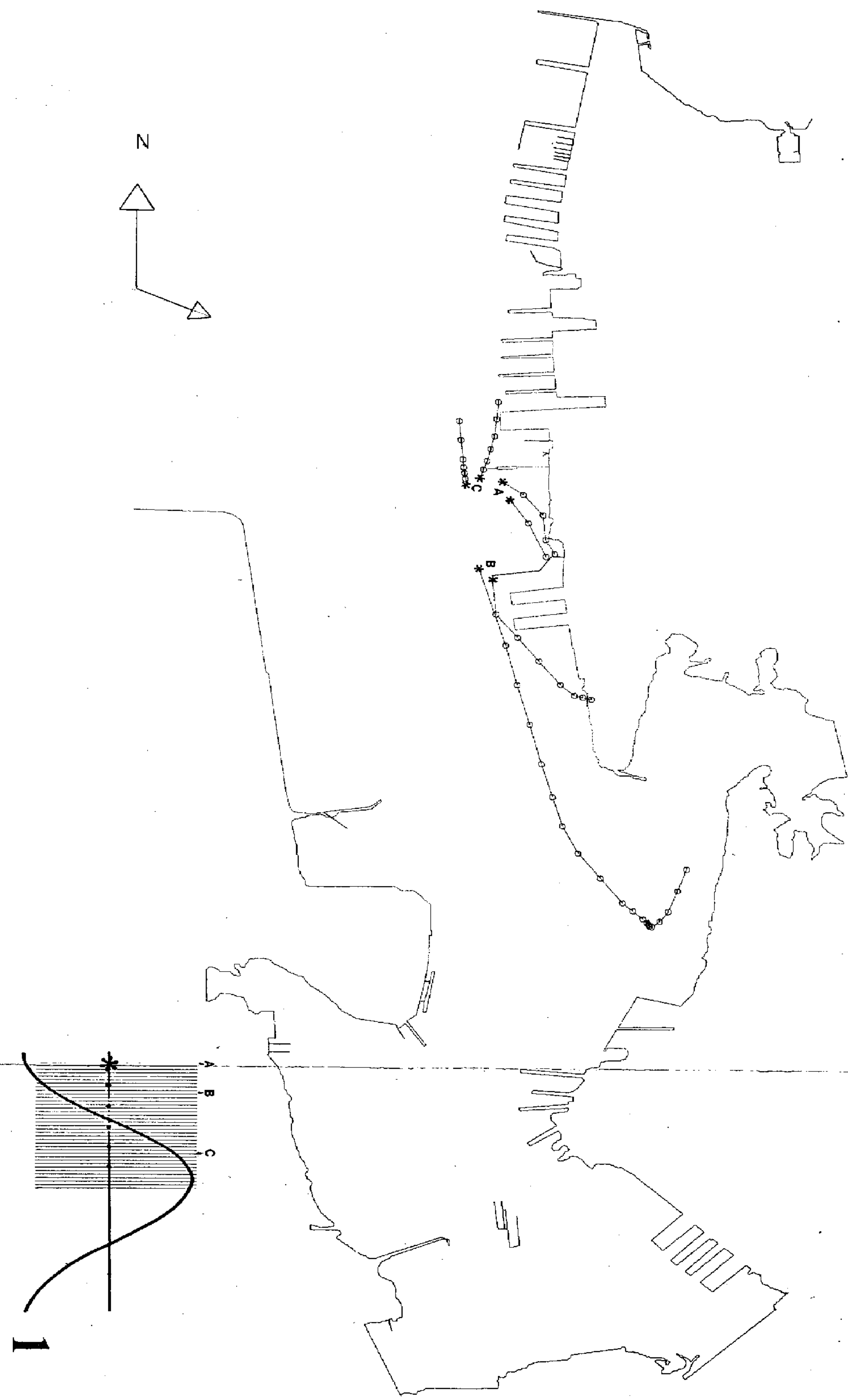
HHGIPLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 423767 AM R



HHGIPLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 42376 AM A



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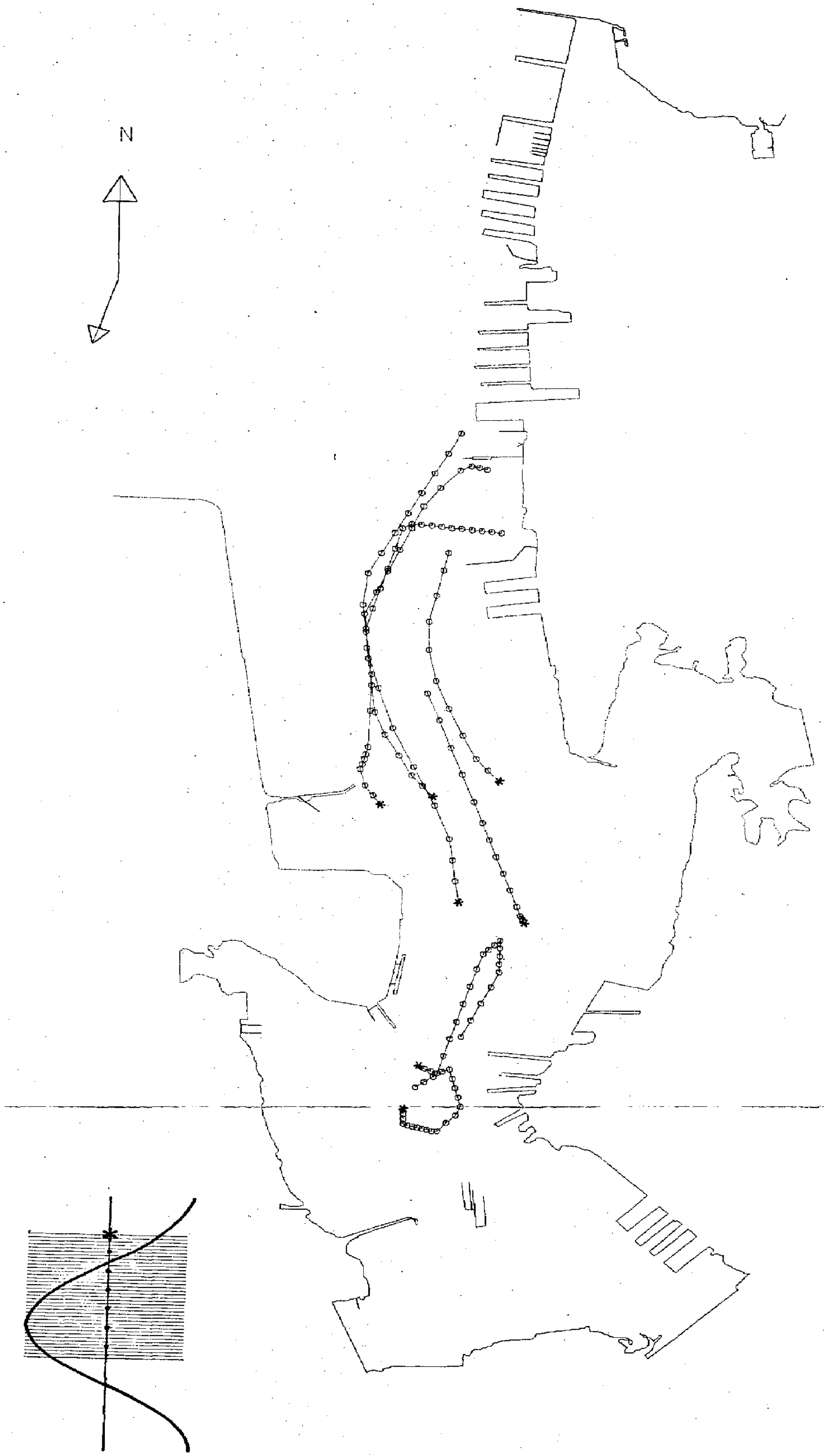
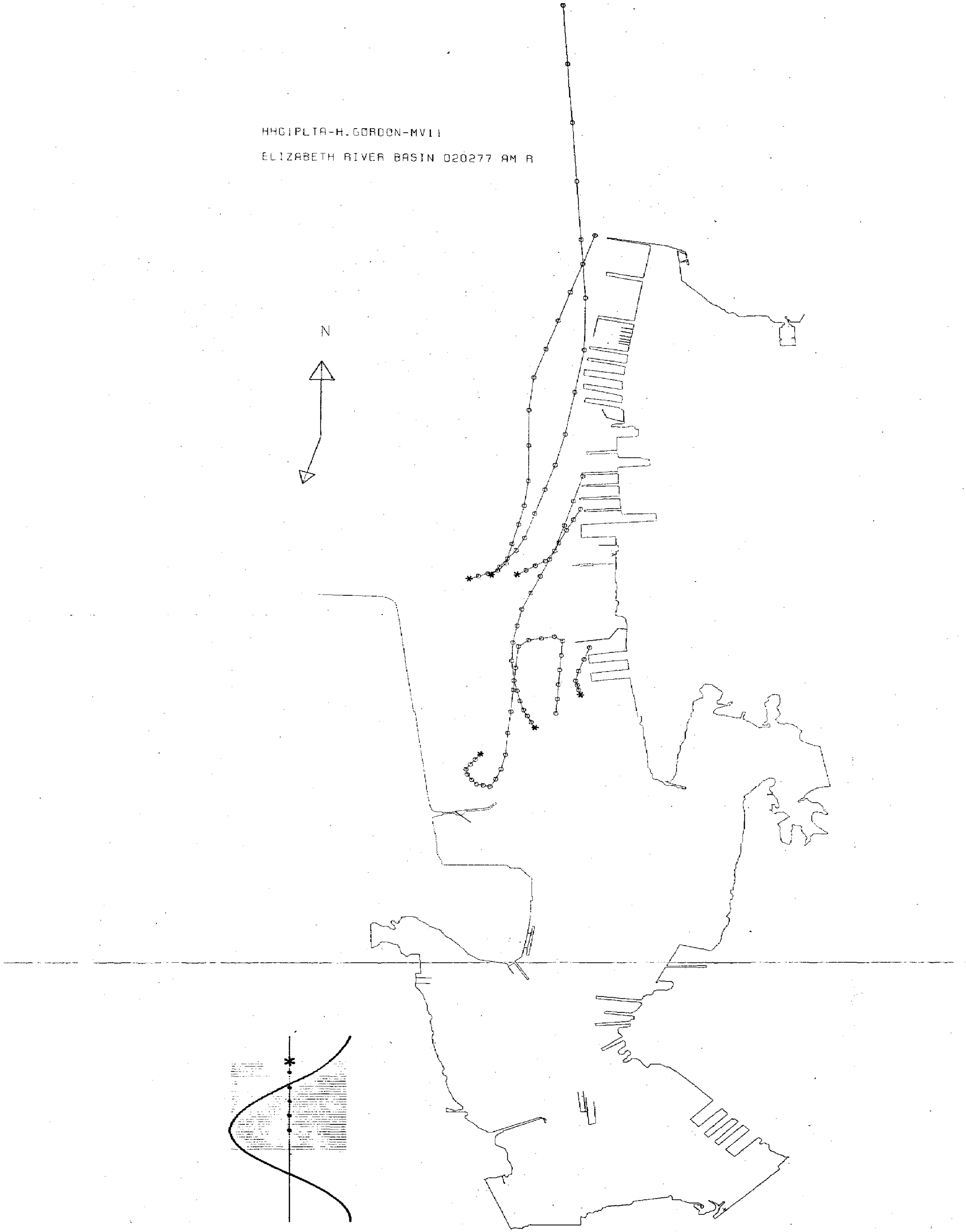
ELIZABETH RIVER BASIN 020277 AM A





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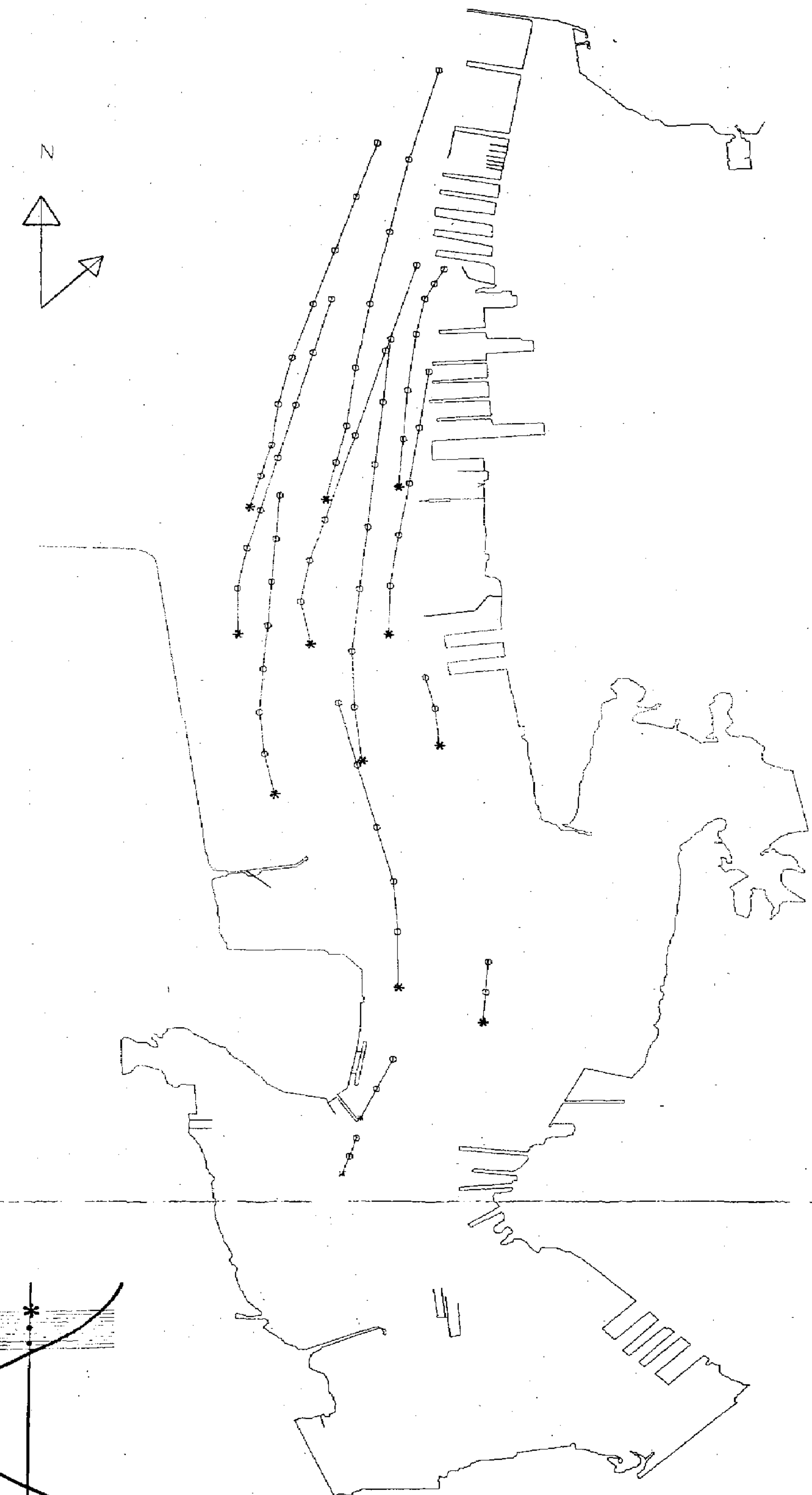
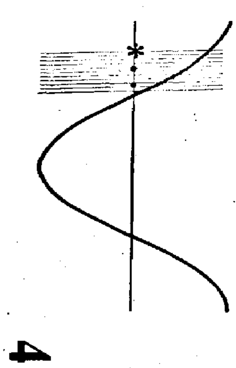
HHG1PLTA-H.GORDON-MV11

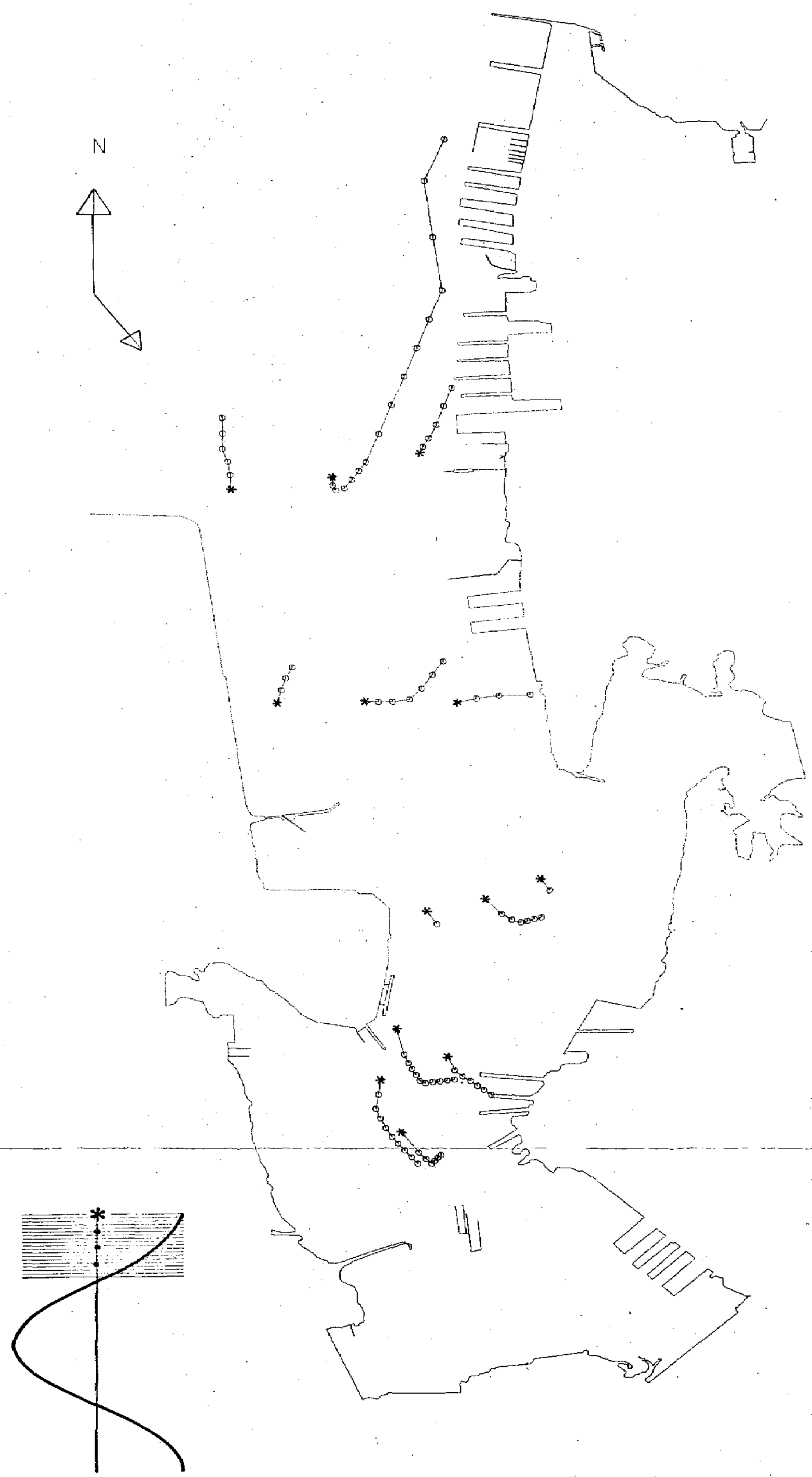
ELIZABETH RIVER BASIN 020377 AM R





HHGIPLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 020777 AM R



5

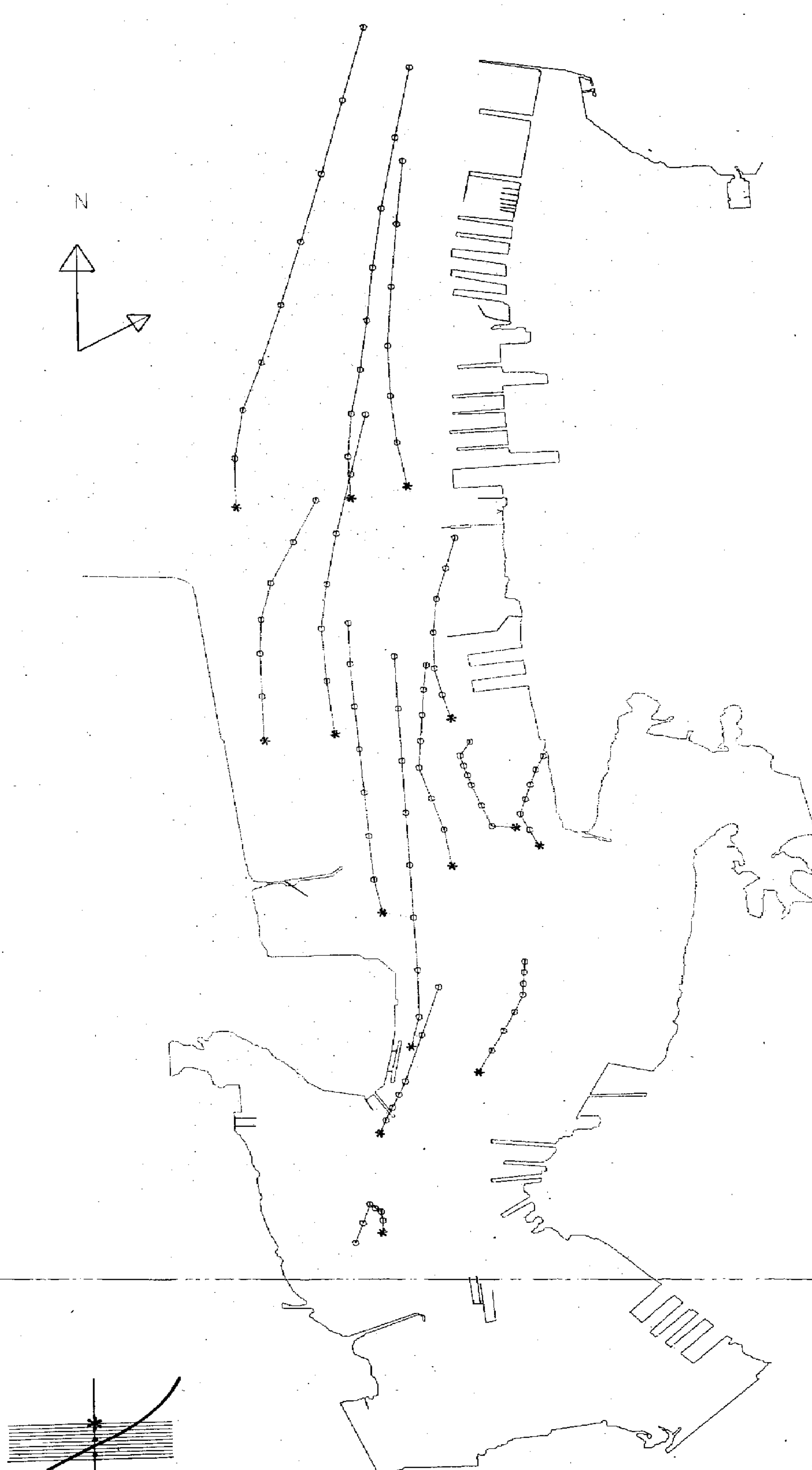
HHGIPLTA-H.GORDON-MVII

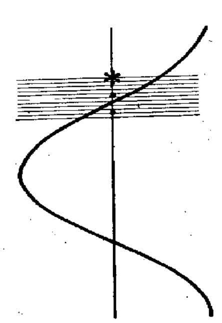
ELIZABETH RIVER BASIN 020777 PM R

6

HHGIPLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 020977 PM R

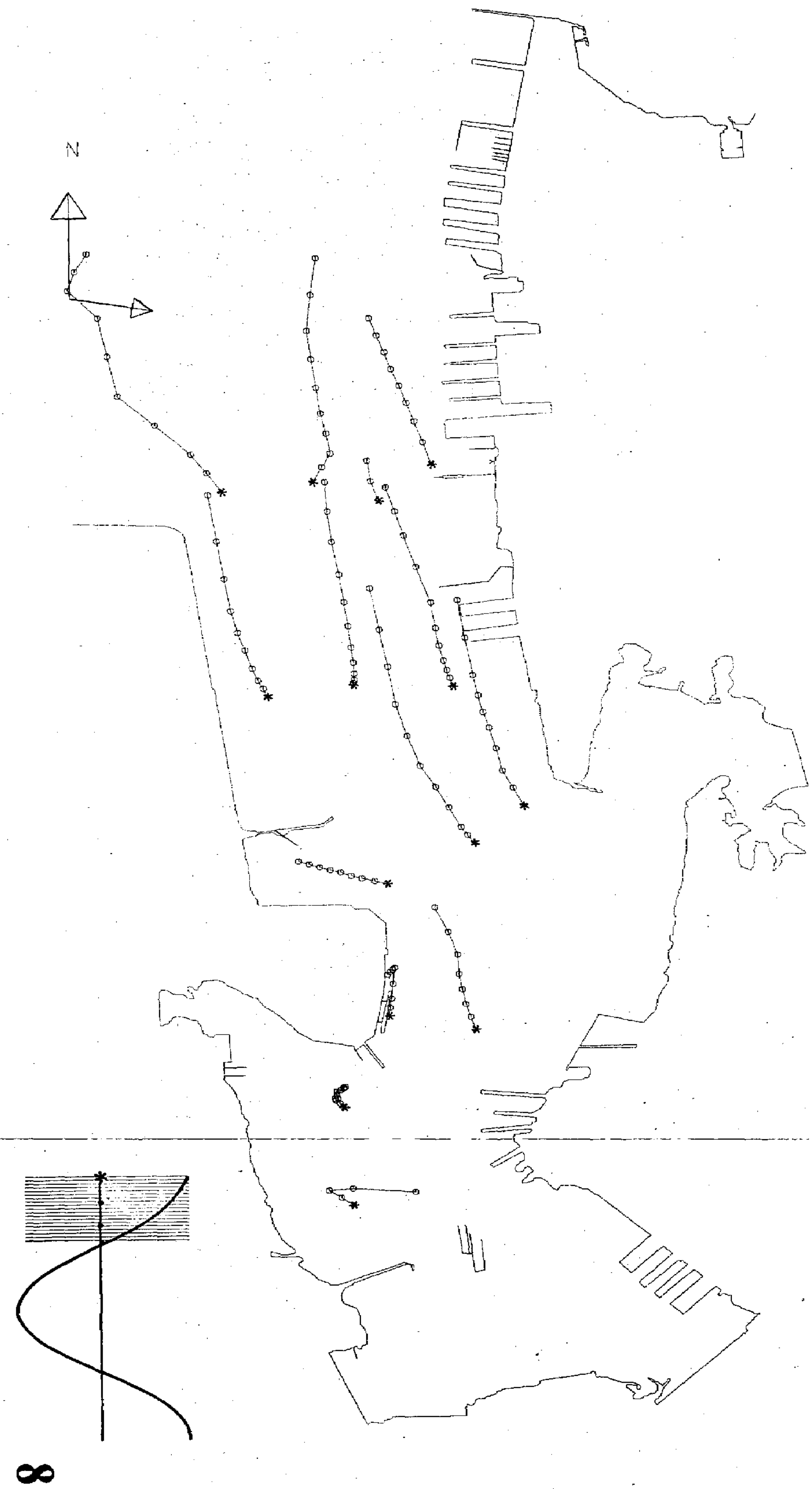




7

HHGIPLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 021077 PM R



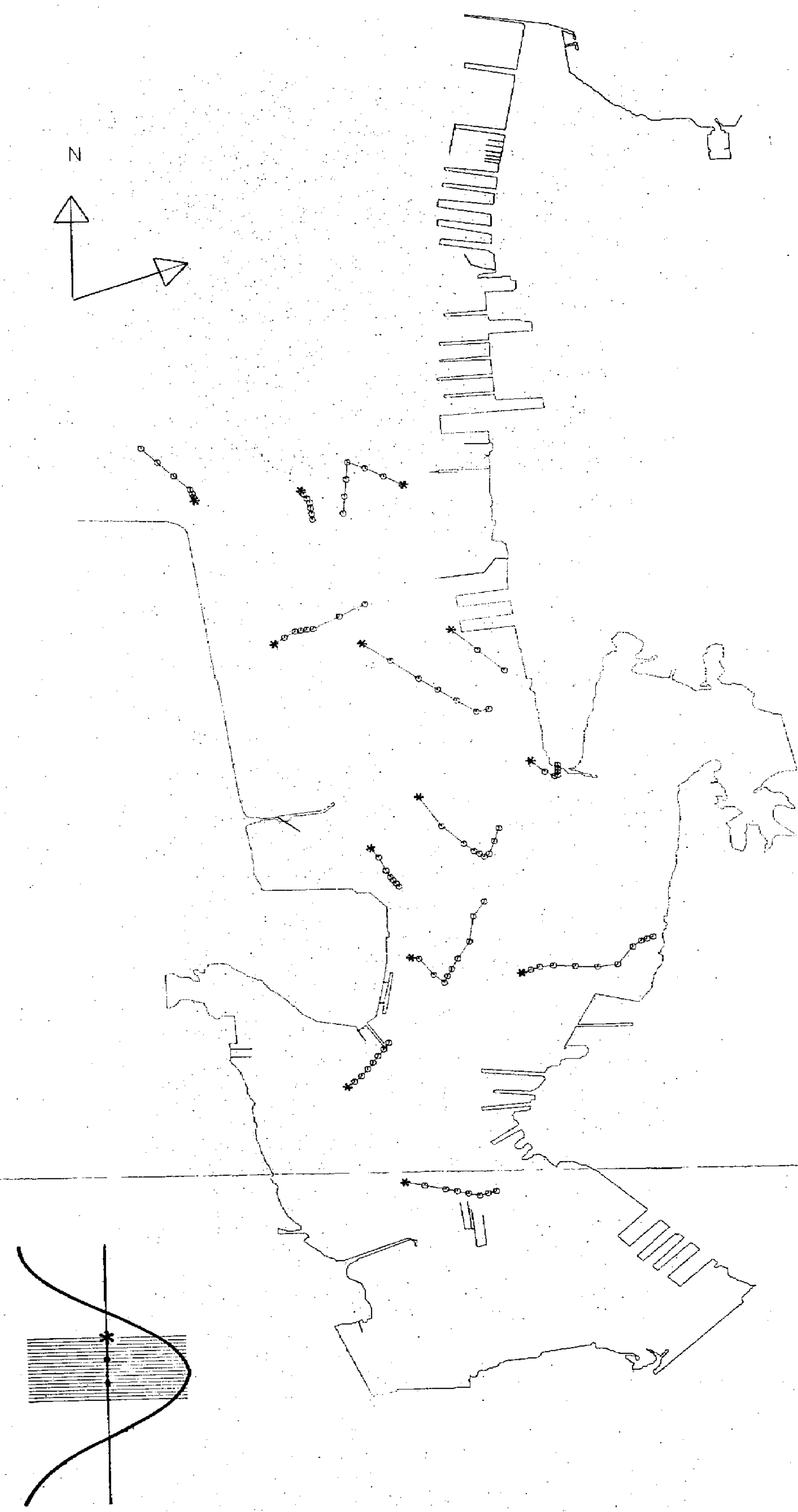
HHG1PLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 021177 AM R

9

HHG1PLTA-H.GORDON-MV11

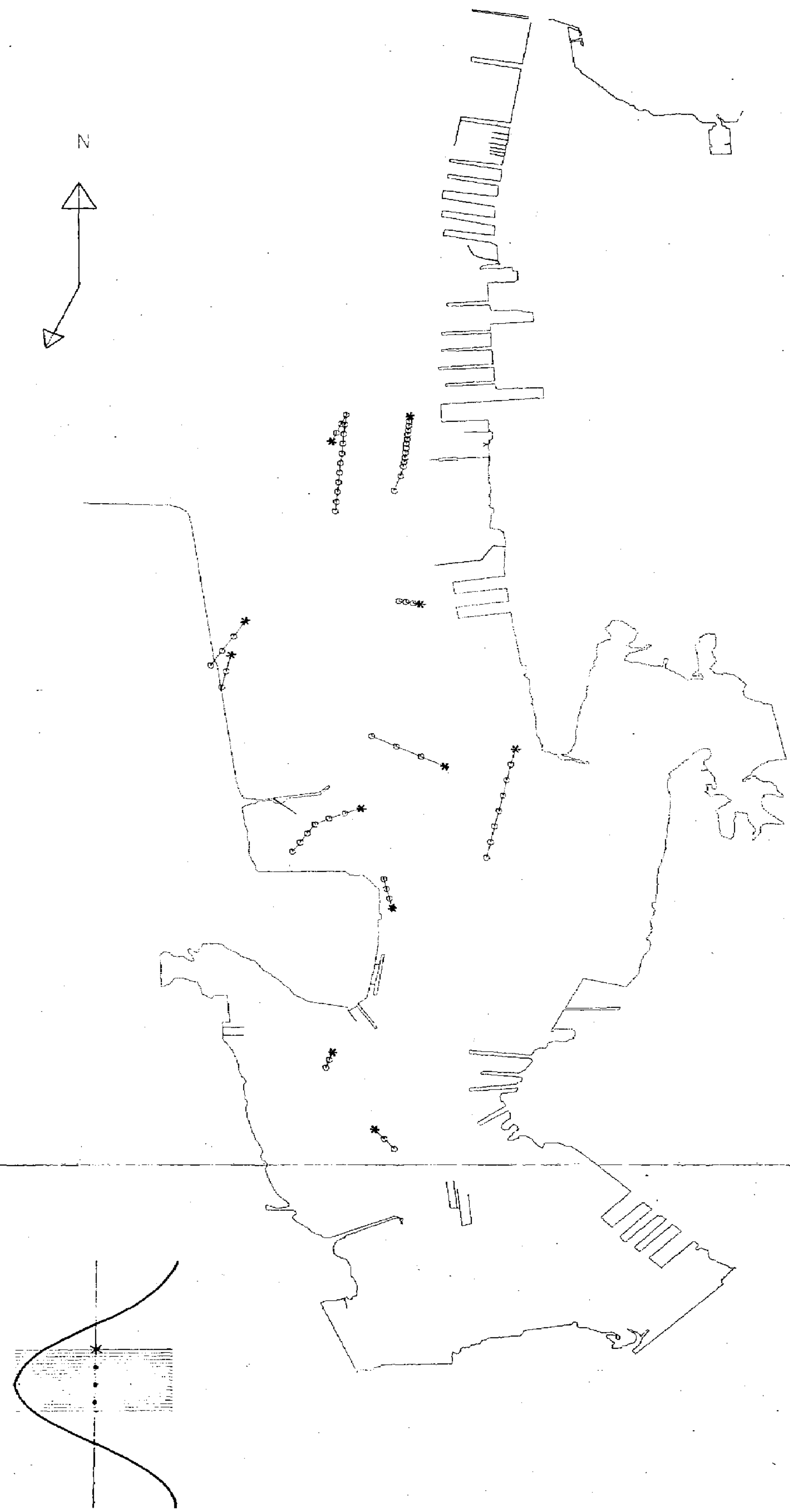
ELIZABETH RIVER BASIN 021177 PM-A



10

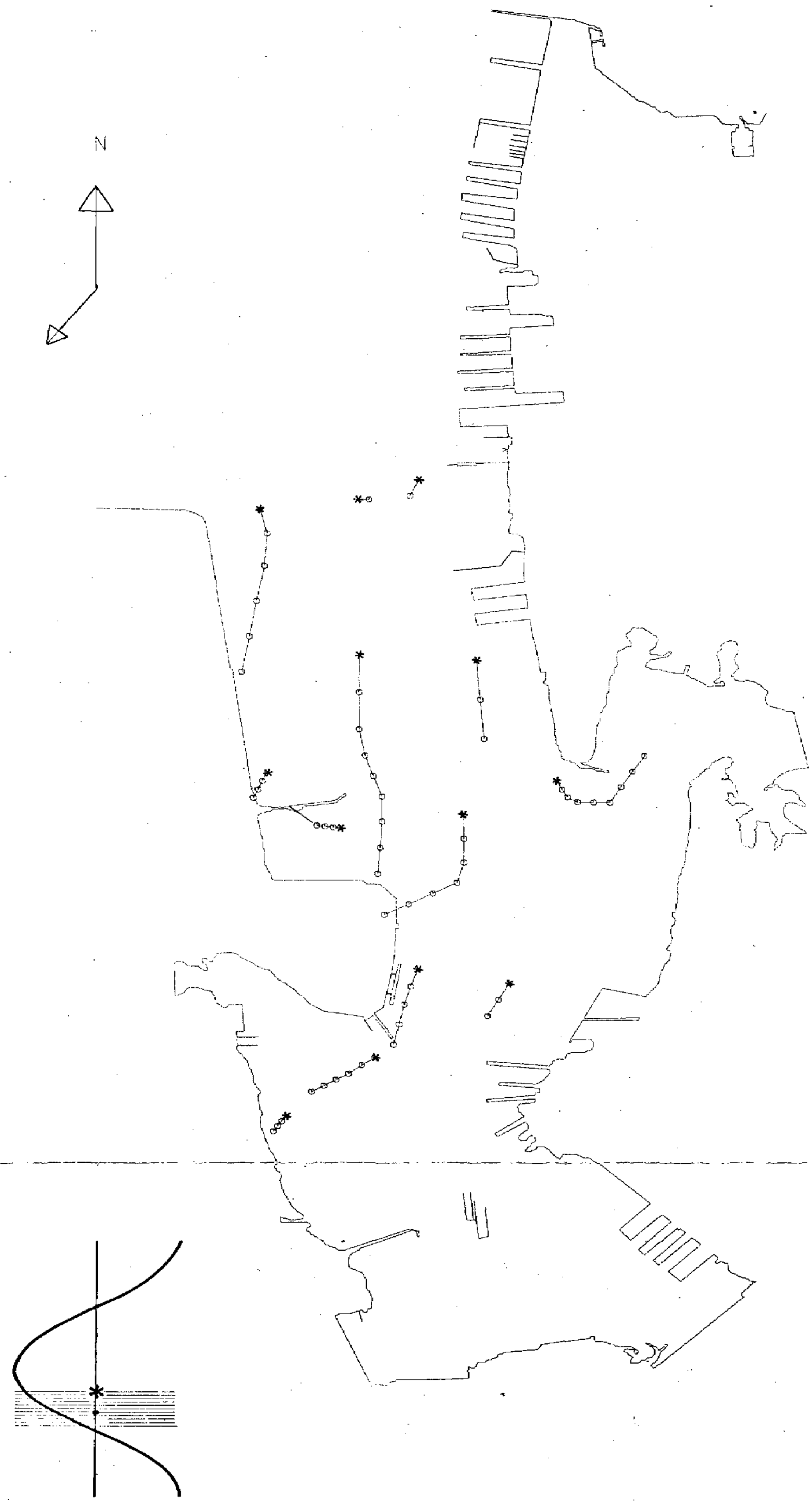
HHGIPLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 021577 AM R



HHG1PLTA-H.GORDON-MV11

ELIZABETH RIVER BASIN 021577 PM R



DREDGING EFFECTS

THE EFFECTS OF DREDGING IMPACTS ON WATER QUALITY AND ESTUARINE ORGANISMS: A LITERATURE REVIEW

by

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Introduction

The primary purpose of this section is to evaluate the effects of total suspended solids (TSS) levels normally generated by hydraulic cutterhead and clamshell dredges where a confined disposal site is utilized. The emphasis of this review will be on the sublethal and lethal effects of increased TSS concentrations on various estuarine organisms. There will also be a limited treatment of the effects of dredging on other water quality parameters whenever it is applicable to the types of dredging activities being considered in this report.

This report will be divided into two parts. The first will discuss the impacts of non-open water disposal hydraulic cutterhead and clamshell dredging on water quality. The second will present available data from the literature on the effects of TSS on specific estuarine organisms.

The literature on the effects of dredging, spoil disposal and suspended sediments on water quality and aquatic organisms has been very ably reviewed and summarized by a number of workers. For a more detailed analysis than is presented here Bouma (1976), Morton (1977), Stern and Stickle (1978), Allen and Hardy (1980), Saila (1980), and the Corps of Engineers Dredged Material Research Program Snythesis Report Series are suggested.

Water Quality Aspects

The most obvious impact of dredging on water quality is the increase in suspended solids (turbidity) created by the disturbance of the bottom sediments. Despite the extensive research on dredging impacts very little has concentrated on the dredge cutterhead or clamshell as a source of suspended solids. Most of the information available deals with levels of TSS generated at the pipeline or barge disposal site where levels in grams to tens of grams per liter have been observed (Chesapeake Biological Laboratory, 1970 and May, 1973). Documentation of the levels of suspended solids created by the dredge itself are very few. The San Francisco Bay Maintenance Dredging EIS, 1975 cited from Williamson and Nelson (1977) reported near field levels of TSS from removal operations of 43-70 mg/l for a pipeline, 12-282 mg/l for a clamshell and 74-871 mg/l for a hopper dredge. After reviewing the available literature Barnard (1978) made the following comments on the general ranges of suspended solids created by different types of dredges. Clamshell dredges usually produce a plume of suspended solids 300 m downstream on the surface and 500 m downstream near the bottom. They produce a maximum TSS concentration of approximately 500 mg/l while the average water column concentration will be about 100 mg/l. Cutterhead dredges normally produce a suspended solid plume near the bottom of a few 100's mg/l for a few hundred meters downcurrent. Hopper dredging without overflow will generate suspended solids in the range of a few grams/liter adjacent to the dragheads.

Wakeman et al (no date) cited from San Francisco COE (1975) reported a reduction of light transmission of approximately 4% below background levels adjacent to a cutterhead dredge. They also reported highly variable turbidity values for a clamshell dredge. These values ranged up to 26% reduction in light transmission below background levels.

Boon and Byrne (1975) in a monitoring report on a dredging operation on Hampton Bar reported typical surface plume TSS concentration of 20-40 mg/l during maximum current conditions. Concentrations within 400 yds of the hydraulic dredge were 50 mg/l and higher. A visible plume approximately 400 x 4000 yds was produced during flood tide. Background TSS levels were 5-15 mg/l.

Boon and Thomas (1975) in a report on dredging operations associated with the construction of the second Hampton Roads Bridge Tunnel reported TSS concentrations of 15-30 mg/l in the surface plume of a hydraulic dredge at distances of less than 1000 ft. Background levels were 3-9 mg/l. They also recorded natural bottom TSS levels of 120 mg/l over the existing tunnel during maximum tidal current velocity.

The issue of dissolved oxygen (D.O.) reduction as a result of dredging is also clouded by the fact that most reports refer to D.O. reductions during the open-water disposal of the dredged material. Even in this instance the reduction of D.O. has generally been relatively small except in bottom water density flows and of a relatively short duration (CBL, 1970; COE, 1976; Barnard, 1978). Near-bottom D.O. levels may be less than 2 mg/l near the discharge pipe during open-water disposal (Barnard, 1978).

However, Brown and Clark (1968) did report D.O. reductions from 16% to 83% below the expected minimum in the Arthur Kill between Staten Island, N.Y. and New Jersey during dredging operations. The usual method of dredging was clamshell and hopper barge which was dumped at sea. They described the bottom sediments as containing "accumulations of waste discharges that are deposited continuously. The bottom, which is characterized by a black, soft, oily silt, emanates odors of chemicals, oils, and hydrogen sulfide."

May (1973) reported substantial D.O. reduction at the discharge pipe and in bottom density flows out to 1200 feet from the discharge during open water disposal.

Wakeman et al (no date) cited from San Francisco COE (1975) reported a D.O. reduction of less than 1 ppm, uniform with depth, adjacent to a cutterhead dredge. The reductions around the clamshell dredging were again variable with average reduction being approximately 2 ppm. Some increases in D.O. were also noted, probably caused by the agitation of the water column by the bucket. The background surface D.O. was 8-9 mg/l.

Observations by the JBF Scientific Corp. in San Francisco COE (1975) showed an aeration of surface waters by a clamshell dredge and a D.O.

increase in bottom waters of approximately 3 ppm. They postulated that an upwelling was created by using the 18 cu. yd. bucket, drawing highly oxygenated water into the plume.

The literature reviewed for this report did not contain any information on the release of nutrients, heavy metals and pesticides by dredging per se. All mention of this effect was either associated with open-water disposal or the information related to both dredging and disposal operations with no distinction in the data being made.

The material reviewed on open-water disposal operations did report that releases over background of manganese, ammonium nitrogen, orthophosphate; and reactive silica can occur for short periods of time (Barnard, 1978). Burks and Engler (1978) reported that releases of short duration of chlorinated pesticides, PCB's and ammonia can occur when their levels in the sediment are elevated. They also reported that heavy metals can be released under very specific conditions of pH and oxidation-reduction potential. These conditions are usually not found during typical open-water disposal operations, however.

The nature and extent of any nutrient and/or pollutant release and its resultant impact is dependent upon a number of site specific characteristics including: concentration in the sediment, amount of organic and fine grained material in the sediment, pH, oxidation-reduction potential and duration of release.

Kaplan et al (1974) reported significant increases in particulate phosphates, silicates and chlorophyll a immediately after a hydraulic dredging operation in a small enclosed coastal embayment which also received the effluent from the disposal area. There was no appreciable difference in levels of nitrates, nitrites and dissolved organic and inorganic phosphates before and after dredging.

Although not strictly an impact on water quality the increased rate of sedimentation in the vicinity of dredging operations can have an adverse effect on the area. Here again most of the impacts described in the literature refer to open-water disposal operations.

Wilson (1950) cited from Bouma (1976) studied the effects of shell dredging along the Texas Gulf coast. He reported that "suspended silt and resulting sedimentation extended in significant concentrations approximately 300 yards from the dredge" and that oysters placed in baskets were covered with silt within 300 yards of the dredge if they were at the same depth as the adjacent bottom but were not covered if they were placed higher than the surrounding bottom.

Mackin (1961) made several theoretical observations on the sedimentation possible from cutterhead and clamshell dredged utilizing open-water disposal on adjacent oyster leases. These hypotheses were based on average turbidities in ppm (not mg/l TSS) in the sediment plume, current velocities, open-water disposal immediately adjacent to the dredge and the distance to nearby oyster leases. The amounts of sedimentation theoretically expected ranged from 0.2 inches on a seven acre lease 1500 feet from a cutterhead dredge with average plume values of 500 ppm turbidity to 0.5 inches on a 1000 foot long area immediately adjacent to the disposal area with an average plume value of 200 ppm turbidity from a clamshell dredge. He stated that the maximum distance the spoil was transported from the discharge pipe of a hydraulic dredge was 1300 feet.

Ingle (1952) in a study of the effects of dredging on fish and shellfish reported that it appeared that all potentially deleterious particles had settled to the bottom within 300-400 yards of an active dredge with overboard disposal. Average sedimentation rates at 75 yards from a dredge were .228 inches/hr. just off the bottom and .108 inches/hr at mid-depth.

Hellier and Kornicker (1962) measured the sedimentation rate around an open-water spoil disposal site in Aransas Pass, Texas. Stations were established at 0.03, 0.5, 1.0, 1.5 and 2.0 miles in a line perpendicular from the channel. The spoil was deposited between the first two stations. Background sedimentation rates were 2-3 mm for a nine month period. One week after dredging there were seven cm of sediment on the 0.03 mi. station and 22 cm on the 0.5 mi. station. Sedimentation at the 1.0, 1.5, and 2.0 mi. stations was negligible.

Boone and Byrne (1975) in a study of a dredging project on Hampton Bar, Va. reported bottom deposition resulting from the dredging activity was primarily restricted to an area within a 200 yard radius of the dredge.

Impacts on Estuarine Organisms

Phytoplankton. The reported effects of dredging and dredge spoil disposal on phytoplankton and primary production are many and varied depending upon the situation at each site. These range from a significant reduction in carbon uptake by phytoplankters (Sherk et al, 1976) to a substantial increase in primary production (Subba Rao, 1973) to no observable effect (Flemer, 1970) to a combined effect of reduced photosynthesis by increased light attenuation and the stimulation of photosynthesis by the introduction of nutrients (Odum and Wilson, 1962). For specific levels of impact please refer to Table 1.

Crustaceans. The possible impacts of dredging on this group of organisms include interference with feeding, clogging of gills and heavy metals and pesticide uptake. The levels of TSS normally encountered in upland disposal type dredging operations, a few hundred mg/l maximum, will probably cause some reduction in feeding efficiency and probably some interference with respiration of selected copepods (See Table 2). However, the areal extent of the highest levels of TSS is very small, a radius of a few hundred meters maximum around the dredge. The impact, in all but the smallest of water bodies, should be minimal.

Peddicord and McFarland (1978) reported uptake by decapod crustaceans of heavy metals and polychlorinated hydrocarbons on a limited basis. These accumulations occurred after days of exposure to fluid mud concentrations (grams to tens of grams/liter) of highly contaminated sediments. Neither the TSS concentration levels nor the duration of exposure can be expected during dredging with upland disposal operations. Sullivan and Hancock (1977) reviewed the general impacts of dredging on zooplankton.

Mollusks. While the adults of this group of organisms are very susceptible to adverse impacts from dredging due to their sessile nature, it is also a group that has adapted to the most turbid portion of the water column. The pumping rate of adult bivalves can be adversely affected by levels of TSS generated by dredging, a few hundreds of mg/l (Table 3). However, they are also adapted to survive long periods with both valves closed or at reduced pumping rates to accommodate naturally occurring periods of adverse conditions.

The eggs of oysters are susceptible to a substantial reduction in their development at TSS concentrations of silt in the upper range of those expected from dredging operations (See Table 4). Oyster egg development is affected by lower concentrations of silt than are hard clam eggs. The larvae of oysters and clams, however, do not appear to be significantly affected until they are exposed to concentrations of silt in excess of normal dredging operation levels. Here again oyster larvae appear to be more susceptible than clam larvae (Table 4).

Fishes. With the exception of juvenile striped bass and silversides concentrations of TSS lethal to fishes are not even approached until they are exposed to levels one to two orders of magnitude above dredging levels for extended periods of time (Table 5).

The sublethal effects listed in Table 6 are also not experienced by fishes until levels of TSS above normal dredging operations are reached with exposure times that do not appear realistic for animals as motile as fish. The significance of the changes in blood chemistry listed is not completely understood but are symptomatic of an organism undergoing oxygen deprivation.

The effects of increases TSS concentrations on the eggs and larvae of fishes are listed in Table 7. The only effect on the eggs of four species by TSS levels at the extreme upper limit of those expected from a dredging operation was a one hour delay in hatching over controls. Lethal concentrations (LC_{50}) of TSS on the fish larvae studies were far in excess of anticipated levels from dredging.

Several general observations are in order on the experiments done to ascertain the impact of suspended solids on aquatic organisms. Direct comparisons between the impacts natural sediments and those of processed materials, e.g. Kaolin, Fuller's earth, etc., cannot be routinely made because in some instances effects may have been observed at low levels with the processed materials but similar effects were not observed until much higher levels of natural sediments were reached and vice versa. The degree of contamination of natural sediments with heavy metals, hydrocarbons, pesticides and other pollutants can also play a significant role in the observed impacts on aquatic organisms.

Dissolved oxygen levels and temperature also affect the impacts of suspended solids. Organisms appeared to fair better at high dissolved oxygen levels and low temperatures than they did at low dissolved oxygen levels and high temperatures (Peddicord et al, 1975).

The habitat in which the organisms are normally found also influences the level at which the organism is impacted by suspended solids. Those living in naturally highly turbid areas are usually better adapted than those preferring relatively clear water.

Summary and Conclusions

In general, it may be concluded from the results of this review that the effects of dredging with confined upland spoil disposal are limited. They include:

a. Minor impacts on phytoplankton due to reduced light penetration which is often offset by increased nutrient availability.

b. Limited interference with zooplankton feeding immediately adjacent to the dredge due to increased TSS.

c. Reduction in development of oyster eggs due to increased TSS.

d. Possible slight increase in sedimentation adjacent to the dredge which might affect adjacent shellfish beds.

e. Based on the nutrient and pollutant release data from open-water disposal operations, very limited increases of manganese, iron, ammonium nitrogen, orthophosphate and reactive silica can be expected. Under very specific conditions the possibility also exists for the limited release of other heavy metals and pesticides during dredging operations.

f. In some instances there is a reduction of D.O. of 1-2 mg/l when dredging normal harbor sediments.

These impacts are primarily restricted to the immediate vicinity of the dredge, a radius of a few hundred meters. Tidal and wind generated currents will usually provide sufficient mixing and dilution to return the water to near background levels within this distance.

Table 1. The effects of various suspended solids on phytoplankton

SPECIES	LIFE STAGES	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
Monochrysis lutheri	NA	2,250 mg/1	NS	SiO_2 median size = 17 µm	80% reduction in carbon uptake	Sherk, et al., 1976
M. lutheri	NA	250 mg/1	NS	SiO_2	approx. 23% reduction in carbon uptake	"
Chlorella sp.	NA	1,000 mg/1	NS	SiO_2 median size = 6.2 µm	90% reduction in carbon uptake	"
Chlorella sp.	NA	250 mg/1	NS	SiO_2	approx. 30% reduction in carbon uptake	"
Nannochloris sp.	NA	250 mg/1	NS	SiO_2	approx. 28% reduction in carbon uptake	"
Nannochloris sp.	NA	1,000 mg/1	NS	SiO_2 particles < 15 µm	90% reduction in carbon uptake	"

Table 2. The effects of various suspended solids concentrations on crustaceans

SPECIES	LIFE STAGE	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
Eurytemora affinis	adult	500 mg/1	NS	SiO_2 (15 µm)	ave. 49.5% reduction in algal uptake	Sherk, et al., 1976
" "	"	500 mg/1	"	Fuller's earth	42% reduction in algal uptake	"
" "	"	500 mg/1	"	natural sediment	ave. 62.6% reduction in algal uptake	"
Acartia tonsa	adult	100 mg/1	NS	SiO_2 (15 µm)	ave. 66.6% reduction in algal uptake	"
" "	"	100 mg/1	"	Fuller's earth	ave. 67.5% reduction in algal uptake	"
" "	"	500 mg/1	"	nat. sediment	72.9% reduction in algal uptake	"
Crangon nigromaculata	adult	50,000 mg/1	200 hrs.	Kaolin	LC_{50}	Peddicord et al., 1975
Homarus americanus	adult	50,000 mg/1	NS	Kaolin	no mortality	Saila et al., 1968
" "	"	1,600 ppm	NS	harbor sed.	no martality	cited from Stern and Strickle, 1978
Palaemon macrodactylus	adult	77,000 mg/1	200 hrs.	Kaolin	LC_{20}	Peddicord et al., 1975
Cancer magister	adult	3,500 mg/1	21 days	contaminated sediment	LC_{10}	Peddicord and McFarland, 1978
Crangon nigricauda	4-6 cm	21,500 mg/1	21 days	"	20% mortality	"

Table 3. The effects of various suspended solids concentrations on mollusks

SPECIES	LIFE STAGE	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
C. virginica	adult	4,000-32,000 mg/1	extended	sediment	detrimental	Wilson, 1950
"	"	100-700 ppm	NS	mud	no apparent problems	Mackin, 1961
"	"	100-4,000 mg/1	NS	silt	57-94% reduction in pumping	Loosanoff & Tommers, 1948
Mytilus edulis	2.5 cm	100,000 mg/1	5 days	kaolin	10% mortality	Peddicord et al., 1975
" "	10 cm	100,000 mg/1	11 days	kaolin	10% mortality	Peddicord et al., 1975
" "	10 cm	96,000 mg/1	200 hrs.	kaolin	LC_{50}	Peddicord et al., 1975
Crepidula fornicata	adult	200-600 mg/1	NS	NS	pronounced reduction infiltration rate	Johnson, 1971
Mytilus edulis	2.0-2.5	2,300 mg/1	21 days	contaminated sediment	LC_{10}	Peddicord and McFarland, 1978

Table 4. The effects of various suspended solids concentrations on the eggs and larvae of mollusks

SPECIES	LIFE STAGE	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
Crassostrea virginica	egg	188 mg/1	NS	silt	22% reduction in number developing to straight hinge larval stage	Davis & Hidu, 1969
" "	"	250 mg/1	NS	silt	27% " "	"
" "	"	375 mg/1	NS	silt	34% " "	"
" "	"	<1000 mg/1	NS	Fuller's earth	no significant reduction in number developing to straight hinge larvae	"
" "	"	<2000 mg/1	NS	Kaolin		
Mercenaria mercenaria	egg	750 mg/1	NS	silt	8% reduction in number developing to straight hinge larvae	Davis, 1960
" "	"	1000 mg/1	NS	silt	21% " "	Davis, 1960
" "	"	1500 mg/1	NS	silt	35% " "	
" "	"	125 mg/1	NS	Kaolin	18% " "	Davis, 1960
" "	"	"	NS	Fuller's earth	25% " "	
" "	"	4000 mg/1	NS	SiO_2 <5 u	31% " "	Davis & Hidu, 1969
C. virginica	larvae	>750 mg/1	12 days	silt	significant reduction in survival	Davis & Hidu, 1969
" "	"	2000 mg/1	"	Fuller's earth	20% reduction in survival	Davis & Hidu, 1969
" "	"	500 mg/1	NS	SiO_2 <5 u	78% reduction in survival	" "

Table 4. continued

SPECIES	LIFE STAGE	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
<u>Mercenaria</u> <u>mercenaria</u>	larvae	1000 mg/1	NS	silt	normal growth	Davis, 1960
" "	"	500 mg/1	12 days	Kaolin	50% reduction in survival	" "

Table 5. Lethal effects of various suspended solids concentration on fishes

SPECIES	LIFE STAGE	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
Leiostomus xanthurus	adult	13,090 mg/1	24 hrs.	Fuller's earth	LC_{10}	Sherk et al., 1975
" "	"	68,750 mg/1	"	Patuxent silt	LC_{10}	"
Morone americana	adult	9,970 mg/1	"	Patuxent silt	LC_{10}	O'Conner et al., 1976
" "	"	3,050 mg/1	"	Fuller's earth	LC_{10}	Sherk, et al., 1975
Fundulus majalis	"	23,770 mg/1	"	Fuller's earth	LC_{10}	"
" "	"	97,200 mg/1	"	Patuxent silt	LC_{10}	"
F. heteroclitus	"	24,470 mg/1	"	Fuller's earth	LC_{10}	"
Menidia menidia	"	580 mg/1	"	Fuller's earth	LC_{10}	"
Brevoortia tyrannus	juvenile	1,540 mg/1	"	Fuller's earth	LC_{10}	"
Anchoa mitchilli	adult	2,310 mg/1	"	Fuller's earth	LC_{10}	"
Morone saxatilis	5-6 cm	4,000 mg/1	21 days	uncontaminated sediment	LC_{10}	Peddicord and McFarland, 1978
" "	"	400 mg/1	2 days	contaminated sediment	LC_{50}	"

Table 6. The sublethal effects of various suspended solids concentrations on fishes.

SPECIES	LIFE STAGE	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
Morone americana	adult	650 mg/l	5 days	Fuller's earth	increased micro-matocrit, hemoglobin concentration & Red Blood cell count over control	O'Connor et al. 1977
M. americana	"	2000 mg/l	6 days	Natural sediment	significant increase in RBC, hematocrit & hemoglobin	"
" "	"	"	14 days	"	control & experimental similar	"
Trinectes maculatus	adult	1240 mg/l	5 days	Fuller's earth	increased hematocrit & RBC count; reduction in liver glycogen content	"
Fundulus majalis	adult	960 mg/l	5 days	Fuller's earth	increased hematocrit	"
F. heteroclitus	adult	1600 mg/l	4 days	"	" "	"
Leiostomus xanthurus	adult	1270 mg/l	5 days	Fuller's earth	no significant difference in blood chemistry over control	"
L. xanthurus	"	16,960 mg/l	7 days	Natural sediment	"	"
Opsanus tau	adult	14,600 mg/l	3 days	Natural sediment	"	"
Morone saxatilis	adult	1500 mg/l	14 days	Fuller's earth	increased hematocrit	"
M. saxatilis	"	1500-6000 mg/l	6 days	Natural mud	no significant change in blood chemistry over control	"

Table 7. The effects of various suspended solids concentrations of fish eggs and larvae.

SPECIES	LIFE STAGE	CONC.	EXPOSURE	MATERIAL	EFFECT	SOURCE
Perca falvescens	eggs	500 mg/1	NS	natural fine grained sediment	No statistically significant effect on hatching success, although a several hour delay in hatching was frequently observed about 100 mg/1	Schubel & Wang, 1973
Morone americana	"	"	"	"		"
Morone saxatilis	"	"	"	"		"
Alosa pseudoharengus	"	"	"	"		"
M. americana	larvae	2679 mg/1	48 hr.	NS	LC_{50}	Morgan et al., 1973 cited from Sternand Stickle, 1978
M. saxatilis	larvae	3411 mg/1	"		LC_{50}	"
M. americana	larvae	3730 mg/1				
	eggs	4000 mg/1	NS	NS	Delayed hatching one day	"

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Summary and Conclusions

The aim of this report is to address the effects of dredging impacts on the Hampton Roads estuarine system. Its scope is limited by certain qualifications which were established at the beginning of the study. These qualifications must be considered before application of the conclusions and recommendations of this report can be deemed valid or appropriate for the dredging operation in question.

The results of this report apply only to channel maintenance dredging where accumulated silt and clay are excavated from the bottom of an existing well-defined channel. Both hydraulic cutterhead and clamshell bucket methods of dredging are considered.

The application of the results is primarily restricted to the principal study area which is Hampton Roads, the Elizabeth River and the Lower James River. Limited application of certain aspects of this study may be made to other areas by interpretation and extrapolation where very similar conditions exist.

Dredging operations utilizing a confined upland disposal area are the only types considered. The dredge cutterhead and clamshell bucket are the only point sources of suspended solids considered in this report. Any impacts associated with disposal operations, open-water or otherwise, cannot be interpreted using the conclusions of this report.

The study area is heavily utilized by marine resources despite its high degree of urbanization, industrialization and commercial shipping use. The Hampton Roads area supports large populations of hard clams. The Lower James River supports vitally important extensive seed oyster beds. The entire area is heavily utilized by a variety of finfish for spawning, nursery areas and/or feeding grounds.

The results of the field investigations and model predictions of the levels and distribution of suspended material and sedimentation indicate that:

a. Both hydraulic and clamshell dredges generated suspended solids levels in excess of 200 mg/l.

b. Dispersion and settling reduced the suspended solids generated by the dredges to background levels within approximately 300 meters down current to the dredge.

c. Sedimentation rates predicted by the model decreased with increasing distance from the dredge. They ranged up to several millimeters 125 m laterally from the dredge, at right angles to the current flow and at the same depth as the dredging.

In light of the impact threshold for marine resources utilizing the area and the suspended solids and sedimentation levels for dredging given in the literature and those observed and predicted by the model in this study, the following observations on the effects of dredging on these organisms and water quality are offered:

a. Minor impact on phytoplankton photosynthesis due to reduced light penetration which is often offset by increased nutrient availability.

b. Limited interference with zooplankton feeding immediately adjacent to the dredge due to increased suspended solids.

c. Reduction in the development of oyster eggs into larvae due to increased suspended solids in excess of 200 mg/l.

d. Pronounced reduction in the pumping rate of oysters when levels exceed 100 mg/l.

e. Increase in sediment accumulation in areas adjacent to the dredged area. This sedimentation may be significant enough within a few hundred meters to have an adverse effect on oysters, particularly spatfall and spat survival.

f. Lethal impacts on fishes should be minimal except for juvenile striped bass and atlantic silverside which are susceptible to levels of suspended solids on the order of 500 mg/l. White perch appear to undergo respiratory stress at approximately the same level.

g. The eggs of several species of fish can experience a slight delay in hatching (a few hours) during exposure to suspended solids levels in excess of 100 mg/l.

h. Generally, the releases of nutrients, heavy metals and pesticides should be small in quantity and of short duration.

i. In some instances, there will be possibility of a reduction in Dissolved Oxygen by 1-2 mg/l near the dredge. This depends on numerous factors including the sediments being dredged, water temperature, and the dispersion capacity of the water body.

Based on the above information, the potential exists for dredging operations in close proximity to productive oyster beds and certain fish spawning areas at certain times of the year to have an appreciable impact on these resources. Other resources will be impacted but the extent and duration should be minimal.

In developing a management plan for dredging for Hampton Roads and the lower James River, it might be advisable to designate and classify areas of particular concern. The designation and classification of these important resource areas with respect to their potential for being affected by dredging at different times of the year could prove to be an effective tool for managing dredging in the Hampton Roads and lower James River area.

A suggested scheme for designated areas of particular concern would include the following classifications which could be applied during the appropriate times of year:

Restricted - The potential exists for serious adverse impacts on adjacent resources. Dredging and disposal operations should be prohibited, except, possibly, for emergency situations during the most vulnerable times of the year to protect the resources.

Conditional - Potential exists for adverse impacts on adjacent resources during certain times of the year. But due to the level of anticipated dredging and/or disposal impact, the proximity of the resources, or the marginal value of the areas to the resources, there are no absolutely critical times of the year when dredging should be prohibited. However, there may be times of the year when dredging and disposal operations should be avoided, when possible, to minimize unnecessary adverse impacts.

Open - Areas where the resources present are not especially susceptible to the adverse effects of dredging and/or disposal operations and time-of-year dredging restrictions are generally not warranted. This, however, does not preclude restrictions for exceptional situations which must be evaluated on a case-by-case basis.

The application of this classification system for designated areas to the Hampton Roads-lower James River area included in the present study would involve the following:

1. The designation of the area between Deep Water Shoals and a line from Newport News Point to Pig Point in the lower James River as a restricted area for dredging during the oyster spawning and setting season (July, August and September). Dredging within 500 meters of any other productive oyster bottom in the Hampton Roads study area during these months should also receive a restricted classification.
2. A conditional classification for the Southern Branch of the Elizabeth and its tributaries upstream of the I-64 bridge during

the principal anadromous and resident fish spawning season (mid-March through June). This area is also heavily utilized as a nursery for postlarvae and juveniles of numerous fishes.

3. A conditional classification for dredging in the Southern Branch of the Elizabeth River during the warm weather months (July through September) might also be considered to help minimize the potential for creating dissolved oxygen depletion by adding the effects of dredging to already oxygen stressed conditions. However, this would be contingent upon the development of a sufficient body of data to indicate whether dredging contributes significantly to the reduction of dissolved oxygen levels.

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