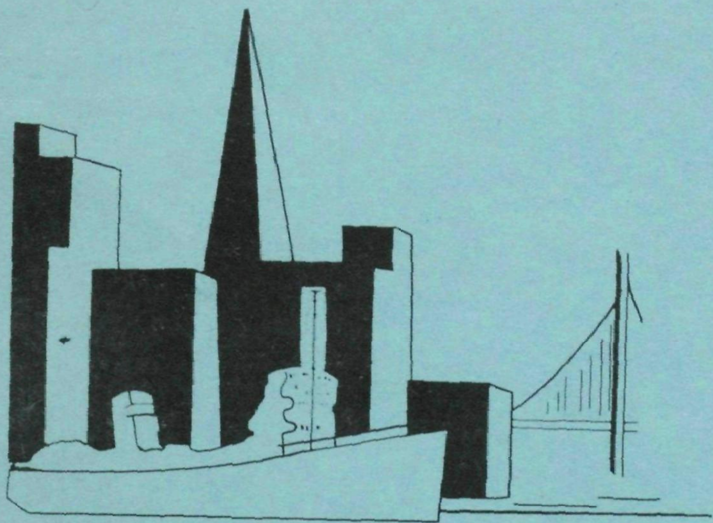

IDENTIFYING AND PRIORITIZING LOCATIONS FOR THE REMOVAL OF IN-PLACE POLLUTANTS

MAY 1976

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PLANNING AND STANDARDS
WASHINGTON, D.C. 20460

IDENTIFYING AND PRIORITIZING LOCATIONS FOR THE REMOVAL OF IN-PLACE POLLUTANTS

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NOTICE

This document is a preliminary draft. It has not been formally released by EPA and should not at this stage be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

SECTION 1

INTRODUCTION

Over the years, pollutants have been building up in the sediments of the ports, harbors, and waterways of the United States. These pollutants have come from many sources, including wastewater outfalls, non-point sources, accidental spills, and dredge material disposal. Since many of the pollutants naturally adsorb and chemisorb to the fine sediment particles (clay, silt) the pollutants often are transported considerable distances by the water, before settling out. When such particles eventually settle, the result can be a system of in-place pollutants, distributed over large areas, or an accumulation of "hot spots" where the level of pollution is considerably higher than in adjacent areas.

Recognizing the problems of in-place pollutants in natural water systems, Congress enacted Title I, Section 115 of the Federal Water

Pollution Control Act of 1972, PL 92-500, requiring the following action of the Environmental Protection Agency:

IN-PLACE TOXIC POLLUTANTS

> Sec. 115. The Administrator is directed to identify the location of in-place pollutants with emphasis on toxic pollutants in harbors and navigable waterways and is authorized, acting through the Secretary of the Army, to make contracts for the removal and appropriate disposal of such materials from critical port and harbor areas. There is authorized to be appropriated $15,000,000 to carry out the provisions of this section, which sum shall be available until expended.

This report presents the results of a national study of in-place pollutants in harbors and navigable waterways of the United States. Its purposes are to document the rationale used and to present the priority devised for selecting locations for further consideration under Sec. 115. The priority system was used to arrive at a list of locations that may be considered semifinalists. A final list awaits the results of definitive measurement programs in the harbors selected via this priority system.

Two overall tasks have been conducted to achieve the purposes of this study. Task 1 included a survey of available existing data on sediment chemistry in the United States in waters of interest to Sec. 115. This survey had collected 652 sets of analyses as of December 2, 1974. In a Task 1 report dated September 28, 1974, analyses of 623 sets of data received to that time were presented. The function of Task 1 was to reduce the data to a form amenable to easy screening. With the data in this form, the bulk of relatively unpolluted areas could be eliminated quickly.

Task 2, in order to produce the semifinal priority list, included the development of criteria, the gathering of detailed information on 23 locations, and the comparison of those locations based on the developed criteria and the gathered information.

Subsequent chapters present the processes by which criteria were selected and the numerical values chosen for use with each criterion. For criteria related to pollution or sediment chemistry, the project heeded two principal guides:

1) The stipulation in Section 115 that there be "emphasis on toxic pollutants";
2) The need for a means of quickly scanning large amounts of data.

To follow the second guide, a method was developed with computer reduction of data to a form which could be scanned quickly by an investigator. This method used the concept of a Pollution Index, developed later in the report. The Pollution Index is uniquely valid and applicable to the specific task of setting priorities.

To supplement the criterion of relative degree of pollution, other criteria were developed. These include overall environmental conditions, so that the likely effects of the removal of in-place pollutants on the surrounding human and natural environments could be assessed. Finally, physical criteria lead ultimately to cost estimates for each of the final locations, so that the Section 115 funds can be spent in the optimum manner. These cost estimates await the input of additional data not available at this time.

Using the priority system, the list of potential harbors has been reduced and detailed information has been compiled and analyzed for the 23 locations resulting from the initial screening. Using the criteria developed in this report, comparisons of these critical harbors and waterways have been made, leading to a proposed priority list of areas which merit further detailed investigation.

It should be stressed that the available data are not of sufficient quantity or quality to make final assessments as to how to utilize the Section 115 funds most effectively. However, the existing data can be used to establish which harbors warrant further investigation.

All recommendations and results documented in this report are based upon available field data. While it may be difficult to make decisions based upon existing data, it is impossible to make decisions based upon no data. Thus, the possibility exists that other "hot spots" may be found, but these cannot be considered at this time. The priority system developed, however, is general enough so that additional data can be compared to all other harbors very quickly, allowing changes in the semifinal list of harbors, as required.

SECTION II

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The data currently available on sediment quality in United States harbors and navigable waterways are not adequate to set final priorities for removal or inactivation of in-place pollutants in response to Section 115. However, they are adequate to establish a list of harbors and waterways from which the final locations may be selected after additional sampling and analysis. Data inadequacies have two distinct results:

   a) There may be hot spots which have not been sampled;

   b) Inadequate intensity of sampling permits only priority groupings, rather than firm rankings of locations.

2. Screening methods based upon relative pollution may be adequate to arrive at a semifinal list of locations, but all of the locations on this list have areas so badly polluted that other considerations must be used in making the final determination.

3. The quantity of the available sediment chemistry data varies substantially from region to region. The use of national statistics presented in this report for inferring regional differences, must be done with caution. Results of samples taken close together often varied from laboratory to laboratory and a variety of analytical techniques were used. Moreover, some of the data are more than five years old, and conditions may have changed.

4. In most cases the pollutant form, or nature of its complexing with other elements, is not discernable from the data. Other factors such as redox potential, pH, alkalinity, and salinity have often not been included in data sets. Since these variables can significantly affect the mobility and toxicity of a given chemical, it is difficult to predict the effect on the ecosystem of any given hot spot.

5. Very little information exists on chlorinated hydrocarbon concentrations in sediments. The same is true of free sulfides, which are very important due to their toxicity and interactions with heavy metals.

6. Since the levels of pollution in the locations on the semifinal list are so high, it is not important to be concerned about fine distinctions in the toxicity of one constituent relative to another, at these initial screening stages of the Section 115 investigation.

7. Dredging and disposal in acceptable disposal areas appears to be the only realistic form of rehabilitation at this time. Covering of in-place sediments is impractical in cases where a navigation channel must be maintained, undesirable from a long-term point of view, temporary in cases where erosion and resuspension due to current and storms exist, and very expensive in any case. Treatment is feasible under some conditions but tends to be very expensive.

8. Histograms of pollutant concentrations reveal that most hot spots have concentrations far in excess of the values used by EPA as criteria for determining pollution status of dredged material. On a national level, the median appears to be a more realistic descriptor than the arithmetic mean, and the national median values agree closely with those levels promulgated earlier by EPA as criteria for polluted sediments.

9. Extensive data exists demonstrating the existence of hot spots. However, in most cases the data was not taken in such a quantity or manner that the area or volume of a hot spot can be defined. Thus it is not possible at this time to estimate the volume and area affected, hence the cost for disposal cannot be established. Determination of these highly important considerations awaits the results of additional sampling.

10. Some regions of the country appear to be more highly polluted than others, as would be expected. However, some areas such as New England and the Great Lakes had far more extensive data available than other regions and it is not known how much bias is introduced to regional comparisons by the differing magnitudes of available data.

11. The magnitude of sediment pollution in the United States is such that the Section 115 funds cannot begin to have a significant effect unless they are very carefully expended. Perhaps the most reasonable method of spending the funds is to select a single harbor, or two harbors, in which a major rehabilitation is possible with the existing funds. Areas already scheduled for routine dredging should be excluded from Section 115 and the funds used in areas where other federal or state funds will not be available.

12. Final selection of harbors, and areas within harbors, should not be attempted until a definitive sampling and analysis program is conducted in the locations of interest. Based upon the priority system developed on this contract, we recommend the following priority list of locations.

<u>Priority 1</u>	Detroit River, MI Baltimore Harbor, MD Indiana Harbor, IN Duwamish Waterway, Seattle, WA Michigan City Harbor, IN San Francisco Harbor, CA
<u>Priority 2</u>	Bridgeport Harbor, CT New Bedford Harbor, MA Corpus Christi Harbor, TX
<u>Priority 3</u>	Providence River and Harbor, RI New Haven Harbor, CT Eastchester Creek, NY Newark Bay, NJ Sampit River, Georgetown, SC Monongahela River above Pittsburg, PA Mississippi River below St. Louis, MO Cleveland Harbor and Cuyahoga River, OH

Priority 3 (cont.)

Milwaukee Harbor, WI
Neches Waterway, Beaumont, TX
Richmond Harbor, CA
Oakland Harbor, CA
Los Angeles Harbor, CA
San Diego Harbor, CA

Recommendations

1. Priority 1 list of locations should be published in the Federal Register, or circulated to each EPA and Corps of Engineers Regional Office. EPA and Corps of Engineers comments were actively solicited on the 23 locations resulting from initial screening, but new information may have become available to regional and district offices. Comments should be solicited on the locations selected and if other locations are recommended, these should be considered using the same priority system that generated the Priority 1 list. If regional offices feel that other locations are worse than the proposed list, preliminary sampling should be done to verify this. Until such time as data becomes available indicating otherwise, the Priority 1 list should be the basis of future Section 115 investigations.

2. A pilot study should be conducted on one of the Priority 1 locations to establish the following, and to be used to guide investigations in the other 5 areas:

   - analytical procedures for lab analysis
   - sampling methods
   - sample handling methods
   - 3 dimensional distribution of pollutants
   - chemical form of pollutants
   - exchange rate between sediment and water column (pollutant mobility)
   - toxicity of existing form of pollutants to local organisms
   - original source of pollutants and whether these sources are still active

3. After conducting the pilot study, the other 5 locations should undergo the same type of study. Based upon the results of these 6 studies, a final determination as to the most effective way to distribute the Section 115 funds amongst one or more of the locations should be established.

4. If the local studies and the results of rehabilitation actions prove that significant and cost-effective benefits can be realized, other funds should be sought to expand the work of removing in-place pollutants which was begun by Section 115.

SECTION III

DEVELOPMENT OF A SEDIMENT CHEMISTRY DATA BASE

Data Collection

Section 115 addresses ". . . harbors and navigable waterways . . ." and charges EPA with identifying in-place pollutants and subsequently seeing that they are removed ". . . from critical port and harbor areas." Since the key word critical has not been defined and harbors and navigable waterways has a broad context, data were collected on a broader scope than perhaps necessary, realizing that the data from sites subsequently not of interest could be ignored.

Data on in-place pollutants are available from many sources. Agencies and organizations involved in dredging operations are the best source of this information since they are directly involved in this area. Data are also available from numerous other sources. Much of the available data was not originally collected with dredging in mind and thus has to be interpreted for the requirements of this study.

The following sources were used to collect sediment chemistry data:

1. JBF Scientific data bank, compiled during previous, more limited surveys
2. Army Corps of Engineers, District and Division Offices and Waterways Experiment Station
3. Environmental Protection Agency, Regional and Field Offices
4. Other Federal Agencies and Commissions
5. State Water Pollution Control Agencies
6. Port Authorities
7. Universities and Colleges
8. Marine Research Institutes
9. Professionsl papers and reports

As each individual sediment analysis data set was received, the data were screened for applicability. If acceptable, an ascending bibliographic reference number was assigned to each set. Occasionally more than one data set was obtained for the same geographic location. In many cases, several data sets were obtained which represented various portions of a given bay or harbor. Regardless, individual bibliographic numbers were assigned for each data set received for cataloging purposes. Similarly, where several data sets were obtained for various reaches of a river, each set was given a different reference number.

At the time of this writing, 652 reference numbers have been assigned representing that number of acceptable data sets. A data set consists of the results of up to 33 sediment chemical analyses performed for any number of sediment samples, collected in a finite area within a commonly named hydrographic unit (e.g., Boston Harbor). The term "location" is used to refer to such hydrographic units.

The above description implies that the 652 data sets do not necessarily represent 652 different locations. For instance, the data set for reference number 419 provides the results of analyses of sediment samples collected at various sites in an area referred to by the investigators reporting the data as Savannah Harbor. Another data set, reference number 457, provides data from samples collected at various sites in an area referred to as Savannah Estuary. Hence, there are fewer than 652 locations to be considered.

Data Reduction

Data were collected under Task 1 for the sole purpose of providing inputs to a priority system for guiding the performance of Section 115. Since the quantity of data collected was extremely large, and the objective highly specific, several simplifying techniques were adopted to reduce the data tabulation, reduction, and analysis tasks to a manageable size.

Hot Spot Screening

The primary goals of the data handling task were to provide a method of locating those harbors and navigable waterways that contained hot spots and some means of rank ordering the locations so that the relatively unpolluted ones could be quickly eliminated from further consideration.

The following rationale was adopted:

1) Data on sediment chemistry must be available or else a location is not to be considered.

2) For purposes of initial screening, it is only necessary to record the highest value for each pollutant in any location.

The first point is necessary since many locations were suggested as being "polluted" but no data existed for these locations. While there may be locations more polluted than those in the data bank, there is no alternative but to require that data exist before a location is given consideration.

An examination of data reveals that the hot spots of the semifinal list are so grossly polluted that they would meet any rational criteria as polluted. To avoid confusion, it should be pointed out that the selection of the semifinal list, and ultimately the final list, has no relationship to EPA criteria for polluted dredged material, other than exceeding those criteria (criteria listed in Table 6).

The hot spots identified are thus highly polluted and the objective is to rank order the locations, relative to each other, rather than with regard to previously published criteria.

Based upon (2), high values from each location were put into a data base. The data base is a tool that can be used to call attention to those locations that have at least one set of measurements defining a hot spot. For a location to qualify under Section 115, it is necessary that it have at least one hot spot; thus the method adopted identifies those locations of interest while enormously reducing the data handling problem. In this report, the data used for analysis and selection of the semifinal list are taken from the data file generated by using only the highest value for each pollutant in each location. This will be referred to as the high-value data file.

A computer program was written to operate upon the high-value data file to obtain the minimum, maximum, mean, median, and standard deviation of each sediment chemical parameter in each of the eleven Army Corps Divisions. The results of the calculations on the file were presented in the Task 1 interim report and a summary of the levels is presented in Table 1.

A scan of the standard deviations listed in Table 1 reveals that the arithmetic mean is not a good indicator of central tendency for the data. Figure 1 is a histogram displaying 441 sediment mercury concentrations in the high-value data file.

The shape of the mercury histogram demonstrates why the arithmetic mean is a poor indicator and suggests that the median would be more appropriate. Note that the interval size on the histogram was chosen so that the data could be grouped in 20 intervals.

The mean for mercury given in Table 1 is 6.09 mg/kg, a value clearly biased by a few, exceptional high values as can be observed from the histogram. The median for mercury given in Table 1 is 0.5 mg/kg, a value which does more closely reflect the central tendency of the data.

Histograms were prepared for many of the chemical sediment parameters of Table 1 using the data from 623 locations. Comparison of these histograms with the statistic data of Table 1 repeatedly demonstrated that the median was clearly the best singular indicator of central tendency for the data.

Median values calculated for each Corps Division are summarized in Table 2. The table provides a quick reference by region for each

TABLE 1

Statistical Measurements of All Divisions in the United States

DIV=ALL DIS=ALL

STATE=ALL CITY=ALL PLACE=ALL TYP=ALL

NAME		NO. SMP	MIN	MAX	MEDIAN	MEAN	SD
VOL SLDS	MG/KG DW	559	231.66	975838.00	78000.00	99218.87	101825.87
COD	MG/KG DW	536	0.0	910000.00	59000.00	94511.75	110530.81
TKN	MG/KG DW	487	0.0	855374.00	1600.00	5083.72	40187.82
OIL&GRSE	MG/KG DW	463	0.0	903000.00	1400.00	7114.28	43886.95
MERCURY	MG/KG DW	441	0.0	962.00	0.50	6.09	57.52
LEAD	MG/KG DW	454	0.01	13890.00	42.00	188.33	959.79
ZINC	MG/KG DW	446	0.09	10897.00	100.00	349.69	1011.62
ALUMINUM	MG/KG DW	17	10.00	30000.00	8560.00	10305.84	9370.20
CHROMIUM	MG/KG DW	197	0.02	5745.00	65.00	199.04	569.00
CHROMATE	MG/KG DW	1	40.00	40.00	40.00	40.00	0.0
MANGNESE	MG/KG DW	83	3.30	4800.00	510.00	696.38	704.43
IRON	MG/KG DW	210	160.00	290000.00	19890.00	29521.96	36911.53
NICKEL	MG/KG DW	193	0.40	6070.00	32.00	95.35	447.08
COPPER	MG/KG DW	259	1.00	312940.00	62.00	2390.15	24823.17
ARSENIC	MG/KG DW	141	0.00	9660.00	3.00	77.85	812.97
CADMIUM	MG/KG DW	241	0.0	7490.00	3.10	47.25	486.25
NITRITE	MG/KG DW	19	0.06	250.00	0.24	30.24	64.29
NITRATE	MG/KG DW	44	0.31	250.00	8.60	25.24	53.36
TOT PHOS	MG/KG DW	236	0.36	81490.00	900.00	2227.33	6420.65
OTH PHOS	MG/KG DW	4	0.46	120.00	0.61	32.45	58.49
SOL PHOS	MG/KG DW	25	0.77	2780.00	9.19	257.87	620.83
H2S	MG/KG DW	2	6.00	100.00	6.00	53.00	66.47
SULFIDE	MG/KG DW	19	0.28	594000.00	930.00	58170.58	150329.19
FECAL CO		3	10.00	12384.00	5863.00	6085.66	6190.00
TOT COLI		2	1.00	100.00	1.00	50.50	70.00
TOC	MG/KG DW	96	400.00	142000.00	27000.00	36014.16	32155.17
BOD	MG/KG DW	36	5.43	301600.00	3930.00	19010.52	52680.07
PESTICDE	UG/KG DW	23	0.00	7.50	0.00	0.63	1.87
PCB	UG/KG DW	21	0.00	15.10	0.04	0.92	3.27
MOISTURE	% DRY WT	1	48.00	48.00	48.00	48.00	0.0
IOD	MG/KG DW	4	92.00	675.00	116.00	335.75	281.80
PHENOL	MG/KG DW	53	0.22	35000.00	95.00	1629.62	5611.07
CYANIDE	MG/KG DW	12	0.03	35.00	0.22	5.12	10.40

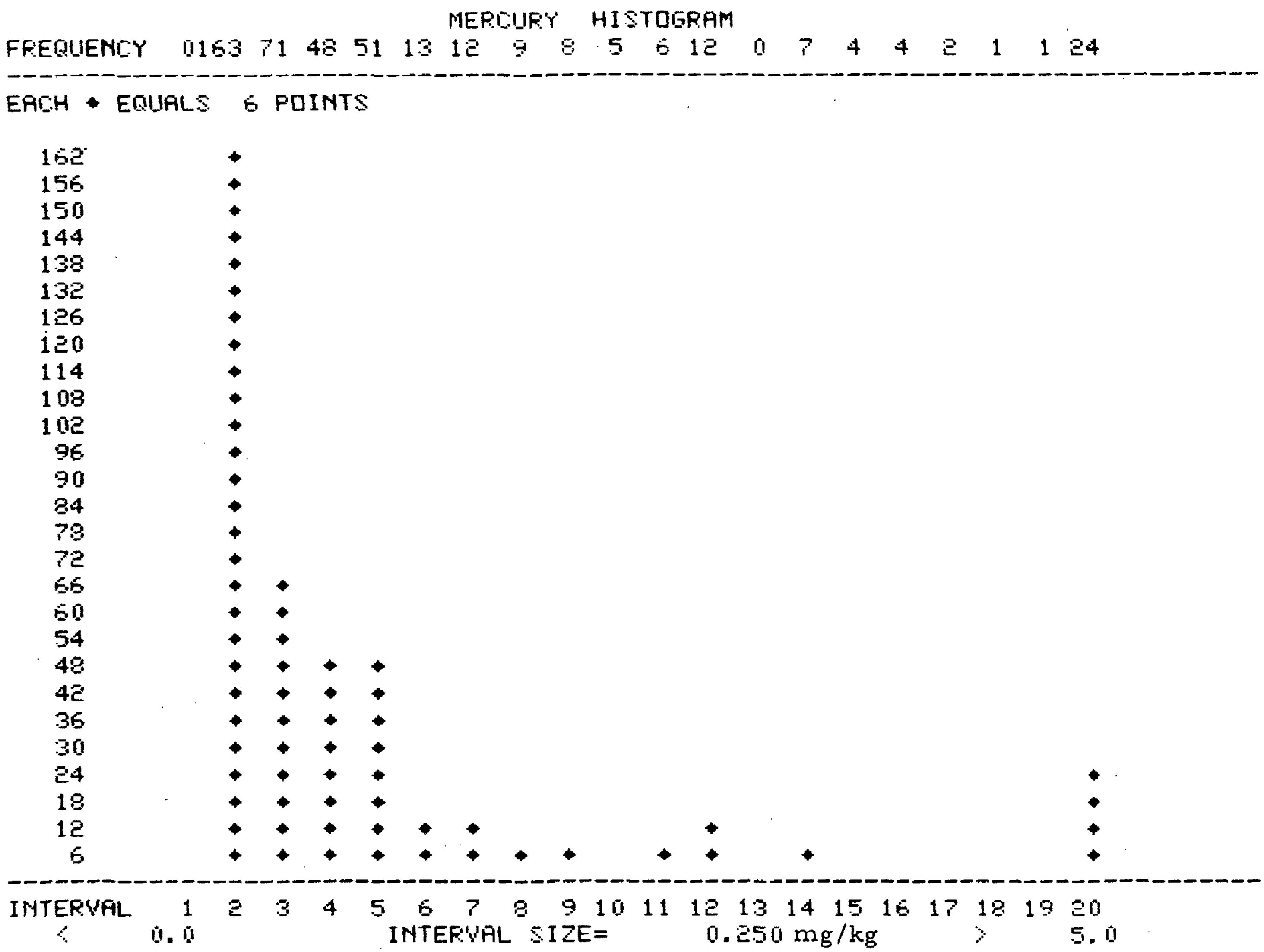

Figure 1. Mercury Histogram for all Locations Reporting Sediment Mercury Concentrations

TABLE 2

U.S. Regional[1] Medians from Selected High Value Sediment Analyses (mg/kg dry weight)

Parameter	Missouri River Division[3]	Mississippi Valley Division	North Atlantic Division	New England Division	Ohio River Division	South West Division
Mercury		0.10	0.79	0.55	0.30	0.16
Lead	607	9.00	100.00	105.00	40.00	19.20
Cadmium			10.00	4.20	1.00	0.81
Arsenic				19.20	0.50	2.27
Zinc	0.09	39.00	536.00	193.50	126.00	65.00
Nickel			59.00	42.20	5.20	18.00
Copper			60.00	93.10	10.90	10.00
Chromium	0.02		574.00	74.00	93.00	19.00
Volatile Solids	231.66	28500.00	45200.00	89800.00	82000.00	57000.00
COD	28.00	23000.00	34600.00	123200.00	65800.00	23300.00
TKN	0.59	700.00	1059.00	3140.00	2300.00	1040.00
Oil & Grease	15.00	500.00	11700.00	2880.00	1800.00	480.00
Nitrite	1.00					
Nitrate	1.00				0.31	
Total Phos	0.36		552.00	110.00	1200.00	598.22
BOD	6.43			5860.00	9000.00	
Aluminum		764.40[2]				
Manganese			812.00			320.00
Fecal Co	5863.00			10.00		
Total Coli				100.00	1.00	
TOC				18900.00		
Pesticide						
PCB				0.13		
~~Phenol~~					160.00	
Sulfide						
H_2S						
Oth Phos						
IOD					31006.00	
Iron						
Cyanide						

(1) The Regions listed comprise the eleven U.S. Army Corps of Engineers Division
(2) One sample only.
(3) Two samples only.

TABLE 2 (cont.)

U.S. Regional[1] Medians from Selected High Value Sediment Analyses (mg/kg dry weight)

Parameter	North Pacific Division	South Atlantic Division	Pacific Ocean Division[4]	Sough Pacific Division	North Central Division
Mercury	0.42	0.70	0.73	0.60	0.91
Lead	42.00	37.00	52.00	54.00	61.00
Cadmium	10.00	2.00	1.10	2.08	10.30
Arsenic		1.00	7.80	2.10	4.00
Zinc	90.00	124.00	120.00	160.00	99.40
Nickel	20.00	34.00	470.00	37.81	44.00
Copper	40.00	49.00	69.00	67.00	78.00
Chromium	10.00	53.00	198.00	83.00	65.00
Volatile Solids	72000.00	108800.00	160000.00	77000.00	94000.00
COD	43000.00	82800.00	67970.00	50000.00	98700.00
TKN	1000.00	1497.00	43.69	1600.00	2620.00
Oil & Grease	1520.00	1600.00	70.00	1400.00	2957.00
Nitrite				50.00	0.12
Nitrate				50.00	8.40
Total Phos	547.00	1550.00		452.00	910.00
BOD		111000.00		715.00	3075.00
Aluminum					12800.00
Manganese		1020.00			510.00
Fecal Co					
Total Coli					
TOC	10520.00	30700.00		31900.00	
Pesticide			0.27	0.23	
PCB	1.00			0.14	
Phenol					62.20
Sulfide	520.00		80.30	930.00	119500.00
H_2S	100.00				6.00
Oth Phos	120.00	0.46			0.61
OD	1160000.00			92.00	
Iron	160.00[3]	20000.00	57000.00	25938.00	18380.00
Cyanide				0.20	0.44

(1) The Regions listed comprise the eleven U.S. Army Corps of Engineers Division

(3) Two samples only.

(4) Six samples only.

sediment pollutant reported. A comparison of the divisional medians in Table 2 with the national medians in Table 1 provides some insight into the relative levels of each parameter in each division, but this table must be used with caution since it reflects the intensity of the sampling program as well as the levels of the pollutants found. Finally, some of the statistics were drawn from a small sample size as Table 1 indicates.

Discussion of the Data

The national comparisons made in this report suffer from the fact that the data bases in some regions of the country are far more comprehensive than in others. Some variation exists in geographical coverage, but the more significant differences are in the number of chemical analyses routinely performed. For example, the data from the New England and South Pacific Divisions of the Corps of Engineers cover a wide range of metals, chlorinated hydrocarbon insecticides, and polychlorinated biphenyls (PCB). In contrast, other sections of the country have focused on very few analyses: typically, organic parameters, oil and grease, mercury, lead, and zinc. Given these variations, it is not possible to compare locations fairly on a national basis and the output of the data file could lead one to believe that one section of the country is more polluted than another when it is possible that one simply did not undergo as comprehensive a sampling program as the other.

Table 3 indicates the regional variations in analyses for some heavy metals.

TABLE 3

Number of Data Sets From the Regions Defined by Corps of Engineers Division Boundaries

Region	Number of Locations with Data for: Cadmium	Arsenic	Nickel
New England	36	29	34
North Atlantic	10	0	9
South Atlantic	51	28	29
Ohio River	5	3	2
North Central	56	25	51
Mississippi Valley	0	0	0
Missouri River	0	0	0
Southwest	28	27	27
North Pacific	4	0	6
Pacific Ocean	5	2	5
South Pacific	46	28	30

Significant regional variations exist also in the number of separate data sources which responded to inquiries. In New England, the Corps of Engineers and state agencies have compiled extensive sediment data. Further south on the Atlantic Coast, much of the sampling and analysis has been done by EPA. In the Great Lakes and along the Gulf Coast, most of the data has been provided by EPA, state agencies, and universities. Very little information was found in the Mississippi River Valley and in the Mountain States. On the Pacific Coast, local Port or Harbor Authorities have provided useful data, supplemented by the Corps of Engineers and EPA.

As indicated in the rationale, the task of setting priorities must be based on exisiting data. Suggestions have been made by local and regional officials that certain harbors and waterways which have not been sampled may have high concentrations of in-place pollutants. In the absence of data, such locations cannot be considered. Similarly, where a small amount of data exists for a location, no extrapolations or interpolations have been made to estimate areas or volumes of polluted sediments.

A problem that was identified during the data collection phase was inaccuracy, or errors, in the analyses provided. Verification of the accuracy of analytical results has not been made and is beyond the scope of this study. In at least two instances in the San Francisco Bay area, checks of analyses by the data originators showed initial results to be incorrect by a wide margin. The original inaccuracies arose in different laboratories, and there is no reason to assume that similar problems do not exist elsewhere.

Accordingly, when existing data are being supplemented in any area, spot checks should be made at the old sampling sites to confirm the accuracy of the sediment quality data used in this report.

Another concern is that the concentrations measured are highly dependent on sampling location and depth within the sediment. A large amount of data is therefore required before any large area can be characterized effectively.

Several locations, such as Houston, and much of New York Harbor, have been shown by the data to have widespread contaminated sediments, with no one sample site qualifying as a hot spot. Such locations may be eliminated by the priority system used for this study. The possibility remains that sampling in these areas has failed to include the most polluted sites. This study, with its scope limited to the existing data base, must ignore that possibility for the time being.

Task 1 provided data, a high-value data file, and a computer program for using the file, so that locations with hot spots could be identified and printed out in a manner that would allow application of additional criteria in Task 2.

SECTION IV

DEVELOPMENT AND APPLICATION OF THE PRIORITY SYSTEM

General Considerations

The statement of work directs the contractor to develop a system for prioritizing the locations for removal or inactivation of in-place pollutants using the available funds, considering factors such as present and potential toxicity, threat to human and other uses of the water and substrate, critical use of the waterway for navigation and commerce, and any feasible alternatives to dredging and disposal.

While these are all worthy factors to consider, quantifying them and applying them to the hundreds of potential locations within the United States is a formidable, and in some cases, impossible task. For instance, is the salmon resource in the Pacific Northwest more important than the striped bass resource in the Northeast, or the shrimp resource in the Gulf of Mexico? Is the level of 30 mg/kg mercury worse in river A than a comparable level of cadmium in river B?

Another difficult question is the present and potential toxicity of any given deposit since almost nothing is known about the exchange rate for pollutants between the sediment and the water column, and most bioassay data are for the water column.

A common approach that is used to make decisions involving many parameters is to assign weighting functions to each parameter, or groups of parameters. This approach is highly subjective unless unique weighting functions can be found.

The priority system selected consists of two parts. An initial screening was made to reduce the number of locations to about 23 and then a second level of more detailed screening was used to arrive at the semifinal list.

The initial screening was done using a unique approach involving the high-value file that was generated on Task 1. The first step was to classify the pollutants in several groups, related to their toxicity. Since quantitative knowledge of the effects of in-place pollutants on biota is presently rudimentary, the use of groups of pollutants which are similar in their toxic concentrations is an appropriate interim technique for simplifying the information processing in this study. All pollutant values in the data file were then subjected to a normalizing process to determine their concentration relative to other areas in the country. This normalization was achieved by defining a Pollution Index (PI) as:

$$PI = \frac{\text{Concentration of Pollutant Present}}{\text{National Median of that Pollutant}}$$

Once this was done, the PI value (multiples of the national median present in the sample of interest) for all pollutants within a group could be added to allow comparisons of pollution levels, in different locations. The second, or semifinal, screening method involves a detailed look at each location. To achieve this detail, in a reasonable amount of time, the number of locations was reduced by the initial screening phase.

Three types of descriptors were identified along with the types of inputs that could be used for screening candidate sites, as follows:

Physical Descriptors

- location
- area affected
- volume
- depth of water
- water current
- waves (storms)
- character of material (probably silt & clay)
- availability of disposal sites
- cost/yard for disposal
- cost to clean up

Chemical Descriptors

type of pollutant
level of pollutant (high, low, mean)
number of samples
toxicity
water quality

Effect on Man and Ecosystem Descriptors

area usage (i. e., recreational)
access
property values
commerce
potential improvement
population
commercial value of port

Our approach was to attempt to collect these data for the semifinal list of locations and then a rank ordering could be made in a number of ways. For instance, the areas could be rank ordered in terms of

- estimated volume to be dredged
- estimated cost of removal and disposal
- relative level of contamination (Pollution Index)
- access, or population
- area usage
- property values

A third, or final, rank ordering which involves determining how to optimize the use of Section 115 funds, will require an additional study involving an intensive sampling program.

Initial Screening

Sediment Chemistry and Toxicity

One major area which must be dealt with in this study involves the effects of a particular sediment mass. In addressing this area, questions arise regarding the hazardous levels of constituents, the mobility of constituents, and the biological availability of various chemical forms of each constituent.

Mobility

Addressing the problem of in-place pollutants, and estimating the benefits likely to be achieved by removing those pollutants, requires an understanding of the factors associated with mobility. Several inter-related water and sediment chemistry parameters can enhance or retard the release of pollutants from sediment. Because the interrelations of these parameters are complex, and because a number of locations must be considered in this report, the following discussion is general. Detailed consideration of the factors identified in this section must await further studies in the locations selected for final consideration under Section 115.

Many researchers have dealt with the fate of heavy metals in sediments. Pratt and O'Connor(1) have reviewed the recent work of several investigators on the mobility of heavy metals in anoxic marine sediments They have found that attempts to predict the concentration of metals in sea water or interstitial water from equilibrium models based on the solubility of the least soluble compound have resulted in values much lower than are actually found. Formation of complexes, sorption reactions, and biological processes all affect mobility of metal ions in ways difficult to predict. For example, apparently conflicting results are cited(1) for the mobilization of copper, chromium, zinc, and mercury. The primary factors related to mobility appear to be organic content, redox potential, presence or absence of sulfides, and pH. Even with knowledge of these conditions for most metals no general conclusions can be reached concerning metal mobility. Each sediment must be considered individually.

The factors governing mobility are often quite different within the interstitial, or pore water of the sediment, from conditions in the overlying water. Generally, these factors (reducing conditions, high organic content) result in high concentrations of dissolved contaminants in the interstitial water. Interstitial water may therefore be toxic to bottom fauna and this condition may be more important in a given system than contaminants which are leached into the overlying water.(2)

Much evidence concerning mercury mobilization has been presented by Jernelöv and co-workers[3,4,5,6] whose investigations of aquatic mercury problems in Sweden have contributed to that country's expertise in mercury chemistry. The nature of mercury compounds, and the physical and chemical properties of natural waters, normally combine to bind most aquatic mercury in the sediment. Observed partition coefficients result in a relative distribution in fresh or estuarine waters within the following orders of magnitude[4]:

	Total Mercury %	Methyl Mercury %
Sediment	90-99	1-10
Water	1-10	1
Biota	1	90-99

Hence, at any one point in time, most of the mercury in an aquatic system is found in the sediment. The question of most importance to this study is whether the net flux of mercury (and other toxic materials) is into or out of the sediments; that is, whether sediments should be considered a sink or a reservoir for pollutants.

Jernelöv[3] has also reported on lakes into which mercury discharges ceased between 1925 and 1940. One lake, oligotrophic and with a low rate of sedimentation (covering of the bottom by new, clean material) still shows high levels of mercury in the biota. Other, eutrophic lakes, where the contaminated bottom has been covered by natural sedimentation, are found to contain organisms with low mercury concentrations. This evidence supports the position that sediment acts as a reservoir for continued release of pollutants. Other investigators[7] have observed a similar trend in mercury levels of fish in eutrophic and oligotrophic lakes. Their interpretation was that the enrichment of organic and suspended material in the eutrophic lake tend to remove mercury availability by complexation and adsorption mechanisms[7], rather than by simple covering.

The partitioning of aquatic mercury in the above table also implies the biological concentration of methyl mercury, since the biota contain so much more than the sediment or water. This concentration, or magnification, must be considered when evaluating the effects of mercury in sediments. Although sediments are capable of tying up large influxes of mercury, acting as an environmental "shock absorber"[8], the slow release of small quantities through biological methylation can result in long-term contamination of the biota[4].

The literature does not yield firm conclusions regarding mercury mobility, however. A Canadian study[9] using crayfish found more mercury uptake by benthic animals in a clean sediment-contaminated water system than in a contaminated sediment-clean water system.

Conflicting data on the adsorption and desorption of pesticides are also to be found. Lee and Plumb[2] review several studies on this topic and conclude that more research is needed to determine the conditions under which the net flux of pesticides is into, or out of, bottom sediments.

One proven means for mobilization of pollutants from sediments is uptake by benthic organisms. In a study of Escambia River and Bay sediments near Pensacola, Florida, Nimmo and co-workers[10] found up to 61 ppm polychlorinated biphenyls (PCB) near an industrial outfall. Pink, white and brown shrimp which were exposed to these sediments in PCB-free laboratory water developed up to 14 ppm PCB in whole body residues[10]. The authors did not discuss the mechanism by which the shrimp obtained PCB, but did conclude that its presence in the animals was evidence that PCB in sediments is available to the food web.

Lee and Plumb, in a comprehensive literature review[2], summarize other studies which have failed to detect uptake of contaminants from sediment by oligochaetes, polychaetes, and tubificid worms. Variation is to be expected among organisms, locations, and contaminants.

The same authors cite a study by Seger[2] in which metals were shown to be transferred from sediment to the water column by plants, through root uptake and subsequent release from the plant.

Perhaps the least understood mechanism by which heavy metals may be released from sediments is the formation of complexes with organic or inorganic ligands. Organic complexes are often invoked qualitatively in the literature to explain the presence of metal ions at higher concentrations that are predicted by solubility calculations. Chelation has also been suggested as the means by which aquatic organisms may make available to themselves useful trace metals or suppress levels of toxic aquo metals ions. Analytical problems, however, make these theories difficult to prove or disprove[11].

Several workers have investigated the potential for nitrilotriacetic acid (NTA) a strong complex former, to solubilize metals in sediments. Positive results have been noted for lead[12] as well as other heavy metals. NTA, ethylenediamine tetraacetate (EDTA), and other natural and man-introduced ligands generally coordinate with the heavy, more toxic metals such as mercury, cadmium, and copper, in preference to less harmful cations such as calcium and sodium[13]. This tendency suggests that the more toxic metals are likely to be released from sediments. On the other hand, complexed forms are generally thought to be less toxic than aquo metal ions.

A review of work done in assessing the mobility of toxic materials in sediments thus provides ample evidence that these contaminants can be released to the biota and to the water. Unfortunately, little research has been done which can support general statements regarding the relative mobility of various contaminants. There clearly is too much variability between water bodies in such factors as sulfides, pH, redox potential, presence of chelating agents, alkalinity, and salinity to support general conclusions. Hence, no attempt is made here to rank-order contaminants by relative mobility and availability. Conclusions regarding this question must be based on intensive studies of each location involving the collection of new field data beyond the scope of this study.

Hazardous levels: toxicity. Considerable difficulty is encountered when one attempts to relate the literature on toxicity and bioassays in aquatic systems to the presence of a given constituent in a sediment mass. Very little quantitative information is available on the toxic or sub-lethal effects of known levels of sediment contaminants on a surrounding ecosystem. A further complicating factor is the chemical form in which toxic materials exists. For example, heavy metals may be less toxic to fish when complexed with organic ligands than when simply coordinated with water as aquo metal ions. Bioassay tests at the University of California Sanitary Engineering Research Laboratory indicate that the effluent from activated sludge treatment of municipal wastewater may be less toxic to fish than the effluent from physical-chemical treatment of wastewater from the same source. One mechanism hypothesized for the lesser toxicity of activated sludge effluent is the provision of "organic compounds to sequester heavy metal ions," or chelation. Unfortunately, very few analyses for heavy metals were performed during the reported study; the results presented do not indicate any conclusive difference in metal removal between the biological and non-biological treatment processes[14].

Lee and Plumb[2] discuss the toxicity of different forms of copper (II) in solution. Although the aquo metal ion is highly toxic to many forms of aquatic life, copper complexed with EDTA shows little or no toxicity. The copper (II)- citrate complex, however, does exhibit toxicity. Little other evidence is available in the literature regarding toxicity as a function of chemical form. Chemical form is important to this study since it also governs mobility of contaminants from bottom sediments. The dearth of information available prevents this report from detailed consideration of chemical species, as they affect toxicity as well as mobility.

The effects of polluted sediments on organisms are not well understood. Gannon and Beeton[15] performed laboratory aquarium tests in which the burrowing amphipod, Pontoporeia affinis, was exposed to sediments from several Great Lakes locations. Sediments were collected from relatively unpolluted areas as well as from harbors with a long history of receiving inadequately treated municipal and industrial wastewaters. Clean laboratory water was used over the sediments in all aquaria. In selectivity tests, the amphipods avoided sediments from polluted areas. From viability tests, it was concluded that "in general, sediments from the river sections of badly polluted harbors were more toxic than those from the outer harbors"[15]. No chemical analyses of sediments were presented.

Another Gannon and Beeton bioassay project attempted to correlate toxicity with chemical analyses, but found no direct correlation[16]. Hence, it appears from the literature that polluted sediments can be harmful to organisms, but the relative hazard from each pollutant is unknown.

Criteria for Grouping of Pollutants

It is clear from the preceeding sections that it is not possible at this time to directly relate the data on pollutants in the sediments of the harbors and navigable waters to toxicity effects on the biological species present in those waters.

The approach that was adopted for this study was to utilize the ample data available on aquatic bioassays, rather than to attempt to directly relate levels in the sediment to effects on aquatic life. Prior discussions have established several routes by which pollutants in the sediments may be mobilized. For the screening process it will be assumed that for a given pollutant a higher level in sediment A than in sediment B implies a larger threat to the waters and aquatic life in the volume around sediment A. A final verification of this assumption awaits detailed investigations of the mobility, chemical form, and specific biological life in each location of interest.

A comprehensive study by the National Academy of Sciences[17] has reviewed the literature on aquatic bioassays and has summarized its findings in a proposed set of water quality criteria defining "safe" and "hazardous" levels of a wide variety of water constituents. A tabular summary of that study's findings for the materials included in the data sets collected for this study is given in Table 4.

Based on the National Academy of Sciences concentrations that constitute a "hazard in the marine environment"[17], the pollutants of interest to this study have been classified for relative toxicity into three groups. They are shown in Table 5. The groupings were checked by the criteria of "minimum risk in the marine environment" and by the fresh water recommendations in the NAS report[17]. These reviews produced no conflicts with the grouping scheme shown, with the exception of the minimum risk for nickel. This value (0.002 mg/l) would put nickel in Group I, but since it is based on very limited data, nickel has been left in Group II.

Pesticide toxicity varies widely from one formulation to another, and is related to biodegradation, accumulation, effects on reproduction of fish eating birds, and synergistic effects. There are so many formulations of organochlorine and organophosphate insecticides and herbicides that one cannot generalize quantitatively with respect to toxicity of pesticides. Because so many pesticides are highly toxic, and because of the accumulation and synergistic effects mentioned above, these materials as a class have been placed in Group I. Polychlorinated biphenyls (PCB) are chemically similar to the organochlorine insecticides, and the high toxicity of PCB's causes their ranking in Group I.

<u>Pollution Index Concept</u>

The gathered and cataloged data consisted of up to 33 chemical parameters from 652 data sets. The size of this data bank, and the different levels of each parameter that might be considered harmful, combined to create a massive screening problem. For example, a sediment with an oil and grease content of 200 mg/kg dry weight is relatively free of petro-

TABLE 4

National Academy of Science Numerical Recommendations[17] for Water Quality Criteria of Toxic Substances

Substance	Fresh Water Recommendation	Marine Systems Hazard Level	Marine Systems Min. Risk Level	Remarks
Aluminum		1.5 mg/l	0.2 mg/l	Concentrates in food chain
Arsenic		0.05 mg/l	< 0.01 mg/l	
Cadmium	0.03 mg/l Peak, where hardness > 100 mg/l 0.004 mg/l Peak, where hardness < 100 mg/l	0.01 mg/l	< 0.2 μg/l	Concentrates in food chain (almost no excretion), synergistic effects with other metals, especially copper and zinc
Chromium	0.05 mg/l Peak	0.1 mg/l	0.05 mg/l	Most data on freshwater organisms. Toxicity may vary with oxidation state.
Copper	(a)	0.05 mg/l	0.01 mg/l	Synergistic effects with zinc, cadmium, mercury. Polychaetes can adapt to copper, concentrate it, and develop amounts toxic to their predators.
Cyanides	(a)	0.01 mg/l	0.005 mg/l	No data on marine bioassays
Iron		0.3 mg/l	0.05 mg/l	Normally oxidized. Precipitate solids of more concern than direct toxicity of dissolved species.
Lead	0.03 mg/l Peak	0.05 mg/l	0.01 mg/l	Less toxic in hard water. Few data on sublethal effects.
Manganese		0.1 mg/l	0.02 mg/l	Apparent antagonistic effects with nickel. Few data on sublethal effects.

TABLE 4 (cont.)

Substance	Fresh Water Recommendation	Marine Systems: Hazard Level	Marine Systems: Min. Risk Level	Remarks
Mercury	0.2 μg/l Peak; 0.05 μg/l Average } total (unfiltered)	0.1 μg/l		Minimum risk probably exceeded by any input other than natural weathering.
Nickel	(a)	0.1 mg/l	0.002 mg/l	Few data on marine toxicity.
Pesticides	Specific to each formulation. Range: 0.002-0.04 μg/l for organochlorine, 0.0004-0.4 μg/l for organophosphate compounds	(a)		Levels not harmful to exposed fish can accumulate in eggs and kill the developing fry. Shell thinning in fish-eating birds.
PCB	0.002 μg/l Peak			Toxicity varies with level of chlorination. Marine animals may be more sensitive than freshwater animals.
Sulfides (H_2S, HS^-)	0.002 mg/l H_2S Peak	0.01 mg/l	0.005 mg/l	H_2S more toxic than HS^-; pH governs speciation, with H_2S predominating at lower pH. At normal pH and redox potential, quickly oxidize to sulfates.
Zinc	(a)	0.1 mg/l	0.02 mg/l	Few data on marine animals. Synergistic with copper and cadmium.

NOTES: (a) NAS recommends an ad hoc bioassay using the most sensitive organism likely to be exposed in the water body of concern.

TABLE 5

Adopted Toxicity Categories for this Study

Category	Substance	Hazard Level in Marine Environment (mg/l) (17)
Group I, Highly Toxic	Mercury	0.0001
	Cadmium	0.01
	Sulfides	0.01
	Cyanides	0.01
	Lead	0.05
	Arsenic	0.05
	Copper	0.05
	Pesticides, PCB	. . .
Group II, Toxic	Zinc	0.1
	Chromium	0.1
	Manganese	0.1
	Nickel	0.1
	Iron	0.3
	Aluminum	1.5
Group III, Other	Oil and Grease	
	Organics	
	Biostimulants	

chemical pollution, while a sediment mercury content of 20 mg/kg is one of the highest in the country and is likely to be hazardous to the surrounding ecosystem. Hence, a review of data would require simultaneous consciousness of some threshold value for each of 33 parameters. A computer program could be written to perform this task on its own, but it is preferable that the investigator be able to participate actively in the screening process. In this way, unexpected trends or unique local conditions that could not be anticipated in programming could be noted.

As indicated earlier in the report, it is extremely difficult, if not impossible, to determine rationally and objectively whether a mercury problem in harbor A is more critical than a cadmium problem in lake B without developing quantitative criteria. In this study, such criteria were developed so that a single number representing a mercury pollution index for harbor A can be directly compared to another number representing a cadmium pollution index in lake B. It is important to recognize that sediments surviving to the semifinal screening process will be grossly polluted and fine distinctions between the toxicity for different pollutants is of secondary interest. What is needed is a coarse index to allow initial decisions with regard to screening.

It would be convenient to define a pollution index, or measure of pollution, for the sediments in each location and use this as a preliminary method to screen all locations. A precedent has been established for estimating the effect of combinations of acutely lethal concentrations using 'Application Factors'. The Application Factor is the numerical value of the safe-to-lethal ratio and is generally expressed as follows

$$\text{A.F.} = \frac{\text{safe concentration}}{\text{96-hour LC50}}$$

For 2 or more toxic materials, a surprisingly large number of combinations can be evaluated for toxicity by simply adding their application factors. If the sum is 1.0 or greater, the mixture will be lethal(17).

This suggests the possibility of calculating a sediment pollution index in a similar additive manner, realizing that all that is desired at this first filtering, or elimination phase, is a rough measure of the relative levels of pollution existing in all locations sampled. A finer system would then be used to establish the final list of the Section 115 locations.

The following system was programmed to use as a guide in eliminating from further study approximately ninety-five percent of the locations for which data was collected on Task I.

For each location a Pollution Index (PI) was calculated which considered all chemical parameters measured, and weighted each according to a predetermined weighting function.

The calculation proceeded as follows:

$$\text{Total PI} = \sum_{i=1}^{i} \left(\frac{C_a}{L_a} + \frac{C_b}{L_b} + \ldots \frac{C_n}{L_n} \right)$$

Where C_a is the highest value for pollutant a reported in the location of interest and L_a is the weighting factor. While approaches using weighting factors generally tend to be subjective this need not be the case here because two values of weighting factors are readily available.

In the past, EPA has attempted to define the levels of constituents in sediments that should be considered polluted. The levels suggested are shown in Table 6. Also shown are the national median values from the Task 1 high-value data file. For those parameters for which EPA criteria are provided the high-value national medians are surprisingly similar. Thus one could use either the national medians or the EPA criteria for the weighting functions. The results would be similar using either approach.

Since EPA criteria do not exist for all the pollutants of interest it was decided to use the national medians for the weighting functions when calculating a Pollution Index.

Conceptually, the Pollution Index is a measure of pollution in any harbor relative to the national median values for those pollutants present in the harbor. Table 7 shows a hypothetical case for 2 harbors being compared using the Pollution Index concept. Harbor A has a PI of 23.33 and Harbor B a PI of 5.49. While this does not mean that Harbor A is 4 times as polluted as Harbor B, it does mean that Harbor A should be considered more polluted than Harbor B, and that is the type of distinction desired for the first screening.

TABLE 6

Median Values Calculated From Task 1 High Data File

Parameter	High Value Medians (mg/kg dry weight)	EPA Sediment Guidelines (mg/kg dry weight)
Mercury	0.5	1 (1)
Lead	42	50 (1)
Cadmium	3.1	2 (2)
Arsenic	3.0	5 (2)
Zinc	100	130 (2)
Nickel	32	50 (2)
Copper	62	50 (2)
Chromium	61	100 (2)
Volatile Solids	78,000	60,000 (1)
COD	59,000	50,000 (1)
TKN	1,600	1,000 (1)
Oil & Grease	1,400	1,500 (1)
Nitrite	0.24	none
Nitrate	8.6	none
Total Phosphorus	900	none
BOD	38,000	none
Aluminum	8,560	none
Manganese	512	none
Fecal Coli	5,900 (3)	none
TOC	27,000	none
PCB	0.04	none
Phenol	95	none
Sulfide	930	none
H_2S	6.0	none
Oth Phosphate	0.61	none
IOD (4)	460	none
Iron	20,000	none
Cyanide	0.22	none

(1) EPA-1971 criteria (guidelines) for open-water disposal of dredge spoil
(2) EPA Region IX '72-73 proposed criteria for dredge spoil disposal
(3) Count per 100 grams dry weight
(4) Immediate Oxygen Demand

TABLE 7

Comparisons Using the Pollution Index Concept

Pollutant	National Median mg/kg	Harbor A		Harbor B	
		mg/kg	$\frac{C_a}{L_a}$	mg/kg	$\frac{C_a}{L_a}$
Mercury	0.50	10	20.0	2.0	4.0
Cadmium	3.1	6.2	2.0	1.6	0.52
Arsenic	3.0	1.0	0.33	2.0	0.66
Nickel	32.0	32.0	1.0	10.0	0.31
Pollution Index			23.33		5.49

In the previous section, pollutants were grouped, relative to values recommended by the National Academy of Science. The Pollution Index concept can now be applied to the field data by grouping those pollutants of most concern and using their pollution index as a basis for screening. Finally, a constant, or additional weighting factor, could be applied to each pollutant, to allow for differences in its mobility and toxicity, making the Pollution Index concept completely general. Those constants do not exist, nor would their use be warranted for this initial screening.

<u>Application of Intitial Screening Methodology</u>

The initial screening methodology was applied to approximately 10,000 individual sediment analyses collected during Task 1. These data, which include 33 analytical parameters, represent sediment samples collected from nearly 700 harbor and waterway locations throughout the United States. This initial screening was designed to reduce the number of locations to between 20 and 30.

PI values were calculated for every location in the high-value data file. Table 8 shows a summary of the PI calculations for the first 623 locations collected in Task 1. The magnitude of the screening task is indicated by the fact that 44 locations had a PI over 100. This means that the sum of the pollutant concentrations in these harbors, after each was divided by the national median, is 100 times greater than the sum of the national medians alone.

A number of arbitrary guidelines were adopted to conduct the initial screening. Adoption of other guidelines could result in a different list than the one obtained. The guidelines adopted were:

1. Consider only Group I toxic materials: mercury, cadmium, free sulfide, lead, arsenic, copper, cyanide, pesticides, and PCB's.

2. Of the above materials, free sulfide, cyanide, pesticides, and PCB's all were represented by small amounts of data. Accordingly, the national medians may not be valid reference numbers. Do not consider PI for these materials, but maintain a less formal record of any high values for later reference.

3. Take the sum of PI's for mercury, cadmium, lead, arsenic, and copper at each location.

4. Try various threshold values for individual and total PI's. Consider both individual and total, so that a location with all five elements analyzed is not given a bias over a location with fewer analyses. For example, with a total PI threshold of 50 and an individual PI threshold of 10, there remained more than 50 locations.

5. Threshold values which produced the desired number of between 20 and 30 locations were 60 for total PI and 20 for individual PI. These criteria are independent; that is, a location with an individual PI greater than 20 qualifies for further study although its total PI may be less than 60. Further, a location whose total PI is greater than 60 qualifies although none of its individual PI's are greater than 20.

The results of the initial screening are shown in Table 9, and this list forms the basis for generating a semifinal list in Task 2.

TABLE 8

Summary of Pollution Index Levels For All Locations

Range of Total Pollution Indices	Number of Locations	Cumulative Number of Locations	Percent of Total Locations	Cumulative Percent of Total Locations
0 - 10	323	323	49.5%	49.5%
11 - 20	128	451	19.6	69.2
21 - 30	66	517	10.1	79.3
31 - 40	32	549	4.9	84.2
41 - 50	21	570	3.2	87.4
51 - 60	12	582	1.8	89.3
61 - 70	8	590	1.2	90.5
71 - 80	10	600	1.5	92.0
81 - 90	4	604	0.6	92.6
91 - 100	2	606	0.3	92.9
over 100	46	652	7.1	100.0

TABLE 9

Locations Selected for Detailed Investigation on Task 2*

Location	Qualifying Parameter
1. New Bedford, MA	Total PI = 187
2. Providence, RI	Total PI = 71
3. New Haven, CT	Total PI = 60
4. Bridgeport, CT	Total PI = 274
5. Eastchester Creek, NY	Lead PI = 22
6. Newark Bay, Passaic River, NJ	Total PI = 94
7. Baltimore, MD	Total PI = 613
8. Georgetown, SC	Lead PI = 26
9. Pittsburgh, PA	Lead PI = 31
10. St. Louis, MO	Arsenic PI = 32
11. Cleveland, OH	Cadmium PI = 22
12. Detroit, MI	Total PI = 204
13. Michigan City, IN	Total PI = 3,229
14. Indiana Harbor, IN	Total PI = 2,451
15. Milwaukee, WI	Total PI = 84
16. Neches River, TX	Total PI = 80
17. Corpus Christi, TX	Total PI = 148
18. Seattle, WA	Total PI = 149
19. San Francisco, CA	Total PI = 186
20. Richmond, CA	Mercury PI = 28
21. Oakland, CA	Total PI = 67
22. Los Angeles, CA	Total PI = 65
23. San Diego, CA	Total PI = 70

*NOTE: 2 additional locations, Royal River, Maine, and Menemsha Creek, MA., also qualified but were dropped due to their small size and isolated locations.

Semifinal Screening

Discussion of Descriptors

Early screening was based entirely on the degree of pollution in sediments. To develop a semifinal priority list, however, additional criteria were considered. Quantifiable criteria have been sought wherever possible to make the comparisons among areas as objective as possible. Three general classes of criteria have been considered and developed: physical descriptors, chemical descriptors, and descriptors of sediment's interactions with the human and natural environment. During the Task 2 data collection phase, it was found that information does not currently exist to allow use of most of the descriptors and this will have to be generated.

Physical Descriptors

The principal use of physical criteria is to determine the cost and overall practicability of removing or otherwise rendering harmless a contaminated sediment mass. Information in this category includes location, water depth, physical character of material (silt, clay) and other factors described below.

Area and Volume of Polluted Sediment. The data available do not permit estimates of these very important criteria. Sample stations are generally too few to establish isopleths of pollutant concentrations. In only a few cases have analyses been reported showing the depth of pollution in sediments. An intensive sampling program will be necessary to determine areas and volumes for the locations of interest. Without this information it will be impossible to define the size of the rehabilitation task in each area, to predict the amount of material to be dealt with, to estimate costs for rehabilitation, and to determine the requirements for disposal sites.

Availability of Disposal Sites. It is unlikely that permits for open-water disposal of the material from many of the areas in the semifinal priority list would be approved, unless specific sites for highly polluted sediments are defined. Therefore, if dredging is to be the means of rehabilitation, diked or upland disposal may be required. In some areas these disposal methods are already in effect for dredged material, but in other areas, there would be great difficulty in arranging diked or upland disposal. This difficulty can be expected in the form of public opposition or simply because extensive shoreline development has eliminated possible sites in the area, resulting in excessive costs for transporting the material inland.

Diked areas of themselves are not a panacea for disposal of dredged material. The liquid effluent must be monitored and, if necessary, treated. Effluent from a diked disposal area near Corpus Christi, Texas, has damaged oyster beds to the extent that other disposal sites are being sought. Since the material from locations on the semifinal list will be highly polluted, and since acceptable open-water disposal sites do not appear to be available within a realistic distance, the availability of diked area disposal is a critical consideration in this study. Table 10 shows the initial screening list of 23 locations and comments on the availability of confined disposal areas.

Unit Cost for Dredging, Disposal, or Other Alternatives. Dredging costs are influenced by the type of equipment used; equipment choices in turn depend on equipment availability and the physical features of each location. For example, many inner harbors are not accessible by large, economical hopper dredges. Until areas and volumes are known, equipment cannot be specified.

Costs of disposal depend on distance to the disposal site and whether the disposal area must be constructed solely for receiving the material dredged for rehabilitation. The existence of a diked or upland disposal area for dredgings related to navigation will reduce the cost of disposing material dredged pursuant to Section 115, but the lack of current knowledge of volumes of hot spots and plans for future disposal precludes any detailed ranking by physical and cost factors at this time.

TABLE 10

Ranking of Locations in Terms of Potential for Confined Disposal of Sediments

Location	Rank	Explanation
Cleveland Indiana Harbor Milwaukee	1 t (t = tie)	Diked area exists adjacent to waterway
Seattle San Diego	4 t (tied for fourth since there are three locations in first place)	Diked area planned or feasible adjacent to waterway
Neches River Detroit Michigan City	6 t	Diked area exists within 50 kilometers
Baltimore Corpus Christi	9 t	Diked areas under serious study, appear likely, but timing and location of diked area uncertain
Newark Bay Eastchester Creek Los Angeles	11 t	Possible landfill for new port facility contruction in the area
Pittsburgh St. Louis Georgetown	14 t	Insufficient local awareness of a problem to evaluate diked area potential
New Bedford Providence New Haven Bridgeport Richmond San Francisco Oakland	17 t	Diked area politically and economically difficult to implement

Chemical Descriptors

Early screening used chemical descriptors (Total Pollution Index) as the sole criterion. For developing the semifinal list of harbors and waterways, these chemical descriptors have been used in a more comprehensive way.

Maps are presented later in this report which indicate the locations of hot spots and which provide some information concerning areal extents of pollution for the locations recommended for further study. In addition, several techniques were used to rank-order locations according to degrees of contamination. Each of these methods is described below.

Method 1: Total PI, Single Sample

All samples for each of the 23 locations were examined and the sample having the highest PI was selected. This method identifies the highest value of pollutants, in any one sample, for each of the areas of interest. In those cases where analyses were run for different depths from a single core sample, the highest value for each pollutant was used to represent the sample.

Method 2: Average PI, Single Sample

The PI values from Method 1 were each divided by the number of pollutants present in each sample. This generated an average PI per constituent in the sample and helps to avoid biases against those locations where only a few pollutants were analyzed.

Method 3: Total PI, Maxima from All Samples

All samples from each location which included analyses for Group 1 pollutants were examined. A spacial composite sample was developed, including the highest value for each Group 1 pollutant found in the harbor or waterway. For example, if mercury was high in one sample, and lead was high in another taken several hundred yards away, the two extreme values would be included in this composite. The effect of this method is to de-emphasize those locations where all the highest values of all pollutants were detected in a single sample. Once the spacially composited sample was tabulated for each location, the total PI was then calculated.

Method 4: Average PI, Composite Sample

This method takes the Method 3 composite sample, and as in Method 2, an average PI is established by dividing by the number of pollutants in the composite sample.

Method 5: Sum of Ranks from Methods 1 through 4

To reduce conflicting ranks from Methods 1 through 4 to a single index, rankings can be added and the sums can then be ranked. For example, it is logical that the following simple hypothetical system of locations, criteria, and ranks can be reduced by summing the ranks for each location:

RANKINGS

Location	Criterion I	Criterion II	Criterion III	Sum	Overall Rank
A	1	1	2	5	1
B	2	3	3	8	3
C	3	2	1	7	2

A further scan of the data was also made to identify sites of the following materials in high concentration:

Group II Contaminants: Zinc, nickel, chromium, manganese, iron, aluminum

Group I Contaminants with Few Reported Analyses: Free sulfides, cyanide, pesticide, PCB

Oil and Grease: These materials have fractions which are not biodegradable. They have been implicated with mortality in bioassays[15], and have a great capacity to concentrate chlorinated hydrocarbons and other harmful, nonpolar compounds[18].

Descriptors of Sediment's Interactions with the Environment

Several criteria have been considered for evaluating the sediment's effects on human and ecological values at each location. To be useful, these criteria should be definable in terms of effects before and after rehabilitation of the waterway. Unfortunately, such factors are not easily set into objective criteria.

Recreation. Most of the locations under study are in regions of abundant water resources (i.e., the oceans and the Great Lakes), thus so many alternative recreation areas are normally nearby that confident prediction of future use of a rehabilitated harbor or waterway is not practical.

Property Values. No national index of property values exists, so comparisons between areas are difficult. Furthermore, the value of waterfront property after removal of polluted sediment cannot be predicted.

Ecological Values. Knowledge of the effects of polluted sediments on ecosystems is lacking in most areas. The return of desirable species to a rehabilitated waterway is difficult to predict. Further, each aquatic ecosystem has its own unique features which should not be considered more or less valuable than those of other locations.

Subsequent Pollution Likelihood. If the sources of sediment contaminants are known, then the status of abatement of those sources must be considered. Little benefit is to be gained if in-place pollutants can be expected to re-appear. Locations cannot be rank-ordered objectively by this criterion, since the reliability of wastewater treatment systems and spill control techniques is uncertain.

Shipping. Cargo statistics are used as a measure of waterfront activity occurring at each location. Where multiple use potential exists for a waterway, shipping has the potential to enhance other uses. For example, the opportunity to view the harbor activities of maritime commerce from waterfront parks or from recreational boats can have significant value as an amenity.

Population. City and area populations are used to rank-order locations. Although predictions are not ventured regarding the numbers who will directly benefit from a more desirable waterway, population gives an objective index of potential beneficiaries.

By "area" is meant the Standard Metropolitan Statistical Area, as defined by the Bureau of the Census. The Census definition of a SMSA is quite detailed; a greatly simplified definition could describe a SMSA as any region, with at least one urban center of over 50,000 population, within which region there are demonstrable economic and social interdependencies. These interdependencies are mainly defined in terms of geographical patterns of non-farm employment. Most SMSA's encompass two to six counties.

Summary

The considerations discussed above have led to selection of the following objective, numerical descriptors by which the 23 locations can be ranked.

Chemical:
- Total PI, Single Sample
- Average PI, Single Sample
- Total PI, Composite Maximum Values
- Average PI, Composite Maximum Values
- Sum of the ranks of the above 4 descriptors

Physical:
- Availability of Confined Disposal Sites

Interactions with Environment:
- City Population
- SMSA Population
- Shipping Traffic

Column No.	(1)		(2)		(3)		(4)		(5)	
	Total PI 1 Sample		Average PI 1 Sample		Total PI Composite of Entire Location		Average PI Composite of Entire Location		Sum of Ranks Columns 1 thru 4	
LOCATION	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
A New Bedford	142	7t	28	10	187	6	37	7t	30	8
B Providence	71	12	14	18	71	13	14	16t	59	16
C New Haven	42	17	21	11t	60	17	20	11t	56	14
D Bridgeport	190	4	38	8	274	4	55	4	20	5
E Eastchester	35	20	7	23	35	22	7	23	88	23
F Newark/Passaic	75	11	15	17	94	10	19	13	51	11t
G Baltimore	361	3	90	4	613	3	153	3	13	3
H Georgetown	27	23	9	21t	41	20t	14	16t	80	21
I Pittsburgh	32	21t	16	16	32	23	16	15	75	20
J St. Louis	32	21t	32	9	46	18	11	21	69	17t
K Cleveland	36	19	12	20	43	19	14	16t	74	19
L Detroit	172	5	172	3	204	5	41	6	19	4
M Michigan City	3229	1	1076	1	3229	1	1076	1	4	1
N Indiana Harbor	2449	2	816	2	2451	2	817	2	8	2
O Milwaukee	56	16	19	14	84	11	21	10	51	11t
P Neches River	80	10	20	13	80	12	20	11t	46	10
Q Corpus Christi	129	9	42	7	148	9	30	9	34	9
R Seattle	142	7t	71	5	149	8	37	7t	27	7
S San Francisco	171	6	43	6	186	7	46	5	24	6
T Richmond	37	18	9	21t	41	20t	8	22	81	22
U Oakland	67	13	17	15	67	15	17	14	57	15
V Los Angeles	63	14t	13	19	65	16	13	20	69	17t
W San Diego	63	14t	21	11t	70	14	14	16t	55	13

a. Population of Bronx County
b. Population of Gary + Hammond + East Chicago
c. Population of Beaumont
d. Total cargo traffic on Monongahela River above Pittsburgh
e. " " " on Mississippi River for 70 miles above Ohio River confluence
f. Total cargo traffic to and through Detroit on Detroit River
g. t = tie

TABLE 11

Data and Rankings for 23 Locations, Using the Selected Criteria

(6) Other Pollution Criteria	(7) City Population 1970 Value	Rank	(8) SMSA Population 1970 Value	Rank	(9) Cargo Tonnage 1973(19) Value	Rank	(10) Confined Disposal Feasibility (Table 10) Rank
(all entries in this column highest in the national data bank)	101,777	21	152,642	21	411,075	22	17t
	262,907	15	910,781	15	10,236,062	14	17t
	137,707	18	355,538	18	13,709,265	13	17t
	156,542	17	389,153	17	3,553,980	18	17t
	1,471,701[a]	3	11,571,899	1	1,974,777	20	11t
	382,417	12	1,856,556	11	21,999,547	8	11t
Cr 5745 mg/kg	905,759	4	2,070,670	9	53,786,715	2	9t
	10,449	23	-	22t	1,485,731	21	14t
	520,117	11	2,401,245	7	37,592,584[d]	3	14t
	622,236	9	2,363,017	8	18,319,148[e]	9	14t
CN 35 mg/kg	750,903	5	2,064,194	10	24,828,323	7	1t
	1,511,482	2	4,199,931	3	131,676,382[f]	1	6t
	40,135	22	-	22t	167	23	6t
[Oil & Grease 170,000	330,187[b]	14	633,367	16	17,897,777	11	1t
Ni 6070 mg/kg]	717,099	6	1,403,688	13	5,635,524	16	1t
	115,919[c]	19	315,943	19	34,490,769	4	6t
Zn 11,000 mg/kg	204,525	16	284,832	20	27,171,559	5	9t
PCB 1,170 mg/kg	530,831	10	1,421,869	12	17,000.178	12	4t
	715,674	7	3,109,519	4t	4,485,745	17	17t
	112,389	20	3,109,519	4t	18,259,836	10	17t
	361,561	13	3,109,519	4t	7,414,679	15	17t
[Pesticides	2,816,061	1	7,032,075	2	25,977,491	6	11t
1.4 mg/kg]	693,931	8	1,357,854	14	2,063,356	19	4t

Data are provided in the following sections on all selected descriptors, allowing objective rank ordering. It is most difficult to judge how each descriptor should be weighed against the others. To arrive at the semi-final list, the chemical descriptors have been used to select the 9 most polluted locations. The number was reduced to 6 by considering city population and disposal site availability. Use of the other factors, which appear less important to the execution of Section 115, is left to the discretion of the reader.

Application of Descriptors

The available data for criteria and descriptors selected in the previous section for the 23 remaining locations are presented in Table 11. The ranking of each location under each category is also given. An inspection of the rankings in Table 11 shows the difficulty of setting priorities. Only one location (Baltimore, Maryland) has ranks in all categories higher than 10. Hence, some systematic way of evaluating the many criteria is necessary.

Several methods of evaluation have been considered. The following discussion describes two possible decision sequences in setting priorities for Section 115. The processes are of necessity subjective, and other, equally "good", processes would yield different priority lists. With the data presented and the description of the prioritization processes which follows, other rank orderings can be achieved, if desired.

Pollution Emphasis Approach

Table 12 presents a rank ordering of the 23 locations with regard to the 4 chemical descriptors defined earlier, plus a fifth descriptor established by summing the rank of each location in the first four columns. The resultant ranking by sums represents an overall evaluation of relative sediment pollution which should mask the biases inherent in each of the individual chemical criteria.

An examination of Table 12 reveals that the top 9 locations are the same (although the rankings within the top 9 vary) for all five criteria. The one

TABLE 12

Rank Ordering of Locations
Considering Chemical Pollutants

Order	Total PI 1 Sample	Average PI 1 Sample	Total PI Composite	Average PI Composite	Summation of Chemical Ranks
1	M	M	M	M	M
2	N	N	N	N	N
3	G	L	G	G	G
4	D	G	D	D	L
5	L	R	L	S	D
6	S	S	A	L	S
7	A, R	Q	S	A, R	R
8	A, R	D	R	A, R	A
9	Q	J	Q	Q	Q
10	P	A	F	O	P
11	F	C, W	O	C, P	F, O
12	B	C, W	P	C, P	F, O
13	U	P	B	F	W
14	V, W	O	W	U	C
15	V, W	U	U	I	U
16	O	I	V	B, H, K, W	B
17	C	F	C	B, H, K, W	J, V
18	T	B	J	B, H, K, W	J, V
19	K	V	K	B, H, K, W	K
20	E	K	H, T	V	I
21	I, J	H, T	H, T	J	H
22	I, J	H, T	E	T	T
23	H	E	I	E	E

TABLE 13

The 9 Most Polluted Locations,
Rank-Ordered by Average Pollution Index
for Spacially Composited Analyses (Method 4)

Order		Location	Average PI Composite
1	M	Michigan City	1076
2	N	Indiana Harbor	817
3	G	Baltimore	153
4	D	Bridgeport	55
5	S	San Francisco	46
6	L	Detroit	41
7	A	New Bedford	37
8	R	Seattle	37
9	Q	Corpus Christi	30

exception to this statement is in the "Average PI 1 Sample" column at order 9. These 9 worst locations from the chemical viewpoint are listed in Table 13, where they are ranked by the composite pollution index for the entire location averaged for the number of pollutants analyzed (Method 4) This type of pollution index, since it is a composite from many samples and since it is averaged for the number of parameters analyzed, is a very good descriptor for comparing locations.

Since it was calculated for only the worst (Group 1) pollutants, the fact that Michigan City's composite is 1076 times the national median values, is very persuasive evidence that it belongs on the list. When considering additional candidates for addition to the worst 9, the next, or tenth, location had a composite average PI of 21. Considering the limited funds available for Section 115, it appears that the list should be reduced rather than expanded. For this reason, among others, we feel that the chemical descriptor is not sufficient and additional criteria must be applied.

Multiple Criteria Approach

Certainly the criterion of relative pollution is very important to this study, but it is conceivable, given the extreme conditions within the 23 locations, that relative pollution may have had its most valid use in the initial screening phase. Given the lack of knowledge regarding effects of polluted sediments, it may be reasonable to assume that any location in the top 23 is in a condition where relative pollution has little further meaning, since all 23 sites show such high sediment pollution levels.

Extending this rationale, a selection system can be devised giving city population and disposal criteria an equal weight with pollution after the initial screening has revealed the worst locations. These three criteria may be considered as related to relative pollution, potential social benefits, and probable relative costs of rehabilitation. Table 14 shows the rankings of the top 10 locations by the sum of the ranks for each of these three criteria. as determined from Table 11.

TABLE 14

Ranking of the Top Ten Locations by Multiple Criteria

Order	Location	Sum of Three Criteria (Chemistry, Population, Disposal Feasibility, Columns 5, 7, and 10 of Table 11)
1	Detroit	12
2	Baltimore	16
3	Indiana Harbor	17
4	Milwaukee	18
5	Seattle	21
6	San Diego	25
	Cleveland	25
8	Michigan City	29
	Los Angeles	29
10	San Francisco	30

Considering the previously mentioned desire to reduce the number of locations below nine, one can compare the lists of Tables 13 and 14 for common locations. These are 6 such locations common to both lists: Indiana Harbor, Seattle, Michigan City, and San Francisco.

As another check on this priority list of 6, a review of the national data for extremely high concentrations of pollutants not included in the numerical criteria has been made. Pollutants considered are chromium, cyanide, nickel, zinc, PCB, pesticides, and oil and grease. The highest value for each of these materials in the data bank often appears in locations which have been selected already for the priority list of 6 locations, but exceptions exist. Corpus Christi Inner Harbor's maximum reported sediment zinc value is 11,000 mg/kg dry weight. Cleveland Harbor's cyanide value of 35 mg/kg is the national maximum, as is the pesticide value of 1.4 mg/kg in Los Angeles. Because of their relatively low rankings by other criteria discussed above, these locations are not included in the priority group of 6 locations. It is likely, however, that other possible prioritization schemes might select these two locations.

Table 15 shows our recommended locations for further consideration under Section 115. The 6 shown in Priority 1 are the prime candidates. If for any reason locations are dropped from Priority 1, we recommend that these be replaced from Priority 2. Priority 3 shows the remaining locations from the 23 surviving the initial screening.

Clearly, the foregoing selection processes are but two of many possible approaches. Borderline locations in these approaches, such as New Haven, Neches River, Milwaukee, and San Diego, can be expected to be quite sensitive to the specific selection process used. Other locations such as Baltimore would probably be selected by any approach. Locations such as Georgetown and Richmond are likely to be eliminated by most approaches.

Descriptions of each of the selected harbors are given in Appendix A as a data summary and guide for future work. Somewhat briefer descriptions are also given for the locations which are not included in the above priority list of 6.

TABLE 15

Recommended Semifinal List for Section 115 Consideration

Priority 1 Locations

Detroit
Baltimore
Indiana Harbor
Seattle
Michigan City
San Francisco

Priority 2 Locations

Bridgeport
New Bedford
Corpus Christi

Priority 3 Locations

Providence
New Haven
Eastchester
Newark
Georgetown
Pittsburgh
St. Louis
Cleveland
Milwaukee
Beaumont
Richmond
Oakland
Los Angeles
San Diego

SECTION V

METHODS OF REMOVAL OR INACTIVATION OF IN-PLACE POLLUTANTS

The methods to be considered for rehabilitation of polluted sediments are dredging, covering and treatment. Within each of these broad areas are several sub-topics. The dredging alternative requires consideration of pollution control at the dredging site, and at the disposal site. The covering and treatment options each have many possible variations in process selection which strongly affect cost and efficiency of inactivation of pollutants. Finally, treatment still implies a need for disposal sites but the options for selection of a site are greater after treatment.

Dredging Considerations

Present dredging practices and disposal methods have been reviewed for their applicability to safe and economical removal and disposal of in-place pollutants.

Dredges. Dredges may be broadly classified as either mechanical or hydraulic. Mechanical dredges include the clamshell and bucket type, and hydraulic dredges include the hopper and pipeline dredge.

Mechanical dredges are sometimes further classified into grab, dipper and ladder dredges and the dredged material is usually placed in a container and transported to a disposal site. The material excavated remains at approximately the original water content throughout the dredging process.

Hydraulic dredges can be divided into two catagories - hopper dredges and pipeline dredges. They share one common mode of operation in that a centrifugal pump causes material to be removed from the dredging location and be discharged either into the hoppers of the dredge itself, into barges, or back into the water at some distance away.

In the United States, the only hopper dredges are owned and operated by the Corps of Engineers. Intakes are either of the plain suction type or equipped with a draghead.

Some hopper dredges have the capability of sidecasting, or pumping the dredged material directly back into the water, but in most cases when loaded, the hopper dredge moves to open water and discharges the dredged material by bottom dumping. On occasion, the discharge is made behind a levee or dike. Hopper dredges are frequently used in open areas, bays, large river mouths, etc. as typified by the mouth of the Mississippi River and have storage volumes between 380 and 6100 cubic meters (500 and 8000 cu yds).

Hauling and Dumping Equipment. Mechanical dredges normally are used in conjunction with bottom dumping scows or barges. The scow is filled and then towed to a dump site, where it is bottom dumped, usually in open water, but occasionally in a diked area. Dump scows presently used for open water dumping of dredged materials are of several basic types employing different dump actuating mechanisms and configurations. Older and smaller scows generally contain 6 or 8 pockets, each of which contain double, gravity dump, bottom doors held closed by cables and a ratchet and pawl type mechanism. Release of the pawl for dumping is provided by hydraulic jacks operated by control valves located within the scow bridge; the scowman manually controls operation of the valves for each pocket mechanism.

Some of the dump scows or barges are of the hinge type configuration. The barge is comprised of a port and a starboard section which are hinged topside (fore and aft); the two sections rotate about the hinges during dump operation. Large diameter hydraulic pistons located beneath the fore and aft hinges cause the two sections to separate below, thus allowing the dredge material to be dumped into the water. Dumping is normally actuated with hydraulic control valves by a scow-man, although it can be remotely controlled. Dump time is on the order of several minutes. Scows and barges range in size from 765 to 3060 cubic meters (1000 to 4000 cu yd) capacity, and may be self-contained or remotely powered and controlled.

The problems of dumping from a hopper dredge are similar to those of a scow, or barge, except that the vessels are self contained, and therefore do not have problems of remotely controlling the dump. The navigation equipment on the hopper dredges may be generally superior to that on tugs. Furthermore, the transit speed to and from the dump site is faster than the typical tug-barge combination. Finally, the hopper dredge may have adequate power to supply the needs of treating and/or pumping the material from the dredge into the water.

Pipeline dredges also utilize a centrifugal pump to move the dredged material but they do not have onboard storage. A barge provides the flotation, energy, and workspace, from which a ladder and cutterhead are suspended into the area to be dredged, Dredged material is then pumped via a pipeline to the disposal site.

Since a pump is used, the dredged material must be slurried with overlying water. Solids content of these slurries may range from a few percent up to perhaps 30 or 40 percent depending on the nature of the solids. Hydraulic pipeline dredges are rated by the diameter of the discharge line with the largest being about 30 inches and a typical value of about 24 inches. The following table indicates typical flow rates.

Hydraulic Pipeline Discharge Rate (gpm)

Discharge Velocity ft./sec.	Discharge Pipe Diameter			
	8"	18"	24"	30"
10	1,620	7,500	13,520	21,120
15	2,420	11,240	20,280	31,690
20	3,230	14,990	27,040	42,250
25	4,040	18,740	33,800	52,810

Discharge from the pipe is typically into open water or land disposal areas, either diked or undiked. The length of the discharge pipe varies, usually from a few hundred to a few thousand meters. One notable installation was 12,000 meters long, required several booster pumps, and discharged into the Craney Island (Norfolk, Va.) land disposal site.

Disposal of polluted dredge material is often performed in diked areas. Pipeline discharge to the diked area is preferable for retention of pollutants, because the alternative of barging material into the diked area requires a large gap in the dike for passage of the barges.

Disposal Considerations

Criteria for Disposal of Dredged Material

Until recent years the method of disposal of sediments dredged during construction and maintenance of channels and harbors was governed primarily by the cost of the disposal operation. In most cases the disposal method deposited the materials back into the waterway at a short distance from the dredging site. In the last few years an increase in environmental awareness has prompted numerous studies on the effects of dredging. Legislation has been passed which promises to put strict limits on how dredged material disposal may be accomplished.

The Environmental Protection Agency has been charged under the Marine Protection, Research, and Sanctuaries Act and the Federal Water Pollution Control Act Amendments of 1972 with promulgating regulations and procedures to ensure that degradation of the waters of the territorial sea, the contiguous zone, and the oceans will not occur as a result of dredging operations. At this time the criteria for ocean dumping have been published, and the criteria for disposal on inland waters are still being developed.

Criteria for the disposal of dredged material in the ocean have undergone an evolution from the original interim criteria published in the Federal Register on May 16, 1973 and the interim regulations of April 5, 1973, to the Ocean Dumping Final Regulations and Criteria of October 15, 1973. In 1971 the Corps of Engineers published EC 1165-2-97 presenting 7 guidelines, covering volatile solids, COD, total Kjeldahl Nitrogen, oil and grease, mercury, lead, and zinc. It was on the basis of these early guidelines that many of the Corps Districts began their sampling programs. These early guidelines were based upon EPA bottom sediment criteria (the "Jensen Guidelines").

The October 15, 1973 final criteria cover Ocean Dumping, under the Marine Protection, Research, and Sanctuaries Act of 1972, PL 92-532 and section 403(c) (Ocean Discharge Criteria) of the Federal Water Pollution Control Act Amendments of 1972, PL 92-500. Inland or navigable waters are covered by PL 92-500, section 404(b), for which EPA is currently preparing criteria.

The Marine Protection, Research, and Sanctuaries Act of 1972 covers both the dumping of industrial wastes and dredged materials. Permits for dumping industrial wastes are issued by EPA with the permit decision based on allowable levels of pollutants in the waste material.

Permits for dumping dredged materials are issued by the Corps with the permit decision based upon the effect that the material may have on the disposal site. This approach considers both the nature of the material to be disposed of and the nature of the site into which it will be placed. The criteria define two conditions of dredged material: unpolluted and polluted. Unpolluted material may be dumped in approved dump sites. Polluted material may be dumped subject to a number of restrictions. All dredgings to be disposed of under Section 115 will be polluted, unless treated before dumping.

Disposal Options

Open Water Disposal. Open water disposal of dredged materials has been practiced in the United States for a number of years and, as land disposal sites become harder to find, this alternative method of disposal has become of increasing importance. In some parts of the United States (e.g. New England) dredge material is almost exclusively disposed of in open water.

Open water disposal involves many factors including problems of precise navigation to the dump site, particularly under adverse weather conditions and at night; dispersion of the material in the dump site following dumping; obtaining a positive indication that the dump actually took place at the proper station; and possible treatment of the dredged material to decrease its dispersion or to limit the availability of toxic materials to the environment.

The dump site factor which presently has the greatest degree of uncertainty associated with it is dispersion following dumping. Dispersion affects the disposal activity in a number of ways. Since the intent usually is to have all of the dredged material end up in the site, any influence that causes the material to miss the site, or end up in a part of the site not intended, should be examined and provision made to compensate for these factors.

Until recently very little study has been done on dispersion of dredged materials. Johnson (20) recently completed a study of dispersion models for the Corps of Engineers Waterways Experiment Station and has published a report on the subject. He identified, and examined several math models for predicting the dispersion and settling of barged wastes in the ocean, but found no models for estuarine or riverine environments. He points out that Schroeder and his associates at Oregon State University are currently involved in developing a model for tracing dredged material released by a pipeline. Johnson states that in the ocean environment, sensitivity analyses and field verification are needed for models such as the Koh-Chang model; that model development is necessary for predicting the short term fate of dredged material in the estuarine environment; and that model development for riverine environments should await developments of Schroeder's work.

A very sophisticated and general model for dispersion of dredged materials in open water has been developed by Koh and Chang (21). Their model has the capability of handling the three cases of: instantaneously releasing the material from a bottom dumping barge (or hopper dredge), pumping the material through a pipe under the barge while the barge is moving, or releasing the material in the barge wake.

Edge (22) has developed a model for barge dumping into the ocean environment. It is composed of a combination of jet theory and sedimentation theory. The first part of the model assumes a negatively-buoyant jet discharged downward into a stratified environment and then sedimentation theory is used to provide a description of the transport of material from the end of the jet to the floor of the ocean. Clark, et al (23) developed a similar approach in which they present a technique for analyzing disposal from a hopper barge.

If the wastes follow a jet pattern, they will ultimately come to rest on the ocean floor since they are negatively buoyant. If sufficiently diluted with entrained fluid, they may become neutrally buoyant and stabilize at some intermediate depth. At this point the material is affected by local currents, flocculation, gravitational attraction, and possibly wave action. The material then settles toward the bottom while being moved about by currents and turbulence.

A dispersion model has recently been presented by Christodoulou, et al. (24) which predicts the quasi-steady state sediment concentration as a function of space and tidal time and the disposition pattern in the region surrounding a continuous vertical line source. In addition to sediment settling velocities, net drift, and dispersion coefficients which are also required by the other models, an off-shore sinusoidal tidal velocity is input. Effects of wave action and vertical stratification are not considered. The assumption of no vertical stratification would probably be valid in many instances, particularly in relatively shallow ocean dump sites.

Recent studies have been funded by the U.S. Army Corps of Engineers at a dump site in Long Island Sound. Gordon (25) made measurements of turbidity in the water surrounding scows discharging non-cohesive dredge material, high in silt content, at the New Haven dumping grounds. The observations show that 99% of the material is quickly transported to the bottom in a high speed, density current. Impact with the bottom produces an outward spreading, turbid cloud. The residual turbidity in the water column, which drifts in the tidal stream, contains less than 1% of the material discharged.

Gordon has obtained quantitative data and from these data he postulates the following qualitative model for dumping at this site. Dredge material dumped in the ocean will quickly fall to the bottom as a density current which then spreads laterally, depending upon the spreading velocity, topography, and local currents. A small residual cloud of material will stay in suspension and be acted upon by local currents and density gradients. This material will eventually settle to the bottom, but perhaps well removed from the original dump site. In most cases, this latter material represents a very small fraction of the total dumped volume.

Dumping Methods. While one part of the open water dumping problem is location of the vessel at the dump site, and another is dispersion of the material which will lead to choices on where to release, a third consideration is that some control on dispersion, and therefore placement, may be obtained by control of the dumping method.

Researchers in the development of dispersion models have recognized that the method of release will have a significant effect on the dispersion process. In general, three methods of release are employed:

- Instantaneous bottom dumping in which a large mass of material is suddenly released such as from a scow hopper. The initial downward velocity (convective descent) may carry the material to such a depth that the bottom is encountered or the pycnocline is passed before longer term dispersion effects become significant.

- Jet discharge in which the material is released through a pipe under the barge either by pumping or by gravity dump. In this case the material behaves as a buoyant jet.

- Wake discharge in which the material undergoes an initial mixing phase when turbulent mixing dominates over buoyancy effects. Although industrial wastes are sometimes discharged in this manner, dredged materials are not.

Consideration of several dumping methods may lead to an optimum method of placement within a dump site. In situations where current is primarily the problem, the dump point above the site may be selected to optimize the placement of materials in the site. However, Gordon's results (25) in Long Island Sound indicated that less than 1% of the material remained in the cloud above the dump site. While the details of this finding must be carefully checked, the implications are that, under some circumstances, most of the material will quickly reach the bottom almost directly under the dump point.

If a vertical density gradient exists, there is considerable evidence showing that some of the fine-grained material may be intercepted in its vertical descent and possibly transported horizontally for some distance before ultimately settling to the bottom. One way of avoiding this problem is to dump the material below the pycnocline so that settling will predominate rather than long term diffusion. Among the ways to do this are shrouds, pipes, and curtains that would keep the material together, as a mass, until it was below the pycnocline. This approach could present an enormous technical and logistic problem, to say nothing of the increased cost.

Another approach to dumping, in the presence of a density layer and high currents involves making modifications to the material itself. Nalwalk (26), Saila (27) and Gordon (25) all found that the dispersion was significantly reduced if the water content of the dredged material was reduced during the dredging operation. The pressure exerted on the material by the bucket dredge, and the barge itself, reduced the water content and made the material remain relatively intact all the way to the bottom. In fact, individual bucket-formed balls of material were observed on the bottom at the dump site. These effects were very evident if clay was present.

This suggests the possibility of processing the dredged material, in one of a number of ways, to maintain a high average density of the material, so that it will successfully pass through the density layer, minimizing dispersion. One way of doing this would be to either modify the bucket, or the barge, so that the material could be compressed, reducing the water content. This would be more difficult in a hopper dredge but is still possible. It will probably only be effective on cohesive material.

Another possibility is the addition of a material, like clay, that would aid the dredged material in retaining a higher density as it passes through the water column. Chemicals could also be added to assist in this process. Formation of a gel, or grout, might also be effective.

Another method of dumping which could be employed to minimize dispersion is encapsulation. When the quantity of material is small and the material is highly toxic, containers such as 55-gallon steel drums could be used. Another possibility might be the application of a surface layer to the material prior to dumping so that entrainment of ambient water and dispersion during the descent phase would be minimized and the substantial negative buoyancy of the dredged material mass can be utilized. All of these alternatives would substantially increase the cost of disposal.

Land Disposal. In general, land disposal of dredged materials includes both unconfined and confined disposal. Unconfined disposal has been done on marshlands, islands and bars in river channels, on beaches for beach nourishment, and on upland areas. Since the needs of this study are related to the disposal of highly toxic in-place pollutants, the application of unconfined disposal methods appears doubtful in that, first, little control is normally available over the long term location of these materials, and second, the unconfined disposal sites are generally more sensitive to such factors as toxicity and aesthetics. Thus, land disposal of toxic dredged materials will probably be limited to confined disposal.

Confined land disposal sites vary widely in design, construction, and utilization. U.S. Army Corps of Engineers Technical Report H-72-8 (28) indicates that there are presently about 200 active dredging projects that rely in whole or in part on confined disposal of the dredged material.

The relative number of confined sites is increasing due to concern for the effects of dredged material pollutants on water quality. Since pollutants are often associated with fine grained material and also since disposal of fine grained material is more difficult to control in open water or unconfined areas, a disproportionately large amount of the fine-grained material is confined on land. Also the relative amount of fine-grained and/or polluted material being confined on land will increase over the coming years.

Alternatives to Conventional Dredging and Disposal

General Considerations

Alternatives to conventional dredging consist of dredging and treating the material prior to ultimate disposal or leaving the material in place and sealing it with a cover to prevent migration of the polluted material or penetration by benthic organisms.

An evaluation of techniques for covering of pollutants requires examination of a number of aspects including the nature and mobility of the pollutants, the type of cover and its effectiveness as a chemical or physical barrier, the effect on the barrier of benthic organisms, and the technical, economic, and operational feasibility of covering the area.

Covering of In-Place Pollutants

One possible alternative, which is primarily applicable outside of navigation channels, is to apply a cover over the site. The reasons for doing this would be to reduce the availability of the pollutants to the surrounding environment and to protect the site from erosion and subsequent redistribution of pollutants such as may occur during a storm.

Early work on the effectiveness of covers was conducted in Sweden. Jernelöv (29) found that in a system without macro-organisms, formation and release of methyl mercury occurs almost entirely in the upper centimeter of the sediment. Thus, in this situation natural sedimentation must be an important factor for turnover of mercury deposits in the sediment. Addition of Tubificidae in very high amounts change the situation somewhat, but it still is mercury deposits in the upper 2.5 cm of the sediment that give the dominating contribution to the formation and release of methyl mercury. When Anodonta (mussels) are present - with a very high population density - the depth at which deposits of inorganic mercury contribute is expanded to about 9 cm (29).

The fact that both Tubificidae and Anodonta tend to expand the active depth of the sediment according to their length and to the depth in the sediment they reach and mix supports the idea that they influence the process of methylation and release of methyl mercury from the sediment mainly through physical activity - mixing sediment and increasing the through-flow of water. This makes the population density an important factor. In many lakes stratifications in the sediment within centimeters are regarded to represent different periods of time. This implies that mixing of sediment layers through activity of organisms is not very important.

It appears to be possible to "lock in" the mercury in the sediment by a covering layer of 3 cm if there were no macro-organisms or only Tubificidae present. But if Anodonta is present a covering layer of 10 cm would be required.

Landner (30) investigated ways to restore polluted lakes in Sweden, especially with regard to heavy metals pollution, and concluded that several approaches are possible. These include:

- introduction of oxygen consuming substances in order to create constant anaerobic conditions in the bottom sediments.

- introducing inorganic materials with strong adsorption characteristics to fix the mercury in non-methylable form.

- covering with an inorganic material.

He used a 0.5 to 1 mm thick cover of lime to cover fiberous sediments polluted with phenyl mercury and found this reduced the available mercury by a factor of 5. A similar experiment was conducted using silicate minerals as a cover and he found a significant reduction in the available methyl mercury. Less effectiveness was attained in the case of phenyl mercury.

Landner also conducted tests in lakes, where freshly ground quartz mineral was spread over the bottom to attempt to seal in-place methyl mercury. The results obtained were inconclusive because of the difficulties associated with obtaining a uniform layer on the bottom. Due to a shortage of funds, the quartz was barged to the site and then spread by hand, using shovels. Large patches of the bottom remained exposed, using this method.

EPA has funded a number of projects to evaluate the effectiveness of bottom covers and, while these have also been directed toward heavy metals problems, the results are of interest to the in-place pollutants program.

Feick, Johanson, and Yeaple (31) conducted aquarium studies with organic and inorganic mercury and evaluated the effectiveness of several covering materials (sand, kaolin clay, silica, zinc sulphide, milled pyrite, Zn S-FeS, thiols, polyethylene). Tests were also conducted on combinations of these (i.e., a chemical complexing agent below a sand barrier). They found that oxidizing of the polluted sediments resulted in increased availability to the ecosystem, hence the desirability of a "blanket" or cover to keep the sediment anaerobic. Plastic films (polyethylene) did not appear to be an effective barrier for sealing against methyl mercury. In dredging simulation, they found that about 99% of the mercury present remained bound to particulate matter. This implies that, for heavy metals, dispersion and resuspension should be avoided to control the spread of the pollutant.

Bongers and Khattak (32) investigated the effectiveness of sand and gravel as a cover for mercury-contaminated sediments. The release of toxic mercurials by mercury-enriched river sediments was examined in the laboratory. These tests indicated that about 1 μg of methyl mercury was released per m^2 per day. The release of such toxic mercurials could be prevented by a layer of sand, 6 cm in thickness, applied over the mercury-enriched sediments. Layers of fine or coarse gravel (6 cm deep) were as effective as sand. Thinner layers of sand, 1.5 and 3 cm in thickness, appeared to be unsatisfactory. The cost of applying 3-inch layers of sand or gravel over contaminated river sediments is estimated to be about $3000 to $4000 per acre.

The formation of methyl mercury occurred in sediments with low and high organic content, in sediments with low and high cation exchange capacity, and in aerobic and anaerobic sediments.

A convenient indicator of the potential toxicity of a contaminated sediment is the presence of metallic mercury. The slow release of metallic mercury occurred in aerobic sediments, but the release was much faster in anaerobic sediments. Using ascorbate as an artificial electron donor, metallic mercury could be released at high rates from aerobic sediments as well. Ascorbate appeared to be a helpful indicator of the presence of divalent biologically accessible mercury.

Although the laboratory investigations proved the soundness of the sand blanket approach, its practical and economic feasibility must be determined in a combined field and laboratory analysis program.

Widman and Epstein (33) evaluated polymer film overlays for mercury contaminated sites, under contract to EPA. This work was based upon previous studies for the U.S. Navy with regard to using covers to reduce turbidity during diver salvage operations in the ocean.

Concepts for dispensing of polymer films underwater and over mercury contaminated sludges were generated. The candidate systems examined were based on coagulable materials, hot melt polymer compounds, and preformed films. A large number of laboratory blends of the candidate materials in the first two categories were made and qualitatively evaluated to identify promising formulations. Experimental equipment appropriate to each concept was designed and experiments were conducted in an 18 foot long test tank to establish the feasibility of the material-equipment systems.

The results of these experiments suggested that commercially available preformed films could be successfully dispensed from a roll and applied as an overlay on the mercury contaminated sludge.

Dialysis experiments were conducted to determine the permeability of the candidate materials to organic and inorganic mercury compounds. Preformed nylon and high-density polyethelene performed best in all categories. Microbiological and biological experiments showed that the preformed films and hot melt polymers were most promising.

A cost analysis showed that a preformed film overlay can probably be deployed for 1.5 cents to 3.3 cents per square foot, hot melt films for about 2.5 cents per square foot, and a coagulable nylon film for about 4 cents per square foot.

The logistics associated with covering of in-place pollutants with a plastic film appear quite restrictive, but further evaluation is warranted for any location where more conventional rehabilitation methods are not feasible. One potential hindrance is that the U.S. Coast Guard is currently considering the recommendation of an international ban on the dumping of plastics in the ocean.

Saila (27) has investigated the effectiveness of covers for material in Rhode Island Sound, including stability associated with material that is in a mound. Gordon (25) indicates that stability can be enhanced in some cases by actively cultivating a biological population, such as tube dwelling polychaetes.

Pratt and O'Connor (1) have considered the problem of providing a cover over polluted dredge materials in a dump site. They felt that the cover need not be totally sealed, at least in the case of the moderately contaminated sediments of their study. In that case they stated that a cover should be judged successful if it reduces the exposed surface area by 90 to 95 percent and providesa blanket thick enough to keep the dominant benthic species from contact with the contaminated material. A practical consideration was that only unconsolidated sediments can be spread evenly enough to cover a large area, so that although clay material would be desirable in a cover due to its adsorptive capacity, spreading of a cover containing significant amounts of clay may not be practicable.

To investigate the effectiveness of covers Pratt and O'Connor developed a mathematical model of a sand cover which allowed the heavy metals to migrate through the cover and followed the total heavy metal load as a function of depth and time. The model is essentially a one dimensional diffusion model with linear (Langmuir) adsorption. It was concluded that migration of metal ions would occur at a rate proportional to the size of the particles in the cover. If the cover particles are only slightly larger than those in the polluted material, then the covering material would only become marginally polluted.

Another class of pollutants, pesticides and hydrocarbons, also require consideration of covering. These materials, like heavy metals, are sparingly soluble and tend to concentrate in sediments. Desorption from sediments has been observed, however, by Rowe et al. who concluded that the effect of adsorption and desorption would be to increase organisms' exposure time and to decrease initial concentration levels (34).

Covering Methods. Most of the work that has been done on covering technology is related to the effectiveness of the cover once it is in place, with little thought as to how to obtain an effective cover from an operational point of view. Except from the work by Landner, where material was spread manually from a surface barge, little has been done.

The basic problem is one of finding a way to spread material on the surface of a dispersive medium, in such a manner that it will provide a reasonably complete cover over the site that may be a number of fathoms below the surface of the water. The cover need only be total if the material is very polluted and/or if the current and wave action are such that resuspension becomes a problem.

Spreading of material manually (i. e. shoveling) can be ruled out as ineffective and expensive. Thus, more automated means are required. It is possible to conceive of dump scows or hopper dredges criss-crossing the area dumping clean sand to obtain a cover. If the water is not too deep, a way to consider would be to pump cover from the area immediately adjacent to the site and direct this over the polluted area using a grid pattern and precise navigation.

Perhaps the most feasible way to obtain a good cover would be to utilize technology that was investigated by the Army Corps of Engineers for a totally different environmental problem - oil pollution.

Tobias (35) has reported on a study that involved a modified hopper dredge to spray specially treated sand on the surface of an oil spill, causing it to sink to the bottom. It was later established that this method is unacceptable, for oil spills, from an environmental point of view. However, it appears to have potential value with regard to obtaining a cover for in-place pollutants.

The study examined the feasibility of taking a hopper dredge to an adjacent sand bank, filing the dredge with sand, transiting to the site of the oil spill, and then pumping the sand onto the spill to cause it to sink. The sand was released through special arms that deploy on either side of the dredge, giving it a large sweep width. In addition, chemicals were mixed with the sand so that it became hydrophobic and oleophilic. In the case of covering pollutants in the sediment, other chemicals would be employed (such as sulfur, thiols, iron scrap) depending on the chemistry of the site and the pollutant which are to be immobilized.

Tobias investigated the possibility of modifying a dredge like the Corps of Engineers' GOETHALS. Alterations consist of the addition of spray booms (port and starboard) with associated rigging and a chemical storage and dispensing system. Preliminary cost estimates for modifying this dredge come to about $125,000 for the first system. The equipment would be portable, could be installed in about 2 days, and the equipment could either be transported to the various areas as needed, or several systems could be used to cover the East, Gulf, West Coasts and the Great Lakes.

It is possible to consider installing a system like this on a barge but the hopper dredge is particularly appealing because it can acquire its own sand and has most of the equipment needed to achieve the desired goal.

Another interesting problem involves the determination of how well the site has been covered. This goal probably can be accomplished using the correct fathometer, since the reflective strength of a fine grained bottom is significantly different from that of a sand bottom. Thus a high resolution fathometer, of the appropriate frequency, will give an excellent account of the integrity of the cover, while perhaps lacking in vertical definition as to the thickness of the cover. This latter parameter may be measurable using coring techniques.

Treatment of Dredged Materials

In previous sections consideration has been given to dredging equipment and methods, dredged material disposal methods, and techniques which might be employed to seal the pollutants in place as an alternative to dredging. In this section the possibility of treating the dredged material is addressed.

The type of treatment that might be utilized in any particular situation would depend on many factors such as the nature and concentration of the pollutant, the sensitivity of the environment near the dredging and disposal sites, the method and location of ultimate disposal, and the type of dredge used, rate of dredging, and the cost. In addition, since treatment is relatively expensive when compared to the dredging operation, the availability of funds will have an influence on the overall dredging and disposal system.

For a number of reasons the concept of treating polluted material as it is being dredged is appealing. The treatment possibilities are quite limited, however, due to the rate at which the material is dredged and the types of treatment which are effective in altering dredged material characteristics.

There are two very important disadvantages of at-dredge treatment. First, dredge production rates are very high. If no buffer capacity is available, treatment must occur at the same rate as production. The result would be a treatment process of far larger capacity than would be required for treatment at a longer term average rate. Second, dredge output is highly variable even from moment to moment. Most treatment processes are adversely affected by fluctuations in either flow rate or composition. Some processes may not function adequately under varying input conditions, or at the least a more conservative, and therefore more expensive, design would be required.

One of the most promising approaches to the treatment of polluted dredged materials is on-land treatment where buffer capacity can be provided by storage areas. Among the advantages are: smaller treatment facilities since treatment could occur at a long term average rate, relative freedom from the dredging operation, and ability of a single facility to serve many dredging operations. The principal disadvantage is the need for transportation of the dredged material to the treatment site.

There are two fundamentally different categories of land treatment facilities: rehandling areas and permanent dumps. In a rehandling area the dredged material is processed in some manner and then deposited in another site, either land or water based. In a permanent dump the material may still be treated, but ultimate disposal is in the same site.

Rehandling facilities are an interesting concept. Polluted materials would be transported to the facility for processing, but ultimate disposal would be at other locations. A typical rehandling facility might include the following operations:

- Separation of water from solids
- Destruction of organics
- Treatment of the separated water to enable discharge

Separation of Water from Solids. The most easily operated, and probably the least expensive dewatering process would be settling ponds. When dredged materials are allowed to settle for a period of several days, almost all solids will settle out. The supernatant water can be drained off, perhaps treated, and discharged to the waterway. Techniques can then be employed to further dewater the solids by air drying and drainage with the result being a dry material which can be excavated and used as land fill, dumped in an open water disposal area or incinerated. The method of ultimate disposal would determine the optimum degree of dewatering.

The area requirements for a rehandling facility would be determined by the rate of dredging, weather conditions, the nature of the material, the dryness required, and the method of mechanical agitation to encourage drying. The time required to achieve the optimum water content would probably be between ten days and several months.

The operating cost of the drying process, including mechanical agitation to speed the process, would be about $1.00 per cu yd. The capital cost for the underdrain system would be about $1000 per acre. Other systems involving mechanical dewatering devices would also be effective, but would be far more expensive.

Destruction of Organics. When high concentrations of organic matter are present in the polluted dredgings incineration can be employed to destroy the organics and thus greatly reduce the concentration of volatile solids, oil and grease, organohalogens, and oxygen demanding material.

Incinerators are likely to be an effective and economical method for altering the chemical characteristics of dredged materials. Assuming that the solids content of the dredged material was 45 percent of which 20 percent were volatile, then the capital cost of a multiple hearth furnace incineration system with a capacity of 100,000 cu yd/hr would be about $1.1 million including installed equipment, buildings, and all other equipment for an operational facility. The operating and maintenance cost would be about $135,000/yr. With a ten year writeoff on mechanical equipment, the cost per cu yd. of solids processed would be $2.74. The incinerator ash would be 80 percent of the original solids content, but it would be sterile and not contain any organic pollutants, so that open water disposal may be acceptable means of ultimate disposal. If heavy metals which remain in the ash were found to be a problem, landfill of the material is also a possibility. The total cost for a system including a rehandling-drying area ($1.00/ cu yd.) would be about $4.75/cu yd. While this represents a large percentage increase over present disposal costs, in cases where highly polluted materials are encountered, an incineration system may be the only practical means for disposal of these materials.

It should be emphasized that, in general, incineration cost estimates are very sensitive to the type of material being considered since one of the most important cost factors is the need for auxiliary fuel. The water content of the material to be incinerated should be consistent with self-sustaining combustion.

Treatment of the Separated Water. Quiescent settling of dredged materials for several days will produce a supernatant water with only a very small fraction of the initial suspended solids content. However, the residual suspended solids and dissolved materials may exceed limits set for discharge into the waterway adjacent to the land disposal site. Examples of potential problems are coliform bacteria, suspended solids, heavy metals, and phosphorus. A method which would be effective in removing these contaminants is precipitation with inorganic salts and polymers in combination. The most economical method for treatment would require only a small tank for mixing of chemicals, a somewhat larger tank for flocculation, and a diked settling pond. Inorganic salts such as lime, alum, and iron salts are capable of precipitating dissolved metals and the plant nutrient phosphorus. When applied in conjunction with polymers a rapidly and completely settling floc will be produced and will result in treated water which should meet water quality standards for discharge. If bacterial pollution is present, such as from municipal sewage outfalls, disinfection with either chlorine or ozone would be effective.

Treatment Facilities' Use and Costs. Any scheme to treat dredged materials in response to Section 115 must consider the long-term local problems in disposing of dredgings. If in place polluted sediment is not likely to be replaced by continuing pollution or spills, then facilities are not likely to be justifiable for the one-time treatment operation. Local sewage treatment plants should be considered in such cases, especially if they are new and have the excess capacity typical of new plants. Adequate grit removal facilities are especially important.

If, on the other hand, polluted sediments can be expected to reappear, perhaps the Section 115 funding may be combined with conventional dredging funds for the construction and operation of long-term dredged material treatment facilities.

An important factor in deciding on solutions to the problem of in-place pollutants will be the costs of the dredging, treatment, and disposal operations. In some cases such as hopper dredging and hydraulic pipeline dredging, disposal is closely associated with the dredging. In others, particularly where land disposal or treatment is involved, the disposal operation should be considered separately.

It is difficult to specify precisely the cost of dredging, since it varies depending upon geographical location, type of material to be dredged, and the disposal method employed. In addition, inflation and shortage of materials and supplies are causing wide fluctuations in the present market costs. Cost estimates and recent bid abstracts received from the Corps of Engineers confirm that costs should not be generalized. Unique local conditions cause wide ranges in estimates.

Recent bid abstracts for dredging in Texas, received from the Galveston District of the Corps of Engineers, show a range of bids to be $0.15 to $2.47 per cubic yard. One contract received bids for levees and spillways in a disposal area ranging from $65,000 to $118,000. Other investigations have found that costs for bucket dredging and open water disposal in New England are approximately $2 to $3 per cubic yard (36). The Detroit District of the Corps of Engineers reports costs of maintenance dredging as $0.34 and $0.87 per cubic yard for the Detroit and Rouge Rivers respectively. These costs assume open water disposal, and would be increased to $4.41 and $5.75 per cubic yard if the planned diked area at Pointe Mouillee were implemented (37). Johanson and Bowen (36) have estimated that additional costs of approximately $0.50 to $4.00 per cubic yard would result if feasible treatment schemes were combined with dredging and disposal operations.

Pollutant Control at the Dredging Site. Turbidity control is being used in the field with silt curtains, or turbidity barriers. Pervious and impervious barriers have both been tried. Pervious barriers allow the water to flow through, trapping the silt particles. In most cases, the pervious barriers rapidly become impervious due to clogging of the material pores. This often results in increased weight and drag, and the barrier either sinks or is distorted and/or destroyed due to drag forces if there is appreciable current.

Impervious barriers can control turbidity around dredging and disposal areas. Some state governments have set requirements on the maximum allowable turbidity increase due to a dredging operation. Barriers may protect an area by enclosing it, or more commonly, by containing the turbid water until it has had time to clarify.

Barrier technology is in an early stage of development and decisions with regard to deployment methodology are largely empirical. The barriers are designed similarly to oil pollution containment booms with a flexible plastic skirt held vertical by flotation at the top and weights along the bottom. A major difference between the oil booms and turbidity barriers is that the latter must be available in many sizes since they must extend from the water surface almost to the bottom.
Morneault (38) utilized silt curtains at a dredge site, both around the hydraulic dredge and in conjunction with mosquito control ditches. He found that the value of the curtain (extending only 5 feet below the surface) was not demostrated at the point of dredging operations but was effective in the mosquito ditches to reduce releases into Tampa Bay.

Silt curtains may have very limited use around hydraulic and hopper dredges, because the intense suction exerted at the point of sediment disturbance minimizes turbidity created at the dredging site. Mechanical dredges create a much more significant plume.

Roberts (39) has experimented with barriers and developed a method of determining a recommended deployment configuration based upon fall-out patterns of the material to be dredged. Manufacturers of the barriers claim reductions of turbidity of 30:1 from inside the barrier to outside. They also claim "efficiencies" of 77 to 85% for reduction of turbidity. It has been estimated that the barriers can operate in currents as high as 3 knots, but they must be placed on an angle in the current.

Summary

Covering of polluted sediments with a clean sand is a possible alternative to dredging but the technology of applying the cover has not been developed. Permanence of the cover would also have to be established on an location-by-location basis. Treatment of polluted dredge material appears to be feasible in land disposal areas but not on the dredge. This implies rehandling if the ultimate disposal is to be in open water. Treatment costs, for the simplest of treatment systems are the same order of magnitude as the present cost of dredging,thus treatment would double or triple the cost of dredging.

SECTION VI

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APPENDIX A

DETAILED INFORMATION ON PRIORITY LOCATIONS

General

After the initial screening phase of this study, attempts at further screening were made based upon intensive data gathering on the 23 candidate locations. Information was collected relating to all descriptors which were considered. Based on this information, and upon consideration of how each descriptor related to Section 115, the selection of which descriptors to use was made. This Appendix presents relevant information on locations, whether or not such information was included in the decision processes discussed in the body of the report.

Means of developing information were:

- Visits to locations
- Telephone discussions
- Letters requesting data and general information
- Literature reviews
- Written requests for review of the 23 locations and suggested additions or deletions with supporting data

Agencies and facilities used included:

- EPA Regional Offices
- EPA Field Offices
- Corps of Engineers Division Offices
- Corps of Engineers District Offices
- Port Authorities and Harbor Commissions
- State Water Pollution Control and Public Health Agencies
- Universities (both personal contact and use of university libraries)
- Oceanographic Research Institutions
- Geological Survey Offices
- National Marine Fisheries Service
- JBF Scientific Corporation Library

The same level of effort was attempted for each location's detailed information-gathering. The level of each investigation, however, was unavoidably governed by the availability of information. For example, a few contacts in Baltimore and Seattle produced a wealth of information and further references, while strong efforts in Pittsburgh and Michigan City uncovered relatively little information on sediment data or local water-oriented activities.

The following discussions present the sediment chemistry data and other information which was obtained. Greatest detail is devoted to the six Priority 1 locations. The three Priority 2 locations are discussed in detail regarding sediment data, but briefly in other aspects; the Priority 3 locations are given the least detailed attention.

The figures accompanying the Priority 1 and 2 location discussions show the range of data which was available. For Baltimore, a fairly complete picture of sediment conditions is possible. For locations such as Michigan City and Indiana Harbor, however, only a sketchy outline of conditions can be inferred.

Priority 1 Locations

Duwamish Waterway, Seattle, Washington

Background

Seattle, the port city served by the Duwamish Waterway, has strong ties to its shoreline environment for commercial, industrial, and recreational purposes. Opportunities for water-based recreation abound, and salmon and trout runs up the Duwamish make this industrialized waterway the site of a sport fishery. An upstream state hatchery for chinook and coho salmon, together with natural spawning grounds for these and other anadromous fishes, make the Duwamish a vital resource for both commercial and sport fishing interests. Although Seattle's climate, as measured by mean annual temperature and time of sunshine, appears to minimize outdoor recreation potential, it has been referred to as the "recreational boating capital of the world"[1]. Local water bodies include Lake Washington, Elliott Bay (in Puget Sound), and the Duwamish Waterway, which is maintained for commercial navigation to 8 kilometers upstream from the mouth of Elliott Bay.

Like most cities which are industrialized and which depend heavily on waterborne commerce, Seattle has some problems with water quality. Among these problems are low dissolved oxygen levels in the Duwamish, and spills of toxic materials.

Sediment Chemistry

Analyses of sediment samples in the Duwamish Waterway have been received from six independent sources, and represent eleven separate sampling expeditions. Some of these sampling cruises were primarily interested in synthetic organics: Chlorinated hydrocarbon pesticides such as DDT and polychlorinated biphenyls (PCB). The sediments in the Seattle area contain very high amounts of these materials, as the following data (Table A-1) indicate. Figure A-1 locates sampling stations, and Figures A-2 and A-3 present the geographic trends in the data.

The data for PCB represented schematically in Figure A-2, show the extremely high levels remaining near Slip No. 1 after attempts to clean up the 265 gallons spilled in September, 1974. Even before that spill, however, PCB levels in Duwamish sediments were among the highest in the country.

Concentrations of other pollutants at all locations in the Duwamish Waterway are low relative to the other locations considered for the semifinal priority list, except for one small mercury hot spot. Mercury levels are quite high in the vicinity of Terminal 128, which is currently under construction. Dredging in connection with the development of a barge terminal at that site has probably removed polluted sediments from within the slip area, and further dredging

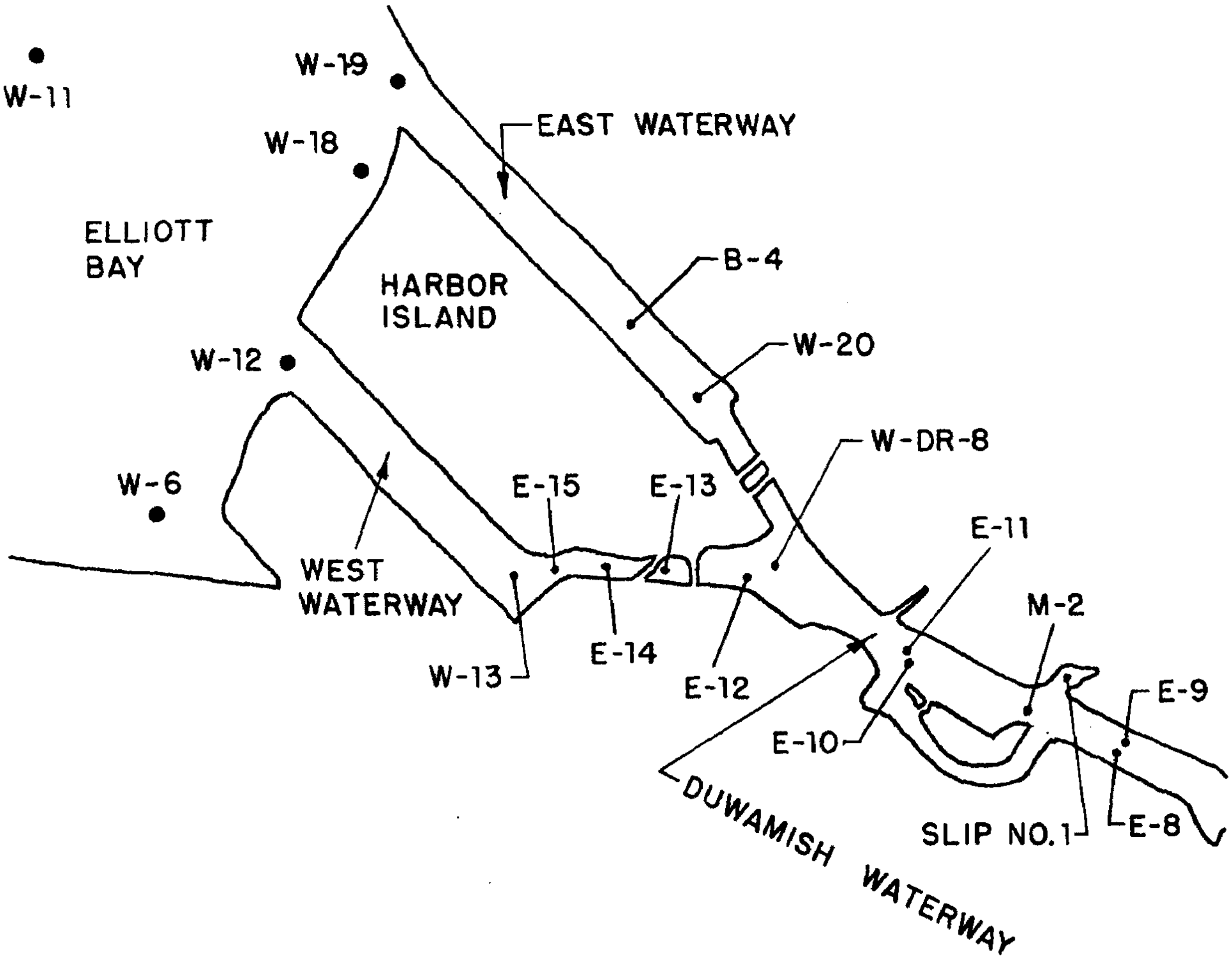
Table A-1

Selected Sediment Analyses (mg/kg dry weight, unless otherwise noted) for the Duwamish Waterway

Station No.	Hg	Cd	Pb	As	Cu	Zn	Cr	Ni	Oil & Grease	Pesticides ppb dry wt.	PCB ppb dry wt.
Reference 2; Sampling Nov. 26, 1974:											
M-2		3.5	89.7		156	1,580	70.8	128			
Reference 3; Sampling, 1971-72:											
B-4	1.8		340		87	270	67	60	9.6	527	6000
B-5	1.0		35		27	73	20	25	2.7	70.1	1600
Reference 4; Sampling October, 1973:											
P-2	1	0	60			180			1600		1000
P-4	68		230			540			1500		
P-5	10		50			240			500		200
Reference 5; Sampling June 5, 1973:											
E-1	0.8	3	60			180			1600		1000
E-2	0.5	3	70			190			3500		1900
E-3	0.4	2	60			160			2100		3000
E-4	0.3	2	50			170			1200		1400
E-5	0.3	2	40			180			1000		1600
E-6	0.3	2	50			160			1600		1100
E-7	0.4	2	70			230			4100		1800

Table A-1 (cont.)

Station No.	Hg	Cd	Pb	As	Cu	Zn	Cr	Ni	Oil & Grease	Pesticides ppb dry wt.	PCB ppb dry wt.
Reference 5: Sampling June 5, 1973 (Cont.)											
E-8	0.4	5	170			6700			3400		1800
E-9	0.4	10	300			810			6100		1600
E-10	0.4	5	200			250			3200		1800
E-11	0.4	4	150			220			19400		3600
E-12	0.5	8	350			600			16300		400
E-13	0.7	3	250			460			7400		1200
E-14	0.1	1	110			210			300		100
E-15	1.5	3	280			660			9200		4200
Reference 6; Sampling November, 1974(after PCB spill and cleanup)											
Slip No. 1											1,170,000
Reference 7; Sampling 1972-1973:											
W-6										3.5	220
W-11										Trace	170
W-12										Trace	2280
W-13										Trace	2500
W-18											500
W-19											330
W-20										20.4	2440
W-DR8										76.0	1297
W-DR9										10.0	610
W-DR10										8.1	333


W-11
W-19
EAST WATERWAY
W-18
ELLIOTT BAY
HARBOR ISLAND
B-4
W-20
W-12
W-DR-8
W-6
E-15
E-13
E-11
WEST WATERWAY
M-2
W-13
E-14
E-12
E-9
E-10
DUWAMISH WATERWAY
SLIP NO. 1
E-8

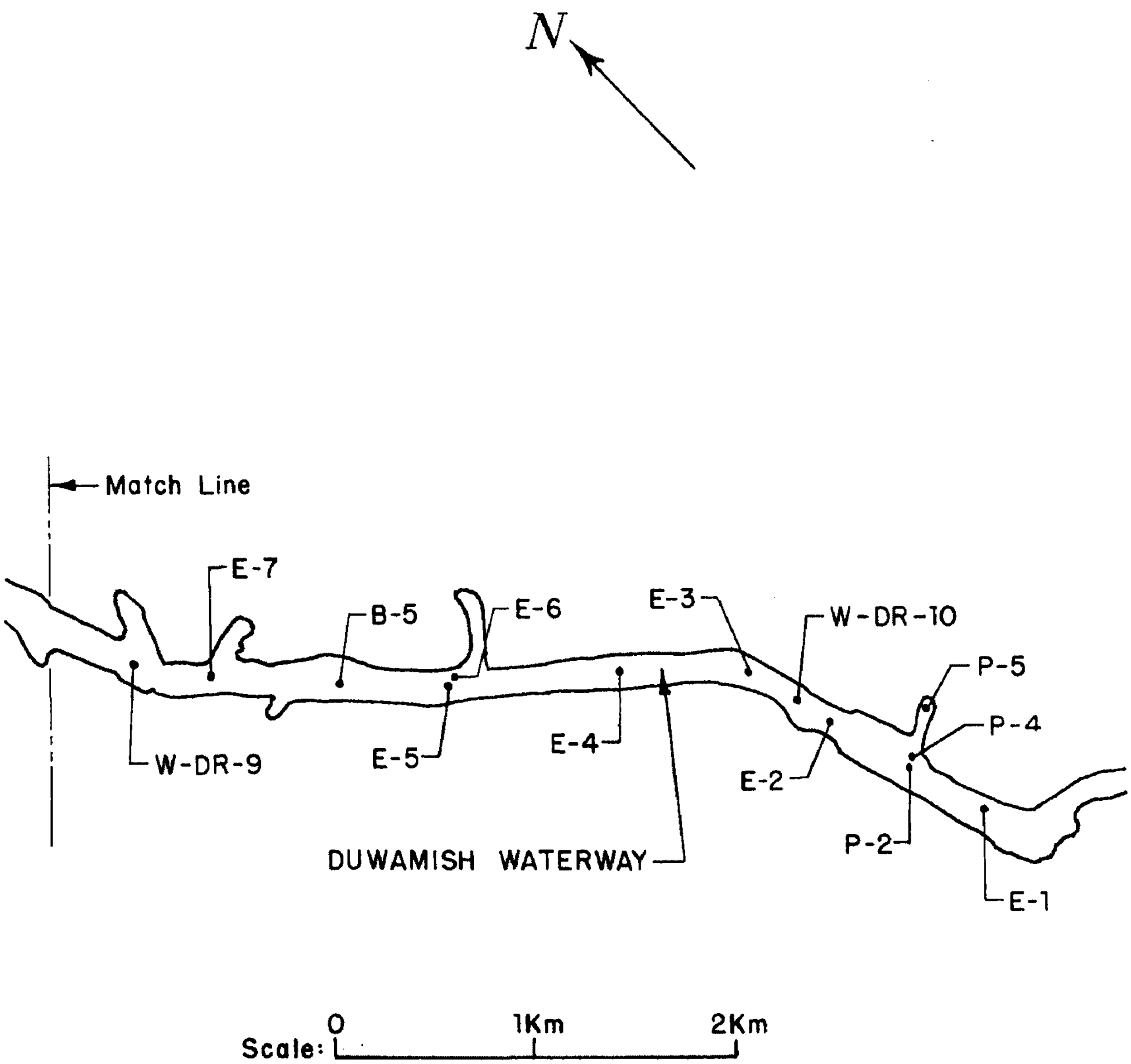
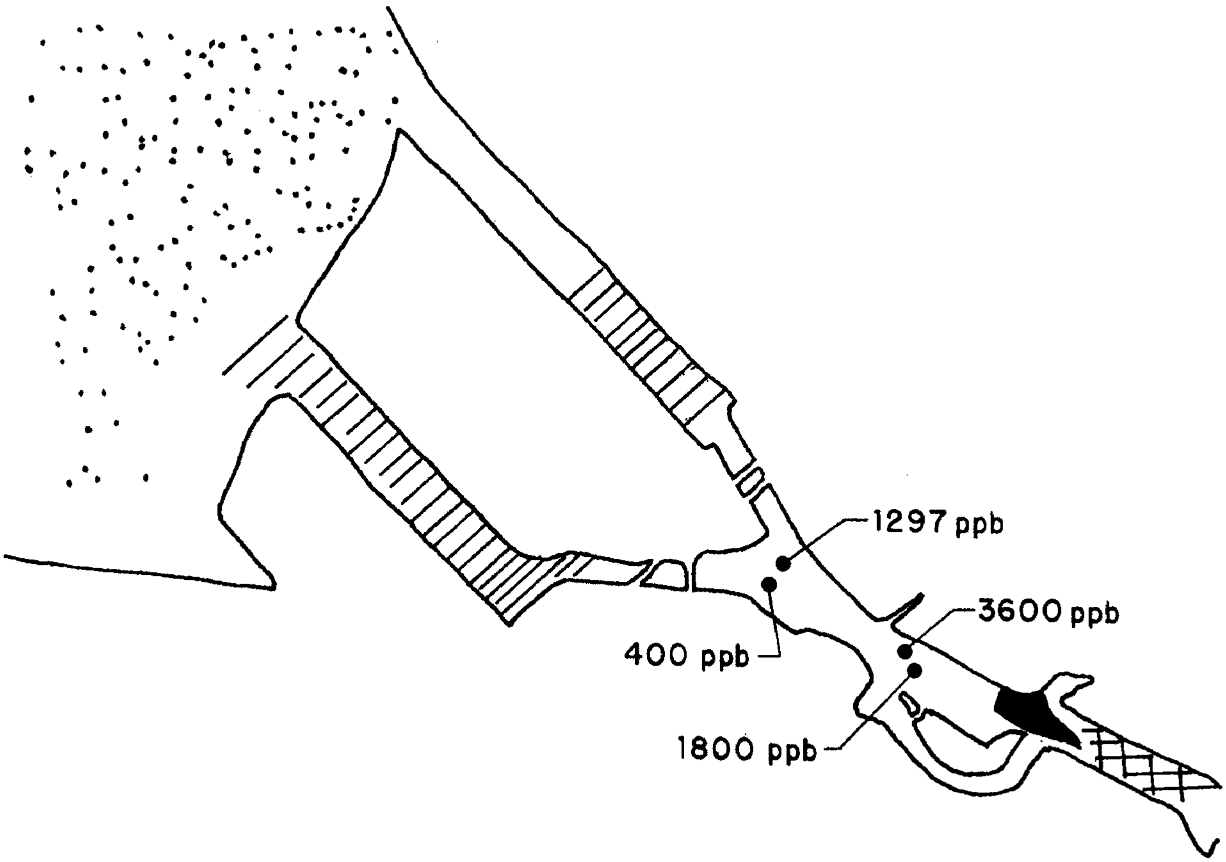
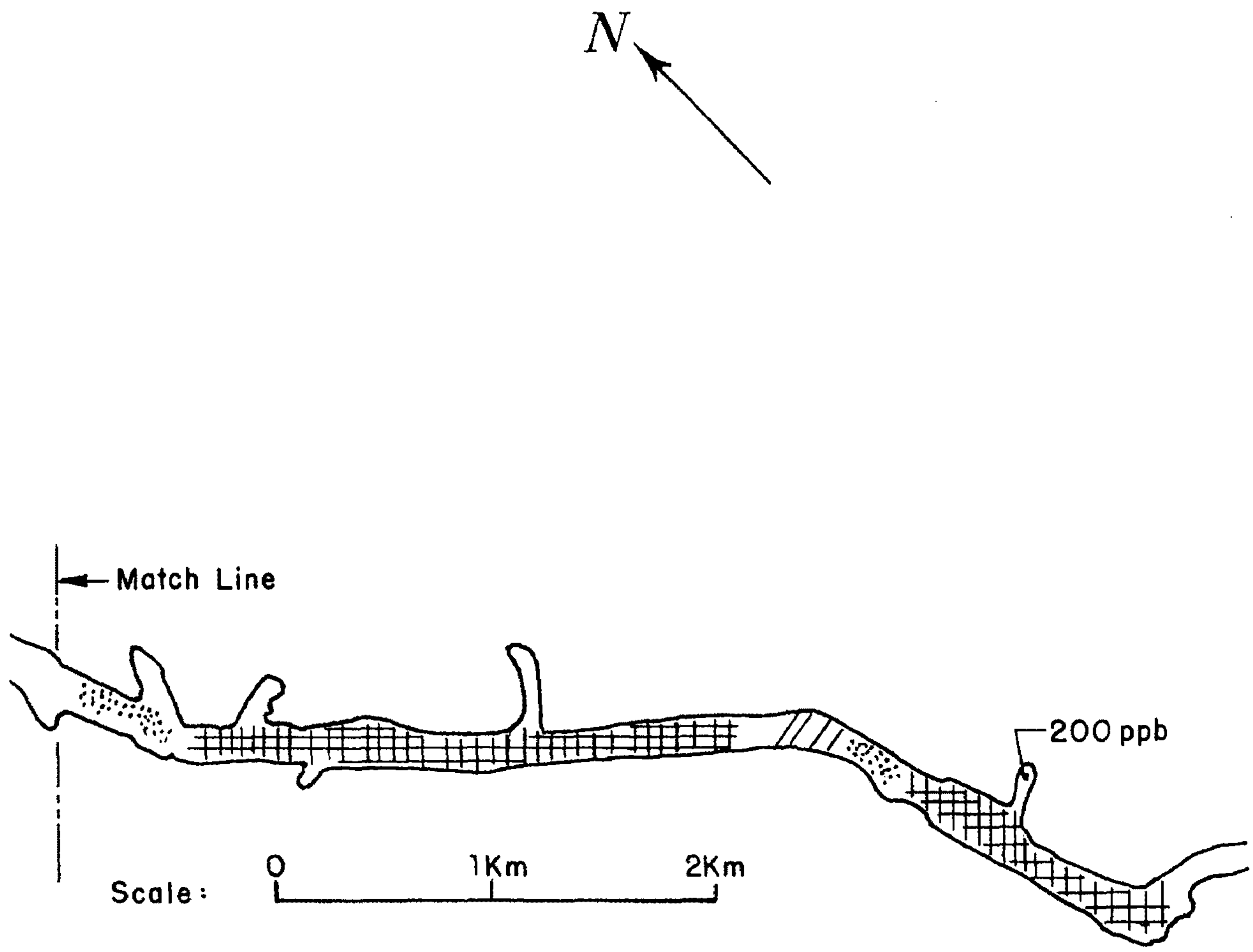


Figure A-1. Selected Sediment Sampling Stations, Seattle Harbor


1297 ppb
3600 ppb
400 ppb
1800 ppb



100-1000 ppb

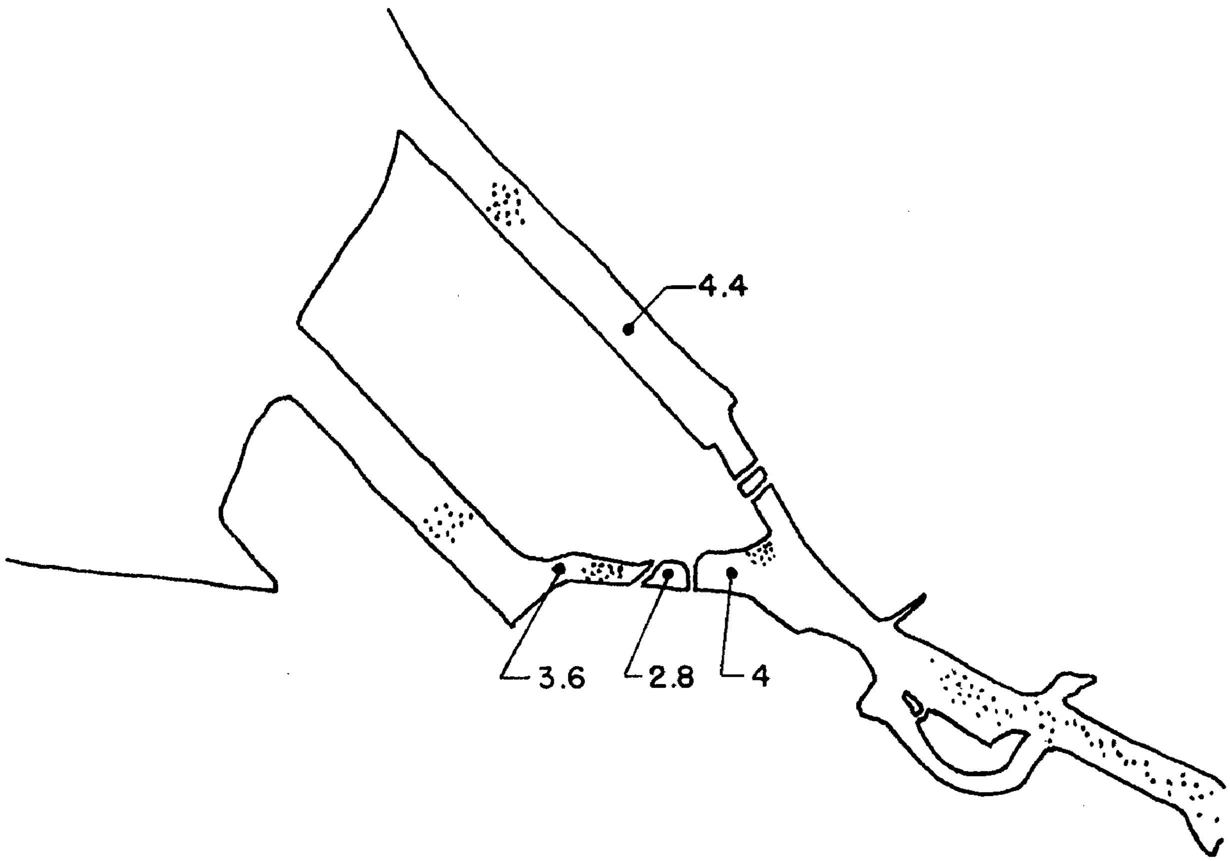
1000-2000 ppb

2000-6000 ppb

September 13, 1974 Spill: Sediment concentrations in part-per-thousand range (>1,000,000 ppb)

Blank Area: insufficient or inconsistent data

Figure A-2. Reported PCB concentrations (ppb dry weight) in Seattle Harbor


4.4
3.6
2.8
4

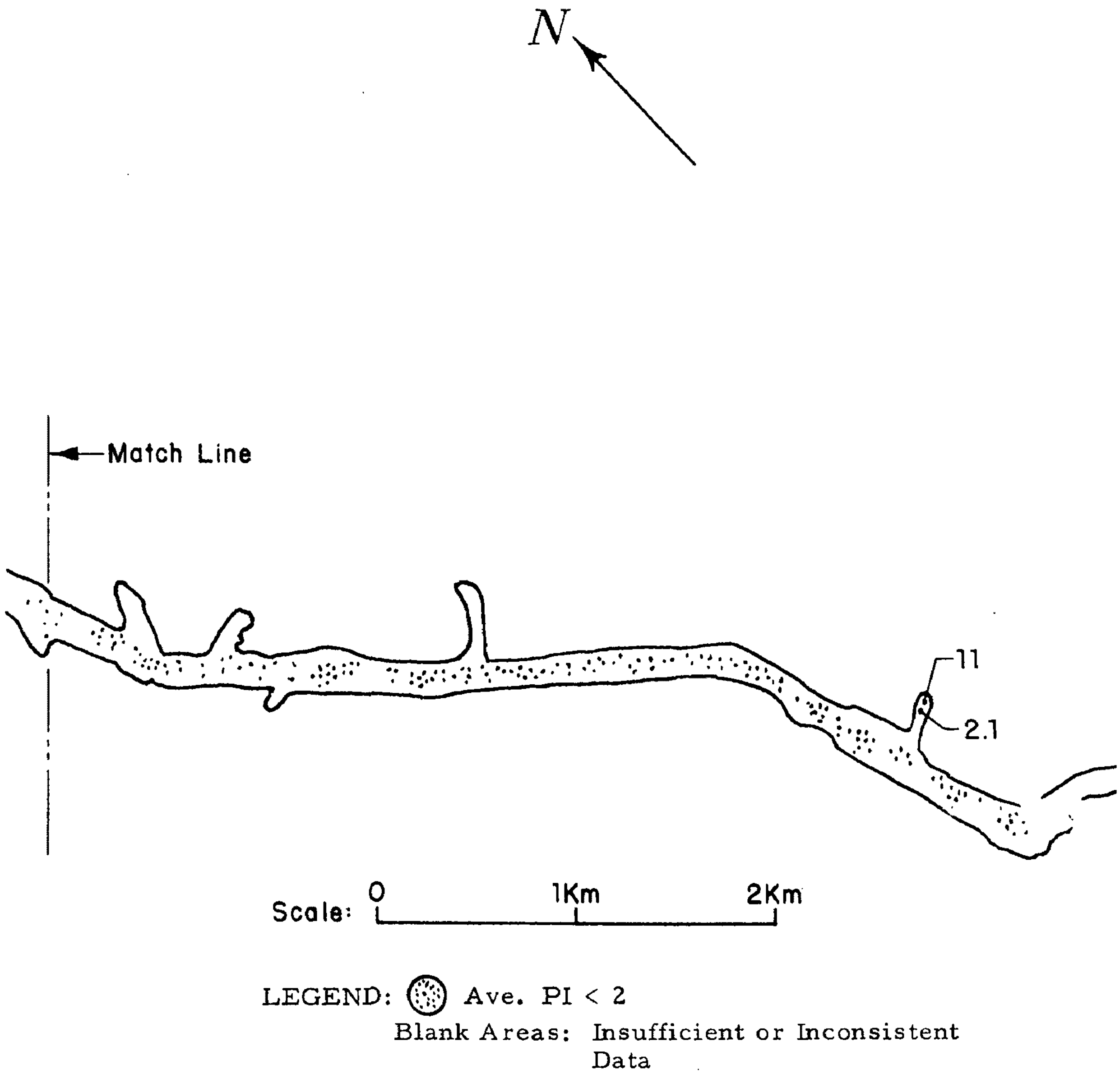


Figure A-3. Average Pollution Indices in Seattle Harbor.

planned in the waterway will probably remove the most polluted materials. All disposal of these materials has been and will be in diked areas. In the waterway at this site, mercury pollution in the sediments persists to a great depth. A value of 68 mg/kg was recorded at the sediment surface, and a depth of 5.8 meters into the sediment in the same core, 20 mg/kg mercury was found[4]. Hence, it is quite likely that portions of this hot spot will remain after the Terminal 128 project has been completed.

Sources of Pollutants

Several municipal and industrial outfalls, as well as spills and storm-water runoff from industrial areas, have contributed materials to the Duwamish sediments. There is also a sanitary landfill/garbage dump upstream of the navigable waterway with over 800 meters of shore frontage. There appears to be no single source of pollutants whose continuance or abatement will affect plans for removing polluted sediment.

Harbor Dredging and Construction

The upper reaches of the Duwamish Waterway, approximately from mile 4.5 to the head of navigation, were scheduled for maintenance dredging by the Corps of Engineers for January, 1975. Open water disposal of the sediments which will be dredged has been approved by EPA. An amount of material approximately equal to that scheduled for removal will be left in place for the time being, until an appropriate disposal site is found; this material violates EPA criteria for open water disposal.

The Port of Seattle and the Corps of Engineers are jointly planning a major project to widen and deepen the Duwamish Waterway. Construction is expected to begin in 1978. Approximately 1.3 billion cubic meters are expected to be dredged. This project, if completed, would probably remove all sediments contaminated with PCB, as well as those less severely polluted with other materials. Close coordination between the EPA, the Port of Seattle, and the Corps of Engineers can assure proper removal and disposal of these in-place pollutants.

Disposal Alternatives

Early awareness of the ecological risks of dumping polluted sediments in Puget Sound, together with a local need for fill material, have combined to present several land and shore disposal options for dredged material. These sites have been enumerated in a report by Green Engineering Associates to the Army Corps of Engineers[8]. Most of these locations are adjacent to the Waterway, so there appear to be few physical or economic constraints to environmentally safe disposal of dredged material. Care must be taken, however, to assure that the return flows from dewatering sites do not re-introduce pollutants to the waterway. Site selection from among the options available is also critical. For example, there is some interest in increased landfill at Kellogg Island, but this choice may conflict with the value of this island as a habitat for waterfowl[1].

Baltimore Harbor, Maryland

Background

Baltimore is one of the most important harbors and industrial centers in the Northeastern corridor between Boston and Washington. One factor contributing to its importance as a port is the land transportation network serving the city. Excellent rail service to the Midwest brings much cargo to and from the port facilities of Baltimore.

Baltimore Harbor branches off Chesapeake Bay and, since the harbor is heavily industrialized, much of the water-based recreation in the area is in the Bay rather than the Harbor. A long history of water pollution, especially in the Inner Harbor areas, has resulted in absence of most of the desirable aquatic species normally found in the Chesapeake Bay area[9].

Sediment Chemistry

Analyses of sediment quality in Baltimore Harbor have been received from many sources. Most of these sources were not original, however, and relied on the data compiled in a comprehensive survey by the Environmental Protection Agency's Annapolis Field Office[10]. This survey included far more sampling stations than any other data set examined in this study for any other location in the country. Unfortunately, however, the data collected for Baltimore Harbor do not include arsenic, cyanide, pesticides, or PCB. Arsenic and cyanide are known to have been discharged in large quantities by industries bordering the harbor[11].

Table A-2 presents selected data from the EPA report. Smaller amounts of data were also received from the Maryland Port Administration and Maryland Department of Natural Resources. The location of each sampling station listed in Table A-2 is shown on Figure A-4. Many more sampling stations than listed were used in the EPA survey; the data from all of these was used in preparing Figure A-5, which shows average pollution indices throughout Baltimore Harbor. The sampling sites not explicitly listed in Table A-2 are generally the less polluted locations.

The data presentation shows that in-place pollutants are widespread in Baltimore Harbor. The worst conditions are generally on the northern shore of the harbor. The entrances to the Northwest Branch, Colgate Creek, and Bear Creek are heavily polluted with heavy metals. Old Road Bay and the inner reaches of the above three tributaries are also problem areas.

Sources of Pollutants

Most of the shoreline of Baltimore Harbor, excepting some areas of the south shore and parts of some of the tributaries, is devoted to industrial and commercial land use. All of the hot spots are adjacent to heavily industrialized areas.

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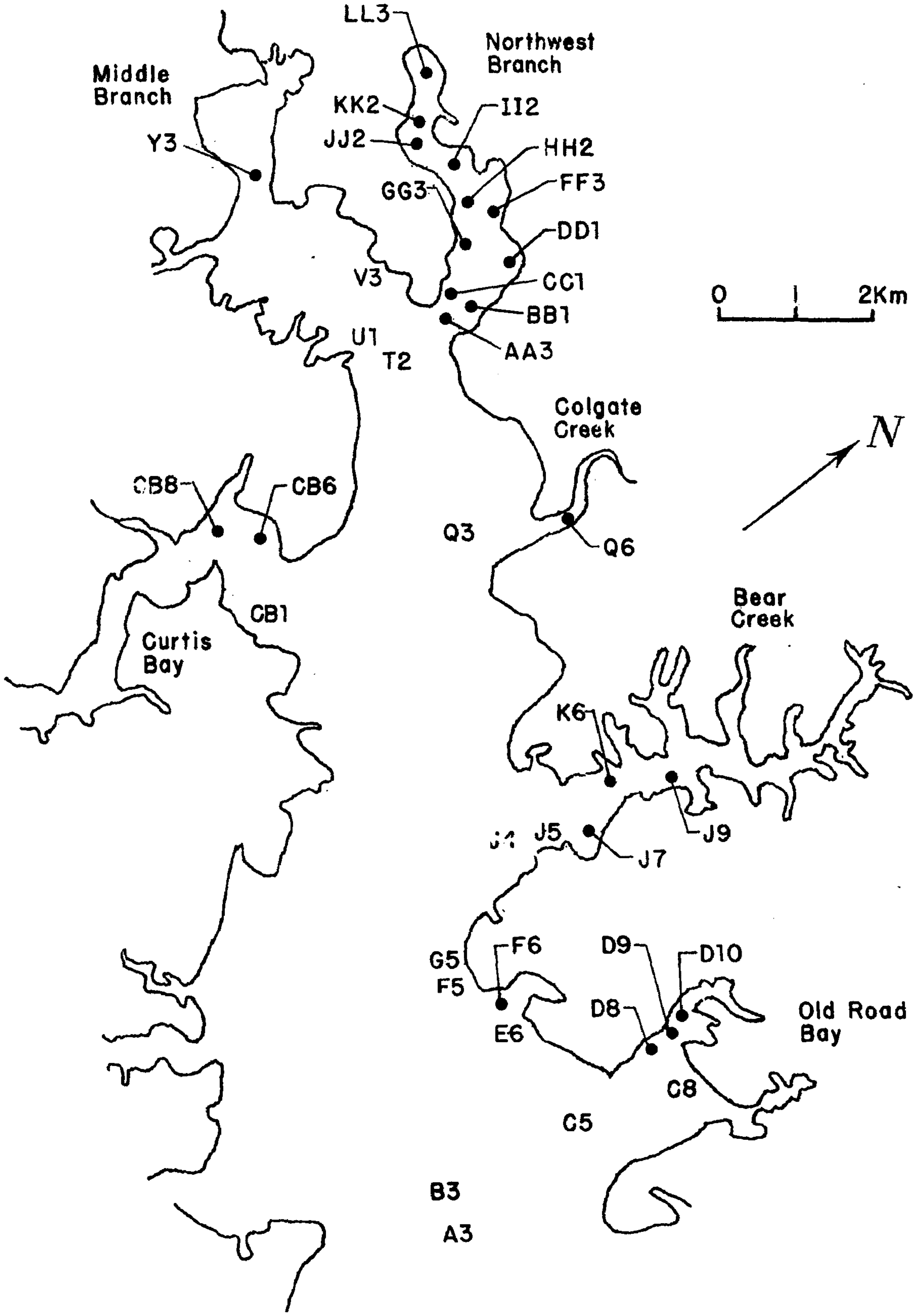


Figure A-4. Selected Sediment Sampling Stations, Baltimore Harbor, Maryland

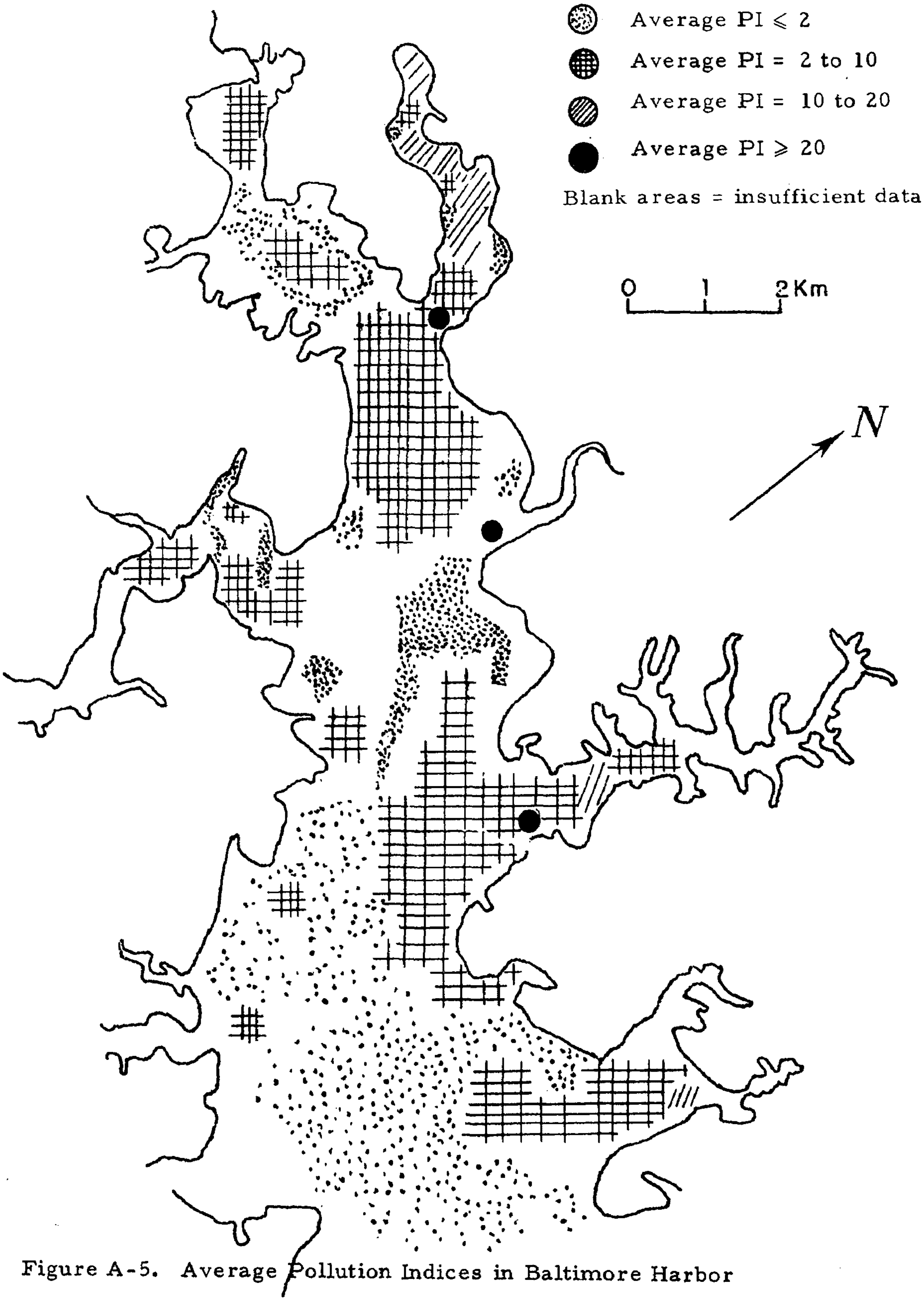


Figure A-5. Average Pollution Indices in Baltimore Harbor

Water sampling at and near industrial outfalls has revealed the sources of many toxic pollutants[11]. A study conducted for the Maryland Environmental Service found several instances of inadequate safeguards against spills of hazardous and toxic materials. That study mentioned known spills of such materials as creosote, paint, dyestuffs, plating solutions, and pickle liquors[12].

Harbor Dredging and Construction

The Corps of Engineers is responsible for maintenance dredging the main channels of Baltimore Harbor. Lack of an approved disposal site has prevented dredging since 1971. The normal maintence dredging requirement is approximately 380, 000 cubic meters per year.

Recent expansion of container berth facilities and channels at the Dundalk Marine Terminal by the Maryland Port Administration may have affected the hot spot at the mouth of Colgate Creek. Other proposed harbor work includes deepening of channels to 15. 2 meters (50 ft), new berths at the South Locust Marine Terminal, and development of port facilities at Hawkins Point[13]. Of these projects, only Locust Point is near a severe hot spot, at the entrance to the Northwest Branch. Construction of the proposed Fort McHenry Crossing of Interstate Route 95, a harbor tunnel, would also have an impact on this area[9].

Disposal Alternatives

Open water disposal of polluted dredge materials in the past has been conducted in the Poole's Island Deep, approximately 16 km (10 mi) northeast of North Point, which is at the entrance to Baltimore Harbor. The many proposed harbor dredging and construction projects have resulted in several studies of alternatives to open water disposal. The most ambitious of these proposals is the Hart and Miller Island Project, which would involve creation of an artificial island from a diked spoil disposal area. After filling with 76, 000, 000 cubic meters (approximately 100, 000, 000 cubic yards) of dredged materials and dewatering, the island would be used for recreational purposes[8]. In addition, many inland and shoreline disposal sites have been identified as reasonable alternatives by agencies proposing to dredge[8,9,11].

Detroit River, Detroit, Michigan

Background

All shipping from Lake Erie to Lake Huron and the western Great Lakes ports passes through the Detroit River. Many heavy industries line the river, and pollution from these sources and municipal wastewater treatment plants has minimized the river's value for recreation and as an amenity. At the southern end of the river, where it discharges to Lake Erie, there are some beaches whose use has also been lessened by pollution. Public access to waterways in the area is poor, except for those with boats[14].

In Detroit, the Rouge River empties into the Detroit River. Near the northeastern section of Detroit, the Detroit River begins at the outlet from Lake St. Clair. Both of these nearby tributaries have been identified as hot spots, although the data did not place them in the 23 locations selected by initial screening. Because of their proximity to the Detroit River's areas of concern, these locations should be considered for further sampling together with the Detroit River.

Sediment Chemistry

As a result of the discovery of high mercury levels in food fish of the Great Lakes in 1970, an intensive study was conducted by the (then) Federal Water Quality Administration[15] to determine the degree of mercury pollution in the sediments, water, and biota of selected areas in the Great Lakes. That study developed much information on the distribution of mercury, and showed extremely high values in sediments of the Detroit River, Trenton Channel/Wyandotte area, near the Michigan shoreline. Table A-3 and Figure A-6 present detailed data on concentrations and locations. In addition to these data, it should be

Table A- 3

Selected Sediment Analyses (mg/kg dry weight) for the Detroit River

Station No.	Hg	Cd	Ni	Pb	Cr	Cu	Zn
Reference 15; Sampling March through May, 1970:							
19747	1.4	< 30	20	59	30	36	150
19748	2.9	< 30	100	160	190	140	600
19755	< 1.0	< 30	230	900	540	290	1300
19756	4.4	< 30	170	160	170	130	440
19757	6.0	< 30	80	110	99	79	430
19758	< 1.0	< 30	30	54	26	41	110
19759	< 1.0	< 30	10	22	9	9	35
River Mile 13.4	21						
13.2	16						
13.1	86						
13.0	16						
12.9	27						
12.8	20						
12.6	14						
12.4	8						
12.0	14						
6.7	26						
3.9	11						
Reference 16; Sampling April and July, 1973:							
River Mile 12.2		1.1	13	17	12	13	53
8.9		5.3	89	100	120	76	430
4.4		1.1	11	11	11	11	35

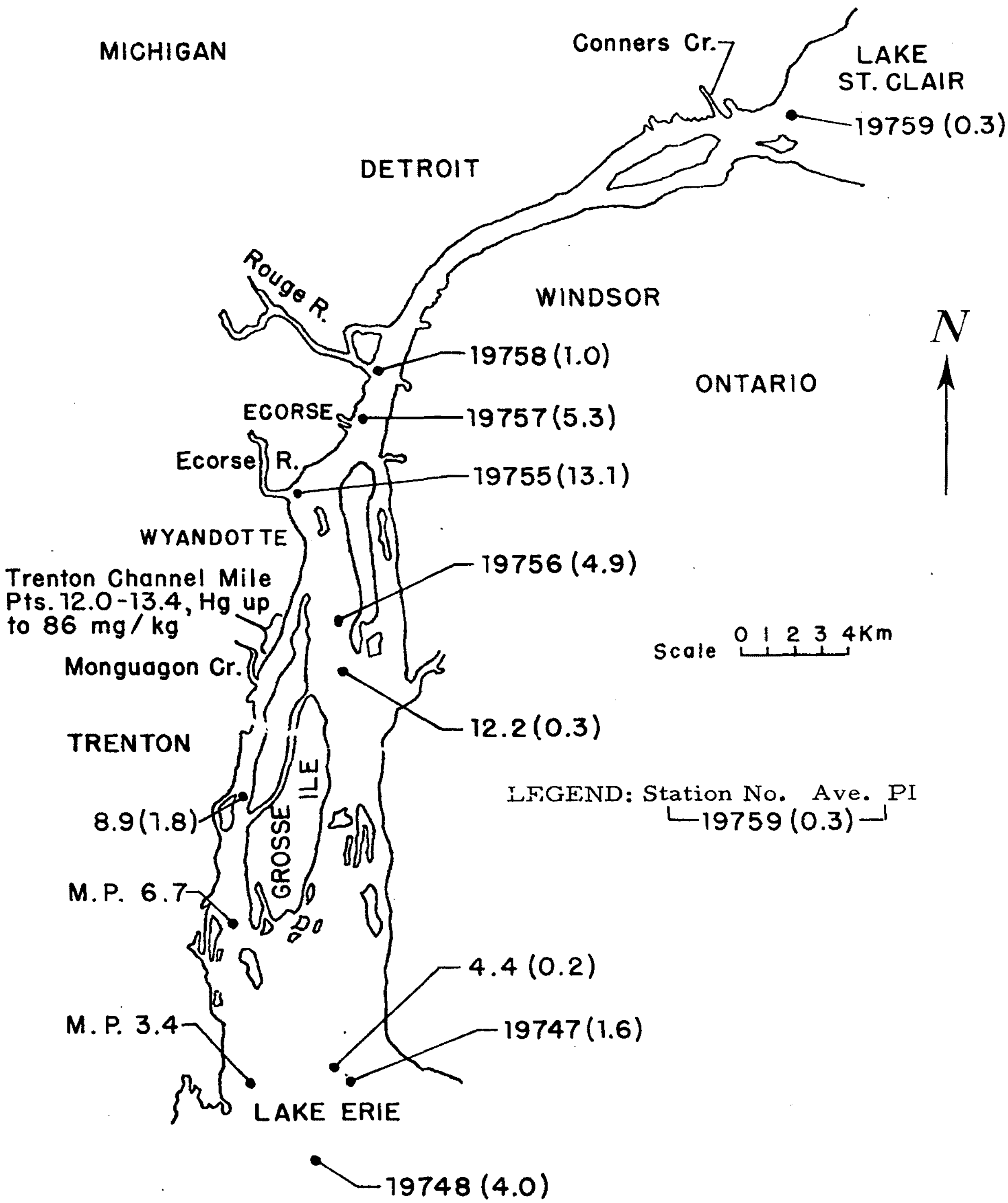


Figure A-6. Selected Sediment Sampling Stations With Some Average Pollution Indices and Mercury Concentrations, Detroit River pointed out that mercury concentrations of 9.2 mg/kg have been detected in the Lake St. Clair shipping channel[15]. In the Rouge River, sediment samples have been collected with 2700 mg/kg of zinc, 690 mg/kg of lead, 28 mg/kg of cadmium, and 73,000 mg/kg of oil and grease[16].

Sources of Pollutants

Major outfalls to the Detroit and Rouge Rivers include nine municipal wastewater treatment plants and over forty industrial outfalls. The industries which have discharged mercury have significantly reduced their discharges; most are mercury cell operations which produce caustic soda and chlorine. Other major industrial dischargers (not necessarily of mercury) include several steel mills, chemical companies, and brass mills.

A program to reduce stormwater overflows from the Detroit municipal sewerage system has significantly reduced pollution from this source. High flows are allowed to back up and be stored within the system, later to be routed through treatment facilities.

Harbor Dredging and Construction

Most maintenance dredging in the Detroit River is performed in the East Outer Channel and Lower Livingstone Channel. These channels are in the area of the Detroit River entrance to Lake Erie, where water velocity decreases and sedimentation is to be expected. The average total annual dredging amounts to about 600,000 cubic meters in the Detroit River and 200,000 cubic meters in the Rouge River.

Disposal Alternatives

A 2.8 million square meter (700 acre) diked area is planned in shallow water at Pointe Mouillee, on the western shore of Lake Erie near the mouth of the Detroit River. This area would be expected to contain the dredgings of ten years' operation in the Detroit and Rouge Rivers, or 13.76 million cubic meters (18,000,000 cubic yards) (including permit dredging by private contractors)[14].

Another diked area, at Dickinson Island in Lake St. Clair, is planned for the materials dredged from the Lake St. Clair shipping channel. These areas were selected by the Corps of Engineers after study of several alternatives, including land disposal in Ontario. Use as mine fill and for fill to create land in other, smaller diked areas has also been mentioned[8].

San Francisco Harbor, California

Background

The San Francisco Bay has long been the center of commercial activity, and especially of waterborne commerce, for Northern California. The City of San Francisco, although a terminal for only about 10% of the tonnage which passes through the Golden Gate at the entrance to the Bay, has the largest population in the Bay Area and is the home of many of the service industries and cultural resources in the region. San Francisco is bounded by water on three sides, and its shoreline and waterfront areas attract both residents and tourists. The The ocean beach on the west, the recreational boating facilities and restaurants on the north, and the commercial port facilities on the east side of the city all have attractions for visitors. Plans are being made to enhance the port facilities with small public areas for resting and viewing the activity of the waterfront: docking, loading, and unloading the ships that call at San Francisco.

The San Francisco District of the Corps of Engineers is conducting a three-year study of the environmental aspects of dredging and disposal considered important to its activities in serving navigation. The draft report of this work should be available in the second half of 1975. The results of this comprehensive study should provide a wealth of information to help guide future decisions regarding the implementation of Section 115 in the Bay Area. In considering the San Francisco Harbor as a priority area, future study should include Oakland and Richmond, other Bay Area harbors among the 23 selected by initial screening. The proximity of these locations presents the opportunity to investigate all three for slightly more effort and cost than is required to consider only one.

Sediment Chemistry

A great deal of data on sediment chemistry has been collected from the Port of San Francisco and from the San Francisco District, Corps of Engineers. The majority of these data indicates that sediments near the port facilities are relatively free of pollution. Absence of hot spots is to be expected because the strong currents near the piers (over 3 knots) tend to resuspend and redistribute sediments. The analyses which cause San Francisco Harbor to be included in the final priority list are in the area of Islais Creek, a harbor channel which cuts into the city and is relatively stagnant. Data are presented in Table A-4 and Figure A-7. Further sampling is especially important at Islais Creek. The proximity of sample sites for which analyses differ markedly indicates either a very small and intense hot spot, differences caused by sampling before and after dredging, or analytic error. The existing data show that one result for cadmium of 500 mg/kg in Islais Creek channel qualifies San Francisco for Priority 1 classification.

Sources of Pollutants

Several industries discharge wastewater to Islais Creek. The Southeast Water Pollution Control Plant formerly discharged in this area, but a deepwater outfall into the Bay has been built. Effluent from storm sewers has been identified as a problem, and diversion to a deepwater outfall is planned for this water.

EPA Region IX and the San Francisco District of the Corps of Engineers have indicated that little is known regarding the sources and transport mechanisms of pollutants found in sediments in the Bay Area, and that this knowledge would be very helpful to their water quality and dredging programs.

Table A-4

Selected Sediment Analyses (mg/kg dry weight) in San Francisco Harbor

Station No.	Hg	As	Cd	Pb	Cu	Cr	Zn	PCB	Oil & Grease
Reference 17; Sampling date unknown, report dated March 1972:									
1-72	0.13	6.7		8	23	93	60	.	700
2-72	0.6	0.15						0.09	
3-72	0.5	0.22			700		200	0.28	
4-72	0.5			46	37	100	127	0.3	7700
Reference 18; Sampling January, 1974:									
45S				2.5	30		130		160
27S				5.0	38		145		360
32				15	40		160		300
80N				7.5	60		443		380
Reference 19; Sampling March, 1972:									
Fisherman's Wharf	0.74		0.44	12.9	64.7		85.3		460
28N	0.9		0.46	7.1	45		98.6		350
48N	0.51		0.37	7.1	103		95.4		780
50 Approach	1.84		0.41	52	37		129		1970
80	7.8		0.41	10	63		93.4		290
Islais Creek Channel	0.51		500	100	400				
Reference 20; Sampling June, 1971:									
1-71	0.9			21					1000
2-71	1.44			20					
3-71	0.89			26					700
4-71	0.73			27					

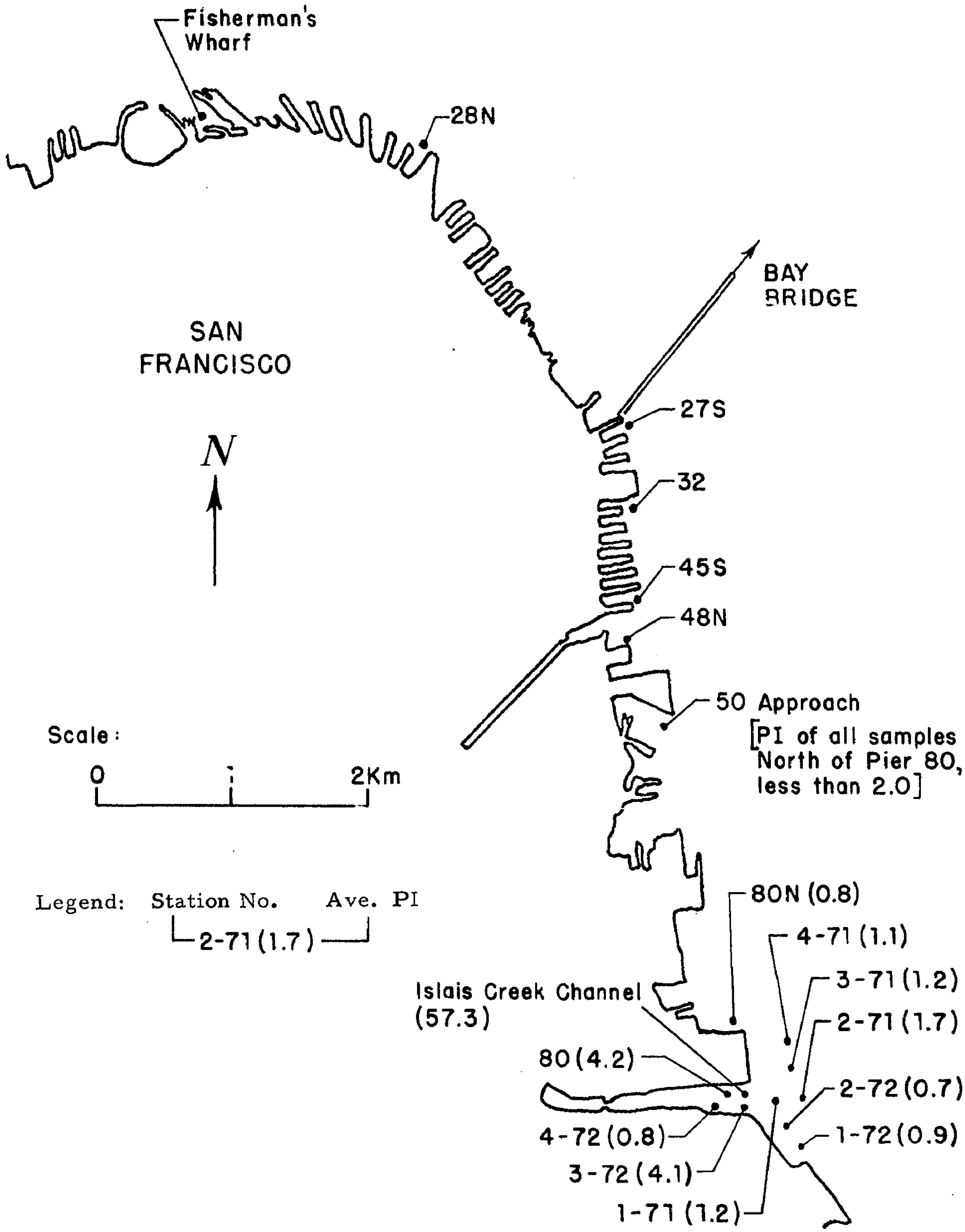


Figure A-7. Selected Sediment Sampling Stations with Average Pollution Indices, San Francisco.

Harbor Dredging and Construction

New dredging work is proposed at the entrance of Islais Creek Channel to make navigation safer, especially for large vessels. This new work would amount to an estimated 330,000 cubic meters of material. Future average annual maintenance dredging in this area is estimated at 15,000 cubic meters[20].

Major expansions of port facilities are planned, or underway, in a 314-acre area between Piers 80 and 98[21]; this program includes the Islais Creek Channel, which is adjacent to Pier 80.

Disposal Alternatives

Much of San Francisco Bay has been filled in the past, reducing its area from 680 to 400 square miles. Further landfill proposals usually encounter strong local resistance. Not unexpectedly, then, most disposal of dredged material from the San Francisco area is in open water. If the material is classed as "not polluted" by EPA criteria, disposal is allowed at one of five sites in the Bay. If "polluted with organic matter," material is allowed for dumping only at a site near Alcatraz. If "polluted with heavy metals," the material is usually dumped in 100 fathoms of water, approximately 30 miles at sea[22].

Several proposals and feasibility studies have identified potential sites for shoreline fill and upland disposal[8, 23]. Those closest to Islais Creek are proposed fill areas for new marine terminals.

Indiana Harbor, East Chicago, Indiana

Background

Indiana Harbor and the Indiana Harbor Canal serve the industrial complex of northwestern Indiana. The principal cities in the immediate area are Gary, Hammond, Whiting, and East Chicago, in which Indiana Harbor is located.

Downtown Chicago is 35 km (22 miles) to the northwest of Indiana Harbor. The shoreline of Lake Michigan between Chicago and the Indiana border is mostly parkland, with some heavy industry at Calumet Harbor. The Indiana shoreline from the Illinois border to the west limit of Marquette Park in Gary, including Indiana Harbor, is heavily industrialized, with many facilities sited on landfills. Indiana Harbor has been shaped by two of these industrial landfills which extend into Lake Michigan. Youngstown Sheet and Tube Company, on the western shore, is sited on 750 acres of fill; Inland Steel Company, on the east, occupies a somewhat larger filled area.

Indiana Harbor and Canal are lined with heavy industries. Petroleum products and steel are the goods produced by most of the industries. More than 70% of East Chicago's area is committed to industry.

Sediment Chemistry

Only one data set has been located for the Indiana Harbor Canal. This information, presented in Table A-5 and Figure A-8, was developed in 1967.

Table A-5

Selected Sediment Analyses (mg/kg dry weight) in Indiana Harbor

Station No.	Cd	Pb	Cu	Zn	Ni	Cr	CN	Oil & Grease
Reference 16; Sampling June 14, 1967								
1	498	934	144	624	506	121	0.56	128,800
2		1058	175	7790	217	72	0.71	170,200
3		250	27	1258	40	40	0.72	55,400
4		360	49	2560	153	61	N.F.	37,100
5	314	1000	92	1930	321		0.40	114,000
6	227	307	24	1440	242	11	0.34	40,100
7	863	997	100	5560	690	117	0.52	129,700
8	1240	1168	104	4520	1120	173	N.F.	111,300
9	4150	1279	53	2355	3100	135	N.F.	111,500
10	7490	1365	36	1980	6070	68	N.F.	80,200
11	1652	741	40	10580	1890	48	N.F.	37,600

N.F. = Not Found

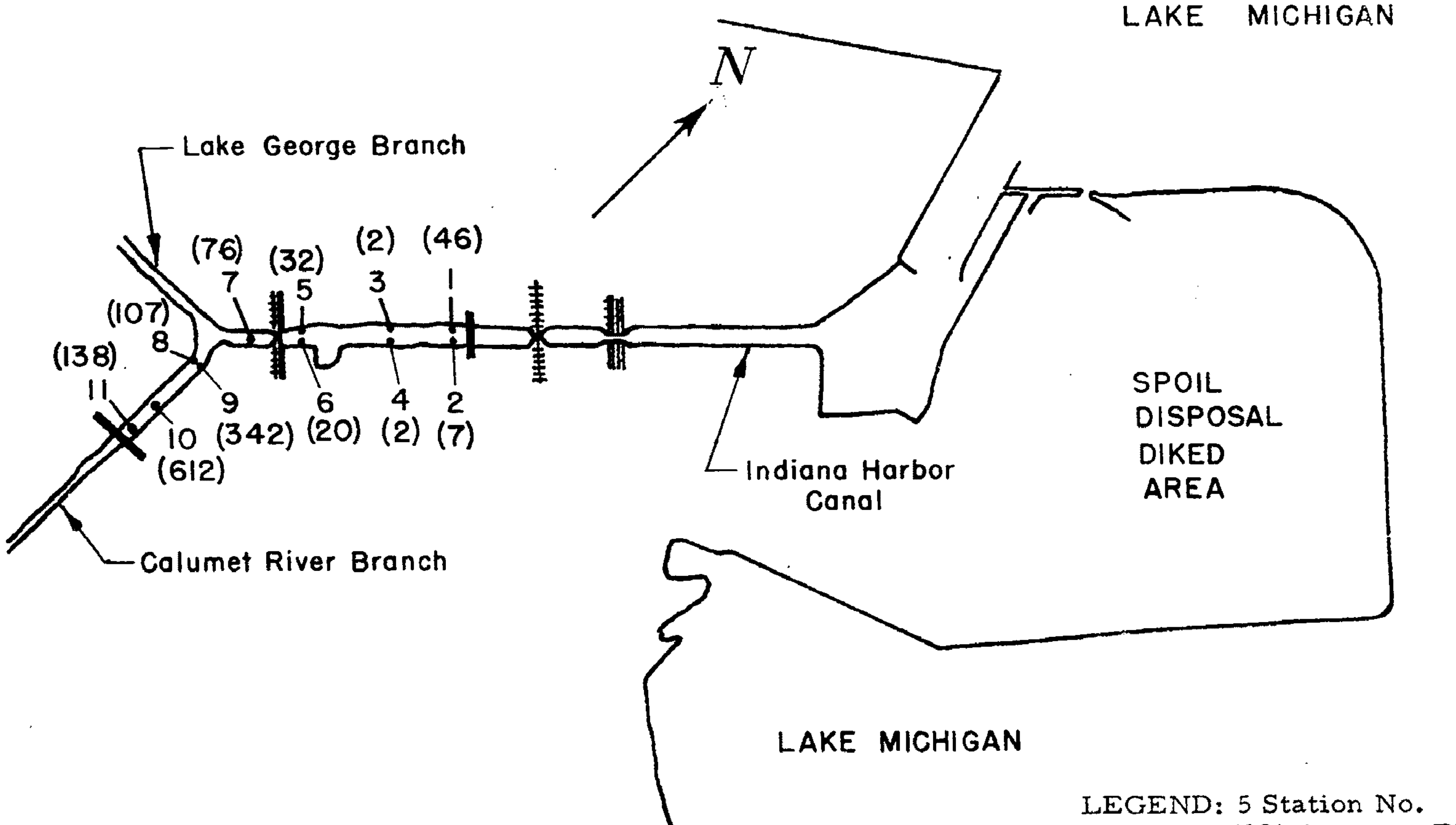


Figure A-8. Sediment Sampling Stations With Average Pollution Indices, Indiana Harbor

The data indicate the extremely high concentrations of heavy metals, expecially in the Calumet River Branch of the canal. More up-to-date data are needed, as well as sampling over a wider area.

Sources of Pollutants

Industrial waste discharges and stormwater runoff from the industrial land in the area have degraded water and sediment quality in Indiana Harbor. This location is unique in that it is the only one reported to receive enough solids from industrial sources so that they are a cause of shoaling, requiring dredging[24]. These discharges are reported to have been reduced significantly in recent years.

Harbor Dredging and Construction

Annual maintenance dredging has averaged approximately 76,500 cubic meters (100,000 cubic yards). The primary construction activity in the waterfront area is continued filling for new industrial land.

Disposal Alternatives

Inland Steel Company is developing a 3.16 million m^2 (780 acre) diked area, for slag disposal and land development. An agreement between the Corps of Engineers and Inland permits disposal of 764,500 m^3 (1,000,000 cubic yards) of dredged material. This represents approximately ten years' dredging in Indiana Harbor and the Harbor Canal. No other disposal method available appears so economically and environmentally desirable, according to conclusions reached by the Chicago District, Corps of Engineers[24].

Michigan City Harbor, Indiana

Background

East of the Gary-East Chicago area on the Indiana shore of Lake Michigan, the principal population and industrial centers are at Burns Harbor and Michigan City. Burns Harbor is approximately 29 km

(18 miles) east of Indiana Harbor, and Michigan City is approximately 22 km (14 miles) further east, 7.4 km (4.6 miles) from the Michigan state line. Between the Burns Harbor industrial complex and the Michigan border, the Lake Michigan shore consists primarily of dunes and beaches. A landfill west of Michigan City and the breakwaters around the harbor are the only interruptions to the natural shoreline in this area.

Trail Creek enters Lake Michigan at Michigan City, and the wide mouth of this stream forms Michigan City Harbor. Salmon runs on Trail Creek have been reported in recent years.

Very little information of use to this study was found for Michigan City. One reason for this paucity of information is the lack of commercial harbor activity; much of the information from other areas was developed by studies related to harbor dredging.

Sediment Chemistry

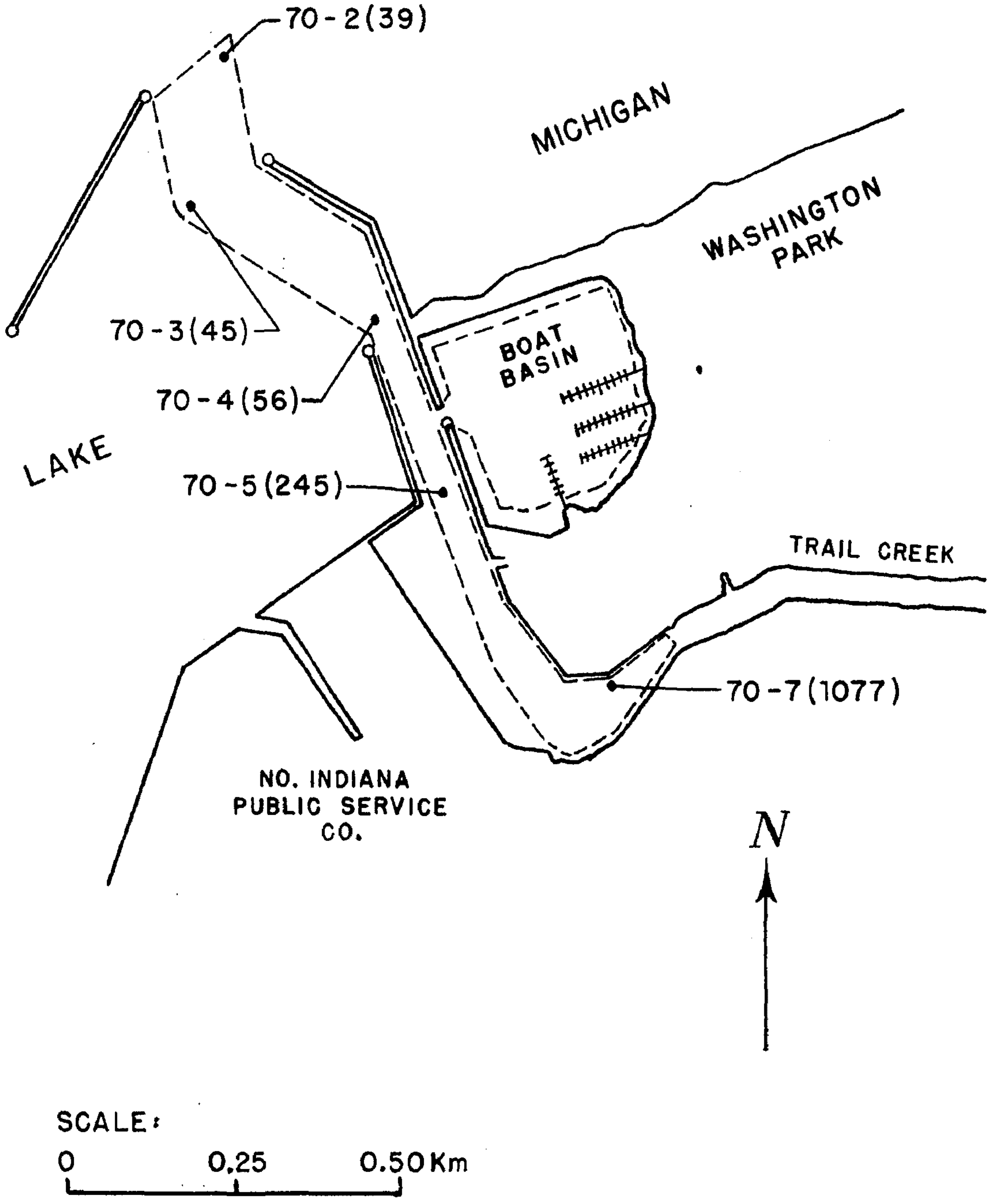
One data set from a sampling effort in 1970 was available. The data, presented in Table A-6 and Figure A-9, show the extreme concentrations of heavy metals, especially in the area of the sharp eastward bend into Trail Creek. Arsenic and zinc are the elements of most concern; the arsenic values appear to qualify Michigan City as perhaps the most intense hot spot in the nation.

Table A-6

Sediment Analyses (mg/kg dry weight) for Michigan City Harbor

Reference 16; Sampling 1970:

Station No.	Hg	As	Pb	Zn	Oil and Grease
70-2	0.06	350	13	16	391
70-3	0.02	400	21	20	172
70-4	0.06	500	11	17	217
70-5	0.20	2,200	33	925	1,354
70-7	1.8	9,660	244	10,897	16,870



LEGEND: Station No. Ave. PI
└70-2 (39)┘

Figure A-9. Sediment Sampling Locations with Average Pollution Indices, Michigan City

Sources of Pollutants

The sources of arsenic and zinc are not known. The Michigan City Sewage Treatment Plant discharges to Trail Creek approximately 2.4 kilometers upstream of the eastward bend into Trail Creek.

Harbor Dredging and Construction

Little commercial shipping takes place at Michigan City, and little effort is therefore expended for navigation improvements. The only commercial cargo recorded by the Corps of Engineers for 1973 was fish[25].

Disposal Alternatives

Polluted sediments could possibly be barged to the Inland Steel diked area at Indiana Harbor, approximately 48 km (30 miles) to the west, if the necessary agreements were made. Another possibility could be a confined fill area adjacent to Bethlehem Steel Company property at Burns Harbor, 22 km (14 miles) to the west.

Priority 2 Locations

Corpus Christi Inner Harbor, Texas

The South Texas coastal area of which Corpus Christi is the business center center has developed an important tourist industry based largely on sport fishing and conventions. The city's shoreline on Corpus Christi Bay, a short walk from the business district, features public beaches, a large marina, a convention center, and hotels. Another factor in Corpus Christi's economic growth has been the development of its harbor as a commercial transportation center for South Texas.

The Inner Harbor, a narrow extension of the Ship Channel with very little fresh water inflow, is the location of many docking and industrial facilities. Serious pollution appears confined to the Inner Harbor, but the close proximity of this area to the public shoreline area poses a threat to the value of that public shore.

Sediment analyses in this area have been received from the Texas Water Quality Board, the Galveston District of the Corps of Engineers, the U.S. Geological Survey, and Texas A&M University. These data indicate cadmium values up to 130 mg/kg and zinc values up to 11,000 mg/kg in the vicinity of kilometer 8 (mile 5) in the Tule Lake Channel. Table A-7 and Figures A-10 and A-11 give details of the data received.

Pilot tests have been made by the Corps of Engineers of a diked disposal area near the Inner Harbor, but the effluent from the area damaged oyster beds. Preliminary studies are beginning an attempt to locate upland sites for disposal of polluted dredge material.

Bridgeport Harbor, Connecticut

Bridgeport is an industrial city 32 km (20 miles) southwest of New Haven and 80 km (50 miles) northeast of New York City. The inner harbor area and Pequonnock River are committed to industrial and commercial facilities. Public beaches and parks are situated on both sides of the harbor entrance. These face seaward primarily, but extend into the harbor for a few hundred meters of shoreline as well.

The sediment chemistry data for Bridgeport and Black Rock Harbors, presented in Table A-8 and Figure A-12, show all harbor branches in Bridgeport to contain high concentrations of heavy metals. Conditions appear worst in the upper reaches of each branch. Lead, copper, zinc, and chromium are high in all branches: Pequonnock River, Yellow Mill Channel, Johnson's Creek, and Black Rock Harbor.

Industrial wastes are discharged from a steel mill, a brass mill, and several metal plating facilities. There are also several industries in Bridgeport which perform metal working and plating operations as intermediate steps in the production of assemblies such as guns and aircraft components. The wastewater from some of these sources is discharged directly to harbor tributaries and from others it passes through municipal treatment facilities.

Table A-7

Selected Sediment Analyses (mg/kg dry weight) in Corpus Christi

Station No.	Hg	Cd	Pb	As	Cu	Zn	Cr	Ni	Oil & Grease
Reference 26; Sampling January 1972 to July 1973:									
Mile 0.5	0.52	1.5	37	6.1	13	252	44	18	
1	2.9	9.0	123	5.0	28	967	102	18	
2	2.8	11.0	176	2.8	27	1300	100	8	
3	9.6	30.0	142	15.5	40	7750	101	11	
3.5	8.4	25.0	204	12.0	62	6930	158	8	
4	5.0	11.0	176	10.0	27	1320	100	9	
4.5	>35.0	29.0	670	19.3	283	7320	69	19	
5	38.5	88.0	534	>25.0	195	7700	109	17	
6	9.33	43.0	413	>25.0	149	6480	83	12	
7	3.32	35.0	196	11.5	45	4970	65	16	
8	0.45	4.7	42	3.2	12	800	19	12	
Reference 27; Sampling September 1972 and January 1973:									
km 0		2*				235*			
0.5		3				500			
1.8		6				1000			
2.7		10				1100			
4		17				2500			
4.8		25				3800			
8		130*				11,000*			
9.5		26				3800			
11		12				2500			
13		24				3300			
Reference 28; Sampling February 5, 1974:									
988+00 (500N)	2.4		89			73			880
1023+50 (0)	1.6		130			190			1100

*All data except those marked are not exact, having been read as points from a graph.

Table A-7 (Cont.)

Selected Sediment Analyses (mg/kg dry weight) in Corpus Christi

Station No.	Hg	Cd	Pb	As	Cu	Zn	Cr	Ni	Oil & Grease
Reference 29; Sampling February 21, 1974:									
Viola Turning Basin	0.3	10				1300			40
Avery Turning Basin	0.7	9.7				1200			20
Navigation Blvd. Drawbridge	3.6	46				4200			410

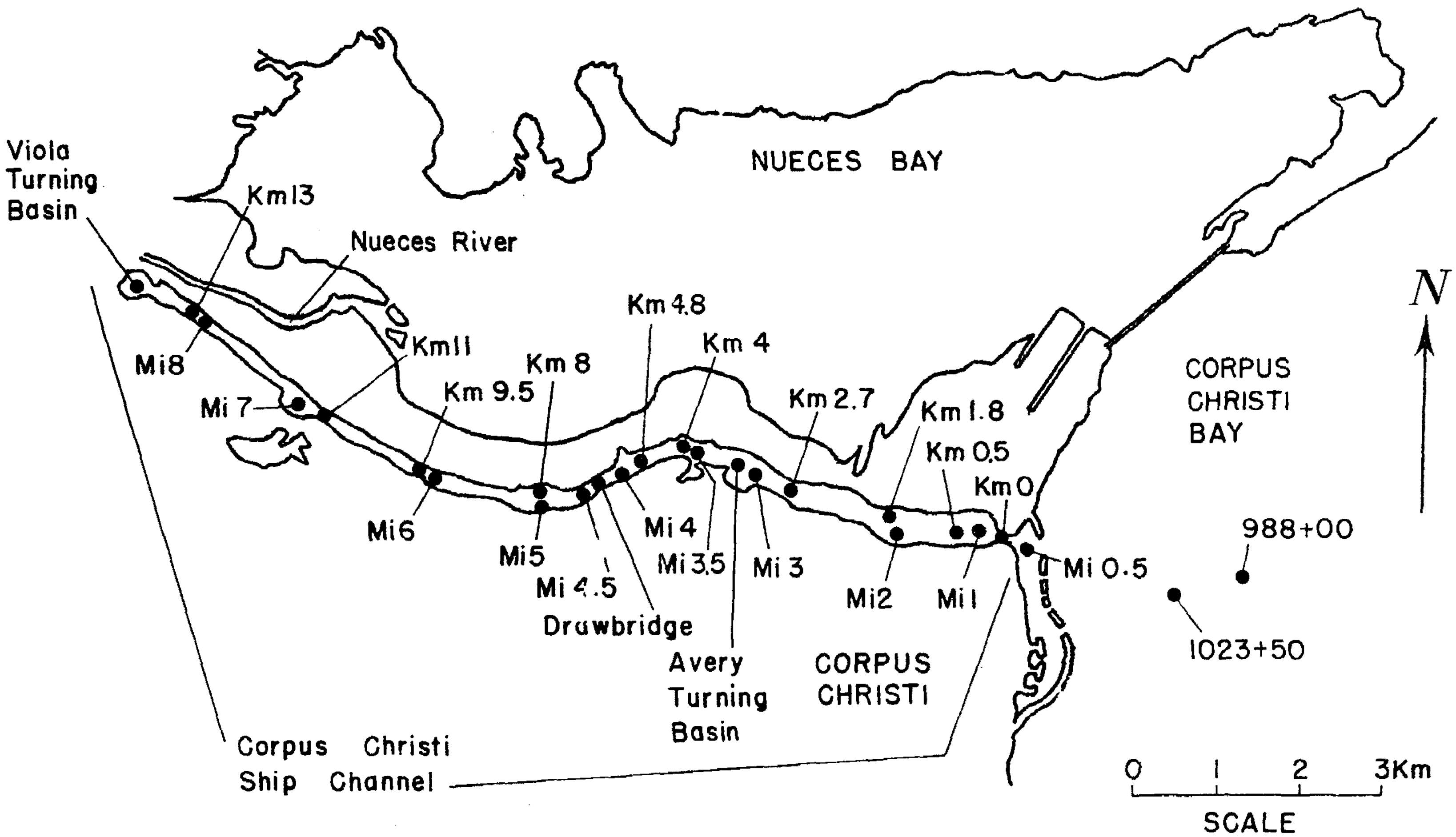


Figure A-10. Selected Sediment Sampling Stations, Corpus Christi

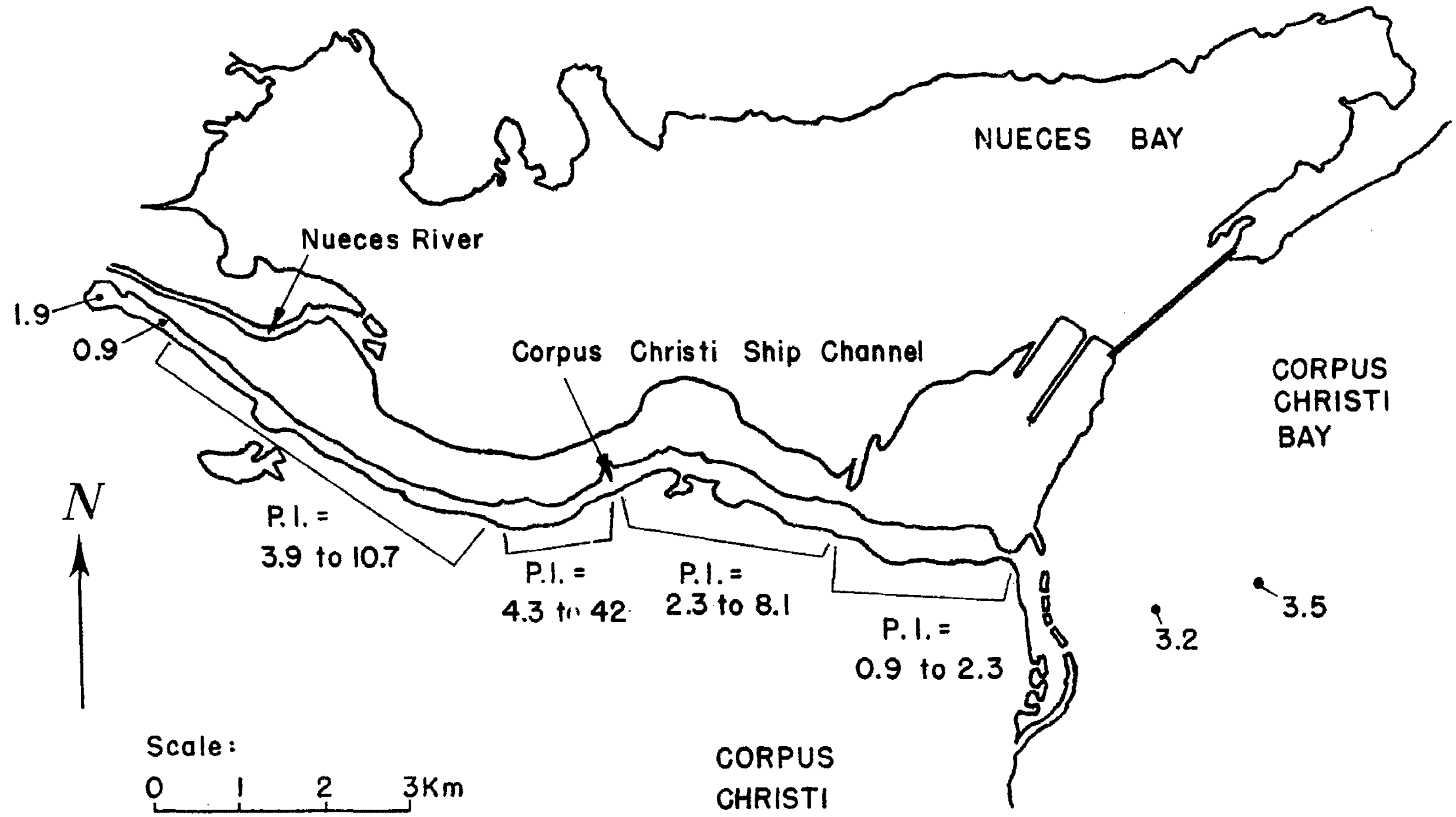


Figure A-11. Average Pollution Indices in Corpus Christi Harbor.

Table A-8

Selected Sediment Analyses (mg/kg dry weight), Bridgeport.

Station No.	Hg	Cd	Pb	As	Cu	Zn	Cr	Ni	DDT	PCB	Oil & Grease
Reference 30; Sampling June, 1973											
KE-9	0.58	3.7	119	31	326	549	280	96	0.05	0.08	3520
KE-10	0.79	4.2	116	9.6	383	316	330	116			3030
KE-11	0.85	3.8	118	11	412	410	353	92			4590
KE-12	0.26	2.4	45	6.1	1238	117	756	71			1160
KE-13	0.64	6.8	302	20	581	415	425	113			4620
KE-14	4.3	141	881	19	2287	2986	3162	415	1.16	2.01	43300
KE-15	0.82	9.2	265	32	768	622	494	165			7180
KE-16	2.1	77	297	20	1466	741	875	119			6060
KE-17	0.85	11	400	9	670	563	571	150			4290
PE-18	1.8	3.6	90	7	398	319	268	134			4060
PE-19	1.0	9.4	273	18	1192	1293	1020	127			6320
PE-20	1.3	12	230	11	2049	1067	2134	231			7680
PE-21	2.5	43	505	39	1860	1460	1772	266			12900
PE-1	11.0	39	1636	51	2115	1429	894	292			23400
PE-2	4.4	32	678	25	1915	943	1152	268	0.17	1.05	15800
PE-3	0.8	10	265	12	506	545	394	93			6110
PE-4	1.1	44	769	28	1161	2118	871	290			11700
PE-5	2.5	18	1000	15	9300	2016	3528	189			31200
GE-6	0.13	4.7	300	5.2	237	379	70	63			5970
GE-7	0.56	5.9	470	7.8	1544	611	618	81			24100
GE-8	0.01	1.8	65	8.8	145	155	31	39			810
Reference 31; Sampling August 27, 1974:											
1559		< 10			40	50	20	< 10			

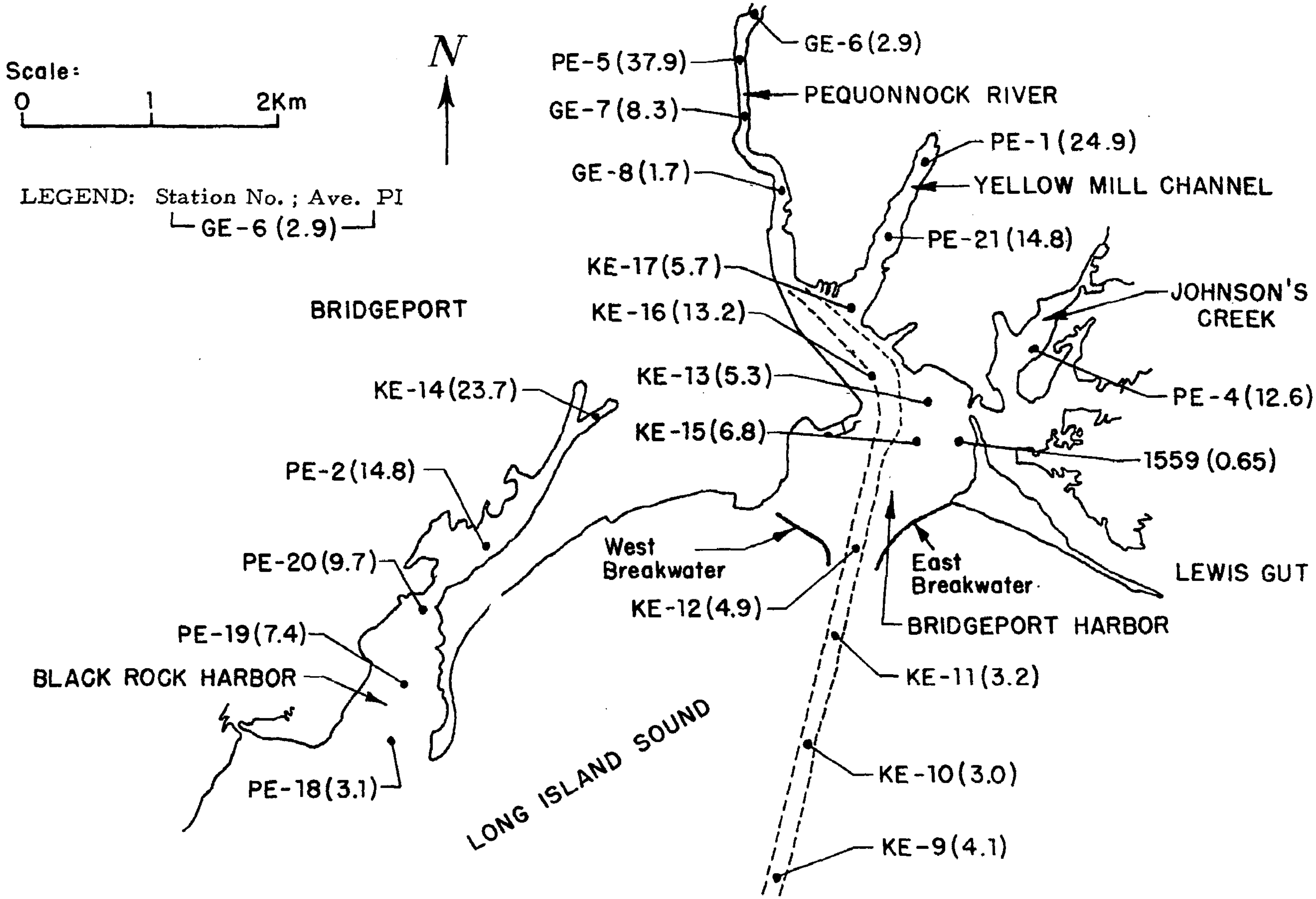


Figure A-12. Selected Sediment Sampling Stations with Average Pollution Indices, Bridgeport

The Eaton's Neck dump site in Long Island Sound has been designated by the Corps of Engineers Waterways Experiment Station as one of four areas in the nation where intensive studies of open-water dumping of dredged material should significantly advance knowledge of the effects of such dumping. This site is approximately 28 km southwest of Bridgeport Harbor, and the studied dumping of material from maintenance dredging projects or from Section 115 action may yield valuable information regarding the fate of pollutants.

New Bedford Harbor, Massachusetts

New Bedford's past and present are intimately tied to the sea. It was a major whaling port, and a whaling museum near the waterfront is a strong tourist attraction. Summer ferry service to Martha's Vineyard and Nantucket Islands brings many passengers through New Bedford Harbor. Commercial fishing fleets operating out of New Bedford are important to the local economy.

Heavy metals concentrations in New Bedford Harbor sediments have been found to be quite high in two sampling expeditions (Table A-9 and Figure A-13). Copper and brass production, and plating facilities are likely sources of many of the pollutants found. Some industries discharge directly to the Harbor and its tributaries, while others are connected to the municipal sewerage system. The outfall from this system is near station NB3, where high values of metals are in evidence. The municipal treatment facilities are in the process of being upgraded.

A small area on the east side of the Harbor, off Fairhaven, has been proposed for deepening. In searching for a disposal site, no feasible shore or upland areas were located by the New England Division of the Corps of Engineers. A study by the New England Aquarium Research Department[33], aimed at selection of the least harmful open water disposal site, selected a location 18 km southeast of New Bedford Harbor.

Table A-9

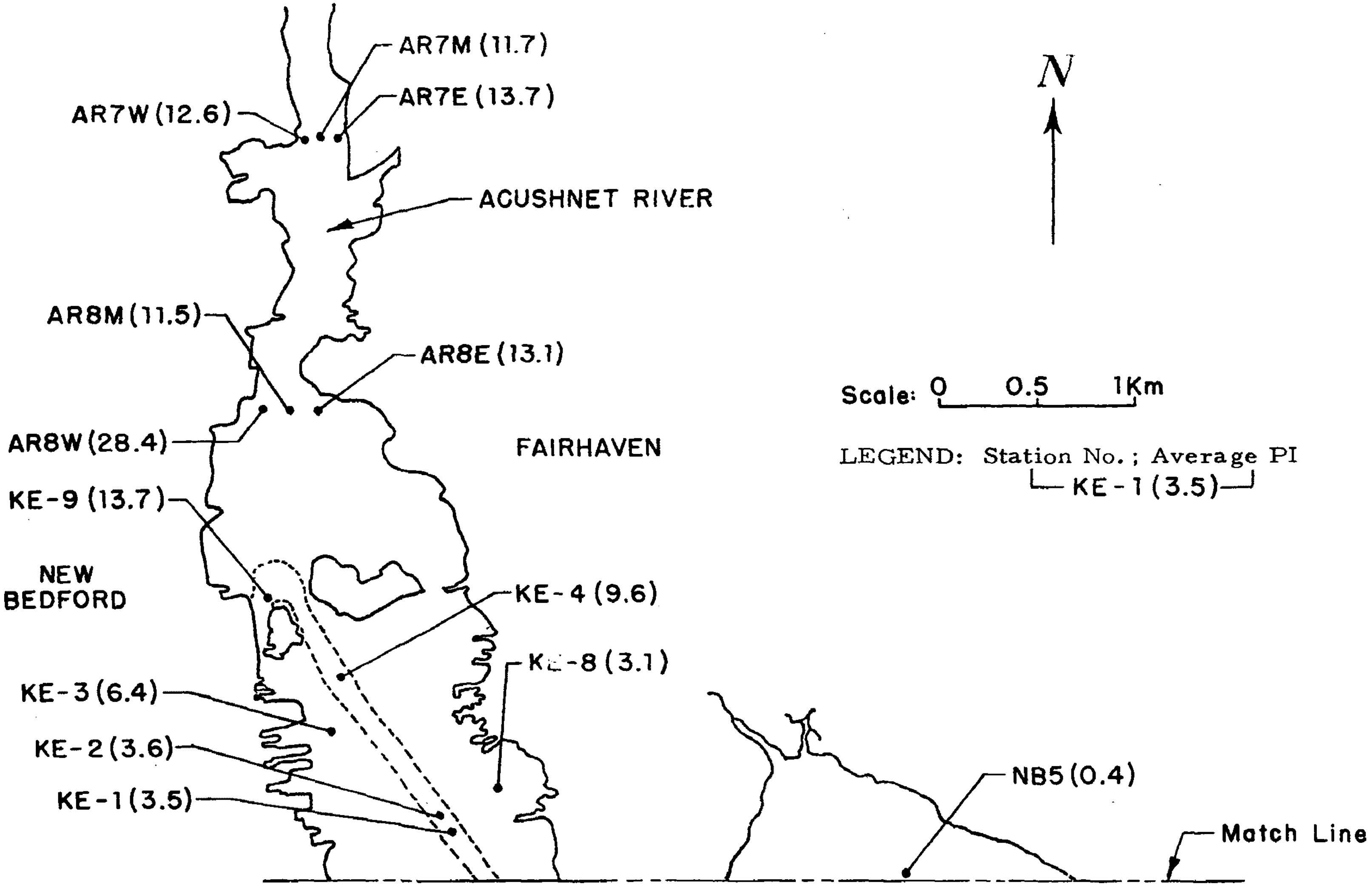
Selected Sediment Analyses (mg/kg dry weight), New Bedford

Station No.	Hg	Cd	Pb	As	Cu	Zn	Cr	Ni	DDT	PCB	Oil & Grease
Reference 30; Sampling October 1972:											
KE-1	0.96	3.4	135.1	11.9	447.5	278.6	145.2	23.6			6010
KE-2	1.09	5.3	92.7	13.3	467.7	238.3	229.4	29.1			5800
KE-3	1.56	12.5	199.8	10.8	1036.2	461.9	536.8	43.7			12590
KE-4	2.25	16.9	261.7	28.1	1401.1	631.3	692.8	53.9	0.1	124.9	16960
KE-5	1.62	5.0	143.5	21.4	357.5	256.3	218.8	35.0			7530
KE-6	0.63	1.4	75.0	8.2	211.4	185.7	46.4	17.9			540
KE-7	1.08	4.3	118.6	1.3	352.7	226.5	178.0	23.7			4310
KE-8	0.44	4.8	75.9	11.0	483.3	207.1	207.1	22.1			3040
KE-9	1.63	18.4	492.4	44.6	2026.9	790.2	744.3	68.7			16090
KE-11	0.30	3.0	79.8	23.8	167.5	177.5	101.7	19.9			1350
KE-12	0.50	3.0	130.4	45.0	226.7	190.6	120.4	25.0			3490
KE-13	0.70	3.3	119.4	48.0	282.2	209.5	180.2	26.1			4710
KE-14	0.85	4.7	156.1	50.4	375.8	278.0	222.9	30.8			6140
KE-15	0.99	1.1	15.8	11.7	21.6	18.4	5.2	4.7			90

Table A-9 (Cont)

Selected Sediment Analyses (mg/kg dry weight), New Bedford

Station No.	Hg	Cd	Pb	As	Cu	Zn	Cr	Ni	DDT	PCB	Oil & Grease
	Reference 32; Sampling 1971:										
AR 7E	1.90	76.0	320	5.2	1920	1700	960	100			
AR 7M	3.1	53	310	5.2	1620	1040	920	72			
AR 7W	3.3	0.9	560	5.2	2540	2300	1380	180			
AR 8E	1.7	40	320	3.2	2520	1070	1280	110			
AR 8M	3.8	40	290	9.2	1680	600	1210	81			
AR 8W	2.7	24	310	14.0	7250	1200	3200	550			
NB 1E	0.9	1.9	410	0.8	1930	95	110	6.8			
NB 1M	1.7	0.7	11	0.0	36	35	21	3.6			
NB 1W	1.7	18	150	5.2	610	430	310	39.0			
NB 2	0.75	0.4	31	0.6	32	410	18	37			
NB 3	7.7	43	510	3.2	760	1170	250	36			
NB 5	0.85	0.1	3.4	0.0	5	5.5	5.1	1.5			
NB 6	0.21	0.9	20	0.6	59	50	27	4.5			


AR7M (11.7)
AR7E (13.7)
AR7W (12.6)
ACUSHNET RIVER
N
AR8M (11.5)
AR8E (13.1)
Scale: 0 0.5 1Km
AR8W (28.4)
FAIRHAVEN
LEGEND: Station No.; Average PI
KE-1 (3.5)
KE-9 (13.7)
NEW BEDFORD
KE-4 (9.6)
KE-8 (3.1)
KE-3 (6.4)
KE-2 (3.6)
NB5 (0.4)
KE-1 (3.5)
Match Line

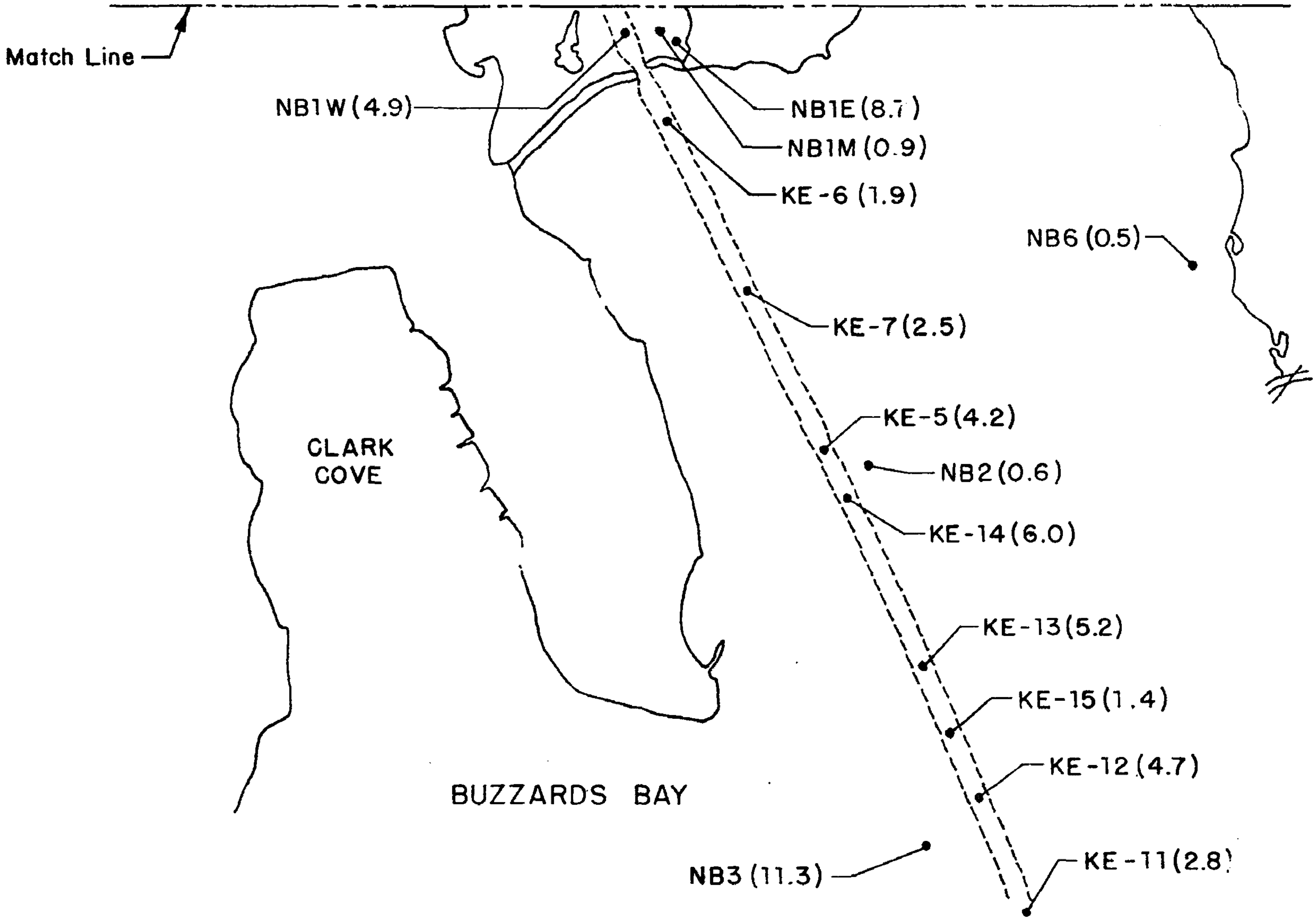


Figure A-13. Selected Sediment Sampling Stations, with Average Pollution Indices, New Bedford

Priority 3 Locations

Monongahela River, Pittsburgh, Pennsylvania

Pittsburgh is well known as the headquarters and major production site of many large steel companies. The traffic on the Monongahela River is primarily devoted to serving steel mills and coal mines in Pennsylvania and West Virginia. Project depth on the river is nine feet and barges are used for waterborne commerce.

Only one set of data was received for sediments in the Pittsburgh area. These analyses were of material in the vicinity of River Mile 11 on the Monongahela and indicated a maximum lead content of 1300 mg/kg. The Ohio River Division of the Corps of Engineers in Cincinnati provided these results. Checks with EPA offices in Philadelphia and Wheeling, West Virginia, with Corps offices in Cincinnati and Pittsburgh, and with the Pittsburgh office of the Pennsylvania Department of Environmental Resources revealed no further knowledge of sediment quality data for the Pittsburgh area. The Corps of Engineers Pittsburgh District is performing a study of the Beaver River Basin near Pittsburgh which will include sediment sampling.

River Mile 11 is immediately downstream of Lock and Dam No. 2, and approximately 10 miles upstream of downtown Pittsburgh. In the communities of West Mifflin, Duquesne, Clairton, North Braddock, McKeesport, and Glassport, the Monongahela River banks are heavily developed with a number of steel mills and railroad freight yards. These communities and mills use the river for water supply, waste disposal, and barge traffic.

Mississippi River, St. Louis, Missouri

During the 1960's, St. Louis' downtown riverfront was revitalized by the construction of the national memorial to westward expansion featuring the Gateway Arch. The river also is used for recreation through party boats, modifications of old river steamers. which dock near the downtown area. This and other recreational uses of the river are hindered by floating fecal material, oil, and packing house wastes in the St. Louis area. The downstream fishery has also been curtailed. Major water-using industries in metropolitan St. Louis include meat packing, dairies, textile and paper mills, chemical and metals producers, and breweries[34].

The investigation for St. Louis revealed limited data; one data set was received, containing high values of one toxic pollutant, and no other data were found after contacting several agencies in the area. The data for the Mississippi River in St. Louis were contained in a Federal Water Quality Administration report[34]. Arsenic was found by that study to reach a value of 96.4 mg/kg in the river sediments at Mile 166.0, approximately 13 miles downstream of the Gateway Arch in downtown St. Louis. Other data in that report for the St. Louis area away from the arsenic hot spot, showed sediments to be far less polluted than the other locations selected by initial screening. An arsenic value of 44.2 mg/kg was recorded four miles upstream of the hot spot, and lead values of 435 and 441 mg/kg were found in the Chain of Rocks Canal, north of St. Louis near Granite City, Illinois. The referenced report presented data which indicated that the arsenic source was probably a single large industrial outfall.

Eastchester Creek (Hutchinson River), New York

Eastchester Creek is a small estuary off the northern side of the East River in the Bronx. The term, Eastchester Creek, is used by the Corps of Engineers to denote the navigation project including Eastchester Bay and the Hutchinson River. One data set, resulting from a pre-dredge survey by the New York District of the Corps of Engineers shows lead values in the navigation channel of 879 and 921 mg/kg dry weight. Other high values include copper, 286 mg/kg, and zinc, 652 mg/kg. These high concentrations were all found between Mile 3 and Mile 5[35].

A great deal of recreational boating occurs in this area, close to Long Island Sound. A large number of people live within a mile of Eastchester Creek, at Co-op City, a high rise residential area developed by the State of New York during the past several years. Open space and recreational land is at a premium for the residents of this area, which is crossed by a number of major highways and rail lines.

Maintenance dredging of approximately 65,000 cubic meters (85,000 cubic yards) is performed about once in 8 years[36]. Disposal of material from an impending maintenance operation is planned in the New York Bight off Sandy Hook, NJ, at an open water disposal site which receives dredged material from many operations in the New York area. Some options to open water disposal of dredged material are being explored for the New York area. Among these are use as fill for land at Caven Point, NJ, and creation of a large diked area in lower New York Bay offshore of Staten Island.

Cleveland Harbor, Cuyahoga River, Ohio

The Cuyahoga River and Cleveland Harbor into which it flows have experienced the abuses of most urban, industrialized waterways. Cleveland's industries depend heavily on Lake Erie shipping. One factor of importance is the ore boat traffic which supplies iron ore to the large steel mills adjacent to the navigable reaches of the Cuyahoga River. Much of the outer harbor, which is made possible by breakwaters, and the Cuyahoga River are committed to port facilities and other industrial and commercial land uses. Steep bluffs surround the Cuyahoga River industrial area and have generally restricted industrial development. Residential and commercial land uses prevail at the higher elevations. Beaches and recreational boating facilities on Lake Erie spread to the east and west of Cleveland.

Sediment chemistry data for Cleveland have resulted from analyses performed by personnel of the Environmental Protection Agency's Region V[15, 16]. The most significant hot spot is at Mile 5.4 on the Cuyahoga River, where a cadmium value of 67 mg/kg has been reported.

Other high values include, in the same sample, 560 mg/kg lead, 2387 mg/kg zinc, 542 mg/kg chromium, and 35 mg/kg cyanide. Elsewhere in the Cuyahoga River, sediment concentrations were generally less than half the levels found at Mile 5.4. The highest levels found in the outer harbor were 250 mg/kg lead, 1222 mg/kg zinc, 14 mg/kg cadmium, and 83 mg/kg chromium.

Steel, chemical, and paint producers are the principal industrial dischargers along the Cuyahoga River in Cleveland. Tank farms for petroleum products are also present. Oil-coated debris of both natural and human origin has been ignited, causing damaging fires on the river.

The Cleveland Southerly Wastewater Treatment Plant discharges to the Cuyahoga River at Mile 6.5, above the head of navigation. Another, larger municipal plant discharges directly to Lake Erie through a submerged outfall.

Normal maintenance dredging of Cleveland's navigation channels amounts to 386,000 cubic meters (500,000 cubic yards) per year. Two forces lowered the amount of maintenance dredging during the period from 1972 to late 1974: high lake levels and lack of an acceptable disposal site. Construction of a large diked disposal area known as "Site 12" in the easterly portion of the outer harbor had advanced to the extent that dredgings could be deposited in it, and maintenance dredging took place in November and December, 1974. This dredging included the area of the hot spot at Mile 5.4 on the Cuyahoga. The data on this spot do not include information on deeper sediments, so the condition of the remaining material can only be learned through further sampling.

The Buffalo District of the Corps of Engineers has long been active in seeking solutions to the problem of dredged material disposal. At Cleveland, it has built, operated, and monitored pilot facilities for diked disposal. The results have been used in the design of "Site 12", a 60-acre diked disposal area on the shoreline of the Outer Harbor near Burke Lakefront Airport. This facility is expected to contain the dredgings for 2-1/2 to 3 years of maintenance work. Plans call for additional facilities with a capacity for 7 to 7-1/2 years. As with other areas on the Great Lakes, the hope for the Cleveland area is that after ten years, pollution abatement measures will remove sources of pollutants so that open lake dumping of dredged materials can be resumed.

Milwaukee Harbor, Wisconsin

The Milwaukee SMSA produces nearly half of the manufactured products exported from the state of Wisconsin. Much of the area's industrial growth has been associated with the growth of shipping on the Great Lakes in general and through Milwaukee Harbor in particular.

Three rivers - the Milwaukee, Menomonee, and Kinnickinnic - converge in Milwaukee, and their combined flow forms the passage from the outer harbor to the river channels within the city. To the north of the harbor area, the Lake Michigan shoreline consists of beaches, parks, scenic drives and high-value residences. The shoreline to the south of the harbor is the site of some industries and electric power plants as well as parkland. Much recreational boating and fishing takes place in the area, stimulated by recently increased populations of trout and salmon in Lake Michigan.

The navigation channels and outer harbor area have been sampled several times in recent years to evaluate environmental aspects of dredging projects. Data used in this study include results of three EPA Region V sampling expeditions (two of which were performed by EPA's forerunner, the Federal Water Pollution Control Administration)[37, 38, 39] and one sample set by Northwestern University[40].

Sediment pollution in Milwaukee is widespread, rather than confined to a limited hot spot. The most serious problem areas appear to be the Menomonee River (copper, 1380 mg/kg); central outer harbor (lead, 431 mg/kg); northern outer harbor (cadmium, 77 mg/kg); and southern outer harbor (lead, 470 mg/kg).

The most obvious point source of pollutants is the Jones Island Sewage Treatment Plant, which is located adjacent to the passage between the outer harbor and inner channels. Other sources of both direct discharge and polluted overland runoff include foundries, tanneries, and a solid waste incinerator[41].

Maintenance dredging, normally 76,500 cubic meters (100,000 cubic yards) per year, has been suspended since 1969 because of the unavailability of an acceptable disposal site. High levels in Lake Michigan have lessened the impact of not dredging on waterborne commerce, but some vessels have been forced to call on the harbor with lighter than normal loads to avoid contact with shoals. A diked disposal area is under construction in the southern portion of the outer harbor, and is expected to be ready for use in early 1975.

The diked area being built will have a capacity of 1.6 million cubic yards and, when filled, will develop 44 acres of new land. The land will be turned over to the City of Milwaukee by the Corps of Engineers. Recreational use is planned for the filled area.

The Chicago District of the Corps of Engineers has designed a unique filtering system for the liquid effluent from the diked area. Sand and gravel media contained within four filter cells will remove particulate matter.

New Haven Harbor, Connecticut

New Haven Harbor, although largely committed to utility, industrial, and transportation facilities in its inner area, has a large amount of public shoreline which could be of great value if water pollution were abated. It is also the site of an important shellfish resource; New Haven and Norwalk Harbors are the two largest oyster production areas in Long Island Sound. One of the three most important commercial ports in New England, New Haven serves all of western New England, especially as an entry point for petroleum.

Of the three data sources identified in this study, two[42, 43] do not qualify the location as a hot spot under initial screening criteria. However, two samples taken by the State of Connecticut[31] were found to contain 2500 mg/kg of copper. One of these samples was taken near the junction of Lighthouse Point Reach and New Haven Reach; the other was at the Tomlinson Bridge.

The sources of copper, as well as some high zinc values (up to 1009 mg/kg), are likely to be brass mills and metal plating shops in New Haven. Two primary wastewater treatment plants discharge to New Haven Harbor, and design work for upgrading these is in progress.

Prior to a current maintenance dredging project, dredging was not done since 1968. The New England Division of the Army Corps of Engineers is sponsoring several university research projects to monitor the effects of the New Haven dredging work. Dredging is being done in the winter months to concide with the period of low levels of biological activity.

Several disposal alternatives have been evaluated by the Corps for New Haven dredgings. Upland sites have been found to be unavailable, and creation of a 243,000 m^2 (60-acre) island, 2.4 meters (8 feet) above mean low water, was deemed impractical for esthetic, safety, and economic reasons. With regard to diked areas on the shoreline, the Final Environmental Statement concludes, "Adequate areas to contain present and future required maintenance dredgings from New Haven Harbor just aren't available." Accordingly, disposal is being performed in the New Haven Dump Ground in Long Island Sound. This operation is also being closely monitored by university researchers.

<u>Newark Bay and Passaic River, New Jersey</u>

Newark Bay is a heavily used commercial harbor at the mouths of the Passaic and Hackensack Rivers. It has direct access to New York Harbor via the Kill Van Kull, north of Staten Island. Its shoreline is heavily developed. The port facilities of Newark and Elizabeth are on the west shore, and Bayonne and Jersey City are on the east.

Municipal and industrial wastes have resulted in poor water quality, and very few desirable aquatic organisms are to be found in this area. Sediment hot spots inferred from Corps of Engineers data[35] are several:

> Channel north of Shooters Island, south end of Newark Bay: mercury up to 17.8 mg/kg, cadmium up to 41 mg/kg, copper up to 1085 mg/kg.
>
> Mouth of Passaic River: mercury up to 6.7 mg/kg, lead up to 481 mg/kg.
>
> Passaic River at Arlington, near mile point 8: lead up to 1000 mg/kg.

An impending dredging project proposes to remove a total of 382,000 cubic meters (500,000 cubic yards) of material from channels on the west side of the bay and from the Passaic and Hackensack Rivers. A major purpose of dredging in the rivers is flood control[36,44].

Disposal is planned for the New York Bight, an open water area east of Sandy Point, New Jersey, where dumping of wastes has been practiced for decades. Other alternatives for disposal include proposed diked areas at Caven Point in Jersey City, and in Lower New York Bay in the vicinity of Hoffman and Swinburne Islands.

<u>Providence River and Harbor, Rhode Island</u>

At the head of Narragansett Bay, Providence has lacked the access to ocean fishing grounds that Massachusetts and Maine ports have enjoyed. Its growth has centered about commercial shipping and heavy industries. Narragansett Bay is heavily used for recreational swimming, boating, and fishing, but these uses are diminished in the Providence River and Harbor area because of pollution and lack of public access.

Although many studies of water quality and the aquatic biology of Rhode Island waters are available, only one set of sediment chemistry data was located[30]. Pollutant concentrations in the samples taken showed highest values off Fuller Rock Light. In this area, copper values of 1358.4 mg/kg, lead values of 835.9 mg/kg, and arsenic values of 63.5 mg/kg have been recorded. The many metal working and plating facilities in the area are likely sources of these materials.

A recent dredging project deepened most of the navigation channel to 40 feet from its former depth of 35 feet. Completion of that project involves rock removal, and that phase of the project has been delayed by an extensive search for a disposal site. Many shore and open water sites have been evaluated, and the final disposition of the material is currently uncertain. Creation of islands, onshore disposal, container disposal, and various means of open water disposal have been evaluated[45]. Because of the prevailing shoreline land uses in the area, it is highly unlikely that onshore disposal can be performed.

Sampit River, Georgetown, South Carolina

Georgetown is a small, historic and industrial community in the Low Country of South Carolina. The Sampit, Pee Dee, and Waccamaw Rivers merge at Georgetown at the head of Winyah Bay. Nearly half of the cargo handled in the harbor during 1973 was pulpwood and logs, reflecting the local importance of a large paper company facility. The balance of cargo was comprised almost entirely of petroleum and iron ore.

One data set was received from the EPA Region IV Office in Atlanta[46]. The local hot spot is the northern bend of the Sampit River, near the downtown area. Lead concentrations of 900 and 1100 mg/kg were recorded in this area.

Maintenance dredging is planned for Georgetown in one or two years. Disposal in the past has been on local marshes, but available areas are diminishing. An environmental statement on Georgetown is in preparation, and should be available in the spring of 1975.

Neches River, Beaumont, Texas

Part of a network of navigation channels which includes the Sabine River, the Neches River is important to the commercial and industrial activity of the Beaumont-Orange-Port Arthur area. Petroleum and chemical industries are concentrated in Beaumont, especially in an area on the east side of the city drained by an industrial canal.

At the mouth of this canal, at mile point 14.7 in the Neches River, a lead concentration of 2,960 mg/kg has been noted in one study[47]. Elsewhere in the Neches River, Sabine River, and Sabine Lake, sediments appear free of pollution relative to other areas selected by initial screening. The industries which discharge to the industrial canal would appear to be the causes of the hot spot at the canal's mouth, because of the extreme peak in lead concentration (as well as in organic parameters) at this location.

Diked disposal facilities for area dredgings in Sabine Lake have been used successfully for some time.

Richmond Harbor, California

Strategically located on San Francisco Bay near the San Pablo Strait, Richmond Harbor handled more cargo tonnage than San Francisco and Oakland combined during 1973[25]. Major marine terminals are located in the Harbor Channel and Inner Harbor area near downtown, and Terminal No. 4 is at Pt. San Pablo, approximately 5 km along the shoreline to the northwest of the main harbor facilities. All municipal terminals and shipyards have rail connections.

In the northwest section of Richmond, between the Richmond-San Rafael Toll Bridge and Pt. San Pablo, the land rises steeply from the bay to an elevation of some 150 meters. Surrounding this high ground at the water's edge are railroad tracks and a road, with some military and industrial facilities.

Richmond Harbor is not considered by the San Francisco District, Corps of Engineers, to be an area of polluted sediments. All of that agency's sampling confirms this statement, and most of the Richmond Public Works Department data show little pollution. However, one sample taken near Terminal No. 1 on September 12, 1972, was found to contain 14.1 mg/kg mercury in part of the core[48]. It is significant to note that analyses of other strata from the same core showed much lower mercury contents. The above analysis was for the 6" to 24" section. The section from the top 6" was reported with 1.94 mg/kg and the 24" to 42" deep section was reported with 1.63 mg/kg.

The area of this sample and other channel locations in the Inner Harbor were planned for maintenance dredging in early 1975. Approximately 190,000 cubic meters (250,000 cubic yards) of material are dredged in this area every 12 months. Disposal in the past has been in an open water site near Alcatraz[49].

Oakland Harbor, California

On the eastern shore of central San Francisco Bay, Oakland is a transportation center for a large area. The many industries in Oakland and Alameda, and the productive farmland of the Central Valley, rely on Oakland's port facilities.

Tourism and recreational boating are also important in Oakland, More than half of the moorings and berths for recreational boats in Alameda County are in Oakland's Inner Harbor. These berths are concentrated near Jack London Square and Brooklyn Basin, and scattered along the Alameda waterfront.

Unpublished data received from the San Francisco District of the Corps of Engineers do not qualify Oakland Harbor as a hot spot. Some data from the Inner Harbor, received from Region IX of EPA[50], however, indicate maximum concentrations of lead, 1800 mg/kg; cadmium, 33 mg/kg; and oil and grease, 33,000 mg/kg.

The sources of pollutants are not known, but Oakland and Alameda industries include heavy equipment manufacturers, metal fabricators, primary metal producers, and chemical and paper plants.

Oakland Outer Harbor undergoes maintenance dredging on a 12-month cycle. The average quantity of material is 230,000 cubic meters (300,000 cubic yards). Portions of the Inner Harbor have been deepened recently from 30 to 35 feet. The Inner Harbor has also been maintenance dredged annually, and the annual volume with the 35-foot depth is expected to be in the 380,000 cubic meter (500,000 cubic yard) range.

Disposal of material deemed polluted with heavy metals is normally done in the Pacific Ocean, at depths greater than 100 fathoms. Other materials from Oakland are normally dumped at the Alcatraz water disposal site.

Los Angeles Harbor, California

The large metropolitan complex centered in Los Angeles is favored by many miles of attractive shoreline. The harbor area of Los Angeles, near the San Pedro and Wilmington districts, supports intense commercial and recreational use. Recreational activities such as sailing, sport fishing, and swimming, are most concentrated in the Cabrillo Beach area near the San Pedro Breakwater. The outer harbor area also supports anchovy spawning and nursery grounds.

The most severe hot spot revealed by the data is the East Turning Basin, with a mercury concentration of 10.4 mg/kg and a copper value of 1800 mg/kg. Near this area, at Berth 184, a nickel concentration of 570 mg/kg has been recorded[51]. All data for Los Angeles were received from the Port of Los Angeles.

In the area of these samples, industrial wastewaters from food processing industries and wastewater carried in by the Dominguez Channel enter the harbor.

The Los Angeles Harbor Department has proposed a $60 million supertanker and LNG facilities program. Landfills for these facilities would be created with dredged material from channel deepening projects, and treatment of dredged material would be performed. Several configurations for the diked landfills will be evaluated with a physical hydraulic model of the harbor at U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi[52].

San Diego Harbor, California

San Diego Bay is protected from the Pacific by Point Loma, North Island, and the Silver Strand, a narrow beach area. Very little fresh water enters the Bay, but tidal flushing and recent pollution abatement have produced Bay waters of rather high quality. The Bay is an important spawning area for ocean fish.

The San Diego Bay is the home base for more than 18% of the Navy's active fleet. Ocean-going tuna boats are also based in San Diego. Sport fishing and other recreational activities are supported by good public access to the harbor and by a warm climate with very little rain.

Many investigations of sediment quality in San Diego Bay have been made in recent years. These are well summarized in an environmental impact statement on harbor dredging[53]. The primary hot spot revealed by the six data sets presented in the referenced statement is near the 28th Street Pier, where shipbuilding facilities are located. An arsenic concentration of 135 mg/kg and a mercury concentration of 8.5 mg/kg were noted in this area. Although this material is likely to have been dredged since samples were taken, nearby sediments may still be polluted.

One potential source of these toxic heavy metals identified in the referenced EIS is sand blasting of ships and general deterioration of paint on hulls. Mercury and arsenic are used in some marine paints. During the past decade, most industrial wastewater discharges to the Bay have ceased. Municipal wastewater is diverted from the Bay by an ocean outfall.

Maintenance dredging at San Diego is very infrequent, but a channel deepening project is underway involving 6.5 million cubic meters (8.5 million cubic yards) of material. Much of this material is to be used in diked landfill areas to create a boat basin, marinas, and land for restaurants and shops.

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