On Reducing the Need for Maintenance Dredging in the Port of New York and New Jersey*

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CONTENTS

CONTENTS

LIST OF TABLES

Page

PART I. REDUCTIONS IN DREDGING THROUGH MODIFICATION TO THE PORT

LIST OF TABLES

Page

PART II. CONTROL OF SEDIMENT AND CONTAMINANT INPUTS TO THE PORT OF NEW YORK AND NEW JERSEY

LIST OF FIGURES

Page

PART I. REDUCTIONS IN DREDGING THROUGH MODIFICATIONS OF THE PORT OF NEW YORK AND NEW JERSEY

PART II. CONTROL OF SEDIMENT AND CONTAMINANT INPUTS TO THE PORT OF NEW YORK AND NEW JERSEY

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EXECUTIVE SUMMARY AND CONCLUSIONS

Dredging and disposal of contaminated dredged material is a major problem facing most ports in the United States. Usually when disposal options are discussed the question of how to reduce dredging without sacrificing the economical operation of the port is raised. Dredging and disposal must continue to keep most of our ports open, but there are measures that can be taken to reduce the amount of material dredged and the levels of contamination. The goal of this study is to examine measures for reducing dredging and disposal of contaminated material for the Port of New York and New Jersey. Because many of the problems and potential solutions are shared by all ports, we hope that this case study can contribute significantly to our understanding of the problem and aid in identifying solutions on a nation-wide basis.

Many approaches can be taken to reduce the need for dredging and the disposal of contaminated material. We studied three basic categories of reduction measures. The first involves reduction in dredging through reduction or elimination of dredging of some projects. Dredging projects in the Port of New York and New Jersey result from the division of the Port's waterways into many channels and channel systems by the U.S. Army Corps of Engineers. Projects vary widely in geographical extent, quantity of material dredged and quality (contaminant levels) of the material dredged. Ship traffic, the type and number of facilities served and the proportion of the traffic accounted for by deep draft vessels varies as well. By comparing the environmental costs of a particular project, as measured by the quantity and quality of the material dredged, with the economic value of the project as measured by ship traffic and cargo handled, it is possible to identify projects that may be candidates for reductions in dredging.

Reductions in dredging requirements by reducing shoaling in channels is a second approach we studied. Changes in the hydraulic regime within the harbor by various means may be an economically attractive way to alter depositional patterns and reduce channel shoaling. Suggestions proposed include: removal of piers and slips, installation of tide gates and other methods of enhancing flushing of the harbor. Another possibility is the relocation of channels to less active depositional zones. Evaluation of each of these measures requires an understanding of sediment transport within the harbor at a level not possible at present. Nevertheless, these possibilities should be considered to highlight needed research.

A third approach we assessed involves reductions in dredging of contaminated sediments obtained by controlling sediment and contaminant inputs to the Port. The first step in this analysis was to inventory the inputs to the system, including; tributaries, urban erosion, runoff, sewage, *in situ* biological production and oceanic sources. Once the primary sources had been identified, various control measures were reviewed to determine their overall effectiveness, cost, technical and legal practicality. Finally, the impact of each measure on dredged quantity and material quality was assessed using our present understanding of sediment and contaminant transport mechanisms in the estuary.

We have not considered how changes in ship design with a shift to broad beam, shallow draft vessels would reduce required channel depths and as a result, maintenance dredging requirements.

Our report is divided into two major parts. The first deals with reductions in dredging through harbor modifications; the second deals with the control of sediment and contaminant inputs to the Port.

Part I, Reductions in Dredging Through Harbor Modifications, includes a description of the study area, environmental and economic evaluations of the major dredging projects, and a discussion of potential hydraulic modifications to reduce dredging. The environmental and economic evaluations contain a summary of available data on dredged material quantity and contamination levels, ship traffic data and other pertinent economic information. Based on an analysis of these data, we identified projects with potential for reduced dredging without adverse economic impact. The maximum reduction in dredging volume that is possible through elimination of projects is approximately 11.6%. Projected new dredging work in various parts of the Harbor may overwhelm any reductions realized in this way, but there will be little contamination associated with sediments dredged for new work.

Hydraulic modifications to the harbor also are discussed in Part I. To be successful, these kinds of measures require the ability to predict how hydraulic modifications affect sediment transport characteristics of the Harbor. In the early 1960's the Corps applied their physical model of New York Harbor to the study of shoaling in the Lower Hudson River. Using a combination of expensive control measures, they predicted up to a 37% reduction in shoaling was possible. However, these measures were never implemented because of cost and uncertainty of effectiveness. Nevertheless, one area of the Harbor where this type of measure warrants further study is in reducing shoaling in berthing slips. Approximately, 1.4 million yd^3 are removed annually from private projects. Experiments by the Corps and others discussed in this report indicate that up to a 17% reduction in slip shoaling may be practical. If implemented harbor-wide this could represent up to a 3.5% reduction in total maintenance dredging.

Part II, Control of Sediment and Contaminant Inputs to the Port of New York and New Jersey, includes a review and tabulation of data available to quantify the sediment and contaminant sources to the Harbor. Although there are large gaps in the data, some conclusions can be reached. It appears that between 70% and 100% of the sediment entering the port from all sources is removed by dredging. The Hudson River and the New York Bight are the major sources of this sediment with smaller contributions from wastewater, urban runoff, *in situ* biological production, shore erosion and Long Island Sound. Assuming that reduced sediment loads are translated directly into reduced dredging, a 14 to 20% reduction in total maintenance dredging requirements is possible. Indications are that for tributary loads, at least, it may take decades for reductions in sediment yields to show up as reduced loads to the estuary. This means that dredging requirements to maintain existing projects may not be reduced significantly for many years.

Data on sources of contaminants to the Harbor are more limited than data for sediment sources. PCB's are characterized best and up to 94% removal of PCB contamination from the Hudson River is thought by some to be possible, although a 72% removal is more likely, and even that may be an over-estimate. The Hudson is the major source of

PCB's to the Harbor, but wastewater and urban runoff also contribute. If the most likely controls are implemented a 27-32% reduction in PCB inputs to the Port is possible. Sources of metals and other contaminants sources must be quantified much better before loads and possible reductions can be quantified.

In summary, measures discussed here could lead to overall reductions in current maintenance dredging requirements of up to 35%; 11.6% through elimination of projects, 14-20% through erosion, wastewater and urban runoff controls and 3.5% through slip shoaling controls. Although this would be a significant improvement, proposed new dredging projects could result in as much as a 40% increase in dredging requirements. This is not to imply that control measures such as those discussed here are not worthwhile. They are. It is clear, however, that significant reductions in maintenance dredging requirements are not to be expected in the near future. The most promising controls appear to be those directed at reducing contamination, but more data are needed to quantify the magnitude and time needed for significant improvements in sediment quality. Reductions in contaminant inputs does not decrease maintenance dredging requirements, but it extends the range of acceptable disposal alternatives. Many decades of stringent controls are necessary to correct decades of past abuse.

PART I. REDUCTIONS IN DREDGING THROUGH HARBOR MODIFICATIONS

Description of the Study Area

The Port of New York and New Jersey lies within the jurisdiction of both states. Because of this and its size and complexity, the Port presents an extremely difficult management problem. When considering development options for the Port, managers must consider not only the economic and environmental concerns common to all ports, but in the case of the Port of New York and New Jersey they must consider the impacts of shifting the balance in favor of one state or the other.

The system of navigation channels providing access to the Port is shown on Figure I-1. Construction and maintenance of the channels are the responsibility of the New York District of the U.S. Army Corps of Engineers. The Corps also is responsible for regulating the construction and maintenance of state, local and privately-operated channels and docking facilities. The channel system has been divided into a number of projects by the Corps. These are shown on a series of maps contained in Appendix A.

General Dredging Requirements

Dredging requirements for the Port have averaged over 8 million cubic yards annually over the last 15 years. As can be seen in Figure I-2, substantial year to year variations occur. The Corps divides their dredging statistics into three categories, shown on Figure I-3. The largest amount of dredging is done to maintain existing federal projects. Most of the annual variation in dredging is caused by variations in the second category--new federal dredging. The third

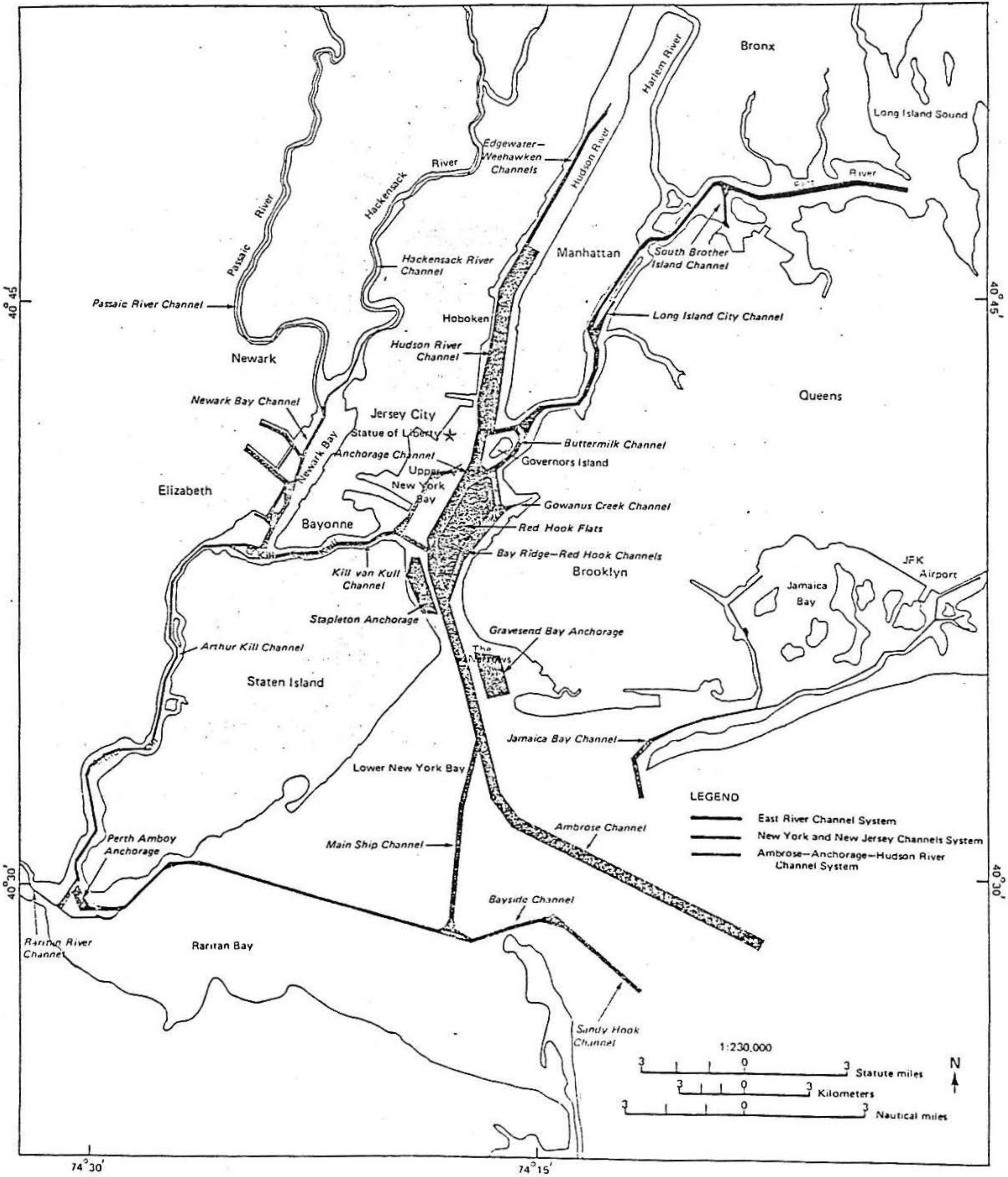


Figure I-1. Major Channel Systems, Port of New York and New Jersey

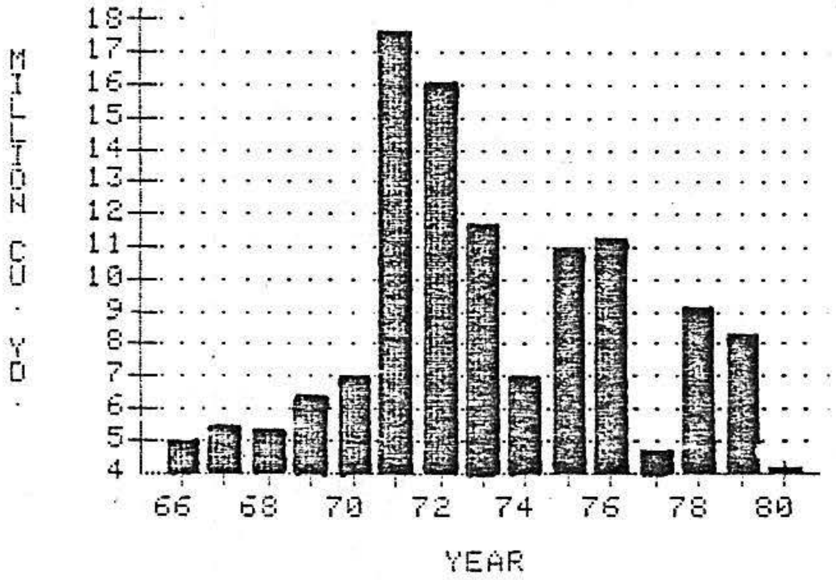


Figure I-2. Annual Dredging 1966-1980,
Port of NY & NJ

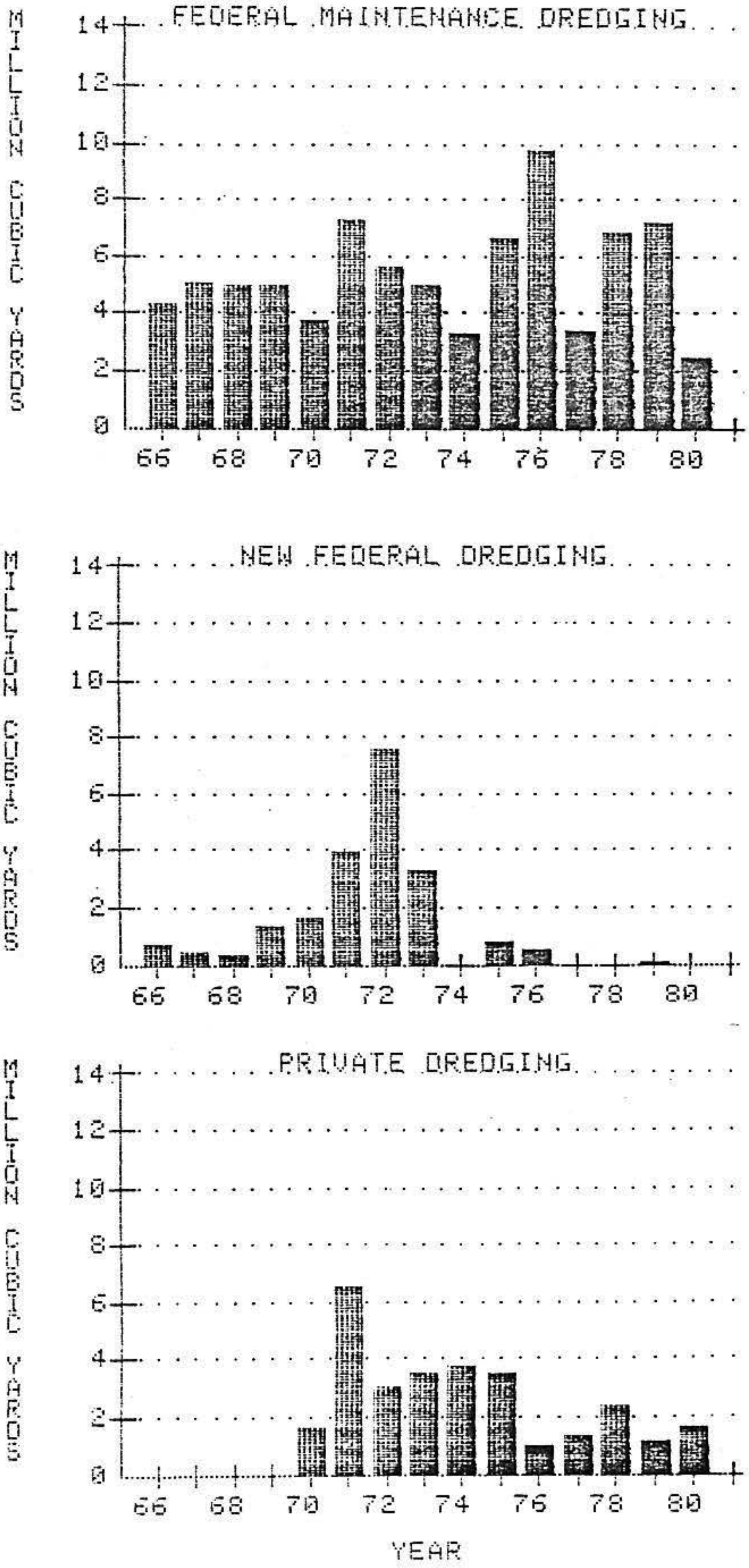
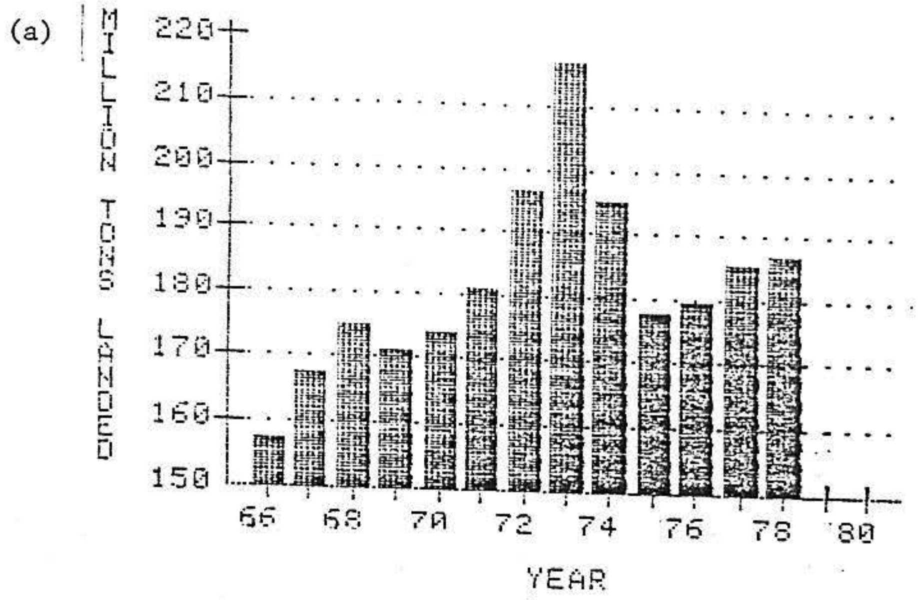


Figure I-3. Breakdown of three types of dredging, Port of NY & NJ category, private dredging, includes maintenance and new dredging done by anyone other than the Corps. This includes other federal, state and local government agencies as well as private interests. The total quantity of material dredged for each project and for each category of projects are summarized by year in Appendix A, Tables A-1 through A-3. Variability in federal maintenance dredging is largely a function of funds available. Certain projects, for example the Ambrose Channel, at the harbor entrance, must be maintained annually. Others are more flexible and maintenance is scheduled around more pressing maintenance and new dredging work. In addition, dredging of some projects has been deferred because of contamination and associated environmental problems. Once acceptable disposal alternatives are made available, these projects may be completed.

Ship Traffic

The Corps also is responsible for publishing annual summaries of ship traffic statistics including tons of cargo landed, and numbers of ships, segregated by draft and type. Three categories of self-propelled vessels--passenger and dry cargo, tankers, and towboats or tugboats--and two categories of non-self propelled vessels--dry cargo and tankers--are considered. These statistics are compiled and published in a series of volumes entitled, Waterborne Commerce of the United States. Unfortunately, there is a substantial delay in publication and the most recent volume available at the time of this writing is for 1978 (USACE, 1978).

Statistics on tons of cargo landed are divided by product category and are given for different segments of the Harbor. Total



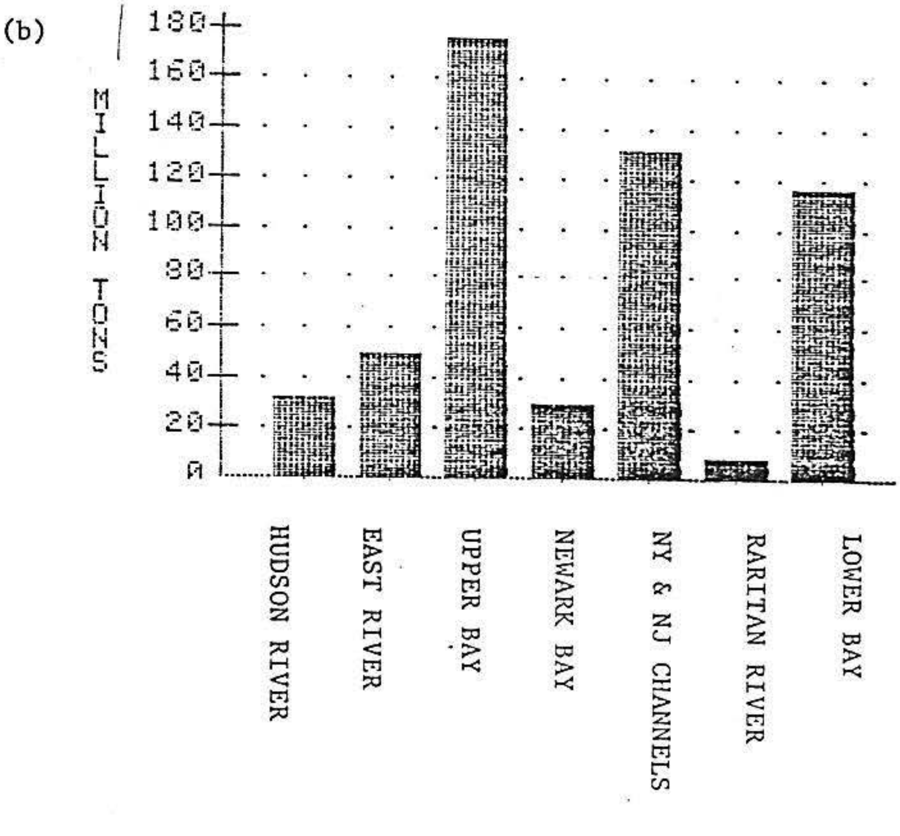


Figure I-4. Ship traffic statistics: a) total annual tonage, Port of NY & NJ 1966-1978; b) average annual tonage for different parts of the Harbor (USACE, 1978).

tons landed in the Port of New York and New Jersey over the period 1966-1978 are shown in Figure I-4(a). Although there are considerable fluctuations, it is evident that the Port is continuing to grow. Figure I-4(b) shows the importance of different segments of the channel systems in terms of tons transported. More cargo moves through four of the seven segments than through the entire Port of Baltimore, Maryland (47 million tons in 1978; USACE, 1978). The smallest segment, the Raritan River, handles on the order of 10 million tons of cargo annually, the bulk of which is petroleum products.

It is difficult to determine what portion of this cargo depends upon deep draft vessels, and is limited therefore by available channel depths. The number of ships using each segment of the Harbor is broken down by draft in the Corps' ship traffic statistics (USACE, 1978). Table I-1 is a brief summary of these data. In every case, the maximum draft ship using the channel is at the limits of navigability for the channel used. The data show that while only a relatively small number of the ships using each segment are deep draft vessels, they carry a disproportionately large share of the total cargo because of their larger volume per foot of draft. Because of the wide variety of ship designs, it is not possible to use a general factor for conversion from draft to tons carried. As a result, the impact of reduced channel depths on cargo deliveries and shipping can not be quantified easily.

Economic Implications of Reduced Dredging

To quantify the impact of the U.S. port industry on the national economy, the Maritime Administration (MARAD) has developed an input-output (I-O) model of the industry (MARAD, 1978). Every industry uses its own output, and the output produced by other industries, as input to produce its products. I-O analysis is based on development of a mathematical model of the interactions among major industries and is used as a tool for predicting the cumulative effect of potential changes. To define the limits of the model, MARAD (1978) used the following definition: "A port industry is any economic activity that is directly needed in the movement of waterborne cargo". Over 8,000 input-output data items were needed to define the model.

MARAD's analysis confirmed that the port industry is indeed a vital component of the U.S. economy. Directly and indirectly the port industry generated gross sales of $28 billion, a $15 billion contribution to the gross national product, over 1 million jobs, personal income of $9.6 billion, business income of over $3.7 billion, federal taxes of $5.2 billion, and state and local taxes of $2 billion.

Since it is one of the two largest ports in the country, and the largest in terms of value of cargo handled, the Port of New York and New Jersey generates a large portion of this economic activity. To quantify its role in the economy, the Port Authority of New York and New Jersey has developed a regional input-output model that can be used to explore the impacts of various factors on the regional economy. One such study, prepared by Ilan *et al.* (1979), investigated the regional economic impact of a hypothetical ban on dredging.

Table I-1

Numbers and drafts of ships using N.Y. Harbor in 1978*

Harbor Section	Max. draft reported	Total Number of ships	Number of ships greater than 30' draft
Hudson River	38	24,889	161
East River	40	26,441	179
Upper Bay	45	105,093	2,958
Newark Bay	37	14,754	308
N.Y. & N.J. Channels	45	63,051	1,128
Lower Bay	45	13,628	2,896

*Based on statistics from Waterborne Commerce of the U.S. for 1978, U.S. Army Corps of Engineers

To assess the economic impacts of a halt in all dredging of the Port it was necessary to make certain assumptions about how shipping would be affected. The assumptions made by Ilan *et al.* (1979) include: 1) all passenger steamship activities would cease within about two years because of shoaling at the Port Authority passenger ship terminal berths; 2) nearly half the Port's general cargo traffic would be lost within about five years because of berth shoaling, and all general cargo would be lost when channel depths reach 20 feet mean low water several years later; 3) given the availability of shipping, petroleum would continue to arrive by smaller or partially-loaded tankers for channel depths down to 25 feet; 4) cargo diverted from the Port of New York and New Jersey could eventually be accommodated both by land modes and by neighboring port facilities; and 5) the lowest value-per-ton exports would no longer be economical to ship from this region, eliminating some regional export production activities.

Table I-2 provides a summary of the economic impacts of a halt to all dredging given the assumptions listed above. These impacts result from losses in waterfront activities and a decline in the wholesale and retail trade industry, finance and insurance industry and in part related government activities. In addition, it can be expected that the regional freight bill also would increase significantly. The added cost of doing business in the region could have further detrimental impacts by discouraging new businesses from moving into the region.

Obviously the loss of the port industry would have a devastating affect on the regional economy. A total halt in dredging activity is unlikely. However, dredging costs are rising and will continue to

Table I-2

Economic Impacts of the Elimination of Dredging in N.Y. Harbor

Halted: 20 million long tons of cargo
10,500 passenger and dry cargo ship arrivals
330,000 passengers

Lost: 61,000 jobs
$ 1 billion in personal income
$ .5 billion in business income
$2.9 billion in regional sales income
$100 million state and local taxes
$300 million federal taxes

Increased: 660 million in moving cargo and oil by other means

Source: Ilan *et al.* (1979) Path N.Y. & N.J.

rise as environmental concerns are met. As a result, some port facilities may lose their margin of profitability due to the expense of maintaining the necessary channels. In the past, government funding of dredging projects has insulated such marginal port facilities from the true cost of dredging. If one of the proposed user fee systems is adopted in the nation's ports, this protection would be reduced significantly and it would be necessary for each region to determine whether it can afford the loss of some segments of the port industry. This will require much more detailed economic analysis of the costs and benefits of dredging projects than those currently available.

Environmental Evaluation of Dredging Projects

To assess the possibilities for reducing dredging in the Port of New York and New Jersey by reducing or eliminating dredging of some projects, it was necessary to assemble available data on the quantity, characteristics and contaminant levels of materials dredged from each project, and the levels of economic activity associated with each project. Because of the form of the data, the Port of New York and New Jersey was divided into 32 projects for our analysis. The project name, an abbreviated code used in data tables, and the location of each project are given in a series of maps in Appendix A.

Project Dredging Requirements

A project by project breakdown of past dredging work was compiled from records of the New York District, Army Corps of Engineers and publications prepared for and by the Corps (Conner *et al.*, 1979;

USACE, 1976 through 1980). Average annual federal maintenance and private dredging volumes for the period 1966 to 1980 are presented for each project in Table I-3. The annual data upon which Table I-3 is based are given in Appendix A, Tables A-1 and A-2.

For many projects there are substantial variations in the annual dredging activity which result primarily from delays of project maintenance during periods when substantial new dredging work is being done. Also, the practice of over dredging up to several feet deeper than needed may result in postponement of annual maintenance for a year, or more. In some cases, reduced dredging in recent years is the result of environmental restrictions on dredged material disposal. If the dredging record is long enough, however, these artificial variations should average out to give a reasonable estimate of the natural shoaling rate in each project.

Ideally, dredging statistics should be based on pre- and post-dredging surveys of the channel to obtain accurate estimates of the amount of material dredged. In practice, a variety of measurement techniques may be used to estimate quantities dredged at various times and locations. The result is that dredging statistics are highly inaccurate, a fact that should be considered before the data are used in any analysis.

Physical Characteristics of Dredged Material

The physical characteristics of dredged material most commonly reported are grain size distribution and water content. These two measurements typically are highly correlated, with sandy sediments generally containing less water. Particle size data for the 32

Table I-3

Quantities Dredged by Project, Port of New York and New Jersey

	Average Annual Dredging (1000 yd^3)		
Project Name	Federal Maintenance	Private	Total
Hudson R. Battery - Weehawkin (HRBW)	423	601	1024
Raritan Bay (RB)	912	18	930
Ambrose Channel (AMB)	834	0	834
Bay Ridge - Red Hook Ch. (BRRH)	704	15	719
Hudson R. Weehawkin - Edgewater (HRWE)	594	2	596
Raritan River (RR)	318	16	334
Newark Bay (NB)	212	72	284
Arthur Kill (AK)	71	195	266
Sandy Hook Channel (SHCH)	256	0	256
Buttermilk Channel (BMLK)	217	35	252
Upper Bay (UB)	162	9	171
Navy Terminal (NTML)	0	150	150
Sandy Hook Bay (SHB)	136	2	138
Main Ship Channel (MSCH)	129	0	129
Passaic River (PAS)	78	39	117
Kill van Kull (KK)	0	114	114
Shooter's Island (SHTR)	111	0	111
Gowanus Bay (GWB)	0	78	78
Westchester CK. (WCHST)	62	0	62
Hackensack River (HCK)	24	34	58
Brooklyn Navy Yard (BKLNY)	0	56	56
Jamaica Bay (JAMB)	30	3	33
Bronx River (BRX)	26	0	26
Flushing Bay (FLSH)	19	0	19
East River (ER)	15	1	16
East River Spur Ch (SPUR)	11	3	14
Harlem River (HRLM)	13	0	13
Newtown CK. (NTWN)	9	4	13
Eastchester R. (ECHST)	3	0	3

dredging projects are presented in Figure I-5 (N.Y. District, U.S. Army Corps of Engineers, unpublished data). The data are not distributed uniformly; 12 of the 32 projects are represented by 2, or fewer, samples each. Variability of grain size within a project is quite large. Since physical characteristics are an important determinant of the settling and dispersive behavior of dredged material, these limitations highlight the inadequacies of available data for characterizing the relative environmental suitability of the dredged material for different disposal options.

Measures of Dredged Material Contamination

Data on the contamination of dredged material are even more limited than particle size data. In addition, there are many ways to measure contamination of dredged material and there is no general agreement on which measure is best or on how to evaluate the results. The objectives of the following analysis are to briefly describe some of the limitations of available measures of contamination and then to compare the relative levels of contamination for different projects in New York Harbor.

Since the late 1960's when environmental concerns about dredging and dredged material disposal and regulations first arose, several different measures of contamination have been used to characterize dredged material. Unfortunately, each of these techniques has inadequacies that limit its validity, even when comparing the relative contamination of different samples of dredged materials.

Contaminants typically tend to be associated with the silt and clay fractions of the sediment. Dredged material that is

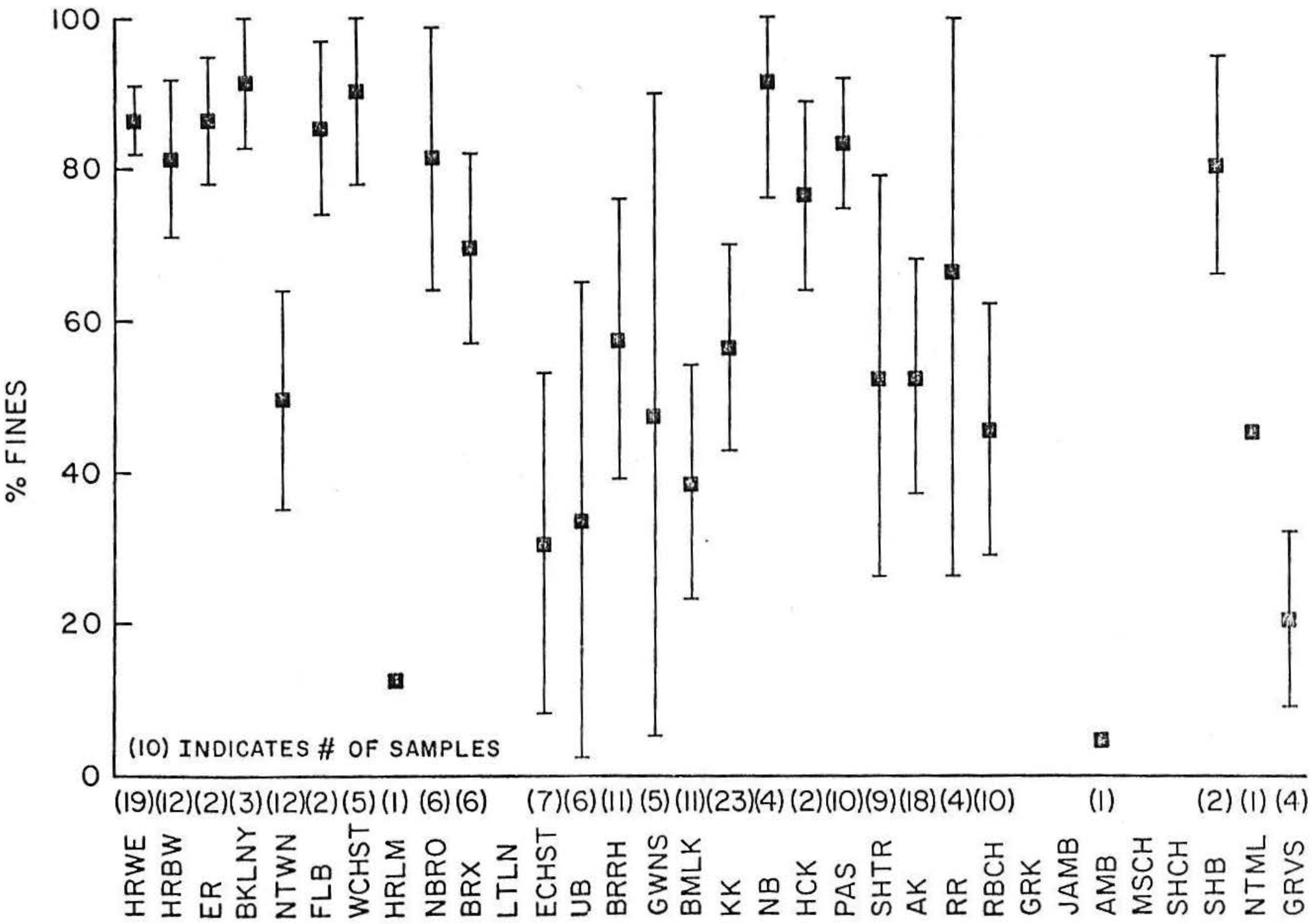


Figure I-5. Particle size data (mean ± 95% confidence limits) for each project predominantly sand generally is less uncontaminated. However, within the fine-grained materials there are large variations in contaminant concentrations. According to Engler (1981), contaminants can be found in any or all of five different phases within the sediment. In order of increasing strength of binding of contaminants to the sedimentary particles these are:

1) Dissolved in interstitial water
2) Mineral exchange phase
    - can be removed by ion exchange
3) Reducible phase
    - associated with manganese and iron oxide and hydroxide phases existing as surface coatings or discrete particles
4) Organic phase
    - soluble after destruction of organic matter
    - contains tightly-bound elements as well as those loosely chelated by organic molecules
5) Residual phase
    - primary and weathered minerals
    - located in crystalline lattice or interlayer positions on clay minerals

The phase in which a contaminant is held determines its availability under different conditions for release and uptake. Slight changes in the physicochemical environment can result in redistribution among phases of certain contaminants, with the possibility of increasing contaminant availability to the environment and the biota.

Three types of contaminant measurements have been used routinely by the N.Y. District Corps of Engineers to characterize dredged material. The earliest test used was bulk contaminant analysis which is designed to assess the total amount of each contaminant present in all phases of a sediment sample. More recently, bulk analysis has been replaced by a combination of elutriate and bioassay-bioaccumulation testing procedures developed jointly by the Corps and EPA (USEPA/USACE, 1977).

Based on the results of several studies by the Corps' Dredged Material Research Program (DMRP), Brannon (1978) concluded that bulk contaminant levels are not related to the actual availability of contaminants to the environment and the biota. DMRP results indicate that contaminants in some phases are not available for release under naturally-occurring conditions and, therefore, should not be considered in assessing contamination potential. According to Brannon (1978), the elutriate test is much more useful in predicting water quality impacts since it measures only available contaminants. Engler (1981) supports these assertions based on much of the same research cited by Brannon (1978). In contrast, a recent paper by Laskowski-Hoke and Prater (1981) reports that a greater number of significant correlations (26 vs. 4) were found between the percent mortality of four test species and bulk sediment chemistry than were found between percent mortality and elutriate chemistry of the sediments.

The elutriate test involves mixing dredged material with a specified volume of sea water for a standard period of time, allowing the suspended material to settle, followed by centrifuging and filtering of the supernatant, and measurement of the dissolved contaminant levels in the filtrate. Extensive laboratory testing of the factors controlling elutriate test results revealed that the availability of oxygen during mixing and the solid to liquid ratio of the mixture significantly affect the results (Jones and Lee 1978). Jones and Lee (1978) also found that elutriate tests conducted under oxic conditions compared favorably with measured releases during field studies of hydraulically-dredged, open water disposal operations. Similar comparisons showed barge dump releases were substantially overestimated using the elutriate test (Brannon 1978). Based on these results, it appears that physio-chemical conditions are critical in controlling contaminant releases in laboratory tests and in dredging operations.

Because test conditions are so critical to the results of the elutriate test, careful control of conditions is required if the tests are to be used for comparison of contaminant levels in dredged materials. Unfortunately, over the ten-year history of the elutriate test, various changes in technique have been made which make comparison of results from different periods tenuous, at best. For example, the Ocean Dumping Guidelines, issued in October 1973, prescribe the initial mixing of one part bottom sediment with four parts water from the dump site and vigorously shaking the mixture for 30 minutes (Little 1973 p. II-6). The 1977 version, "Ecological Evaluation of Proposed Discharge of Dredged Material Into Ocean Waters" (USEPA/USACE, 1977) permits use of either of two mixing techniques; the one described in 1973, or mixing by pumping compressed air through the slurry (p. B5). More recently (August 1981), the New York district of the Corps in its "Guidance for Performing Tests on Dredged Material to be Disposed of in Ocean Waters" forbids the use of compressed air for mixing and substitutes mixing using an industrial-type stainless steel blade mixer.

Although bulk sediment analysis measures contaminants that may not be available to the biota under natural conditions, the elutriate test does not measure some contaminants that may be available through mechanisms other than dissolution. For instance, more tightly-bound contaminants which would not be measured with the elutriate test might be released in the gut of burrowing animals. Two additional problems are shared by bulk and elutriate tests: (1) uncertainty as to how the tests should be used to assess environmental impact (e.g. what levels of contamination are unacceptable) and (2) uncertainty as to what contaminants should be measured.

In an attempt to provide a more direct estimate of the potential of contaminants associated with dredged materials for environmental impact, the EPA and Corps have developed the bioassay and bioaccumulation tests (USEPA/USACE, 1977) which are summarized on Table I-4. Because the measure of the bioassay test is an organism response (mortality), the test is not dependent on the selection of any one or combination of contaminants thought to be important. This eliminates the problem of deciding which contaminants to test for, but substitutes the problem of deciding which organisms to include in the analysis. In the bioaccumulation test, organisms are exposed to dredged material for a period of 10 days and then assessed for body burdens of a selected group of contaminants. This test thus is subject to both problems mentioned earlier: selection of appropriate organisms and contaminants.

The USEPA/USACE manual (1977 p. 15) acknowledges that the ecological significance of bioassays is not clear and cautions that attempts should not be made to infer it. In spite of this, evaluations of dredged material bioassays are made based on the assumption that any statistically significant increase in mortality of test organisms over controls is undesirable. In considering the bioaccumulation test, the report states that it is "impossible to quantify either the ecological consequences of a given tissue concentration of constituent that is bioaccumulated or even the consequences of that body burden to the animal whose tissues contain it" (USEDA/USACE, 1977 p.18). However, the manual endorses the assumption that any statistically significant accumulation in experimental animals relative to animals in uncontaminated but otherwise similar sediments is undesirable.

If it is assumed that the bioassay-bioaccumulation test can not be used to assess directly environmental impact, then most of its value lies in comparing the acute toxicity of one sample relative to that of another. However, whether a sample passes or fails the criterion depends as much on the reference sediment selected for the control as on the nature of the dredged material. Proper selection of reference sediments is vital for a diagnostic analysis, but the procedures do not provide strict guidelines for selection of reference sediments. In addition, two other important procedural aspects make comparison of bioassay-bioaccumulation tests questionable. The first involves the procedures for separation of the liquid, suspended solid, and solid phases. The mixing conditions are not specific enough in the test procedures. As discussed for the elutriate test, the conditions of mixing are critical to contaminant release and, as a result, probably to the uptake of contaminants by test organisms.

Second and more important, the organisms tested may vary widely in background body burdens and in resistance to contaminants because the sources of test organisms are not standardized. For these reasons and possibly others, bioassay-bioaccumulation tests run by different labs are not comparable, and even the comparison of tests run by the same lab at different times is questionable.

Contamination of Dredging Projects

Although a strict ranking of projects based on levels of contamination is not appropriate because of the problems with the available testing procedures mentioned above, it is possible to group the projects into categories based on the results of the different tests for contamination. In the following analysis, each of the dredged material characterization tests described above (bulk, elutriate and bioassay-bioaccumulation) was used to group the projects.

At present the bioassay-bioaccumulation tests are used to determine the eligibility of a given dredging project for open water disposal in New York Bight. If projects failing these tests (Table I-4) are dredged, the material must be disposed of in some other way. In a survey of past testing results Suszkowski and Mansky (1981) reported that LPC values for the suspended solid phase have never been exceeded and LPC values for the suspended solid phase were only exceeded 3% of the time. Solid phase bioassay results have only exceeded the criteria in 3 out of 121 tests according to these authors.

Table I-4

1981 Criteria for Bioassay - Bioaccumulation Test Results

Liquid and Suspended Particulate Phases

1) Three species are tested to determine the lethal concentration of the dredged material phase causing death of 50% of the individuals tested (LC50)

2) Limiting permissible concentrations (LPC) equal to 0.01 x LC50 have been established based on mixing zone calculations

   liquid phase LPC = .07
   suspended particulate phase LPC = .001

3) The LPC must be met in the mixing zone no more than 4 hrs. after dumping to satisfy the criteria (Suszkowski and Mansky, 1981)

Solid Phase

1) Three benthic species are tested and fail the criteria if results are significantly different from the control and survivals are more than 10% lower (Suszkowski and Mansky, 1981).

2) Bioaccumulations are measured in the same three species and fail the criteria if they are significantly higher than the control and exceed suggested matrix values (NACOE, 1981).

3) Matrix Levels for Three Test Species, N.Y. District

Species / Contaminant (in ppm)	Nereis	Mercenaria	Paleomonetes
PCB	0.4	0.1	0.1
DDT	0.04	0.04	0.04
Hg	0.2	0.2	0.2
Cd	0.3	0.3	0.3

(NACOE, 1981)

Although bioassay tests produce very few failures, the bioaccumulation results are another matter. Analysis of the results of bioaccumulation tests show that in nearly half of the tests run to date, petroleum hydrocarbons have been accumulated significantly over controls by all three test species. In addition, PCBs have been accumulated significantly over controls by the sand worm, *Nereis*, in nearly half of the tests (Suszkowski and Mansky 1981). While it is clear that certain contaminants are accumulated by the test organisms, the ecological implications of these accumulations are equivocal.

In an attempt to place the biomaccumulation test results in the proper ecological perspective, the North Atlantic Division of the Army Corps of Engineers developed an Interpretive Guidance for Bioaccumulation (NACOE, 1981). This document is the source of the matrix of concentrations given in Table I-4. The authors of the Interpretive Guidance recommend that to prevent significant additional ecological stress in New York Bight, bioaccumulation of the contaminants shown should not exceed the matrix levels. As its title indicates a great deal of interpretive judgement is required to arrive at the appropriate matrix of contaminant bioaccumulation levels and these judgements are subject to much disagreement among the agencies and individuals involved with dredging in the New York area.

Recognizing fully the limitations and subjectivity of the interpretation of bioassay-bioaccumulation test results, a dredged material classification scheme has been devised for the purposes of this report to group dredging projects based on the current criteria. New York dredging projects have been divided into three groups based on the criteria given in Table I-4. Group I projects are those that have failed any part of the criteria at least once. Since some projects have been tested several times with different results, any one failure, even if it is followed by a pass, is sufficient to place the project in Group I. In the case of private dredging, where many separate locations may be dredged, if any one site fails the criteria then all private dredging bordering that federal project is placed in Group I. Projects that do not fail the criteria but which exhibit bioaccumulation results exceeding the matrix standards for one or more test species are placed in Group II. All other projects are placed in Group III. Results of this classification are given in Table I-5. The locations of projects failing the criteria (Group I) are shown on Figure I-6.

A second dredging project classification scheme was devised utilizing the results of the elutriate test. Elutriate test results are reported for the liquid phase of the bioassay-bioaccumulation test as part of the required dredged material testing and results have been included on testing summary sheets maintained by the N.Y. district of the Corps. These measurements have been used here to rank projects based on contamination as measured by the elutriate test. The basis of this ranking is an index of the form,

$$I_e = A(PCB) + B(Hg)$$

where A and B are factors to indicate the relative toxicity of concentrations of PCBs and mercury. These two contaminants are the only ones included in the index because they are the only contaminants of those for which elutriate data has been compiled that exceed

Table I-5

Classification of Projects Using Bioassay - Bioaccumulation Results

Group I - projects failing criteria at least once

Project Name		Avg. Annual Dredging ($10^3 yd^3$)	
Hudson R. Battery - Weehawkin (Private)	HRBW(P)	601	
Passaic River	PAS	117	
Raritan River	RR	334	
Hudson R. Weehawkin - Edgewater (Private)	HRWE(P)	2	
Newark Bay	NB	284	
East River	ER	16	
Kill van Kull	KK	114	
Arthur Kill (Private)	AK(P)	195	
Newtown CK.	NTWN	13	
Gowanus Bay	GWB	78	Group I
Navy Terminal	NTML	150	Total = 1904

Group II - projects passing criteria but exceeding matrix limits

Brooklyn Navy Yard	BKLNY	56	
Flushing Bay	FLSH	19	
East River Spur Channel	SPUR	14	
Bay Ridge - Red Hook Channel	BRRH	719	
Shooter's Island Channel	SHTR	111	
Upper Bay	UB	171	
Buttermilk Channel	BMLK	252	
Raritan Bay Channel	RB	930	Group II
Harlem River	HRLM	13	Total = 2285

Group III - all other projects

Hackensack River	HCK	58	
Bronx River	BRX	26	
Westchester CK.	WCHST	62	
Arthur Kill (Federal)	AK(F)	71	
Sandy Hook Bay	SHB	138	
Hudson R. Battery - Weehawkin (Federal)	HRBW(F)	423	
Hudson R. Weehawkin - Edgewater (Federal)	HRWE(F)	594	
Eastchester CK.	ECHST	3	
Ambrose Channel	AMB	834	
Main Ship Channel	MSCH	129	
Sandy Hook Channel	SHCH	256	Group III
Jamaica Bay	JAMB	33	Total = 2627

current EPA water quality criteria (0.001 ppb for PCB and 2 ppb for Hg). One example of the ranking of projects using this index with A=2000 and B=1 is shown on Table I-6. The factors A and B reflect the relative toxicity of PCB and Hg based on the EPA standards given above.

The third dredging project classification scheme used here is based on available bulk sediment analyses. A major problem associated with ranking of projects using bulk sediment analyses is that measurements are not available for many projects. To obtain a complete ranking of projects it was necessary to estimate contaminant levels based on actual measurements from surrounding projects. All available bulk contaminant data were compiled first from N.Y. district Corps records and the scientific literature, and mean values for PCBs, Hg, Cd, As and Pb were computed for each project. These contaminants were selected because fairly extensive measurements are available and because they fall within the categories of concern outlined by O'Conner and Stanford (1979). Based on these measured mean values and particle size data for the project with missing data, mean values were estimated for all projects lacking data. The values obtained are given in Table I-7.

A bulk contamination index of the form,

$$I_B = A(PCB) + B(HG) + C(CD) + D(AS) + E(PB)$$

was used to rank the projects in New York Harbor. As in the case of the elutriate index, the letters A through E are meant to indicate the relative toxicity of the various contaminants. Unfortunately, it is

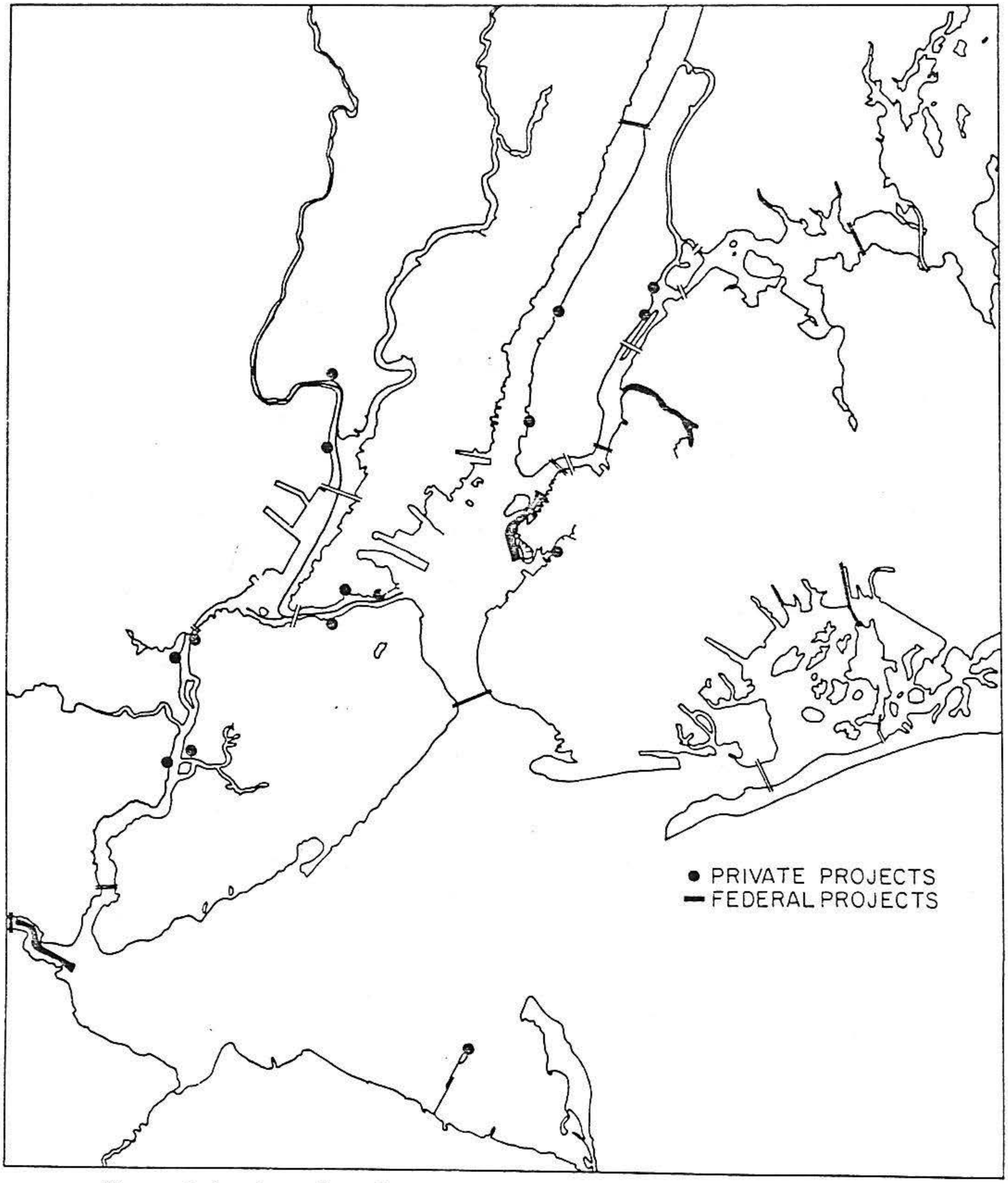


Figure I-6. Location of projects failing bioassay-bioaccumulation criteria

Table I-6

Ranking of Projects using Elutriate Index

	Project Name	Value of Index	Cumulative Annual Dredging ($10^3 yd^3$)
1)	East River Spur Ch. (SPUR)	920.8	14
2)	Shooter's Island Ch. (SHTR)	540.3	125
3)	Upper Bay (UB)	340.3	296
4)	Brooklyn Navy Yard (BKLNY)	340.2	352
5)	Gowanus Bay (GWB)	300.3	430
6)	Kill van Kull (KK)	240.0	544
7)	Bay Ridge - Red Hook (BRRH)	200.0	1263
8)	Passaic River (PAS)	180.2	1380
9)	Hudson R. Weehawkin - Edgewater (HRWE)	160.2	1976
10)	Buttermilk Channel (BMLK)	120.3	2228
11)	Hackensack River (HCK)	120.2	2286
12)	Arthur Kill (AK)	120.2	2552
13)	Raritan Bay (RB)	120.0	3482
14)	Newark Bay (NB)	80.0	3766
15)	East River (ER)	0.4	3732
16)	Hudson R. Battery - Weehawkin (HRBW)	0.4	4806
17)	Newtown Ck. (NTWN)	0.3	4819
18)	Navy Terminal (NTML)	0*	4969
19)	Sandy Hook Bay (SHB)	0	5107
20)	Bronx River (BRX)	0	5133
21)	Harlem River (HRLM)	0	5146
22)	Flushing Bay (FLSH)	0	5165
23)	Westchester Creek (WCHST)	0	5227
24)	Eastchester Creek (ECHST)	0	5230
25)	Raritan River (RR)	0	5564
26)	Ambrose Channel (AMB)	0	6398
27)	Jamaica Bay (JAMB)	0	6431
28)	Sandy Hook Channel (SHCH)	0	6687
29)	Main Ship Channel (MSCH)	0	6816

*Index equal to 0 indicates contaminants below detection limits

Table I-7

Bulk Contaminant Levels

	(all concentrations in ppm)					
Project	PCB	HG	CD	AS	PB	% fines
Hudson River-Battery to Weehawkin	4.80	2.30	5.40	1.00	230	82
Raritan Bay	<0.10*	1.80	3.49	9.90	148	46
Ambrose Channel	<0.10	1.00	2.20	3.00	25	5
Bay Ridge - Red Hook	<0.10	3.10	4.80	6.80	234	58
Hudson River - Weehawkin to Edgewater	0.22	0.70	1.17	4.10	63	87
Raritan River	0.20	2.20	2.60	31.10	161	67
Newark Bay	<0.10	4.22	8.55	5.56	268	92
Arthur Kill	0.46	2.18	4.17	19.60	193	53
Sandy Hook Channel	<0.10	0.03	0.18	2.20	4	5
Buttermilk Channel	<0.10	2.20	6.10	1.90	239	39
Upper Bay	<0.10	1.23	1.63	10.38	77	34
Navy Terminal	<0.10	0.76	1.90	9.00	93	46
Sandy Hook Bay	<0.10	0.30	3.94	11.40	133	81
Main Ship Channel	<0.10	1.90	3.27	6.30	43	5
Passaic River	0.20	11.21	11.84	7.80	478	84
Kill van Kull	<0.10	4.33	8.33	30.80	368	57
Shooter's Island	0.90	9.29	18.76	10.19	400	53
Gowanus Bay	<0.10	1.14	3.58	0.20	108	48
Westchester Ck.	0.60	3.30	7.80	9.80	623	91
Hackensack R.	<0.10	3.76	6.60	20.40	238	77
Brooklyn Navy Yd.	0.20	2.00	6.00	6.00	400	92
Jamaica Bay	<0.10	1.00	1.00	3.00	6	10
Bronx River	0.15	1.50	4.00	4.00	300	70
Flushing Bay	0.20	2.00	6.00	6.00	400	86
East River	0.20	2.00	6.00	6.00	400	87
Spur Channel	0.20	2.00	6.00	6.00	400	82
Harlem River	0.15	1.00	3.00	3.00	200	13
Newtown Ck.	0.7	5.1	94.4	42.10	866	49
Eastchester Ck.	0.186	1.086	2.71	7.24	263	31

*underlined values are estimated

not possible to quantitatively rate the importance of these contaminants as measured by bulk analysis. Lacking better information, EPA water quality standards were used as an indication of relative toxicities. EPA standards as reported by Conner *et al.* (1979 p. C-44) are: PCB = 0.001 ppb, Hg = 2 ppb, Cd = 10 ppb, As = 50 ppb, Pb = 50 ppb which gives A 50,000, B = 25, C = 5, D = 1 and E = 1. The results of this ranking scheme are shown in Table I-8.

Since PCB measurements are unavailable for many projects, many of the rankings shown in Table I-8 are estimated. Because of this, a similar ranking with A=0, which eliminates PCB's from consideration, has been made based only on the more common trace metal measurements. This ranking is shown in Table I-9. The two lists (Tables I-8 and I-9) differ substantially indicating that PCBs are not well correlated with trace metals when compared on a project-by-project basis.

Combined with particle size analysis results the contaminant rankings described above can be used to separate dredging projects into classes based on their suitability for different types of disposal. A system consisting of four classes has been used here as an example.

Class I - projects of high contamination
Class II - projects of medium contamination
Class III - projects of low contamination
Class IV - projects of low contamination and a low percentage of fines

Projects falling in the clean sand category (Class IV) can be identified easily. There is a large gap, in the average percent fines from 13% to 31% (see Table A-4) and the projects below 13% fines are

Table I-8

Bulk sediment ranking with toxicity factors PCB=50,000 HG=25 CD=5 AS=1 PB=1

Project		Index Value	Average Annual Dredging (10^3 yd^3) Each Project	Cumulative
1)	HRBW	240315	1024	1024
2)	SHTR	45736	111	1135
3)	NTWN	36507	13	1148
4)	WCHST	30754	62	1210
5)	AK	23287	266	1476
6)	HRWE	11090	596	2072
7)	PAS	10825	117	2189
8)	BKLNY	10486	56	2245
9)	FLSH	10486	19	2264
10)	ER	10486	16	2280
11)	SPUR	10486	14	2294
12)	RR	10260	334	2628
13)	ECHST	9610	3	2631
14)	BRX	7861	26	2657
15)	HRLM	7743	13	2670
16)	KK	5548	114	2784
17)	NB	5421	284	3068
18)	HCK	5385	58	3126
19)	BRRH	5342	719	3845
20)	BMLK	5326	252	4097
21)	RB	5220	930	5027
22)	SHB	5171	138	5165
23)	GWB	5154	78	5243
24)	NTML	5130	150	5393
25)	UB	5126	171	5564
26)	MSCH	5113	129	5693
27)	AMB	5064	834	6527
28)	JAMB	5039	33	6560
29)	SHCH	5007	256	6816

Table I-9

Bulk sediment ranking with toxicity factors PCB=0 HG=25 CD=5 AS=1 PB=1

			Average Annual Dredging (10^3 yd^3)	
Project		Index Value	Each Project	Cumulative
1)	NTWN	1507	13	13
2)	PAS	825	117	130
3)	WCHST	754	62	192
4)	SHTR	736	111	303
5)	KK	548	114	417
6)	BKLNY	486	56	473
7)	FLSH	486	19	492
8)	ER	486	16	508
9)	SPUR	486	14	522
10)	NB	421	284	806
11)	HCK	385	58	864
12)	BRX	361	26	890
13)	BRRH	342	719	1609
14)	BMLK	326	252	1861
15)	HRBW	315	1024	2885
16)	ECHST	310	3	2888
17)	AK	287	266	3154
18)	RR	260	334	3488
19)	HRLM	243	13	3501
20)	RB	220	930	4431
21)	SHB	171	138	4569
22)	GWB	154	78	5647
23)	NTML	130	150	4797
24)	UB	126	171	4968
25)	MSCH	113	129	5097
26)	HRWE	90	596	5693
27)	AMB	64	834	6527
28)	JAMB	39	33	6560
29)	SHCH	7	256	6816

among the cleanest by any of the ranking methods. For the projects with greater than 31% fines, classification is more difficult since the ranking of these projects is quite variable depending on the contaminant measure used.

After a contaminant measure is chosen, one is faced with the problem of deciding where to draw the line between classes. As discussed previously, any ecologically based criteria would be equivocal because of the lack of predictive understanding of ecosystem responses to disturbances. However, regulatory criteria do exist for the bioassay-bioaccumulation test even though they are subject to considerable interpretation. Using the bioassay-bioaccumulation criteria as a basis for classification, projects have been separated into three groups. Classification using a four class system as described above is then a simple matter. A map showing the location of projects in each of the four classes is given in Figure I-7.

The other contaminant measures do not have similar sets of established criteria for interpretation and action. For comparative purposes, classes dredged material volume roughly equal to the volumes associated with the bioassay-bioaccumulation classes have been made based on the other ranking methods. Maps showing the location of projects in each class are given in Figures I-8 through I-10.

A comparison of the results of each of the four dredging project ranking schemes was made and the results are shown in Table I-10. It is clear from the table that there is considerable disagreement among the results. The projects falling into Class I using each of the ranking methods are listed on Table I-11. A total of 19 out of the 29 projects evaluated, representing nearly 60% of the total average

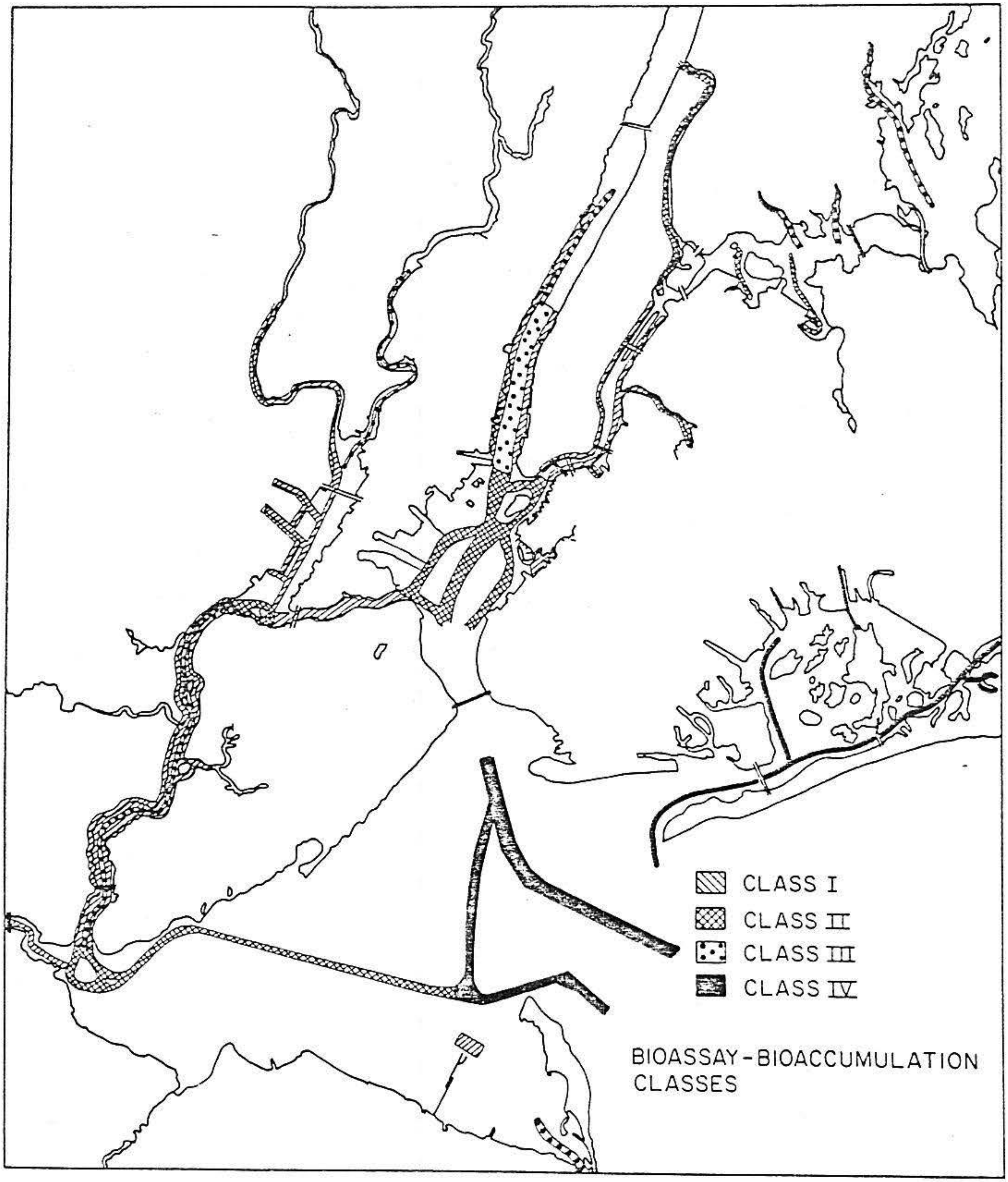


Figure I-7. Classification using bioassay-bioaccumulation test results

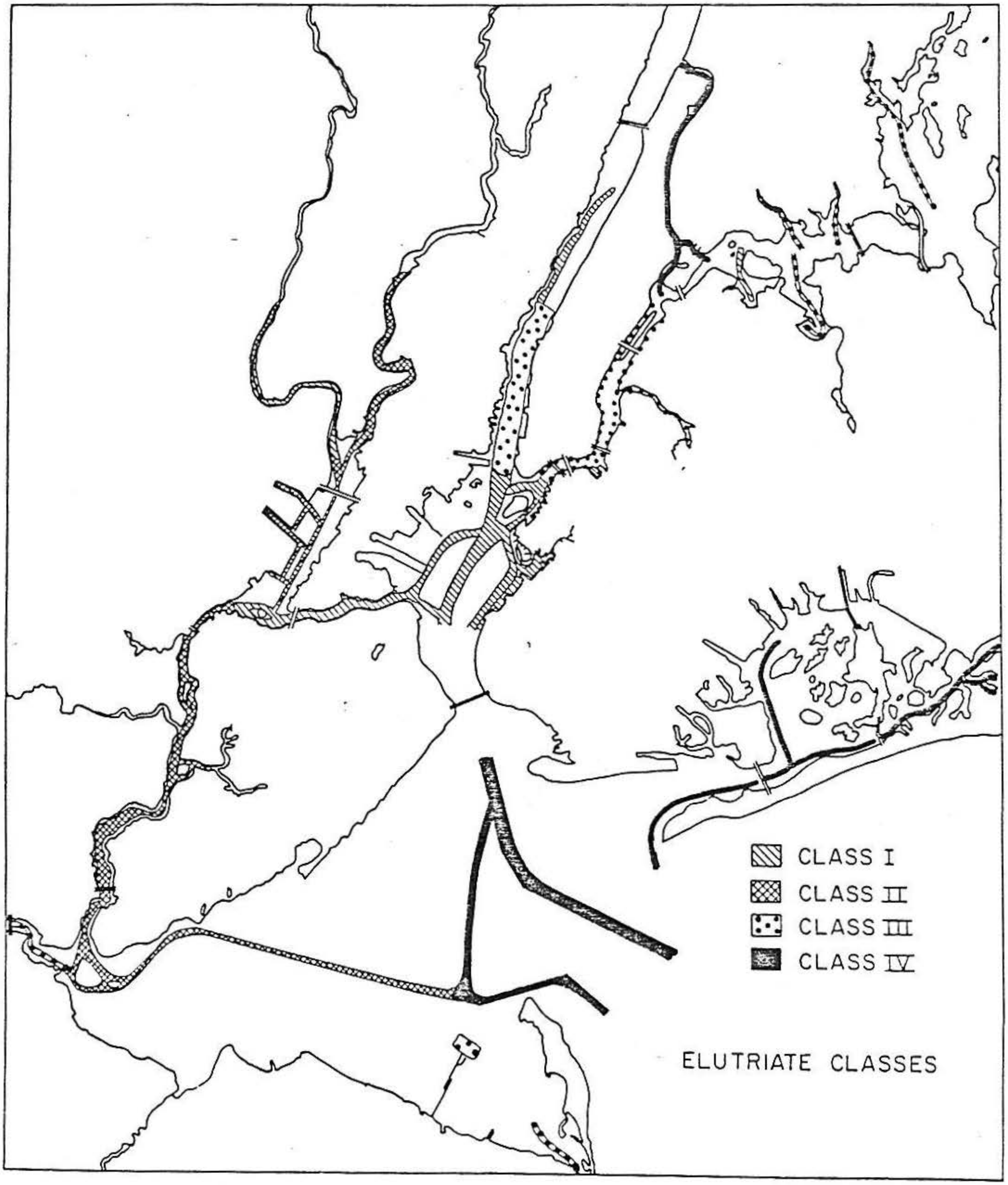


Figure I-8. Classification using elutriate test results

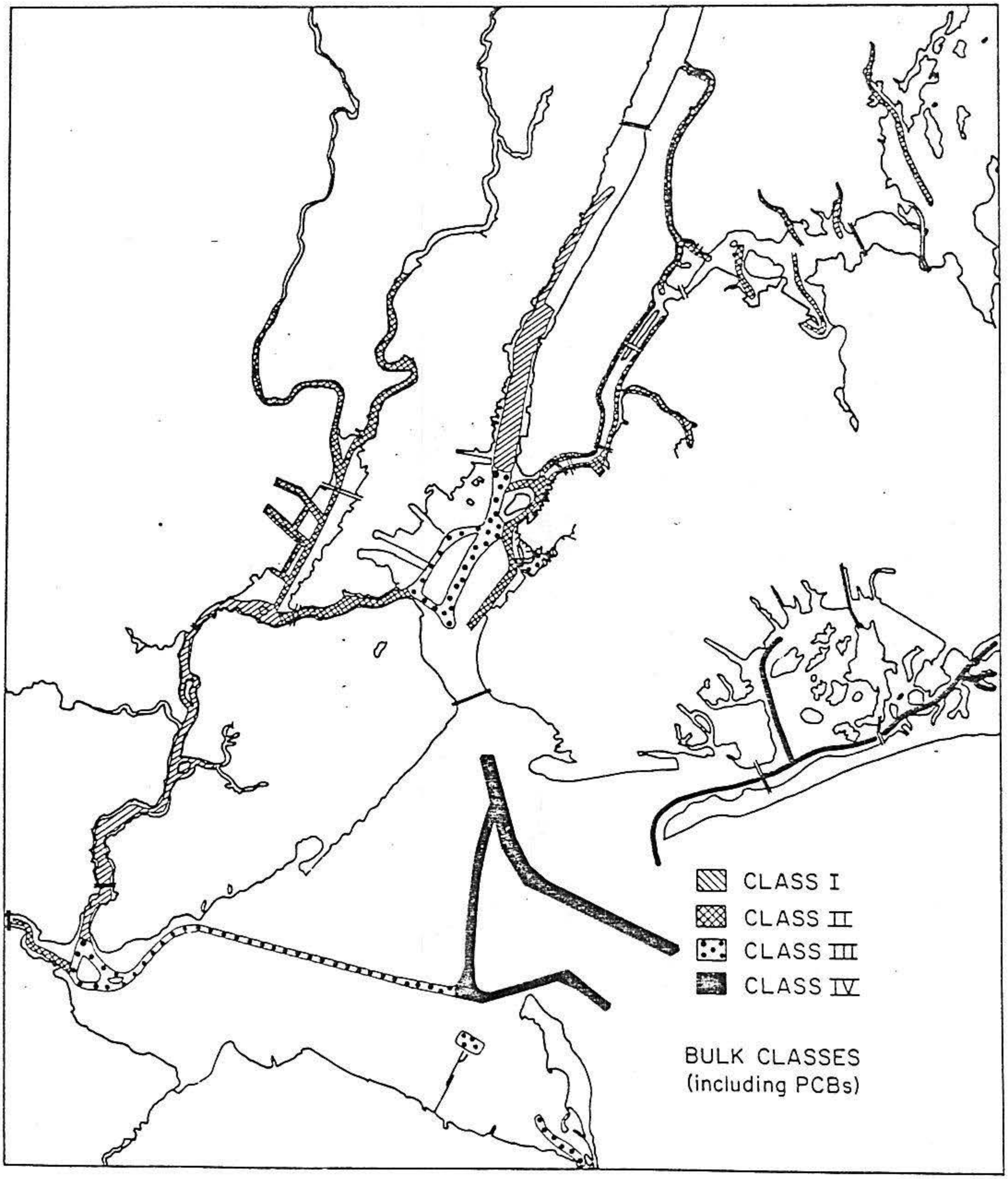


Figure I-9. Classification using bulk sediment test results including PCBs

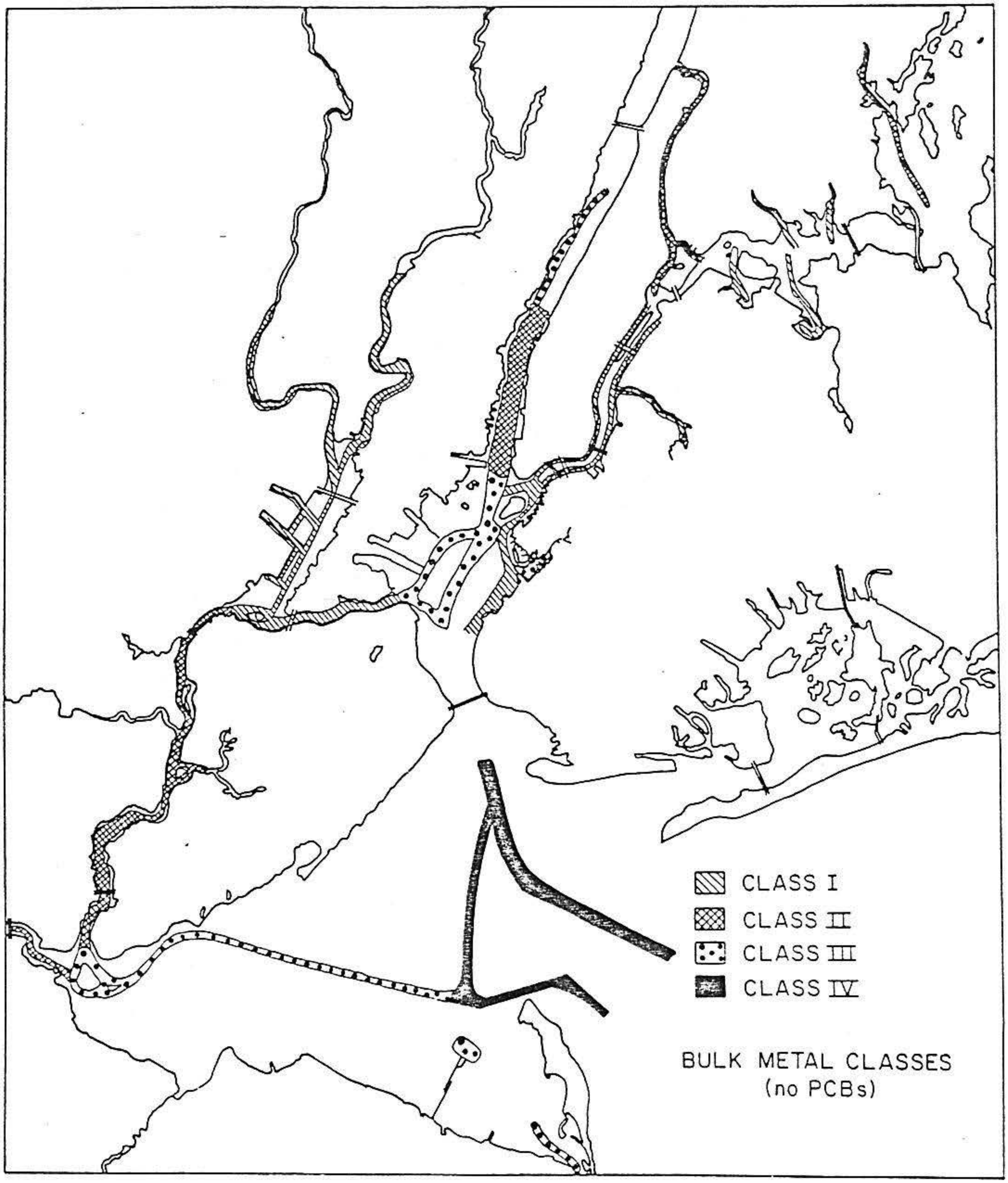


Figure I-10. Classification using bulk sediment tests excluding PCB's.

Table I-10

Comparison of different contaminant measures

Location	Avg. annual Dredging(10^3 yd^3)	Bulk metal contam.	Bulk PCB contam.	Elutriate contam.	Bioassay-bioaccum.
		(numbers are ranks using each method)			
1) HRBW	1024	15	1	16	I
2) RB	930	19	21	13	II
3) AMB	834	27	27	26	III
4) BRRH	719	13	19	7	II
5) HRWE	596	26	6	9	I
6) RR	334	18	12	25	I
7) NB	284	10	17	14	I
8) AK	266	17	5	11	I
9) SHCH	256	29	29	28	III
10) BMLK	252	14	20	10	II
11) UB	171	24	25	3	II
12) NTML	150	23	24	18	I
13) SHB	138	21	22	19	III
14) MSCH	129	25	26	29	III
15) PAS	117	2	7	8	I
16) KK	114	5	16	6	I
17) SHTR	111	4	2	2	II
18) GWB	78	22	23	5	I
19) WCHST	62	3	4	23	III
20) HCK	58	11	18	12	III
21) BKLNY	56	6	8	4	II
22) JAMB	33	28	28	27	III
23) BRX	26	12	14	20	III
24) FLSH	19	7	9	22	II
25) ER	16	8	10	15	I
26) SPUR	14	9	11	1	II
27) HRLM	13	19	15	21	II
28) NTWN	13	1	3	17	I
29) ECHST	3	16	13	24	III

Table I-11

Projects falling into class I using various ranking methods

Project	Class I for:				Cumulative Quantity Dredged ($10^3 yd^3$)
	Bioassay-bioaccumulation	Elutriate	Bulk PCB's	Bulk metals	
NTWN	X		X	X	13
PAS	X	X		X	130
HRWE (private)	X	X	X		132
KK	X	X		X	246
SHTR		X	X	X	357
NB	X			X	641
ER	X			X	657
AK (private)	X		X		852
HRBW (private)	X		X		1453
GWB	X	X			1531
SPUR		X		X	1545
HRWE (federal)		X	X		2139
BKLNY		X		X	2195
BRRH		X		X	2914
WCHST			X	X	2976
RR	X				3310
NTML	X				3460
UB		X			3631
AK (federal)			X		3702
FLSH				X	3721
BRX				X	3747
HCK				X	3805
BMLK				X	4057
HRBW (federal)			X		4480

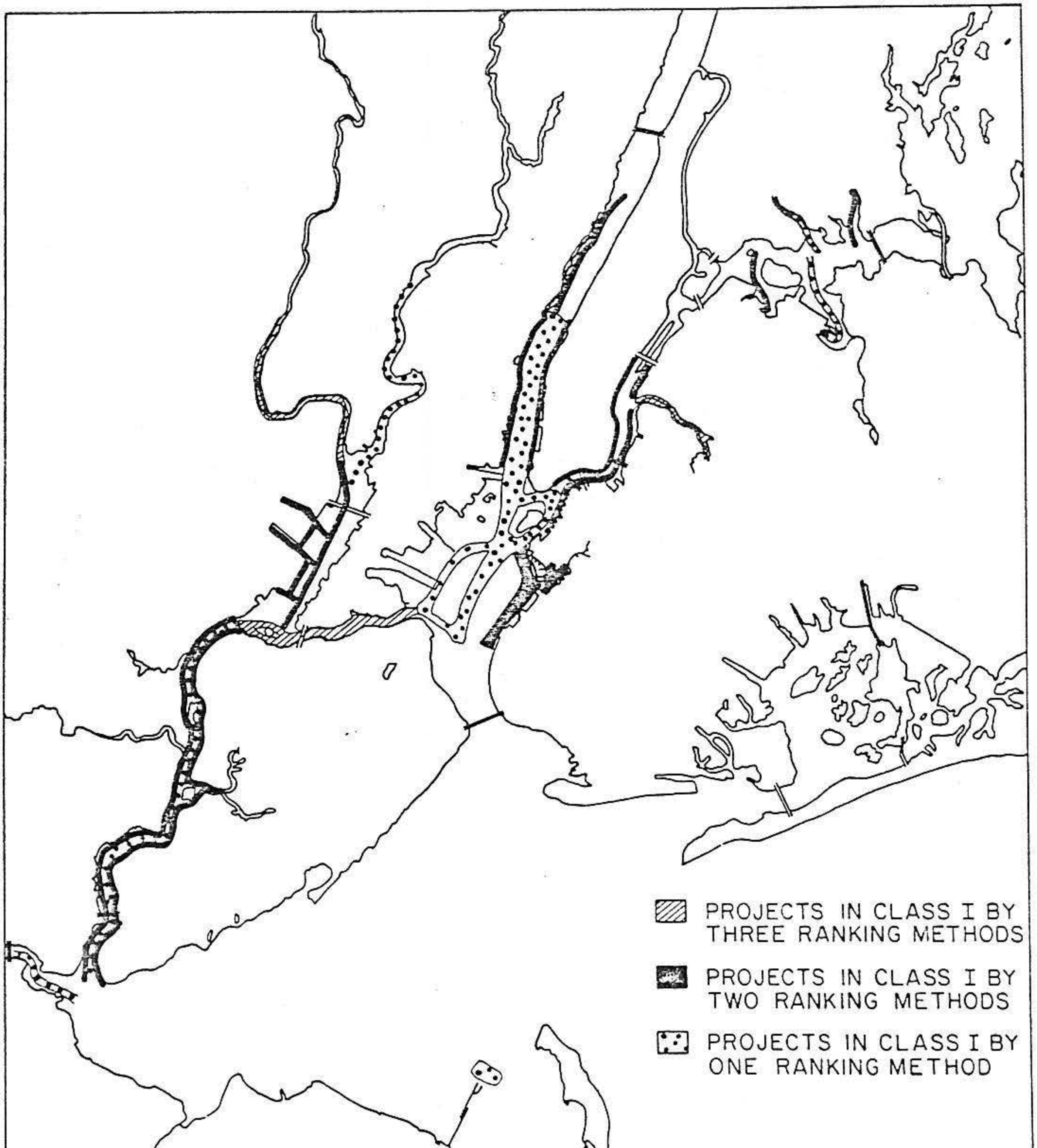


Figure I-11. Classification based on all four methods annual maintenance dredging, is placed in Class I by at least one method. However, not a single project was assigned to Class I by all four methods. Table I-11 suggests another way of classifying dredging projects based on the number of times a given project was assigned to Class I. The results of this classification are shown in Figure I-11.

Conclusions

Based on our analysis of the data, we conclude:

1) The quantity of material dredged from various projects in the Port of New York and New Jersey is subject to some uncertainty because of the lack of consistent measurement techniques and data reporting.

2) Dredging work is not based solely on shoaling rates since economic and environmental constraints may limit work. This makes predictions of shoaling rates highly uncertain when based on reported dredging work.

3) The physical characterization of materials dredged in the past from various projects is constrained by limited historical data on particle size distribution and water content.

4) Characterization of contaminant levels and contamination potential of dredged material is constrained by several factors:

a) Historical data are limited because measurement techniques and test procedures for assessing contaminant levels and contamination potential of dredged materials have changed; and consequently there is no single set of consistent and comparable data for the entire Port.

b) Different contaminant measures give widely varying results and in some cases the same test performed for different sites or by different labs does not give reproducible or comparable results.

c) The interpretation of test results is controversial because of to the complexity of the issues and a lack of understanding of the ecological implications.

It must be recognized that none of the classification schemes described above is entirely satisfactory for scientific or regulatory purposes. Serious objections can be raised for all of them. Our analysis illustrates the complexity of the issues involved that judgements will have to continue to be made in the face of uncertainty and with incomplete data and information. Our analysis indicates some areas of research that could contribute to management of dredged materials.

Economic Evaluation of Dredging Projects

Introduction

The preceeding analysis of dredging projects permits us to target those projects which present the most serious environmental risks. However, the economic importance of these projects must also be taken into account when considering which projects may be candidates for reductions in dredging. Prior to any additional dredging work, maintenance or new, a detailed cost-benefit analysis may be warranted on a case-by-case basis. Preliminary analysis can show which projects clearly are of great economic importance and could not be eliminated without substantial economic impact. Other projects may not be as important and should be evaluated further.

The purpose of the following portion of this report is to identify the borderline projects in New York Harbor, those with a combination of highly contaminated sediments and limited economic importance. The economic importance of a particular project involves many factors which are interrelated, often in a complex way. In addition, even if a project is underutilized at present, the future development options for the area must be considered before abandoning that project. A thorough treatment of all the issues involved is far beyond the scope of this report. However, it is possible to provide a preliminary analysis to separate those projects which are clearly of such enormous economic importance that any reductions in access would be "unacceptable" from those that are borderline and could possibly be considered as candidates for reduced maintenance dredging. This approach permits quantification of the maximum "practical" reductions in dredging that can be realized by reducing or eliminating dredging of some projects.

Availability of Economic Data

As discussed earlier in this report (in Description of the Study Area, Ship Traffic and Economic Implications of Reduced Dredging), the economics of the port industry is very complex and its analysis is limited by the availability of appropriate statistics. When attempting to evaluate the economic importance of individual portions of the waterways, tabulated statistics are limited even more severely. For example, shipping statistics are not tabulated separately for each waterway. Table I-12 is a summary of available statistics for cargo transport and delivery on a project-by-project basis. Major projects

Table I-12 Ranking of projects in terms of cargo handled (USACE, 1978)

			Million Tons of Cargo:		
	Project Name		Landed	Through	Total
1)	Upper Bay Channels		20.3	123.9	144.2
2)	Kill van Kull				
3)	Shooter's Is.	NY & NJ	92.9	28	120.9
4)	Arthur Kill	Channels			
5)	Raritan Bay				
6)	Ambrose Ch.				
7)	Main Ship Ch.	Lower Entrance			
8)	Sandy Hook Ch.	Channels	0	106.5	106.5
9)	East River		20.4	29.6	50.0
10)	Battery to Weehawkin	Hudson			
11)	Weehawkin to Edgewater	River	20.9	21.4	32.3
12)	Newark Bay		14.0	12.7	26.7
13)	Passaic River		8.9	0	8.9
14)	Bay Ridge-Red Hook		4.0	3.7	7.7
15)	Raritan River		7.6	0	7.6
16)	Jamaica Bay		7.2	0	7.2
17)	Newtown Ck		5.8	0	5.8
18)	Hackensack R.		4.3	0	4.3
19)	Gowanus Bay		3.5	.5	4.0
20)	Buttermilk Channel		1.9	.9	2.8
21)	Flushing Bay		2.2	0	2.2
22)	Eastchester Ck.		1.9	0	1.9
23)	Harlem River		.9	0	.9
24)	Westchester Ck.		.8	0	.8
25)	Bronx River		.5	0	.5

have been grouped together in some cases, preventing evaluation of their relative importance. Another limitation is the lack of information on the value of the cargo received by port facilities dependent upon access by a particular project. The Port Authority has tabulated these data on a port-wide basis, but they are not readily available for a project-by-project analysis. These are but two examples of data and information limitations; other data and statistics will be required for a more thorough analysis requiring an extensive research effort. The present preliminary analysis is limited to the available statistics.

Appendix B contains summary sheets describing each project and giving available shipping and dredging data. The descriptions and tabulation of port facilities were derived primarily from the U.S. Army Corps' Port Series No. 5, Port of New York and New Jersey (USACE, 1978). Shipping statistics were taken from Waterborne Commerce of the U.S. (USACE, 1978) and dredging statistics are from the analysis presented earlier in this report. Drawing upon these summaries and the preceeding environmental analysis of the dredging projects, each project is discussed in the following sections.

Dredging Project Evaluations

Bay Ridge-Red Hook Channel. The Bay Ridge-Red Hook Channel system is located in the Upper Bay (see maps in Appendix A) and provides access to the Brooklyn waterfront. Approximately 7.7 million tons of cargo pass through this project annually; 4.0 million tons is landed at the port facilities there with the remainder passing through to another destination. The Port Authority's Erie Basin Terminal is a major facility served by this channel. In terms of maintenance dredging requirements, Bay Ridge-Red Hook is the fourth largest channel in the Port. The sediments are contaminated according to our ranking scheme since the project was placed in Class I by 2 out of 4 of the classification schemes described previously. However, the project is not Class I for the bioassay-bioaccumulation test and qualifies for ocean disposal under the current criteria. Because of the volume of cargo that moves through the channel, the presence of an important PATH terminal and the fact that its sediments pass the current ocean disposal criteria, it is highly unlikely that reduced dredging of the channel would be cost effective. In addition, the future development prospects for the depressed Brooklyn waterfront could be seriously affected by the loss of deep water access.

Bronx River. The Bronx River Channel is of limited economic importance, serving only two-party boat facilities, a scrap metal facility and a sand and gravel facility. It is the smallest project in terms of tons of cargo landed (Table I-12), but also has one of the smallest maintenance dredging requirements. The project was assigned a Class I rating for the bulk metals analysis, indicating that there is some danger of contamination. Based on this information the project is a candidate for detailed cost-benefit analysis and possible reductions on dredging.

Brooklyn Navy Yard. Only two dry dock and vessel repair facilities currently are operating that are dependent upon this project. The dredged material is contaminated having been assigned Class I designation for both the elutriate and bulk metals analysis.

This project clearly deserves further study and should be considered for reduced dredging.

Buttermilk Channel. As can be seen in Table I-12 a relatively small amount of cargo (2.8 million tons) is moved through this channel, although PATH's Brooklyn Marine Terminal and five general cargo/container facilities are served by the channel. The Buttermilk project has a fairly large maintenance dredging requirement and there is some indication that the dredged material is contaminated based on the Class I rating it received for bulk metal analysis. However, since the dredged material is not highly contaminated relative to other projects and because it the presence of a major PATH cargo terminal and the prospects for future development, it is unlikely that reduced dredging of this project would be justified.

Eastchester Creek. Serving eight separate petroleum product facilities, this project is used primarily for deliveries by barge and small tank vessels. Over 84% of the incoming vessels had drafts between 8 and 10 ft., which is the maximum depth of the channel. Since its dredging requirements are very small and it is not Class I for any of the contaminant measures, it is unlikely that reduced dredging would be cost effective.

East River. Based on the ship traffic alone, it is clear that the East River is far too important to be considered for reduced dredging at present. Fortunately, its dredging requirements are relatively small although certain parts of the waterway have contaminated sediments.

East River Spur Channel. Ship traffic data are not available for this project, however, two petroleum facilities are served by the channel. The dredging requirements are fairly small and the sediments are moderately contaminated, having been assigned to Class I for the elutriate and bulk metals tests. Since so few facilities are accessed by the Spur Channel, it appears to be a potential candidate for reduced dredging.

Flushing Bay. Flushing Bay Channel handles roughly 2.2 million tons of cargo annually and nearly 50% of the vessels were at the maximum channel draft. The sediments were assigned Class I only for the bulk metal analysis and channel maintenance requirements are relatively small. In light of the available information, it is unlikely that reduced dredging would be justified.

Gowanus Bay. This project handles nearly 4 million tons of cargo annually. The most important products are petroleum and coal. In 1978, 37 large (33-35 ft.) draft tankers used the channel. The project is the focus of a recent report by the N.Y. District Army Corps of Engineers (NYACE, 1981) which recommends deepening of the channel. A major obstacle to any improvement of the project is failure of the sediments to pass the bioassay-bioaccumulation test. Material dredged from the channel can not be disposed of legally at sea, so alternatives must be found if the channel is to be dredged. Maintenance dredging also has been halted by the failure of sediments to pass the test criteria for ocean disposal and the lack of acceptable disposal alternatives. Given the quantity of cargo delivered and the presence of a major oil terminal on the project, alternative disposal sites probably will be identified to ensure at least the maintenance of present project dimensions.

Hackensack River. Although over 4 million tons of cargo were moved through this waterway, only 3 vessels over 18 ft. draft were reported in 1978. The channel is dredged to 30 ft., apparently unnecessarily deep, and reduced dredging may be justified.

Harlem River. This project carries a relatively small quantity of cargo, just under one million tons a year. Dredging requirements are small and the project has not been dredged since 1973. No bioassay-bioaccumulation tests have been performed because of the date of the most recent dredging. The only contamination test that has been done for this project is the elutriate test and the project is one of the least contaminated of those tested. Since the quantities dredged are small and the material is uncontaminated by available measures, it is unlikely that elimination of dredging is justified. If contamination becomes evident after further testing, this situation may change.

Hudson River Channels. The dredging data for the Hudson River Channel have been divided into two segments, Battery to Weehawkin and Weehawkin to Edgewater. Unfortunately, ship traffic data is combined for these segments. Based on the Army Corps' Port Series Vol. 5 for New York Harbor (USACE, 1978) descriptions of port facilities, it is possible to get some idea of the economic importance of each of the two segments. The Battery-Weehawkin portion of the channel supports many important facilities, including the Path Passenger Ship Terminal which requires deep water (∿42 ft.). The Weehawkin-Edgewater portion of the channel is 32 ft. deep and runs along the New Jersey shoreline. Naturally occurring deep water is found in the central and eastern part of the river. Therefore, the Weekhawkin-Edgewater Channel is necessary only for access to the New Jersey shoreline. None of the facilities operating there in 1978 required more than 20 ft. of water. All of the facilities, with the possible exception of a dry dock and repair facility, handle only tugs, barges, lighters and floating equipment and may not require even 20 ft. depth. The Weehawkin-Edgewater dredging requirements are large, 596,000 yd^3/yr, and the dredged material was assigned to Class I for both the elutriate and bulk PCBs contamination tests. Some private projects were assigned to Class I for the bioassay-bioaccumulation test as well. A careful review of this project is warranted based on this information, and it is possible that reduction or elimination of dredging in the Weehawkin-Edgewater Channel may be practical. The Battery-Weehawkin portion of the channel is quite important and is not a likely candidate for major dredging reductions.

Jamaica Bay. This project is used heavily for petroleum deliveries to Kennedy Airport (5.9 million tons/yr). Dredging requirements are fairly small (33,000 yd^3/yr) and the levels of contamination are low. Reduced dredging is unlikely.

Lower Entrance Channels. The Lower Entrance Channels include Ambrose, Main Ship and Sandy Hook Channels. Ship traffic data are not separated so it is not possible to easily distinguish among the channels. Ambrose Channel is the main entrance to the harbor and is vital to shipping. The Sandy Hook-Main Ship Channel route is used by large and unwieldy ocean tows and barges to avoid the heavily trafficked Ambrose Channel (Hammon, 1976). The dredging requirements are large but the dredged material is primarily clean sand and does not present a disposal problem. It is highly unlikely that dredging will be reduced here. In fact, several deepening proposals presently are being considered that would greatly increase dredging.

Newark Bay. The Newark Bay Channel is used heavily by deep draft container vessels bound to and from the Port Elizabeth-Port Newark Container Terminal. There are also 4 major petroleum facilities in Newark Bay. The channel system is being considered for widening and deepening and is the subject of a recent report by the New York District Army Corps of Engineers (NYACE, 1980). The project most likely will be a candidate for increased rather than for reduced dredging.

Newtown Creek. This project is used primarily by petroleum barges. There are 12 separate petroleum facilities but only the facility located near the mouth of the Creek is considered major (Hammon, 1976). A relatively large amount of cargo passes through the channel (Table I-12). The dredging requirements are fairly small, however, the sediments are highly contaminated, having been assigned to Class I by all techniques except the elutriate test. The project is in need of maintenance dredging, but a suitable disposal site is not available and maintenance has been delayed. Because of the highly contaminated sediment, it is possible that dredging of this project could be discontinued. This would require moving or closing the facilities now dependent upon the channel.

New York and New Jersey Channels. These channels include the Kill van Kull, Shooters Island Channel, Arthur Kill and Raritan Bay Channel. The Kill van Kull and part of the Shooter's Island Channel are necessary for access to the Port Newark-Port Elizabeth Terminal and four major petroleum terminals on Newark Bay. Three other major petroleum terminals are located on Kill van Kull. These channels, along with Newark Bay, are being considered for deepening and widening which would result in increased dredging requirements (NYACE, 1980). Given the high levels of traffic these channels support, any dredging reduction is highly unlikely. Arthur Kill supports 15 major petroleum facilities (Hammon, 1976) so it is unlikely that dredging will be reduced here either.

Raritan Bay Channel completes the loop that makes up the New York and New Jersey Channel system. It provides an alternative route to access the Arthur Kill petroleum facilities and provides access to the Raritan River. Although its dredging requirements are large, the sediment is relatively uncontaminated. A major benefit of the channel is to improve ship traffic safety by reducing traffic over the northern route, thereby, reducing the risk of collisions and resulting spills. Increased safety, combined with shorter travel time to the Arthur Kill facilities and the Raritan River, probably justifies the present levels of dredging.

Passaic River. This project supports many small petroleum terminals and a large refinery near the river mouth. Approximately 8.9 million tons of petroleum products and other material is transported over the waterway each year, most in shallow draft vessels. Only 14 vessels with drafts greater than 30 ft. used the channel in 1978. The sediments are highly contaminated (Class I for all but bulk PCBs) and any reduction in dredging would be beneficial. It may be possible to allow the channel to shoal somewhat without seriously affecting shipping since so few deep draft (≥30 ft.) vessels use the channel, but the channel will continue to require maintenance dredging at some level.

Raritan River. Approximately 7.6 million tons of cargo are moved over this water annually. In 1978, 34 inbound and 52 outbound vessels of 20-25 ft. draft used the channel. This is roughly 2 vessel trips a week by vessels which require either the maximum channel depth, or most of it. The dredging requirements for this project are fairly large and the dredged material is Class I for the bioassay-bioaccumulation test. It is likely that the project would not qualify for ocean disposal having failed the current criteria. It may be possible to reduce the project depth, but eventually dredging will need to be continued if the petroleum facilities are to remain open.

Upper New York Bay. This project handles more cargo and ship traffic than any other project in the port. Any reductions in dredging would create safety hazards that would not be acceptable. In fact, part of the Upper Bay project in the vicinity of the Kill van Kull will be widened and deepened if proposed new work is approved (NYACE, 1980).

Westchester Creek. Westchester Creek Channel provides access to 3 petroleum facilities and handles only 0.8 million tons of cargo annually making it the second smallest project in terms of cargo handled. Dredging requirements are fairly large and the dredged material is moderately contaminated (Class I for both bulk PCBs and metals). Because it carries relatively little cargo but has a relatively large dredging requirement, this project is a good candidate for reduction or elimination of dredging after further analysis.

Conclusions

It must be stressed that our analysis of dredging projects is based on incomplete data and a more thorough review of each project is required before any changes should be recommended. The projects identified above as possible candidates for reduction or elimination of dredging are listed on Table I-13 along with the average quantity dredged on an annual basis. The total of these values represents the maximum possible reduction in dredging assuming all of these projects are eliminated. It is more likely that dredging only would be reduced in these projects, providing somewhat less reduction in dredging. Assuming these projects can be economically eliminated, the maximum possible reduction in maintenance dredging would be 791,000 yd^3, 11.6% of the total average annual maintenance dredging for the Port.

New dredging work presently in the planning stage, could overshadow the reductions discussed above. The Kill van Kull and Newark Bay projects are being considered for widening and deepening which would require 32 million yd^3 of new dredging and an undetermined increase in maintenance dredging (NYACE, 1980). The Gowanus Bay project is also being considered for enlargement requiring 400,000 yd^3 of dredging (NYACE, 1981).

Long range plans for new work also include two projects. One at Arthur Kill/Howland Hook would require removal of 16 million yd^3 of rock and hard pan, which has good potential for providing construction aggregate and thus does not present a disposal problem. The other project involves plans for a large coal terminal at Greenville-Bayonne and would require deepening of the Ambrose Entrance Channel and parts of the Upper Bay. Two project depths are under consideration, 45 or 60 ft., and depending upon the depth selected dredging requirements could be 30 to 100 million yd^3. The new dredged material is likely to be clean, virgin sediment that has not been exposed to significant contamination. However, any change in channel configuration or depth will affect future maintenance requirements by changing the way new sediment accumulates.

It is clear that significant reductions in dredging by the reduction or elimination of existing projects are not possible without some short-term economic sacrifice. By careful selection of sites for the relocation of port facilities or the construction of new facilities, dredging requirements and their environmental impacts can be minimized in the future. The result will be lower channel maintenance costs and reduced ship traffic constraints with their associated economic benefits.

Table I-13 Projects that may be candidates for reduction or elimination of dredging after further evaluation

Project	Average Annual Maintenance	
Bronx River	26,000	yd^3/yr.
Brooklyn Navy Yard	56,000	"
East River Spur Channel	14,000	"
Hackensack River	24,000	"
Hudson River (Weehawkin - Edgewater portion only)	596,000	"
Newtown Creek	13,000	"
Westchester Creek	62,000	"
Total*	791,000	"

[*] This represents the average annual reduction in dredging if the above projects are completely eliminated 11.6% of the average annual maintenance dredging 1966-80.

Hydraulic Modifications to Reduce Dredging

In some areas of the harbor it may be possible to affect the hydrodynamic characteristics of the waterway to shift the locus of sedimentation away from channel areas, thereby reducing the need for dredging. Such alterations in sedimentation patterns require a thorough understanding of the harbor's hydrodynamic and sediment transport characteristics to ensure the desired result. Because of the complexity of the problem, extensive research is vital to the success of any specific project. Up to the present, dredging has been the only answer to shoaling problems, although recently problems of dredged material disposal have prompted the search for other methods to control shoaling. Hoffman (1982) describes four techniques being tested presently to reduce slip shoaling. Examples of successful large scale efforts are lacking, however. This reflects in large part the poor understanding of the processes controlling shoaling.

Reducing Shoaling in New York Harbor

In the early 1960's the Corps of Engineers applied their physical model of the Hudson River estuary to the study of shoaling in the Lower Hudson navigation channels and adjoining berths. At that time, Panuzio (1963) reported that over 5.5 million yd^3 was being dredged annually from these slips and channels. Today dredging requirements have dropped to just over 1.5 million yd^3 largely because of abandonment of underutilized slips.

The model was used to test the performance of two different types of plans to reduce the amount and/or cost of dredging. The first approach employed large sediment traps to capture material in a single location in order to reduce the extent and frequency of dredging.

Thirteen different trap configurations were tested and the most successful reduced channel deposition by over 50% and slip shoaling by approximately 20-25% (Panuzio, 1963). However, the sediment trap option was never implemented. This probably is because it would only relocate and, perhaps, reduce dredging requirements but not eliminate them, and the anticipated savings in reduced dredging costs could not justify the expense of constructing the basin.

The second type of alteration studied involved the redistribution of sedimentation out of channel areas to sites where it would not have to be dredged. These options require more detailed understanding of the circulation patterns of the estuary. The model studies confirmed what we know about the Harbor's estuarine circulation: that when averaged over several tidal cycles, water tends to flow out (seaward) of the estuary in the upper layers and into the estuary in the lower layers. This causes sediment that is delivered by the river to be trapped in the lower estuary where the major shoaling problems exist.

Two factors peculiar to the Hudson tend to focus sedimentation in the area of the navigation channels by disrupting the two layer flow pattern. One is a bathymetric constriction in the channel in the vicinity of the George Washington Bridge; the other is the incoming tidal flow of the Harlem River. Rather than having the landward flowing bottom water carry its sediment further upstream, these two factors introduce turbulence which cause redistribution of the sediment throughout the water column and transport back downstream (Simmons and Bobb, 1965).

The physical model was used to test the effect of removing the constriction and controlling the Harlem River flow into the Hudson. Removal of the constriction at the George Washington Bridge was tested using seven different plans requiring from 5.0 to 10.8 million yd^3 of dredging. The most successful plan would require 7.1 million yd^3 of dredging and construction of a 13,725 ft. long dike parallel to the shore from Fort Lee to Edgewater. The model predicted that this modification would reduce maintenance dredging by 30% in the channel and adjoining slips. Closure of the Harlem River during periods when flow would normally be into the Hudson was predicted to reduce dredging a similar amount (Panuzio, 1963). Simmons and Bobb (1965) reported that when both modifications were tested together a 37% reduction in shoaling was observed.

The advantages of implementing these plans would be reduced shoaling. Although these experiments were done with 1960's shoaling data, if we assume the proportional reduction in shoaling remains the same, today's dredging load could be reduced by about 0.5 million yd^3/yr by either plan or it could be reduced by about 0.6 million yd^3/yr if both were implemented. The disadvantages include the fact that 7.1 million yd^3 of dredging and construction of a large dike would be required to implement George Washington Bridge plan and tide gates would have to be installed on the Harlem River. The cost of these alterations would be high. Combine the costs with the uncertainties associated with the model simulations and the advisability of implementation of either plan is questionable.

Based on 1960 dredging data, the reduction in dredging requirements would have been 1.4 million yd^3 for either modification alone, and 1.7 million yd^3 for the two modifications combined. Since 1960 the demand for dredging on the Lower Hudson has declined, particularly on the New Jersey side above Weehawkin. As a result, if the same modifications were made today, present dredging requirments would not be reduced as much as they would have been in 1960. Given that the proposed modifications apparently were not practical in 1960, it is unlikely that they would be practical today since benefits would be less significant.

Simmons and Bobb (1965) also described experiments to evaluate the effect of deepening the channels above the George Washington Bridge and the effect of realignment of the navigation channel below the Bridge. Neither plan showed significant potential for reduced shoaling.

Reducing Shoaling in Slips

Panuzio (1963) discussed experiments designed to test several plans for reducing shoaling in slips. Techniques investigated included a submerged dike across a slip entrance, an air screen across a slip entrance and an air bubble turbulence generator within the slip. The first two techniques are designed to reduce the amount of sediment entering the slip, and the last technique is designed to suspend sediment in the slip during the ebb tide so it is carried out. The most successful plan reduced dredging requirements by 17% and involved a submerged dike at 35 ft. below mean low water. Use of an air bubble turbulence generator within a slip was nearly equal in efficacy with a 15% reduction in dredging requirements.

The success of the submerged dike plan depends upon the way sediment is transported into the slip. According to Panuzio (1963), sediment is carried into the slip on the flood tide in the bottom layers because of the predominance of bottom water flood tide in the estuary. Thus the sill prevents the entry of the most heavily sediment-laden waters during the flood phase of the tide.

More recently, Hoffman (1982) described research by the U.S. Navy to reducing slip shoaling. He discussed four techniques. Water jets have been used to flush a slip on ebb tide and applied to a berth in the Mare Island Ship Yard, Vallejo, CA. Problems with slumping and disruption of the system by ships anchors have caused them to re-evaluate the design. Silt curtains that collapse to the bottom to permit ships to enter are also being tested at the Mare Island Ship Yard and are being considered for use in the Port of Rotterdam, Holland. It has been predicted that such a curtain in Rotterdam would reduce maintenance dredging requirements by 30% (Hoffman, 1982). Another device, which has been used to prevent shoaling of Rudee Inlet, Virginia Beach, VA, is an eductor. The eductor works on the principle of the Venturi tube, where constriction of flow through a tube creates a vacuum. As a result, sediment is sucked into the eductor and passed through a pipe out of the channel or slip (Hoffman, 1982). The final technique discussed by Hoffman (1982) is agitation dredging, where sediment is suspended by propeller wash or other physical disturbance during periods of favorable flow conditions. In this way, sediment is carried to other less troublesome areas. The Portland, OR, District of the Corps has been experimenting with a modified twin-prop LCM vessel and the technique shows promise.

Conclusions

Design and implementation of control measures to redistribute shoaling patterns are limited by our understanding of hydrodynamics and sediment transport processes and by our understanding of specific estuarine sediment systems. The larger and more complex the system the more difficult it is to develop a workable control measure with predictable consequences. The Port of New York and New Jersey encompasses one of the most hydrodynamically complex systems in the U.S. As a result, it is not possible at the present time to design sediment control measures to significantly and predictably reduce dredging on a large scale.

There is an excellent opportunity to reduce dredging requirements through control measures in the numerous berths and slips that are maintained around the harbor. A prime example is the Port Authority's Passenger Ship Terminal on the Hudson River. Over the past 5 to 6 years approximately 300,000 yd^3 of material have been dredged each year, and because of contaminant levels of this material has been a problem and will continue to be a problem. Numerous other berths could benefit from the sediment control measures discussed above. These techniques will not reduce the overall maintenance dredging requirement, however, since the sediments eventually end up somewhere else in the system.

PART II. CONTROL OF SEDIMENT AND CONTAMINANT INPUTS TO THE PORT OF NEW YORK NEW JERSEY

Sediment Sources to New York Harbor

To evaluate the effectiveness of sediment source controls in reducing the dredging requirement for the Port of New York and New Jersey, it was necessary first to quantify the various sources and to attempt to balance inputs with sinks to determine if the major sources have been estimated correctly. Major sediment inputs to the Port include its tributaries, urban runoff, municipal and industrial wastewater, shore erosion, *in situ* biological production, Long Island Sound and the Atlantic Ocean. Based on existing measurements of sediment inputs, it is clear that the Harbor and surrounding estuary are a trap for sediments introduced by rivers, Ocean and Sound. When all of the sources are totalled and compared with dredging volumes and deposition rates in areas surrounding the channels, a rough balance is obtained.

Tributaries

Because of the large variability of river flows and the larger variability in sediment loads, it is very difficult to obtain an accurate estimate of average annual fluvial sediment input. Available measurements generally span too short a period of time to encompass the full range of flows possible. It is well known that the majority of sediment is moved during floods which occur during a small percentage of the time (Meade, 1981). Such extreme events are difficult to measure and as a result their full impact has not been accurately determined. Another factor affecting the accuracy of sediment yield measurements is the difficulty in sampling the entire cross section of the river. Bed load transport in particular may be significantly underestimated when using suspended sediment measurements to calculate sediment yield.

Given these problems, it must be realized that available estimates of tributary sediment yields are subject to a large degree of uncertainty. Still, they are the best we have. Using U.S. Geological Survey (USGS) flow and suspended sediment data from water years 1975 through 1980, Mueller *et al.* (1981) calculated average annual sediment yields for the major rivers contributing to the estuary. For this period the estuary received an average annual sediment load of 1.387 x 10^6 metric tons (MT) (dry weight). The portion contributed by each major tributary is given in Table II-1.

Other estimates of the Hudson River sediment yield are in fairly close agreement with the values obtained by Mueller *et al.* (1981). Using USGS flow data and his own suspended sediment measurements, averaged over a tidal cycle at MP-18, Olsen (1979) estimated that 1.0 0.3 10^6 MT of suspended sediment are delivered annually to the lower Hudson estuary. A slightly lower estimate was obtained by Ellsworth (1982) using a different technique. Based on data from the New York State Erosion and Sediment Inventory (USDA-SCS, 1974), Ellsworth (1982) estimated that between 0.88 and 1.12 x 10^6 MT of sediment are contributed annually by the Hudson River.

Table II-1 Estimates of Annual Sediment Yields in Metric Tons (MT) for Major Tributaries to the Hudson-Raritan Estuary

Tributary	Mueller et al. (1982)	Olsen (1979)	Ellsworth (1982)
Hudson River	1.304×10^6 MT	$1.0 \pm 0.3 \times 10^6$ MT	$.876\text{-}1.12 \times 10^6$ MT
Passaic River	0.043×10^6 MT	-----	-----
Raritan River	0.024×10^6 MT	-----	-----
Others*	0.016×10^6 MT	-----	-----

* Hackensack, Elizabeth and Rahway Rivers

Waste Water

Mueller *et al.* (1982) provide the best available estimate of sediment discharges resulting from wastewater. They included data for 1979 and 1980 from NYC water pollution control plant operating logs, Interstate Sanitation Commission records and National Pollution Discharge Elimination system files. For the period of record 1979-80, Mueller *et al.* estimate a total annual suspended solids delivery of 248,000 MT. This is down from their earlier estimate of 317,000 MT/yr for the period 1970-74. The decrease reflects the upgrading of raw and primary treatment plants to secondary treatment.

Urban Runoff

The New York City 208 study (NYCDEP, 1978) provides the best data presently available to permit estimation of the contribution of urban runoff to sediment load to the estuary. Twenty-one drainage basins were sampled for 10 storms and one or two dry weather days. Both combined and separate storm sewers were included in the effort. Results were summarized by Mueller *et al.* (1982) who estimate that urban runoff contributes 175,000 MT of sediment annually to the estuary.

Biological Production

We were unable to find any published estimates of the amount of sediment introduced to the entire estuary by *in situ* biological production. Olsen (1979) estimated 420 $g/m^2/yr$ for the Upper Bay, while Suskowski (1978) estimated 8,800 MT produced over 19.17 km^2 of Newark Bay (459 $g/m^2/yr$). Using 640 km^2 for the area of the estuary below river inputs (Mueller *et al.* 1982), and assuming similar inputs for the entire area, these estimates give 0.27×10^6 MT and 0.29×10^6 MT respectively for the annual contribution of sediment to the estuary. Obviously, more data are needed to improve the accuracy of these estimates.

Shore Erosion

Sediment input resulting from shore erosion is not well characterized for most of the Harbor area although indications are that it is not a very important source of sediment to the system. For the lower Hudson River Ellsworth (1982) estimated that approximately 6,000 MT of silt and clay are introduced annually from the shoreline. His estimate is based on field surveys of the shoreline to determine the extent of bulkheading and natural rock outcrops which prevent erosion. Erosion rates have not been estimated for the Upper Bay although in his sedimentological survey of Newark Bay Suszkowski (1978) considers shoreline erosion an insignificant source of suspended material since most of the shoreline is bulkheaded. The Kills and Upper Bay are developed in a way similar to Newark Bay and thus we conclude that the inputs of sediment from shore erosion are insignificant.

The Lower Bay appears to be much more significant as a source of sediment from shore erosion, but it is difficult to estimate erosion rates because of the numerous beach nourishment and construction projects that have been carried out over the years. The best available estimates have been made by the N.Y. District of the Army Corps of Engineers in several separate studies. Coney Island lost about 100,000 MT/yr between 1961 and 1966 although nearly 50% of the total was the result of a single storm (NYD/COE, 1979). Staten Island lost approximately 159,000 MT/yr between 1836 and 1885 (NYD/COE, 1964). Since then shore erosion has not been estimated because of unknown amounts of beach nourishment. Around 82,000 MT/yr were lost from the New Jersey coastline of the Lower Bay over the same period, 1836 to 1885 (NYD/COE, 1960). Totalling the above estimates gives a shore erosion contribution to the estuary of approximately 347,000 MT/yr.

Long Island Sound

Accurate estimates of the quantities of sediment transported through the East River can not be made because of a lack of data. Jay and Bowman (1975) present the most detailed study of the East River to date. They calculated that the long-term average net transport of water is from Long Island Sound into the harbor with a flow of 240 to 340 m^3/sec. The in estimate is based on differences in the average tidal elevations at the Battery and Throgs Neck and takes into account the difference between ebb and flood cross sectional areas. Although advective transport normally is toward the Harbor, Jay and Bowman (1975) report that it may be toward the Sound for a month, or more, at a time. Actual flux calculations by various investigators compiled by Jay and Bowman range from 1100 m^3/sec into the Sound to 620 m^3/sec into the Harbor. However, the mean ebb and flood transport at Hell Gate is 125 x 10^6 m^3/tide which is equivalent to a flow of about 2,000 m^3/sec. Since net flux is so small relative to this, the authors concluded that the flux calculations are of questionable accuracy.

In a discussion of pollutant flux through the East River, Jay and Bowman (1975) describe the total flux as resulting from three components.

1) Advective flux is toward the Harbor on average.
2) Estuarine circulation results in the transport of surface waters toward the Harbor in the River above Hell Gate. Below Hell Gate the River is well-mixed.
3) Dispersive flux depends on the gradient and can not be quantified without more accurate data than are presently available.

Assuming that net advective flux controls sediment transport, Bokuniewicz and Ellsworth (unpublished manuscript) have used a value for net flow of 340 m^3/sec and 8 mg/ℓ as representative of the suspended sediment concentration to estimate that 86,000 MT of sediment annually enter the Harbor from Long Island Sound. However, based on a single transect of the East River in June 1981, (Hirschberg, unpublished data) suspended solid concentration decreases from 9-10 mg/ℓ in the Battery to Hell Gate portion of the River to 5 mg/ℓ at Throgs Neck. These data indicate that a dispersive flux of sediment into the Sound is possible. Obviously, more detailed information is needed to obtain a reliable estimate of sediment transport through the East River.

New York Bight

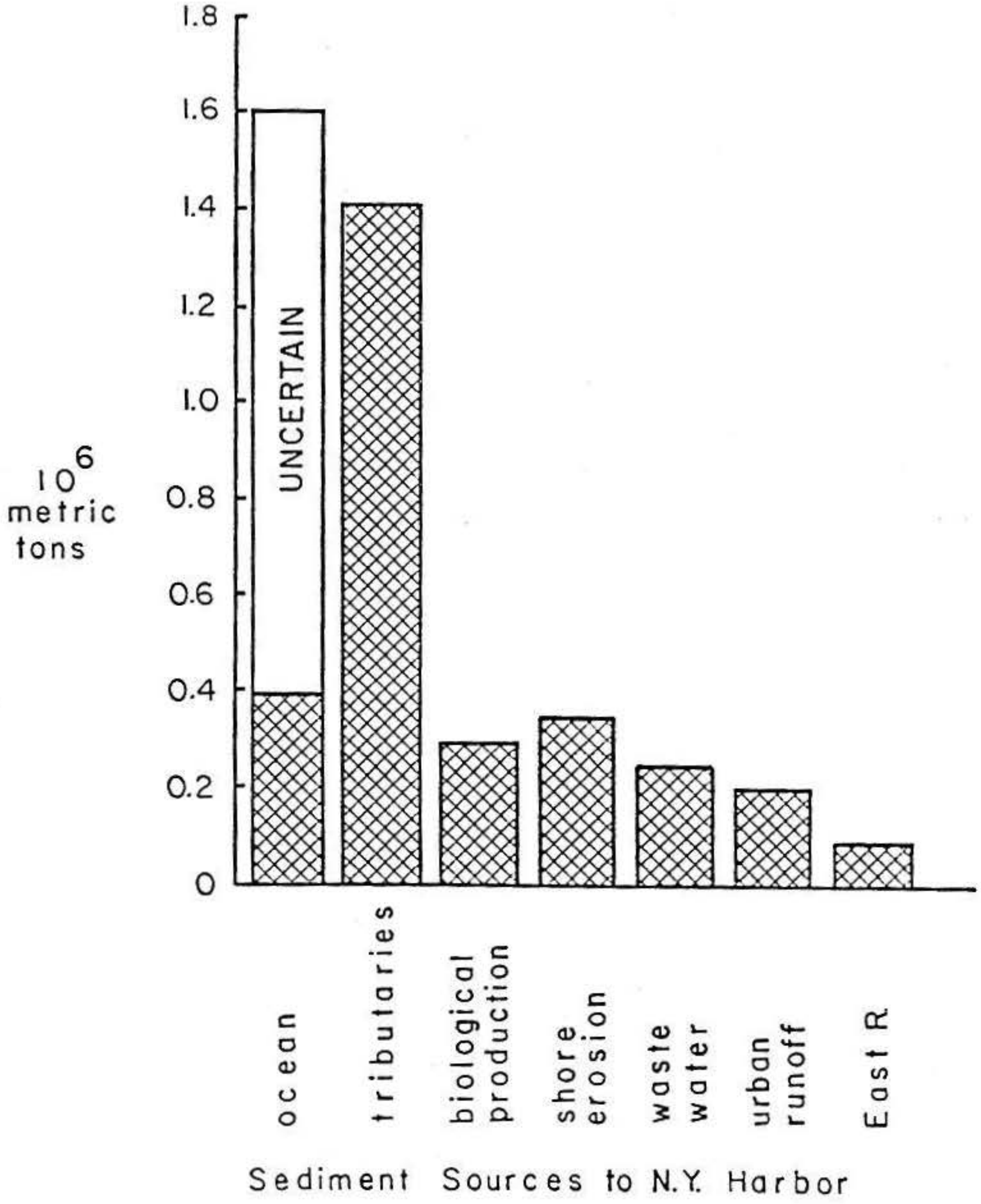
Swift *et al.* (in preparation) have made sediment flux calculations using two different data sets for the Sandy Hook - Rockaway Point Transect. Their calculations show that estimates of sediment flux range from 0.4 x 10^6 MT/yr out of the estuary to 0.7 x 10^6 MT/yr into the estuary. The average flux over the year is 0.4 x 10^6 MT/yr into the estuary. The authors caution that this estimate of net flux into the estuary is conservative and may be underestimated by as much as a factor of four because of a bias in the data toward fair weather conditions.

Olsen (1979) has arrived at an estimate for marine sediment input to the Upper Bay based on a plutonium mass balance using average $^{239,240}Pu$ activities on river suspended matter, surface sediments in the inner harbor and near shore marine sediments. He gives a best estimate for the annual flux of sediment into the Upper Bay of 0.25±0.25 x 10^6 MT/yr from marine and adjacent bay sources. Olsen states, however, that marine sources may range from 0 to 1.2 x 10^6 MT per year. The estimate of Swift *et al.* (in preparation) falls within this range.

Figure II-1 shows the relative amounts contributed by each of the sediment sources discussed above.

Sediment Sinks

Using data on the volumes dredged and the average water content of dredged material taken from each project, as presented in Section I of this report, we determined that approximately 4.4 x 10^6 MT of sediment are dredged each year for channel maintenance in the Hudson-Raritan Estuary. Of this total, approximately 1.4 x 10^6 MT/yr is sand removed from the Lower Bay Entrance Channels, primarily derived from littoral drift and bed transport from the N.Y. Bight and not included as a sediment source in the above estimate of transport



1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
10^6 metric tons
UNCERTAIN
ocean
tributaries
biological production
shore erosion
waste water
urban runoff
East R.
Sediment Sources to N.Y. Harbor

Figure II - 1

across the Sandy Hook - Rockaway Transect. Excluding this sand, approximately 3 x 10^6 MT/yr of sediment is dredged and removed from the Estuary.

A second sink for sediments within the Estuary is deposition in non-channel areas and wetlands. Based on sedimentation rates determined by Olsen (1979) for the Hudson River and Upper Bay and on sediment deposit thickness in Raritan Bay, Bokuniewicz and Ellsworth (in preparation) estimate that between 0.4 to 1.1 x 10^6 MT/yr is deposited in non-channel areas within the Estuary. Combined with dredging, this gives a total of 3.4 to 4.1 x 10^6 MT/yr of sediment stored or removed from the Estuary.

Sediment Budget Summary

The tabulated estimates of sources and sinks for sediment in the Hudson-Raritan Estuary are shown in Table II-2. The estimates are crude, but, they probably are reasonable representations of the relative magnitudes of the sources and sinks. Annual variations in the values are likely to be large because of dependence on weather and hydrologic conditions. Thus, within the accuracy of the available estimates it appears that the mass of sediment entering the Estuary either is stored or removed by dredging.

If we assume that all of the contributed sediment eventually is deposited within the estuary, then dredging accounts for between 71% and 100% of the sediment entering the Hudson-Raritan System. The range in values results from the large uncertainty in the contribution of sediment to the Lower Bay from the Ocean. Tributaries are the dominant sediment source, contributing 37% to 47% of the total, while

Table II-2 Sediment Budget for the Hudson-Raritan Estuary

Tributaries (Hudson, Raritan & Passaic)	1.4 x 10^6 MT/yr
Waste Water	0.25
Urban Runoff	0.2
In situ Biological Production	0.3
Shore Erosion	0.35
Total Internal Sources	2.5
Long Island Sound	.1
N.Y. Bight	.4 - 1.6
Total External Sources	.5 - 1.7
Total Suspended Sediment Input	3.0 - 4.2
Total Dredging	4.4
Sand Removed from Lower Entrance Channels not included in suspended sed. inputs	1.4
Total Dredging Excluding Sand	3.0
Sediment Deposition outside Channels	0.4 - 1.1
Total of Sediment Sinks	3.4 - 4.1

the Ocean may contribute 13% to 30% depending on the estimate used.

Sources of Contaminants to New York Harbor

Although contaminants frequently are linked very closely to sediments, with one notable exception the major sediment sources--the tributaries and ocean--are not the major source of contaminants to the sediments of the Harbor. Wastewater and urban runoff are the major sources of contaminants with the exception of PCBs, which are supplied approximately equal proportions by the tributaries and by wastewater discharges. Mueller *et al.* (1982) provide the most detailed summary available for sources of contaminants to the Hudson-Raritan Estuary. Table II-3 is taken from Mueller *et al.* (1982) and shows the total and relative contributions of the major sources of contaminants to the Estuary.

Sediment and Contaminant Source Reduction

Because the methods used to prevent sediments and contaminants from entering a waterway are so closely related, it does not make sense to discuss sediment and contaminant source reductions separately. For example, improved soil conservation practices are a primary means of reducing erosion and, therefore, sediment inputs. They also reduce contaminant inputs from excess fertilizer (nutrients), pesticides, and herbicides. In urban areas, street cleaning is an effective control of both sediment and contaminants introduced to the waterways in urban runoff. These are only two examples of controls that can be effective in reducing both sediment and contaminant inputs. The following sections of this report discuss

Table II-3 Total contaminant budget from Mueller et al. (1982)

HUDSON-RARITAN ESTUARY
TOTAL MASS LOADS[a]

Constituent	Total Mass Load (metric tons/d)	% Contributed By Each Source					
		Wastewater	Tributaries	Urban Runoff	Atmospheric	Accidental Spills	Landfill Leachate
Flow (m^3/s)	1,000	13	78	6.9	2.5	-	0.04
SS	5,000	14	77	9.7	-	-	0.2
BOD	1,000	71	9.7	18	-	-	0.9
TOC	1,400	51	34	13	-	-	2.2
NH_3-N	130	74	15	8.9	0.7	-	1.2
Org-N	140	66	19	14	-	-	0.7
NO_2-N	2.8	34	54	11	-	-	0.04
NO_3-N	64	10	79	7.2	3.1	-	0.2
Total N	340	61	26	11	0.9	-	0.8
Total P	41	66	27	7.1	-	-	0.05
Oil & Grease	350	48	12	34	-	6[b]	0.4
Fecal Coli[c] - Winter	1.5×10^5	73	0.3	26	-	-	negl.
- Summer	7.8×10^4	50	0.6	50	-	-	negl.

[a] Dashes indicate no data available, except for wastewater where constituents detected less than 90% of the time were excluded.

[b] Petroleum Hydrocarbons

[c] Coliform units are 10^{12} org./d.

Table II-3 (cont'd)

Constituent	Total Mass Load (kg/d)	% Contributed By Each Source Wastewater	Tributaries	Urban Runoff	Atmospheric	Accidental Spills	Landfill Leachate
Benzene	170	96	-	0.6	-	-	3.6
1,1,1 Trichloroethane	370	99.9	-	-	-	-	0.1
1,1,2,2-tetrachloroethane	6.3	-	-	-	-	-	100
Chloroform	140	92	-	4.4	-	-	3.9
1,2-Dichlorobenzene	49	99.9	-	-	-	-	0.1
1,1-Dichloroethylene	15	99.9	-	-	-	-	0.1
1,2-transdichloroethylene	21	99.9	-	-	-	-	0.1
Ethylbenzene	66	96	-	-	-	-	3.8
Fluoranthene	50	-	-	100	-	-	-
Methylene Chloride	930	99	-	0.6	-	-	0.4
Dichlorobromomethane	3.2-3.3	97-99	-	-	-	-	3-1
Trichlorofluoromethane	5.2	-	-	100	-	-	-
Dichlorodifluoromethane	27	-	-	-	-	-	100
Naphthalene	35	49	-	-	-	51	-
Pentachlorophenol	26	100	-	-	-	-	-
Phenol	70	80	-	11	-	-	9
Bis(2-ethylhexyl)phthalate	350-355	77-76	-	23	0.1-1.4	-	-
Butyl benzyl phthalate	41	73	-	27	-	-	-

Table II-3 (cont'd)

	Total	% Contributed By Each Source					
Mass Load		Urban		Accidental	Landfill		
Constituent	(kg/d)	Wastewater	Tributaries	Runoff	Atmospheric	Spills	Leachate
Di-N-Butylphthalate	56-61	89-82	-	11-10	0.35-8.2	-	-
Diethylphthalate	20	80	-	20	-	-	-
Anthracene	29	-	-	100	-	-	-
Phenanthrene	20.5	12	-	88	-	-	-
Pyrene	37	-	-	100	-	-	-
Tetrachloroethylene	530	99.8	-	-	-	-	0.2
Toluene	280	88	-	3.5	-	3.3	5.3
Trichloroethylene	300	95	-	-	-	3.6	1.1
Aldrin	0-1.0	-	*	-	-	100-97	0-3
Gamma-BHC (Lindane)	0.46-4.3	57-6.0	*	-	43-94	-	-
Chlordane	0.13-0.33	77-30	*	-	23-61	-	0-9
DDT	1.0-1.1	-	*	97-91	2.9-9	-	-
Heptachlor	0.2-4	-	*	-	100	-	-
PCB	11-14	44-34	45-41	8.9-6.8	1.9-14	-	0-4.1
Toxaphene	0.1-1.3	-	*	-	-	100-76	0-24

* Negligible or zero loads were estimated from sediment data. Water column data not available.

Table II-3 (cont'd)

Constituent	Total Mass Load (kg/d)	% Contributed By Each Source					
		Wastewater	Tributaries	Urban Runoff	Atmospheric	Accidental Spills	Landfill Leachate
Antimony	1,100	100	-	-	-	-	-
Arsenic	190-210	51-47	49-51	-	0.1-1.4	-	0.2-1.2
Beryllium	41-43	96-91	3.7-8.9	-	-	-	0.25-0.23
Cadmium	130-190	56-38	12-39	30-22	1.6-1.1	-	0.7-0.5
Chromium	2020-2040	50	37	12	0.5	-	0.2
Copper	3,400	52	28	20	-	-	0.19
Cyanide	990	99.8	-	-	-	-	0.20
Lead	2,800	39	29	29	3.5	-	0.26
Mercury	62-92	89-60	8.9-37	2.6-3.2	-	-	0.3-0.2
Nickel	1,700	55	20	23	1.2	-	0.3
Selenium	120-160	65-49	34-51	-	-	-	0.4-0.3
Silver	65-78	95-80	4.8-19	-	-	-	0.2-1.2
Thallium	350	100	-	-	-	-	-
Zinc	9,400	60	19	19	2.1	-	

some of the options for controlling inputs from the major sediment and contaminant sources.

Tributaries

Tributaries are the major source of sediments and PCBs to New York Harbor. Sediment is a natural product of erosion of the land surface, and is most commonly accelerated to some extent by human activities in the drainage basin. Sediment and associated contaminants supplied to the Harbor by the rivers can be reduced through soil conservation and other control measures, but they can not be eliminated. PCBs were introduced to the river over a number of years of wastewater disposal at two manufacturing facilities on the upper Hudson River. Much of the PCBs from these sources now reside in the sediments that line the river bottom. It is presently being debated just how the PCB problem can best be handled and it is still not certain how successful clean-up efforts through dredging would be. In this report the erosion problem will be dealt with first.

Erosion Control

In an erosion and sediment inventory for New York State (USDA-SCS, 1974) the Soil Conservation Service estimated that over 40 million MT of sediment is eroded annually. Their data are summarized in Table II-4. According to the report, proper conservation measures could reduce construction site erosion from 71.5 MT/ha/yr to approximately 6.7 MT/ha/yr. This would reduce total erosion by nearly 3%. If all cropland also were treated adequately with erosion control measures, erosion could be reduced by nearly 27%. The only other

Table II-4 New York State Erosion and Sediment Inventory (USDA-SCS, 1974)

Sheet Erosion Summary

	Ha ($x10^3$)	Average Soil Loss (MT/Ha/yr)	Total Soil Loss (10^3 MT/yr)
Cropland Adequately Treated	1,278	2.82	3,603
Cropland Needing Treatment	803	16.6	13,299
Orchards, Vineyards, Bush Fruits	61	7.25	442
Open Land Formerly Cropped	745	0.63	469
Pasture Land	579	2.23	1,290
Wood Land	6,707	0.97	6,537
Other Land	244	1.55	378
Federal Land	73	0.70	51
Urban Land	601	1.31	789
Construction Sites	19	71.5	1,358
Land not Contributing Sediment	891	---	---
Total	12,001	2.35	28,216

Bank Erosion Summary

	Bank length (km)	MT/km/yr	10^3 MT/yr
Roadbank	247,813	16.5	4,088
Streambank	212,349	41.3	8,756
Total	460,162		12,844
Grand Total			41,060

categories with the potential for major reductions in erosion are road and stream banks. However, the report (USDA-SCS, 1974) does not provide any means to estimate potential reductions in these areas.

A report by the Hudson River Basin Study Group (HRBSG, 1979) estimates that stream bank erosion could be reduced by 5% through implementation of appropriate protection measures in the Mohawk River Basin, where the problem is most severe. It is estimated that these measures would cost $1.2 million. An additional $2.6 million would be required for the remainder of the Hudson River Basin. Road Bank erosion protection is estimated to cost $85 million and the authors conclude that New York State can not afford basin wide protection against road bank erosion. Assuming that a 5% reduction in stream and road bank erosion were obtained, the overall reduction in erosion in the Hudson Basin would be approximately 28%.

Whether or not this 28% reduction in erosion could be achieved realistically and how it could be achieved is another question. Existing and potential erosion control programs are discussed in the New York State Water Quality Plan (NYDEC, 1981). The primary sources of sediment to the rivers of New York State are non-point sources arising from overland runoff, stream bank and road bank erosion. Other sources to the rivers include combined sewer overflows, waste treatment plant effluents and urban storm runoff. These sources are discussed in more detail in the following sections.

The non-point source program is an important part of the overall State Water Quality Plan. Sediment control is its primary focus, although nutrients and pesticides are of concern as well. The New

York State Department of Environmental Conservation (DEC) intends to attack the problem through improved land use management procedures. Their strategy has four objectives: 1) to better define the magnitude and extent of non-point source pollution and identify control measures with significant potential; 2) to place maximum reliance on cooperation rather than regulation; 3) to adjust and strengthen existing programs; and 4) to support resource management objectives in areas other than water quality as well (NYDEC, 1981).

Program development was based on a non-point source assessment relying upon interviews with knowledgeable local sources to identify "stressed" areas. Quantitative data were found to be lacking, thus limiting non-point source management to a very rudimentary level. In the future DEC will work cooperatively with county and local governments to refine non-point source assessments, develop local priorities and implement control measures. To improve understanding of the problems, detailed monitoring will be carried out in a limited number of different kinds of watersheds. Sampling systems will be developed to aid in analysis of water quality problems.

Mitigation of agricultural erosion is achieved primarily through contouring, strip cropping, reduced tillage and other farming practices. Farm conservation planning is done on an individual basis by Soil Conservation District personnel in cooperation with landowners. Under New York State law farms of 25 acres or more are required to have an approved conservation plan.

Silviculture is another source of erosion although it is not believed to be a major problem. The primary means of control is through proper site planning and management. As with farms, landowners having 25 acres or more of forested land are required by law to have an approved soil and water conservation plan. However, it is estimated that less than one-half of all forest harvesting operations in the state currently receive the benefits of professional forestry advice (NYDEC, 1981). DEC's strategy is to focus on education of landowners and loggers and to randomly inspect harvesting operations, with the permission of the owners, to better assess the problem and evaluate accomplishments.

Mining is another activity with the potential for erosion problems. The DEC reports that problems are not severe and that existing regulations and programs are sufficient to control the problem. The Mined Land Reclamation Law provides for control of all substantial mining operations by the DEC. Existing staffing was judged to be inadequate for proper enforcement and a major objective of the DEC is to increase staffing to meet this need. Education of mine operators concerning erosion control and an inventory of inactive mines were also mentioned (NYDEC, 1981).

The DEC concluded that although there are numerous programs that relate to erosion from construction sites, there is an apparent need for a better system of preventive controls. The State Department of Transportation has adequate erosion control standards although there is a continuing need for individual project engineers to improve their enforcement efforts. County, town, village and city programs lack enforceable erosion standards, however. More explicit guidelines are needed to effectively control road bank erosion and highway runoff at the local level. In New York State, city, town or village governments control land use and regulate the design and construction of new developments. To date (NYDEC, 1981) only 55% of local governmental units have adopted some form of zoning controls and few of these include erosion standards. DEC's strategy is to encourage local governments to institute and enforce appropriate erosion controls. Past attempts to institute state-wide controls have been defeated repeatedly in the legislature.

The impact of erosion control measures on river sediment yields is the subject of a recent paper by R.H. Meade (1982). Although soil erosion is the original source of sediments, most rivers discharge a large portion of their annual sediment yield in a very small portion of the time, during storms. As a result fluvial sediments spend most of their time in storage in stream banks and beds. On time scales of years to centuries, important intermediate sources and sinks of sediments are storage sites between the uplands and estuaries. Meade (1982) cites the fact that since the large increase in erosion following settlement of the East Coast, soil conservation practices have improved and the amount of land in crop farming has declined. River sediment yields have not declined, however. Sediment resulting from a century or more of poor farming practices following settlement is stored in the valley bottoms and is the source of continued high river sediment yields.

Meade (1982) reports that the time required for sediments to move through major river systems to their estuaries may be as long as a century. Hence, even though the supply of sediment may be reduced at the source through stringent soil conservation practices the results of past mistakes may be experienced in the river and the estuary for decade to a century. Meade cites a classic study of the Sacramento

River by Gilbert (1917), where excessive sediment released by hydraulic mining filled-in the river bed causing it to rise to peak levels 10 to 20 years after the mining was stopped. During the next 30 to 40 years the bed elevation dropped steadily back to its previous levels. A great deal of sediment is still stored on the flood plains and will be removed more slowly than the channel sediments.

In summary, it is clear that erosion control measures are very important in reducing sediments and contaminants entering the rivers. The extent of the success of control measures is uncertain and the results may not be observable in the estuary for decades. Over the next several decades at least, erosion control measures will probably have little impact on dredging requirements. However, the impacts of erosion go far beyond their influence on dredging requirements; the loss of agricultural and other valuable lands should be of great concern.

Control of PCBs

According to Hetling *et al.* (1978) sediments in some places in the upper Hudson River contain PCBs at concentrations exceeding 1,000 ppm. The contaminant orginated from waste discharges at two General Electric capacitor manufacturing facilities that no longer manufacture or discharge PCBs. At low flow the river transports PCBs at the rate of some 4-5 kg/day and movements by major storms have been measured at 360 - 390 kg PCBs/day transported downstream. During the 1977 water year, approximately 2,600 kg of PCBs were moved downstream past Waterford, NY. Results of sediment transport modelling efforts indicate that 32-54 thousand kg of PCBs will be transported into the

Hudson estuary over the next 20 years, if no action is taken.

The river and estuary are so heavily contaminated with PCBs that a ban on commercial fishing for some species was imposed because of unacceptable PCB levels in the tissues of fish. Some argue that if this situation is to improve, some action will be necessary. Hetling *et al.* (1978) have considered three treatment alternatives for the disposal of PCB-contaminated sediments. Incineration was not considered feasible since costs were estimated on the order of $\$57/yd^3$ of contaminated sediment even if co-generation of electricity were used to offset expenses. Biodegradation is another possibility, however, the technology is still at the stage of laboratory development and can not be used on large scale problems. It was mentioned that biodegradation was promising and might be feasible at some time in the future. Engineered encapsulation was the final alternative considered and was the only one perceived to be feasible at the present time.

Four alternatives for the removal of PCB-contaminated sediments were considered by Hetling *et al.* (1978). If no specific action is taken, maintenance dredging of the river channel will continue for the purposes of shipping interests. Approximately 23×10^3 kg of PCB would be removed from the upper Hudson River at a cost of $2.5 million. This is approximately 11% of the total estimated PCB inventory in the upper Hudson (Table II-5). Dredging to remove remnant deposits between the former Ft. Edwards Dam site and Baker's Falls Dam would remove approximately 56×10^3 kg of PCBs. Combined with maintenance dredging, this alternative would remove 40% of the total estimated PCB inventory in the upper Hudson at an additional $6.3 million. Removal of the so-called "hot spots" (PCB > 50 ppm)

Table II-5 Estimated quantities of PCBs in Hudson River Sediments (from Hetling et al. 1978)

Remnant deposits		63×10^3 kg
Upper Hudson River (above Troy, NY)		134×10^3 kg
Lower Hudson River and its estuary		91×10^3 kg
	Total	288×10^3 kg

would reduce PCB deposits by 142 x 10^3 kg (72%) at a cost of $28.7 million. The final option considered was to attempt to remove as much of the PCB-contaminated sediment as possible. It was estimated that this strategy could remove 95% of the total PCB inventory in the upper river at a cost of $204 million.

The present plan calls for the contaminated sediments to be contained in upland disposal sites until methods have been developed to remove or destroy the PCBs. To date (Dec. 1983) none of the above alternatives has been implemented.

Schubel (in press) cautioned that even if all new sources of PCBs to the Hudson-Raritan estuarine system could be eliminated totally the need to deal with PCB-contaminated sediments already in the system would persist for at least several decades regardless of what management strategy is used. He went on to point out that probably neither of the two end members of management alternatives is acceptable. If the objective is to isolate PCBs from the water and, as a result, from the aquatic resources to eliminate adverse ecological and public health impacts, then the "do nothing" alternative may be unacceptable--at least in the short term. The other end member in the spectrum of strategies--dredging the entire river below Fort Edward and the estuary--is economically unacceptable and environmentally unjustified. According to Schubel, even if this alternative were economically feasible, its environmental impacts might be as large, or larger, than the "do nothing" alternative. As he points out, the problem is not in the dredging; it is in the long-term isolation of these materials after their disposal. Schubel suggested that strategies should be assessed which might lead to the isolation of PCB-contaminated sediments by stabilization through burial in-place or by disposal and capping in subaqueous pits.

Wastewater

Mueller *et al.* (1982) estimate that municipal and industrial wastewater flows into the Hudson-Raritan Estuary at a rate of approximately 130 m^3/sec. Of this, 15 m^3/sec (11%) is raw, untreated sewage, 18 m^3/sec (14%) is primary treated sewage, 82 m^3/sec (63%) is secondary treated sewage, and 12 m^3/sec (9%) is industrial wastewater. According to Mueller *et al.* (1982) although wastewater contributes only 13% of the fresh water flow to the Harbor, it is the dominant source of BOD, nitrogen, phosphorus, oil and grease, and most of the toxic organics and heavy metals.

Numerous approaches can be taken in dealing with wastewater pollution. Perhaps the most obvious approach is to upgrade the level of treatment of wastes at existing sewage treatment plants and to construct plants to treat wastes currently being discharged raw. Another approach is to reduce inputs to the sewage system through industrial pretreatment, or industrial waste-water recycling. For certain contaminants, particularly heavy metals, removal at the source is the only type of treatment that can produce significant results. Reducing the inflow of non-contaminated water can also improve treatment efficiency by providing more concentrated sewage that can be treated more effectively. Control of leaks from the water distribution system and metering of water use to encourage conservation are two possibilities for reducing inflows.

Table II-5 Estimated quantities of PCBs in Hudson River Sediments (from Hetling et al. 1978)

Remnant deposits		63×10^3 kg
Upper Hudson River (above Troy, NY)		134×10^3 kg
Lower Hudson River and its estuary		91×10^3 kg
	Total	288×10^3 kg

The fact that over 70% of New York City's sewers are combined sanitary/storm sewers presents another set of control possibilities and needs. Combined sewers, common in many urban areas, arise when a single network of pipes is used to drain both sewage and urban runoff. In dry weather and for periods of light rainfall, sewage treatment plants are capable of treating all of the load. New York's plants are designed to treat up to two times the average dry weather flow at the primary level and up to 1.5 times the dry weather flow at the secondary level (NYCDEP, 1979).

Regulators are mechanical devices designed to open when sewage flows combined with runoff due to storms exceed treatment plant capacity. When regulators open, raw wastewater is discharged directly to the receiving waters. Frequent maintenance of regulators is necessary to prevent raw sewage from leaking out of the system under normal flow conditions. A survey of New York City's 397 regulators indicated that 25% malfunctioned at any given time (NYCDEP, 1979). Improved maintenance repairs and rehabilitation of the existing regulators would clearly reduce leakage of raw sewage into the river.

A related problem is inflow of sea water into the sewer system. Tide gates are used at overflow discharges to prevent sea water inflow, but because of maintenance and repair problems, many of these do not function properly. The result is diluted sewage and reduced treatment efficiency.

Treatment Plant Improvements

As mentioned above, sediments and contaminants contributed to the Hudson-Raritan Estuary could be reduced significantly by upgrading existing sewage treatment plants to provide full secondary treatment of wastewaters. A number of different plans for upgrading treatment facilities were considered in the 208 Water Quality Management Plan developed for New York City (NYCDEP, 1979). Each of the alternatives is described in the following paragraphs and Table II-6 is a summary of the impacts and costs of each alternative.

Baseline conditions include completion of improvements currently under construction. These include seven secondary treatment plants in New York City; four secondary plants in New Jersey; and one secondary plant in Yonkers. Treatment plants at Newtown Creek, Coney Island and Owls Head would not be upgraded to secondary treatment, but would continue to provide better than primary treatment. Raw sewage will still be discharged from the Red Hook (Brooklyn) and North River (NW Manhattan) sewer service areas. Regulators, which divert the overflow from combined sewage/storm sewers directly to the receiving water body during storms, would continue to be maintained as at present (2 to 5% leakage of dry weather flows estimated, NYCDEP, 1979).

The secondary treatment alternative includes construction of full secondary treatment facilities at North River and Red Hook; upgrading of facilities at Newtown Creek, Coney Island and Owls Head in New York City; and upgrading of treatment plants at Bayonne, Hoboken, Jersey City East and West in New Jersey. Regulators with chronic leakage problems would be repaired and routine maintenance would continue as at present. The primary benefits associated with this alternative are improved removal of suspended solids and BOD; much less chlorine would be needed as primary treatment facilities are eliminated; and the danger of contamination of surface waters by

Table II-6. Comparison of waste treatment options from NYC 208 study (NYCDEP,1979)

	Baseline	Secondary	Secondary + Nitrification	Secondary + 50% CSO Cap.	Present Requirements	Higher Use	Modified Use	Zero Discharge
Susp. Solids	red. 40%[1]	red. 70%	red. 90%	red. 70% +	red. 85%	red.85%	red. 70%	red. 90%
BOD	red. 35%	red. 75%	red. 90%	red. 75% +	red. 85%	red.85%	red. 75%	red. 90%
Nutrients	no chg.	no chg.	TKN red. 90%	no chg.	no chg.	no chg.	no chg.	N red 60% P red 100%
Floatables	no chg.	reduced	reduced	red. 50%	red. 90%	red.90%	reduced	red. 90%
Coliform	red. 35%	reduced	reduced	red. 50%	red. 90%	red.90%	no chg.	red. 90%
Chlorine use	no chg.	red. 35%	red. 35%	incr.5-10%	increased	incr.	incr.	red. 35% +
Metals	small red.	reduced	reduced	reduced	reduced	reduced	reduced	red.25-40%
Toxic organics	no chg.	no chg.	no chg.	no chg.	no chg.	no chg.	no chg.	reduced
Oil & grease	no chg.	no chg.	no chg.	no chg.	no chg.	no chg.	no chg.	reduced
Sludge dry tons per day	385	448	448	471	472	472	444	1,275
Cap. Costs($\$10^6$)	2,067	1,336 [2]	2,063 [2]	1,421 [2]	4,739 [2]	5,007 [2]	1,171 [2]	8,298 [2]
O&M Cost($\$10^6$/yr)	70.1	83.8	99.1	84.6	88.9	98.6	78	229
Land Req.(acres)[3]		31	200	31	46	95	15	461
Energy Req.(MKWH/yr)[3]		530	900	570	571	571	523	1,070
Jobs		1,947	2,151	1,991	2,257	2,257	1,305	5,634

(1) reduced from 1975 conditions (2) cost does not include Baseline costs (3) land and energy requirements are in addition to Baseline requirements

pathogenic bacteria would be reduced. Adverse effects of this alternative are increased capital, operating and maintenance costs; land requirements; energy needs; and increased production of sewage sludge.

Secondary treatment plus nitrification is an alternative that adds nitrification units to all treatment plants. The purpose of these units is to reduce oxygen demands caused by the biological oxidation of nitrogen. The major benefit of this alternative over secondary treatment alone is the conversion of ammonia to nitrate, which reduces subsequent oxygen demand in the receiving water. The treatment process has the added benefit of more complete removal of suspended solids. Since it is uncertain whether or not nitrification is occurring in the receiving waters, it may not improve dissolved oxygen levels beyond those obtained by secondary treatment alone. Capital, operating and maintenance, land and energy costs are higher.

Secondary treatment plus 50% combined sewer overflow (CSO) capture would be achieved by taking advantage of both the excess treatment capacity remaining at treatment plants and by storage of sewage in sewer lines. Storage in the sewer lines would require significant modifications to existing control structures (regulators, valves, etc.) and installation of sewer line dams or sluice gates. In addition to those achieved by full secondary treatment, the major improvement to water quality resulting from this alternative would be up to 50% reduction in pathogenic bacteria and floatables.

The Present Requirements alternative has as its objective complete compliance with all Federal, State, and interstate water quality/effluent standards for the study area. This would require full secondary treatment plus the addition of chemical polymer systems to nine plants that do not meet the USEPA 85% removal requirement with standard secondary treatment. In addition, 90% of all combined sewer overflows would be captured and treated. To do this, available in-line storage would need to be supplemented by additional off-line storage. The resulting improvements in water quality would be an additional 40% removal of floatables and pathogenic bacteria over the secondary plus 50% CSO capture alternative. Suspended solids and BOD removal would improve to 85% removal as required by the USEPA. Costs would be substantially increased over the other alternatives.

The Higher Use alternative is designed to achieve, as nearly as possible, the water uses proposed for the Harbor by the NYC 208 Citizens Advisory Committee. It is similar to the Present Requirements alternative with the addition of more elaborate CSO controls in Jamaica and Eastchester Bays.

The Modified Use alternative is intended to meet most State and regional water quality standards and use classifications with the exception of some shellfishing standards. All treatment plants except Newtown Creek would require secondary treatment. No CSO controls would be constructed. The benefits of this option would be similar to the secondary treatment option.

The Zero Discharge alternative is interpreted to mean no discharge of pollutants beyond levels that could be achieved with best available technology. Water treatment plants would provide tertiary treatment, including single stage lime treatment, granular media filtration and activated carbon absorption. CSO's would be captured and treated fully. Obviously, this was the most costly alternative considered.

The plans described briefly above were subjected to a series of evaluations to arrive at the recommended NYC 208 plan. The recommended plan is essentially the same as the Modified Use plan. Technical evaluation of the plans reviewed 1) the effectiveness in meeting water quality objectives; 2) the flexibility in adapting to future conditions and technology; 3) compatibility with existing wastewater treatment system and available resources; and 4) the reliability of plan elements. Institutional evaluation of the alternatives included 1) legal feasibility of implementation under existing or new laws; 2) management feasibility by the existing agencies; 3) enforcement under existing regulations; 4) political feasibility of sensitive plan elements, and 5) financial feasibility in terms of available funding.

Pretreatment of Industrial Wastes

According to Mytelka *et al.* (1982) an industrial pretreatment program would be the single most effective strategy to reduce toxic metal inputs from industrial sources to the N.Y. Bight. Costs and benefits for dealing with non-biodegradable organics have not been estimated because quantitative loadings to the Bight are not known. Mytelka *et al.* (1982) estimate that best practicable treatment for metals would cost $60 million for capital expenditures alone. Annual costs were estimated at $32 million for an industrial pretreatment program for heavy metals to meet Federal requirements in New York City (NYCDEP, 1979).

The benefits of pretreatment can not be quantified accurately since there is considerable uncertainty associated with present discharge estimates. The major source for most metals is wastewater, however, urban runoff is an important source as well and would remain unaffected by industrial pretreatment. Table II-7 shows estimated metals discharges under two different pretreatment scenarios, treatment by precipitation and best practicable treatment.

In addition to water quality benefits, industrial pretreatment would reduce metals in municipal sewage sludge. However, studies conducted under the New York City 208 Program (NYCDEP, 1979) indicate that even with pretreatment, sludge would not be acceptable for agricultural land application. Additional reduction of loads from water supply and residential/commercial sources would probably be required, particularly for copper and zinc.

The conclusion reached by the authors of the New York City 208 study was that an industrial pretreatment program for heavy metals in New York City would by itself neither significantly improve the quality of the Harbor waters nor enhance the disposability of sewage sludge (NYCDEP, 1979).

It is clear that industrial contributions of heavy metals to the municipal waste stream can be removed most efficiently at the source. It is equally clear, however, that industrial pretreatment alone is not sufficient to eliminate metal contamination. Other sources must be more completely quantified and additional control measures developed and implemented. As is the case with toxic organics and other contaminants, possibly not yet identified, household and commercial contributions to wastewater, solid wastes (and their

Table II-7 N. Y. City Metropolitan Area waste treatment plant heavy metal discharges (Kg/day) and possible pretreatment discharges.

	Current Discharge Estimates	vs.	with Pretreatment	
Metal	(1) NYC 208 1980	(2) Mueller et al. 1980	(1) Precipitation	(1) Best Practicable Treatment
Cd	84.8	49.4 - 106.4	84.8	52.2
Cr	1,667	1,010 - 1,020	782	640
Cu	2,303	1,768	2,057	1,900
Pb	1,208	1,092	1,063	995
Hg	18.6	37 - 81	18.6	6.6
Ni	1,550	935	816	599
Zn	2,480	6,204	2,367	2,218

(1) from NYCDEP, 1979

(2) from Mueller *et al.*, 1982

leachates), and storm water runoff must be fully considered along with the industrial component. The automobile in particular contributes substantially to water quality problems through roadway runoff.

Urban Runoff

For more than 80% of the total area of New York City, storm runoff is collected in the sewer system. Two types of sewers are used for this purpose. Storm sewers are used solely to carry storm runoff to the receiving water body. Combined sewers, which carry both sewage and storm water, transport up to two times the average dry weather flow to treatment plants prior to discharge. The combined sewers are designed with built-in regulators to act as relief valves to prevent overloading of the treatment plants during storms. Combined sewer overflows (CSO) result whenever a significant amount of rain falls on the city. The resulting water quality impacts can be quite severe.

In their 1982 report, Mueller *et al.* estimate that while urban runoff is the source of 6.9% of the flow to the Harbor, it is the source of nearly 10% of the total solids input, 18% of the BOD and 16% of the total metals. For pollutants produced by the automobile, in particular oil and grease, and lead, it is a major source. At the Newtown Creek treatment plant, 24,000 gallons of oil, the equivalent of a moderate spill, was by-passed during one 4-hour storm (Field and Turkeltaub, 1981). In Jamaica Bay, 50% of the hexane extractable material was attributed to CSO's (Feuerstein and Maddous, 1976).

Nationally, the storm and combined sewer program of the USEPA has been sampling for "priority pollutants" in urban runoff. Initial analyses show significant amounts of priority pollutants in urban

Table II-7 N. Y. City Metropolitan Area waste treatment plant heavy metal discharges (Kg/day) and possible pretreatment discharges.

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(1) from NYCDEP, 1979

(2) from Mueller *et al.*, 1982

samples. For example, 59 of the 129 priority pollutants have been identified including all 13 of the heavy metals, polynuclear aromatic hydrocarbons, phythalate esters, aromatic hydrocarbons, halogen derivatives of hydrocarbons and phenols (Field and Turkeltaub, 1981).

The principal secondary (proximate) "source" of conventional pollutants to the Harbor is remobilization of materials deposited within the lines of combined sewer systems during periods of low flow. Figures from the New York City 208 study (NYCDEP, 1979) indicate that approximately 55% of the BOD and suspended solids introduced to the Harbor by CSO's originate from sewer deposition. Most of the metals, toxic organics and oil and grease originate from street surfaces (Wilbur and Hunter, 1979). These sources of contaminants give rise to a "first flush" effect, that is, the first rain to hit the street carries most of the contaminant load that has accumulated in the interval since the last rain. While this does not influence the total mass loads entering the receiving waters it does have important implications for treatment strategies. Treatment programs directed at the "first flush" volume can effectively treat a greater amount of contaminants in a smaller volume of run-off (Kaufman and Lai, 1980).

The removal of sediments and contaminants from urban runoff are linked closely because of the strong affinity of most contaminants for sediment particles. Programs for reducing the impacts of urban runoff on receiving water quality can be divided into two categories: Best Management Practices (BMP), which use non-structural and elementary structural measures to control urban storm water pollution by treating the problem at its source or preventing its opportunity to develop; and structural measures aimed at trapping and treating urban runoff before it enters the receiving water body (Finnemore, 1982).

Non-structural BMP's include preservation of natural land conditions, development controls, limits on embankment slopes, neighborhood cleaning, limiting chemical use, and drainage system maintenance. Elementary structural BMP's include: soil protection (berms, protective dikes, etc.); temporary storage basins; detention ponds; and infiltration ponds. All of these measures are targetted primarily at reducing erosion by controlling runoff and keeping the land surface as clean as practical.

Structural measures include in-line and off-line storage of contaminated runoff with subsequent treatment of the retained contaminants at existing sewage treatment plants during dry weather. By designing storage facilities to capture the "first flush," which is the most highly contaminated runoff, the effectiveness of limited treatment capacities can be maximized. Ultra-high rate filtration systems can also be constructed to insure that urban runoff and CSO's are treated to some degree (Innerfeld and Ruggiero, 1980) even when storage capacities are exceeded.

Land Use Controls

The New York City 208 Report (NYCDEP, 1979) outlines a number of land use management strategies aimed at reducing storm-related inputs to the Harbor. For the most part, these controls are designed for areas under development, which limits their applicability in New York City to Staten Island and parts of Queens. The remainder of the areas draining into the Harbor are largely developed and unlikely to change appreciably with respect to land use characteristics at least over the next decade.

Land use proposals include the formation of "preservation" and "natural area" districts designed to prevent development in areas with steep slopes, wetlands and unique natural areas. It was suggested that the City assume control over such sites by outright purchase, by zoning regulations, or by trading development rights for less sensitive areas. Other zoning arrangements proposed were a series of sequential controls, aimed primarily at currently unsewered areas, permitting development only as treatment facilities became available. Up-zoning of high density areas was also suggested to provide lower population densities and more open spaces to permit infiltration of rainfall, thereby, reducing runoff. An area where this might be implemented is the South Bronx. It was estimated that up-zoning of the area from medium to low density residential would result in a 0.15% overall reduction in runoff. Construction site controls also were considered, although these are not believed to be of significance. Because of the highly developed nature of the City, very little land area is involved in construction activities.

The 208 Study authors estimate that total reduction in runoff volume achievable would be on the order of 1% if the land use management plans discussed above were implemented. A similar reduction in sediment inputs to the Harbor could be expected.

Non-Structural Controls

A number of methods aimed at controlling the amounts of solids and contaminants in urban runoff and involving little or no structural revamping of the sewage system have been proposed. Most commonly suggested have been street sweeping, sewer flushing and catch basin cleaning. The USEPA Report to Congress (1978) presented an evaluation of the relative efficiency of these strategies and estimated the cost of each on a per pound BOD removed basis. They estimated that street sweeping could remove 2 to 11% of the combined sewer-borne BOD at a cost of $3 to $7 per pound BOD removed. Sewer flushing was capable of removing 20 to 50% of the BOD at $2 to $14 per pound BOD removed. They concluded that the cleaning of catch basins was impractical because of the low rate of removal of BOD and the high associated costs.

Each of these low-structural management approaches also has been evaluated with respect to the 208 Study area (NYCDEP, 1979). New York City currently owns 507 street sweeping machines, of which approximately 40% are inoperable at any given time. To effectively reduce the contaminant load from the streets, a street washing unit would need to be assigned to each sweeper. Studies indicate that such a method could reduce BOD from urban runoff approximately 3-4%, although for those metals whose major source is automobiles, such as Pb, Ni, Cu, this figure is on the order of ten percent (NYCDEP, 1979). Each street washing unit costs $35,000; the total cost estimate for repairing sweepers and assigning washers is $21 million.

The New York City 208 Study (NYCDEP, 1979) also evaluated the efficacy of catch basin cleaning. As in the Federal study, no benefits were observed and costs were estimated to be fairly high; $40. per basin cleaned or $5 million overall.

As noted earlier, resuspension and remobilization of materials stored temporarily in combined storm water sewer lines during periods of low flow contribute the largest part of the CSO load, and sewer flushing holds the greatest promise of low-structural approaches for the reduction of that load. There are three general methods for cleaning sewers: 1) the use of water from fire hydrants to flush sewer lines; 2) the use of partitions parallel to the direction of flow to divide sewers into two or three smaller conduits; and 3) the installation of control structures such as sluice gates or dams to allow sewage to be backed up, then released suddenly to flush the lines.

Sewer flushing using fire hydrants is believed to be effective only in the smaller sewer lines. Enormous quantities of water would be required and deposition would still occur down line in the larger sewers. The installation of divided sewer lines probably is not feasible except as lines are replaced for repair or when new lines are installed. Control structures would be the most reasonable approach, but, 19,500 control units would be required at $6,000 per unit, a total of $117 million dollars (NYCDEP, 1979).

Structural Controls

Structural controls generally are aimed at detaining storm waters until they can be treated during periods of low flow, although some attempts have been made to treat storm water during periods of high flow. Detention can be accomplished in a number of ways. Storm waters can be retained on specially designed roof top structures, in site ponds, within the sewer lines, and in off-line storage facilities.

The USEPA (1978) reports that storage systems increase in cost effectiveness as the size of the watershed increases. They estimate that for watersheds of less than 100 acres (0.4 km^2 it is more cost effective to create separate storm and sanitary sewers, whereas over 200 acres (0.8 km^2) storage facilities become more cost effective. In-line storage is practical if the sewer system has a large interceptor capacity. Such a system can remove up to 40% of BOD loads at a cost of \$2 to \$4 per pound BOD removed. Off-line storage can be very expensive in an urban watershed, where space is at a premium, but is considered the only technologically feasible way of removing greater than 65% of BOD.

Several storm-water retention systems have been studied for their applicability to the New York area storm/CSO overflow problem. The New York City 208 Study (NYCDEP, 1979) assessed several types of on-site detention systems. Detention ponds and leaching basins were suggested for construction sites and areas of low- and middle-density residential housing. They estimated that such structures would cost approximately \$2,000 per unit, and that each unit might serve 1-5 dwelling units. They concluded that high-density residential and commercial buildings would be better served by rooftop detention in conjunction with a pumping capacity to deliver the detained waters to the sewer system during periods of lesser flows. Such a system is estimated to cost \$10,000 per unit.

In theory, in-line storage systems offer highly urbanized areas the advantage of utilizing existing structures and making no further demands on space. The New York municipal system has a total storage capacity of 456 million gallons, all of which could be treated in less than 48 hours with present treatment capacities. It is, however, the opinion of the New York City Department of Environmental Protection (O'Hallaran, NYCDEP, personal communication) that the poor state of repair of New York's sewer lines and the frequent malfunctioning if its regulators make it impracticable to consider in-line storage at this time, as the dangers of leaking and flooding outweigh the benefits to be gained.

Off-line tank storage facilities are fairly expensive in urban environments where space is at a premium. Of the twelve Water Pollution Control Plants in the New York metropolitan area, only the Spring Creek plant has tank storage capacity. There are 13 million gallons of off-line storage capacity in addition to the available 12.39 million gallons of in-line storage, serving a drainage area of 3,260 acres. Treatment is restricted to settling, which removes on the order of 30% BOD and 50% suspended solids. Off-line capital costs were $0.96 per gallon, giving an overall storage cost of $0.47 per gallon.

New York currently is experimenting with a novel plan to store storm waters in natural sites. A flow-balance system devised by Karl Dunkers and reported in Urban Innovation Abroad (1981) utilizes streams and inlets to store storm waters by constructing a series of baffles made from plastic sheets suspended from wooden floats. In the lacustrine systems in Sweden where it has been implemented, the storm waters displace the fresh waters within the baffles. A pump operating in the chamber nearest the outfall maintains a continuous flow of water to the treatment plant. In fact, in some cases pumps have been left operating during dry periods, effectively treating highly eutrophic lake waters. Kjessler and Mannerstrale, A.B., Consulting Engineers and Architects currently are under contract with the NYCDEP to modify this system to the estuarine conditions of Fresh Creek in Jamaica Bay. The pilot project will be half-scale and will cost $480,000, in contrast to the estimated $1 billion for tank facilities of similar capacity. If successful, a full scale plant may be constructed and similar facilities considered for other suitable water bodies (O'Hallaran, NYCDEP, personal communication).

New York City also has run a pilot program in high-volume solids removal. Reasoning that a removal system that was effective on both wet and dry weather flows would be more cost-effective than a system reserved solely for treatment of either sanitary or storm flows alone, Innerfeld and Ruggiero (1980) tested an ultra-high rate filtration system at the Newtown Creek Water Pollution Control Plant during the period from October 1975 to July 1977. The Newtown Creek plant has a drainage area of 62.3 km^2, the city's highest flow (310 MGD) and the largest industrial component of all plants. The pilot plant was able to filter raw and combined sewer overflows at a rate of 11 $liters/m^2$ sec, achieving suspended solids removal of 57-75% and BOD removal of 32%. They observed an even higher COD removal (over 40%), reflecting the high industrial component of this effluent. The addition of alum increases these figures to 38% and 50% respectively. Over 95% of settleable solids were removed.

In general, the urban runoff controls discussed above are expensive and for the benefits obtained are thought by many not to be cost effective. A great deal of money would be required just to bring the existing infrastructure up to satisfactory operating conditions. The 208 Study (NYCDEP, 1979) is evidence that the City is making substantial efforts to improve the wastewater situation.

Atmospheric Inputs

Mueller *et al.* (1982) have summarized available data concerning atmospheric deposition of contaminants into the Hudson-Raritan

Estuary. Their data is divided into an urban and rural contribution over water areas of 640 km^2 and 71 km^2 respectively. Estimates of urban contributions were determined based on data from a rooftop sampler located in downtown Manhattan. Rural contributions were estimated from data taken in Chester, NJ, 65 km west of New York City. Mueller *et al.* (1982) cautioned that organic pollutant data in particular are scarce and of questionable accuracy. More data are needed to get accurate estimates.

According to the data of Mueller *et al.* (1982; and Table II-3 in this report) the only contaminants entering the estuary that originate primarily from atmospheric deposition are lindane, chlordane and heptachlor, all of which are chlorinated hydrocarbon pesticides. However, lindane has not been tested for in runoff, spills or landfill leachate; chlordane has not been tested for in runoff or spills; and heptachlor has not been tested for in wastewater, runoff, spills or leachate. In view of these gaps in the data, it is uncertain whether atmospheric contributions of these contaminants are in fact of major importance.

In a review of chemical pollutants of the New York Bight, O'Conner and Stanford (1979) report that quantitative data on these compounds and many other halogenated hydrocarbons are insufficient to evaluate risks to the marine environment. They recommend further investigation of sources, pathways and present levels of contamination in the Bight. The only way to control contamination by atmospheric deposition is to prevent contaminants from reaching the atmosphere through control of contaminants at the source. Much better data on sources and pathways of contaminants into the environment are vital for development of effective management strategies.

For heavy metals, in particular lead, reduced automobile emissions and the shift to lead-free fuels has possibly caused the observed decrease in airborne lead (Mueller *et al.* 1982) over the past few years. Data for vanadium and nickel, which are higher in winter, indicate that fuel oil is an important source of these contaminants. Presumably burning of low-sulfur fuel, which is lower in other contaminants, may be of benefit here.

In general, it appears that atmospheric deposition is a relatively minor contribution of contaminants directly to the estuary. However, urban runoff is not and atmospheric contributions of contaminants to the land surface which are subsequently carried to the estuary by rainfall may be quite significant. In any event, atmospheric contamination is an important concern regardless of its impact on the Hudson-Raritan Estuary.

Landfill Leachate Input

In their analysis of the contribution of landfill leachate to the contaminant load to the Hudson-Raritan estuary, Mueller *et al.* (1982) have attempted to include data from all landfills greater than 5 acres (4×10^3 m^2) in area that are downstream of tributary sampling stations. However, the files for some landfills were unavailable to them because of ongoing litigation. New York City does not monitor any of its landfills, and toxic organics are measured at only a few sites. In addition, reported incidents of illegal dumping and unregulated dumpsites with unknown contents could not be included given resources available to Mueller *et al.*

The authors (Mueller *et al.* 1982) calculated pollutant loads from individual landfills based on average pollutant concentrations, total area and average percolation rates to obtain average leachate concentrations. Over 23 km^2 of landfills were included in their analysis. The degree of natural treatment before contacting ground water or surface water is unknown. Those authors caution that potential loads presented should be considered order of magnitude estimates at best.

Based on this analysis (Mueller *et al.* 1982; and Table II-3 this report) 16 of 60 contaminants studied show greater than 1% of their input resulting from landfills. Of these only 3,1,1,2,1-tetrachloroethane, dichlorofluoromethane and toxaphene are greater than 10% of the total load. For each of these, other potential sources have not been measured, however. As in many cases discussed previously, data are insufficient to quantify accurately the importance of landfills to overall levels of contamination in the estuary. Nevertheless, it is clear that landfills are a serious problem for other reasons, ground water contamination in particular. Efforts must be continued to locate and correct landfill related contamination problems. The USEPA "superfund" program is designed to give the problem much needed attention.

Accidental Spills

Mueller *et al.* (1982) based their accidental spill estimates on the U.S. Coast Guard's Pollution Incident Reporting System data for 1974 to 1979. This includes reported spills of oil and other hazardous materials. Because the amount of each spill reported as recovered frequently exceeded the quantity reported as spilled, presumably because of the recovery of water and debris as well, quantities spilled were used in their analysis.

The quantity of contaminants spilled reported for each year in the period of record was fairly consistent, with the exception of two major spills as isolated events. Causes of the spills included fires at storage facilities, mishaps during transfer operations, and grounding and collisions involving tankers. Most spills, however, were of unknown causes.

Only six contaminants were introduced in appreciable quantities by accidental spills: oil (6% of total load), naphthalene (51%), toluene (3.3%), trichloroethylene (3.6%), aldrin (100-97%), and toxaphene (100-76%). In the cases where spills were shown as the dominant source, however, other sources had not been quantified.

Perhaps the most effective ways to reduce spills to the Harbor, are to increase patrols by the Coast Guard and the Army Corps of Engineers and to impose stiffer penalties for offenders.

Shore Erosion

Shore erosion is a significant source of sediment primarily in the Lower Bay. The shoreline around most of the Harbor has been developed to the extent that bulkheading and other shore protection structures are dominant. Because of this, there is apparently no need for further shore protection measures in these areas. As discussed in previous sections, Coney Island, Staten Island and the New Jersey coast are subject to locally severe erosion problems. Landowners and the Army Corps of Engineers have been attempting to reduce erosion for years with only limited success. Beaches, wetlands and other types of shoreline will continue to be a source of sediments unless widespread shore protection measures are taken. This is highly unlikely because of the recreational and ecological significance of such areas.

Other Sources

The remaining sediment and contaminant sources to the Port of New York and New Jersey are *in situ* biological production, Long Island Sound, and the N.Y. Bight. Biological production probably could not be significantly reduced as a sediment source without an enormous investment. According to Mearns *et al.* (1982), only about 10% of the nitrogen entering the estuary is actually used in primary production. Other factors, including light limitation, the high rate of flushing and low availability of silica are likely limiting factors. As a result, removal of over 90% of the nitrogen sources would be necessary to affect populations in the estuary. Long Island Sound and the N.Y. Bight are natural sources of sediment that probably can not be reduced significantly.

Conclusions

Table II-8 is a summary of the sediment and contaminant source reductions discussed above. Two categories are included in the table. "Possible Reductions" include any measures that have been identified as significant ways to reduce sediment and/or contaminants, and "Probable Reductions" are measures that most likely are to be implemented in the future. The cost estimates are not complete. For example, erosion control measures for stream and road bank erosion in the Hudson River basin are included in the $88 million estimate of those costs, but the significant additional expenditures that would be required for agricultural and other erosion control measures in the Hudson basin and other basins tributary to the estuary are not included. For each measure where significant additional expenditures would be required to achieve the indicated reductions a "+" has been indicated. If all of the possible measures considered here were taken to control sediment and contaminants entering the estuary, it would cost at least $9.4 billion.

Obviously, New Jersey, New York State and New York City can not afford to implement all of these measures. Furthermore, in most cases it is not possible to estimate with acceptable accuracy what reductions would be likely to occur. It has been indicated in the "Probable Reduction" column of Table II-8 whenever information is sufficient to make some judgement.

Quantitative estimates of the possible sediment and contaminant reductions that could be achieved with the control measures that have been investigated to date are given in Table II-9. The major part of the sediment load reductions possible would be the result of tributary basin erosion control measures. Erosion control is an important problem for many reasons in addition to its impact on dredging and, therefore, the probability is high that stringent measures eventually will be fully implemented. Other reductions in sediment load are from wastewater and urban runoff controls. Based on the estimates of the New York City 208 Study (NYCDEP, 1979), sediment reductions of 70% in waste water and very little reduction in CSO (urban runoff) load could probably be achieved. For this reason, actual sediment load reductions achieved will probably only be approximately 14-20% (0.6

Table II-8 Summary of sediment and contaminant source reductions[1]

Source	Possible Reductions		Probable Reductions	
Tributaries	Reduction	Cost	Reduction	Cost
Erosion Control	sed. 28%	$88.8+	unknown	unknown
PCB dredging	PCB 94%	$204	unknown	unknown
Waste water				
Treatment plant improvements	Zero Discharge Table II-6	$8,298+	Modified Use Table II-6	$1,171+
Urban runoff				
Land use controls	runoff 1%	unknown	unknown	unknown
Street washing	BOD 3.5%	$21+	unknown	unknown
Sewer flushing	BOD 18.2%	$117+	unknown	unknown
Roof top runoff control	BOD 7.8%	$1,400	unlikely	unlikely
Storage and treatment	included in Zero Discharge option for waste treatment Table II-6		unlikely	unlikely
Atmospheric	insufficient data			
Landfill leachate	insufficient data			
Accidental spills	reductions unlikely			
Shore erosion	reductions unlikely			
Biological production	reductions unlikely			
Long Island Sound	reductions unlikely			
New York Bight	reductions unlikely			

(1) see text for explanation

Table II-9 Estimated possible reductions in sediment and contaminants

	Total Estimated Load	Possible Reductions			After Reductions	
		Tributaries	Waste Water	Urgan Runoff	Total Reduction	Total load
Sediment (10^6 MT/yr)	3-4.2	0.4 (28%)	0.22 (90%)	0.18 (90%)	0.8 (19-27%)	2.2-3.4
BOC (metric tons/day)	1,000	unknown	639 (90%)	162 (90%)	801 (80%)	199
Nitrogen (metric tons/day)	340	unknown	124 (60%)	22 (60%)	146 (43%)	194
Phosphorus (metric tons/day)	41	unknown	27 (100%)	3 (100%)	30 (73%)	11
Fecal Coliform (org./day)	1.5×10^{17}	unknown	$.9 \times 10^{17}$ (90%)	$.4 \times 10^{17}$ (90%)	1.3×10^{17} (87%)	$.2 \times 10^{17}$
PCB (kg/day)	11-14	4-6 (94%)	negligible	negligible	4-6 (36-43%)	7-8
Other toxic organics	insufficient data					
Cadmium (kg/day)	130-190	unknown	18-40 (38%)	unknown	18-40 (14-21%)	112-150
Chromium (kg/day)	2,020-2,040	unknown	626-632 (62%)	unknown	626-632 (30%)	1394-1408
Copper (kg/day)	3,400	unknown	300 (17%)	unknown	300 (8%)	3,100
Lead (kg/day)	2,800	unknown	197 (18%)	unknown	197 (7%)	2,603
Mercury (kg/day)	62-92	unknown	24-43 (65%)	unknown	24-43 (38-57%)	38-39
Nickel (kg/day)	1,700	unknown	570 (61%)	unknown	570 (34%)	1,130
Zinc (kg/day)	9,400	unknown	620 (11%)	unknown	620 (7%)	8,780

million metric tons per year) rather than the possible 19-27% (0.8 million metric tons per year) reduction. Whether or not this reduction will have a direct impact on maintenance dredging requirements is uncertain, but at most, dredging could be reduced by 20% given the above assumptions.

The waste water treatment plan recommended by the New York City 208 Study (Modified use) would result in a 75% reduction in waste water BOD and would not reduce CSO significantly. This makes the probable reduction in total BOD only 53% vs. the possible 80% reduction. Nitrogen and phosphorous most likely will not be reduced significantly and fecal coliforms will only be reduced slightly. The impact of these changes on dredged material contamination is probably negligible.

Although available data are not sufficient to quantify it, the improved removal of sediments in waste water will reduce inputs of toxic organics and heavy metals. CSO's will remain a major source of these contaminants, however. The most effective control measures for toxic organics and metals are those directed at the initial sources of these contaminants. These sources have not been quantified, however, to the extent necessary to permit development of effective control strategies. Pre-treatment of industrial wastes could have significant impacts on reducing contamination, but costs are currently perceived as being prohibitive (NYCDEP, 1979).

PCB is one toxic organic that has been quantified for the Hudson-Raritan Estuary and removal strategies have been developed. Based on the estimates of PCB load (Mueller *et al.*, 1982) and assuming 94% predicted removals (Hetling *et al.*, 1978), up to a 43% reduction in the PCB inventory may be possible. The program that is finally

Table
II-10 Estimated MAXIMUM probable removal of sediment and contaminants

	Total Estimated Load	Possible Reductions			After Reductions	
		Tributaries	Waste Water	Urban Runoff	Total Reduction	Total Load
Sediment (10^6MT/yr)	3-4.2	0.4 (28%)	0.18 (70)	negligible	0.6 (14-20%)	2.4-3.6
BOD (metric tons/day)	1,000	unknown	532 (75%)	negligible	532 (53%)	468
Nutrients	Slight reductions					
PCB (kg/day	11-14	3-4.5 (72%)	negligible	negligible	3-4.5 (27-32%)	8-9.5
Toxic organics	Slight reductions					
Metals	Slight reductions					

selected for PCB removal from the Upper Hudson will determine the actual removals achieved. It has been predicted that most likely alternative, "Hot Spot" dredging, could achieve 72% removal of PCBs from the sediments. If it is assumed that this converts directly into a tributary load reduction of 72%, the total reduction in PCB would be 3-4.5 kg/day or 27 to 32%. It is not at all clear that such removals are in fact possible, or that dredging of PCB-contaminated sediments and disposal in landfills is desireable.

The estimated probable removals are summarized in Table II-10. It must be emphasized that these are MAXIMUM probable removal estimates. Furthermore, it is not at all clear over what time scales these removals would be translated into reductions in requirements for maintenance dredging and in improvements in the quality of materials dredged. Indications are that tributary erosion control would not affect dredging requirements for at least a period of several decades. Nevertheless, control measures are valuable for reasons beyond dredging and must be encouraged.

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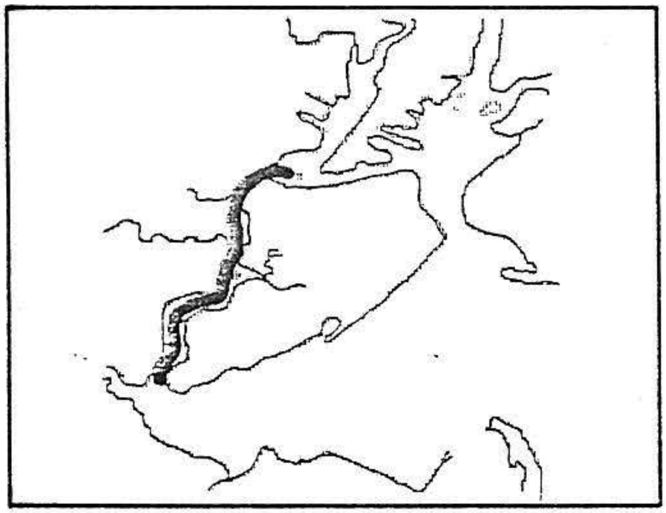
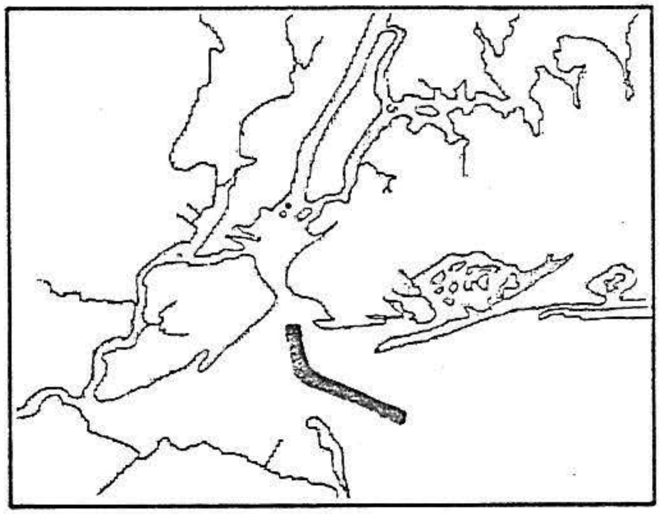
Appendix A

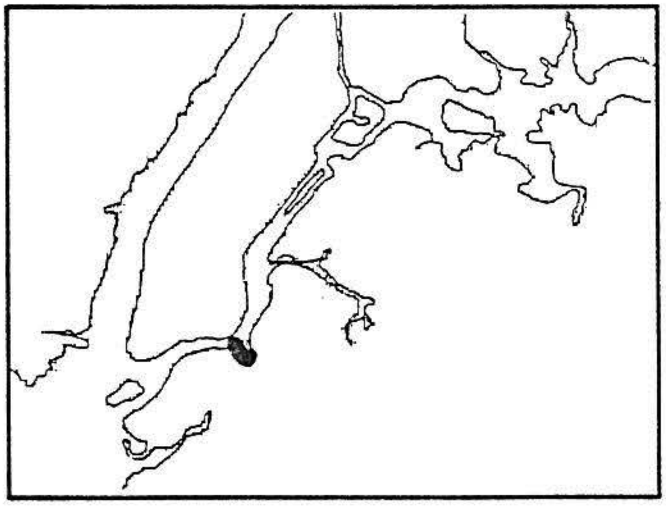
Dredging Project Locations, Quantity Dredged and Contaminant Levels



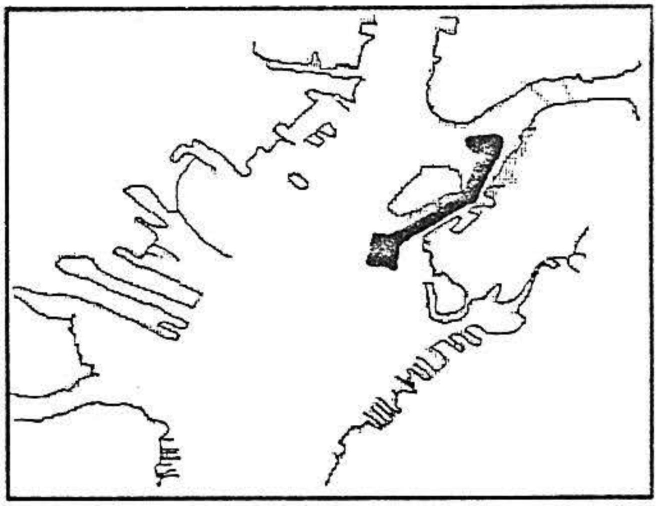
AK - Arthur Kill



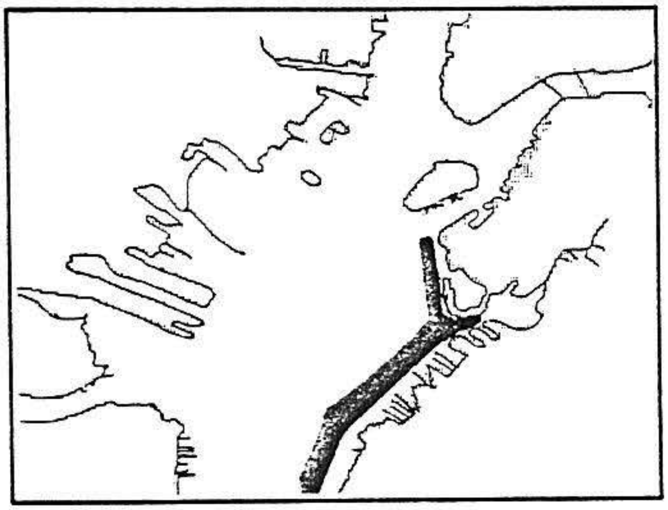
AMB - Ambrose Channel



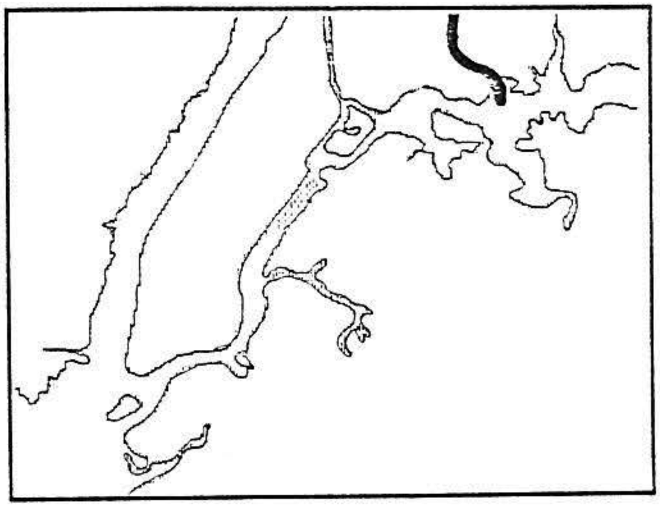
BKLNY -Brooklyn Navy Yard



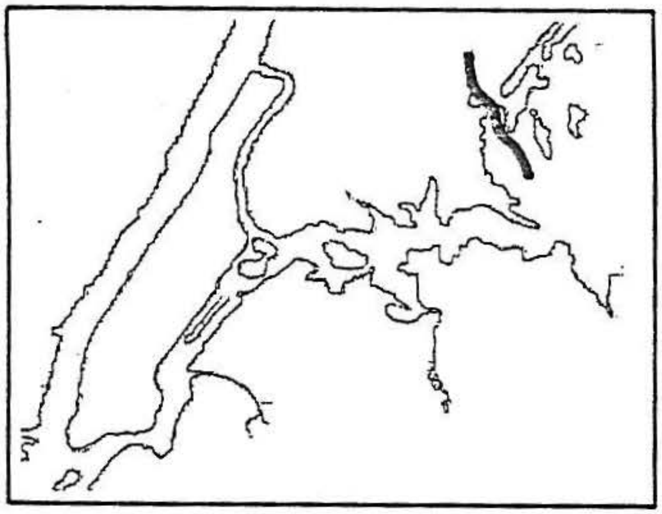
BMLK -Buttermilk Channel



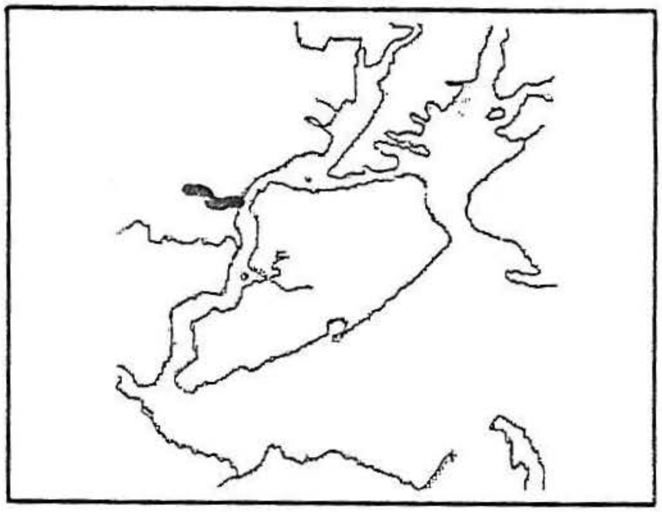
BRRH - Bay Ridge-Red Hook Channel



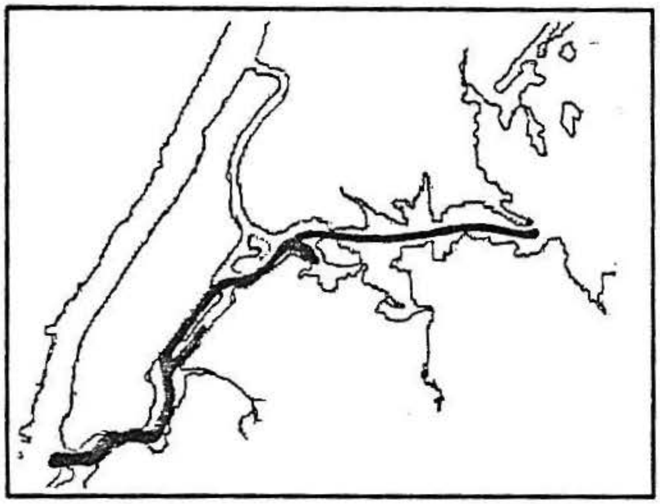
BRX -Bronx River



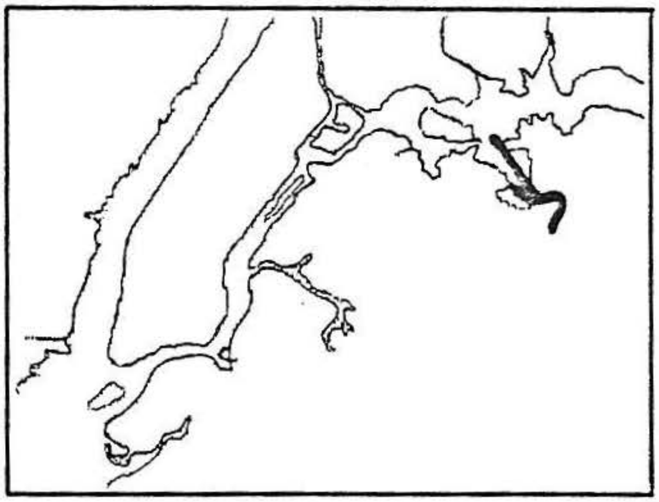
ECHST -Eastchester Creek



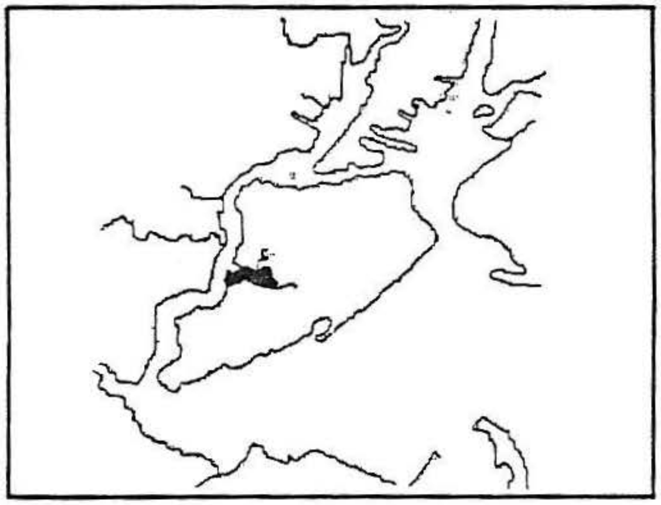
ELZR- Elizabeth River



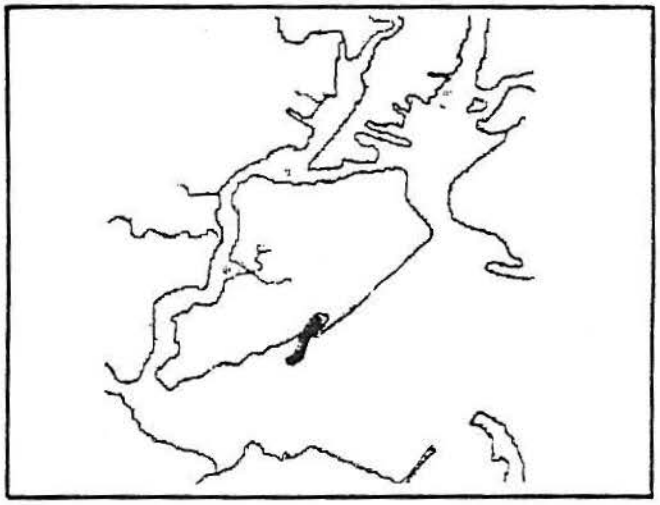
ER -East River



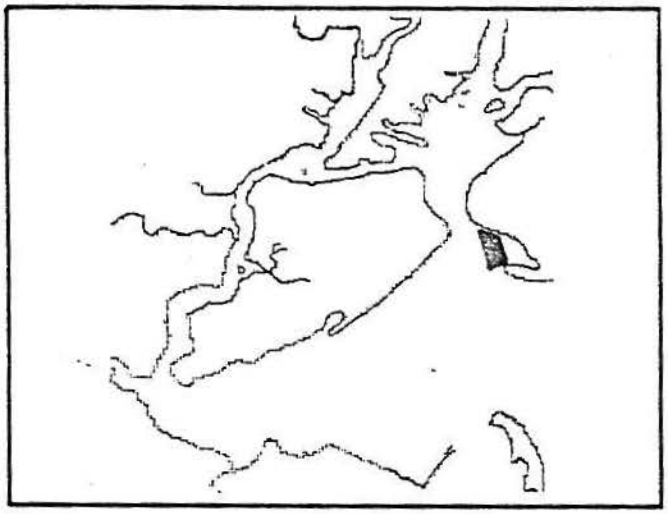
FLSH -Flushing Bay and Creek



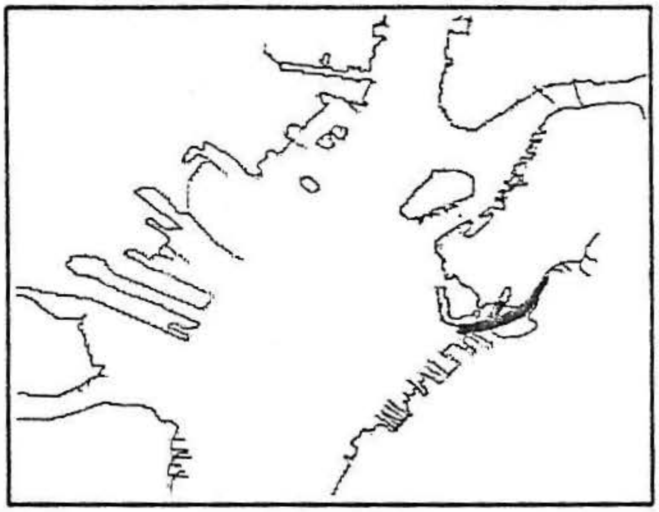
FRKL -Fresh Kills



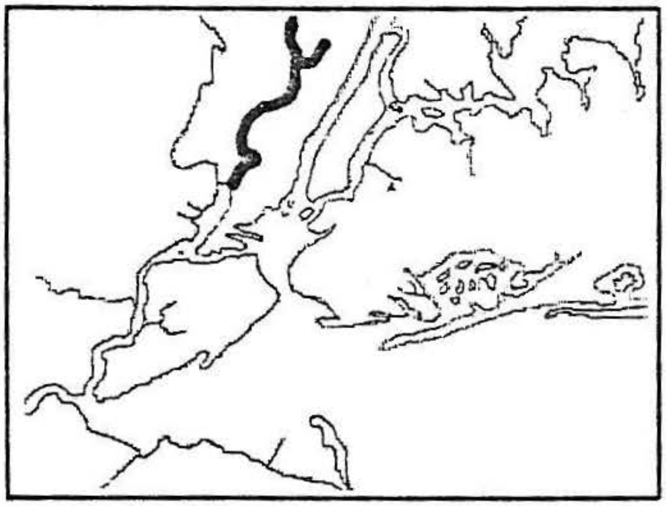
GRKL -Great Kills



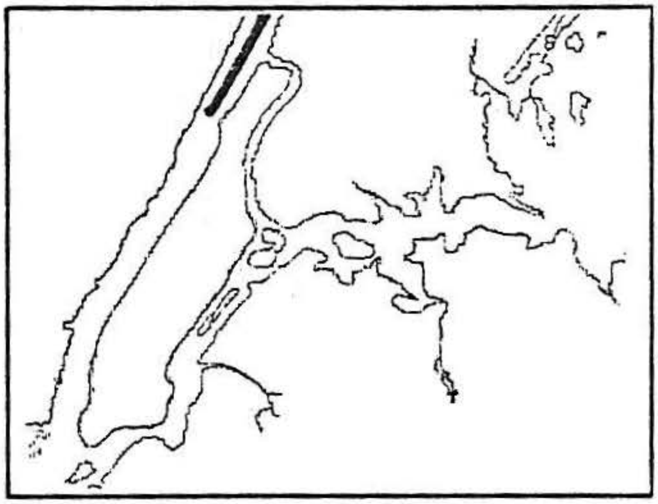
GRVS -Gravesend Bay



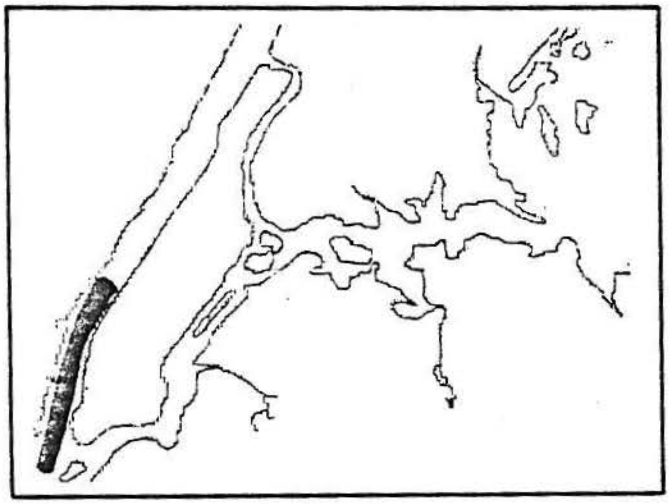
GWB -Gowanus Bay and Creek



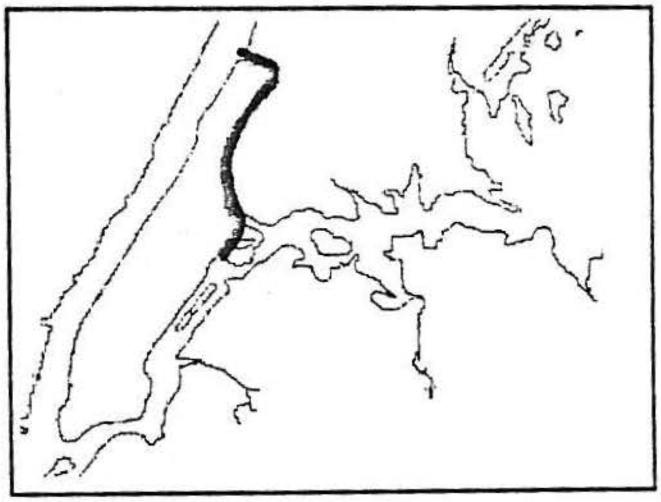
HCK -Hackensack River



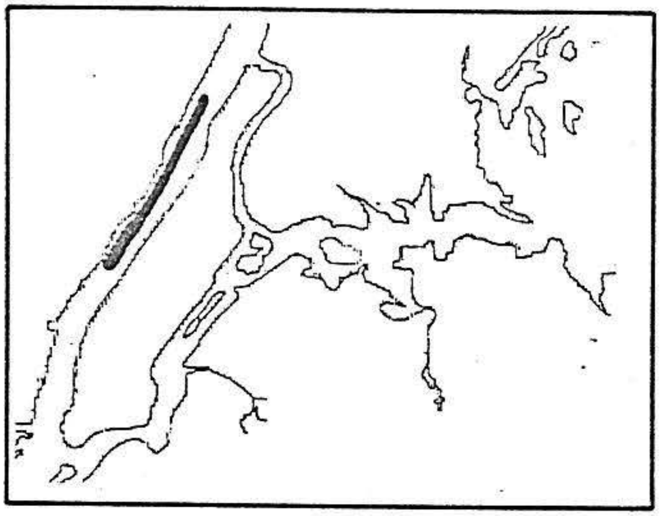
HRAE -Hudson River-Above Edgewater



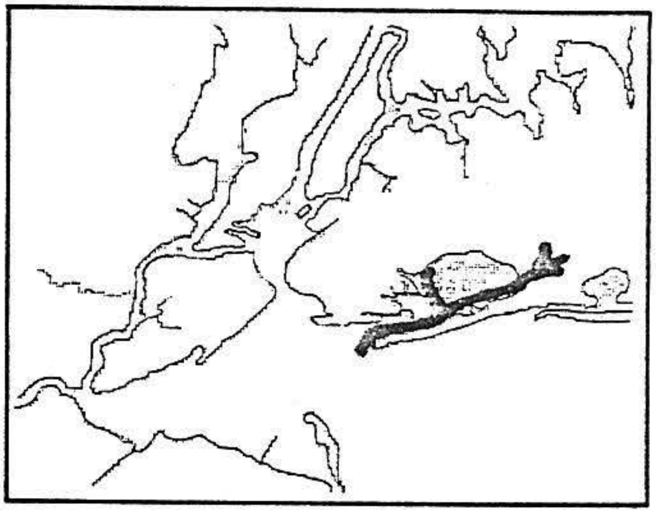
HRBW -Hudson River-Battery to Weehawken



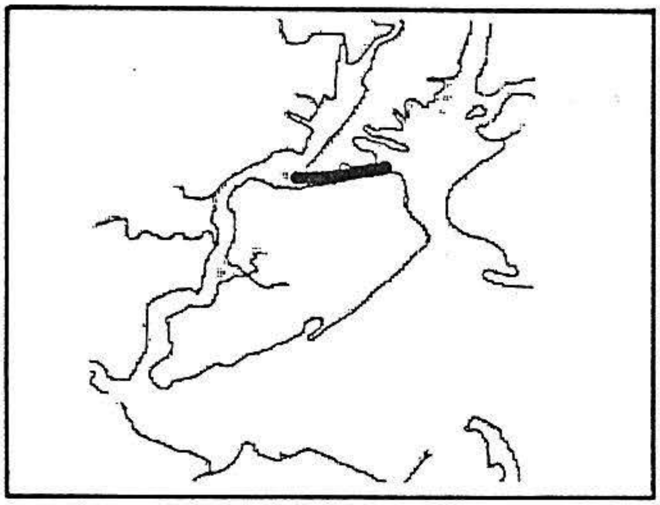
HRLM -Harlem River



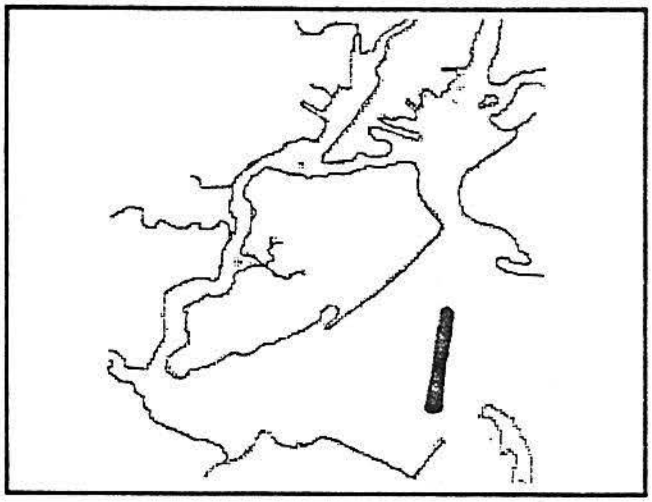
HRWE -Hudson River-Weehawken to Edgewater



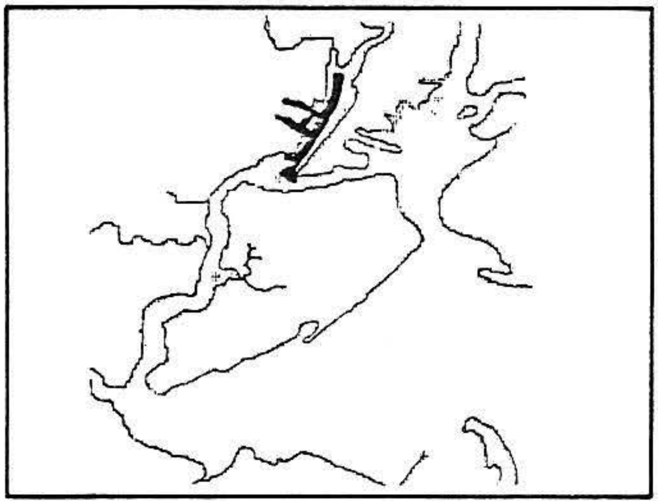
JAMB -Jamaica Bay



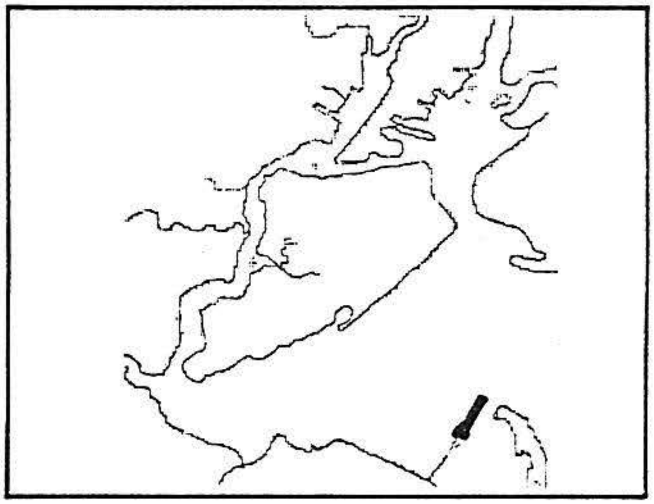
KK -Kill Van Kull



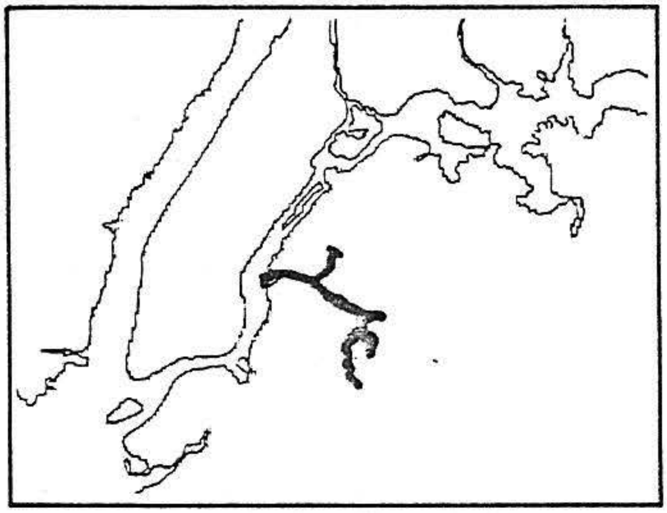
MSCH -Main Ship Channel



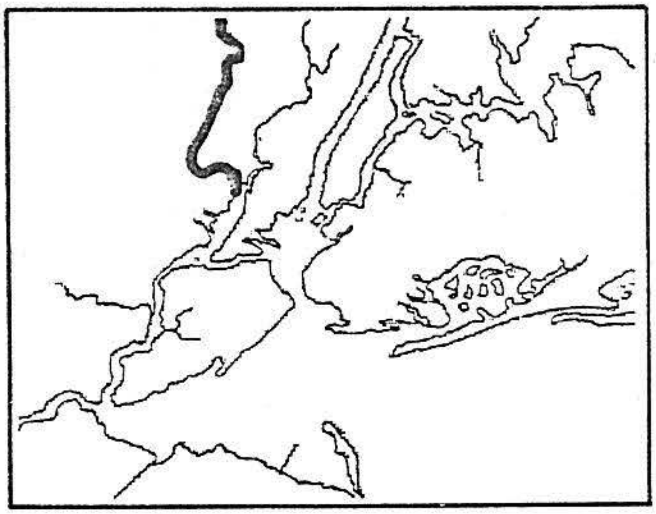
NB -Newark Bay



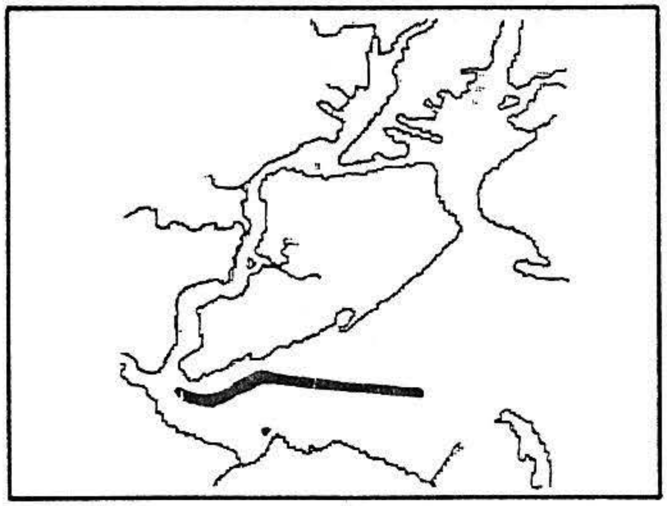
NTML -Navy Terminal Channel



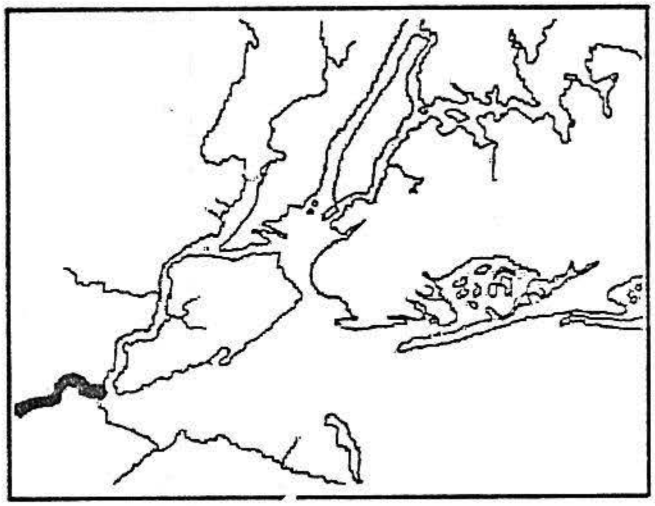
NTWN -Newton Creek



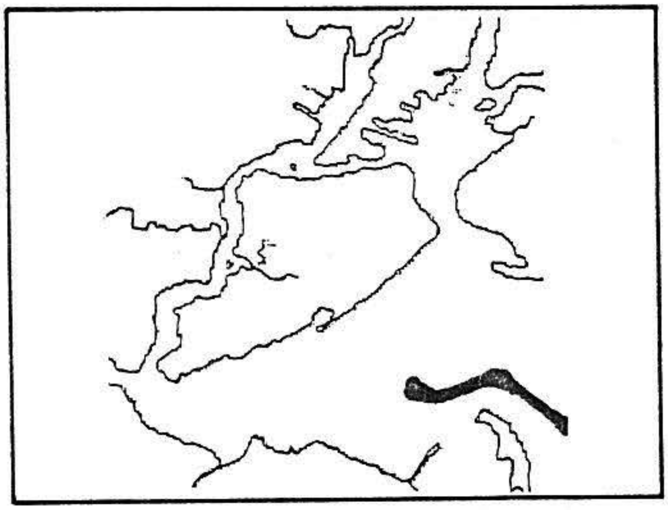
PAS -Passaic River



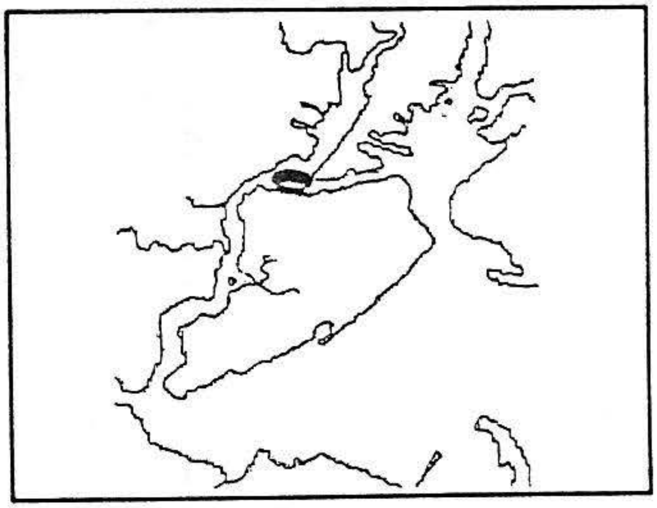
RBCH -Raritan Bay Channel



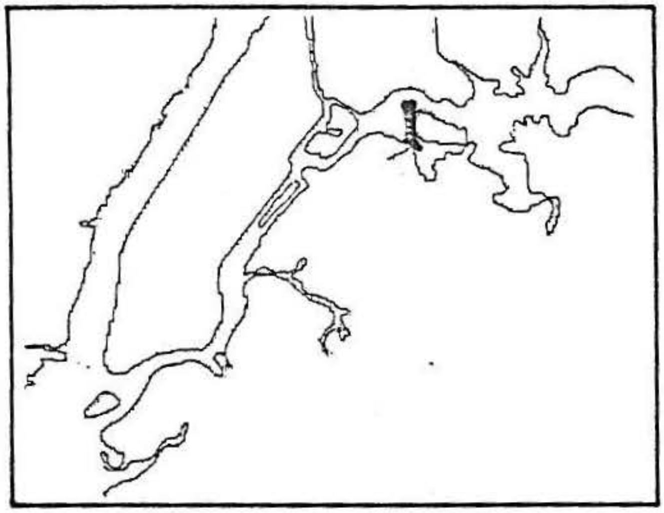
RR -Raritan River



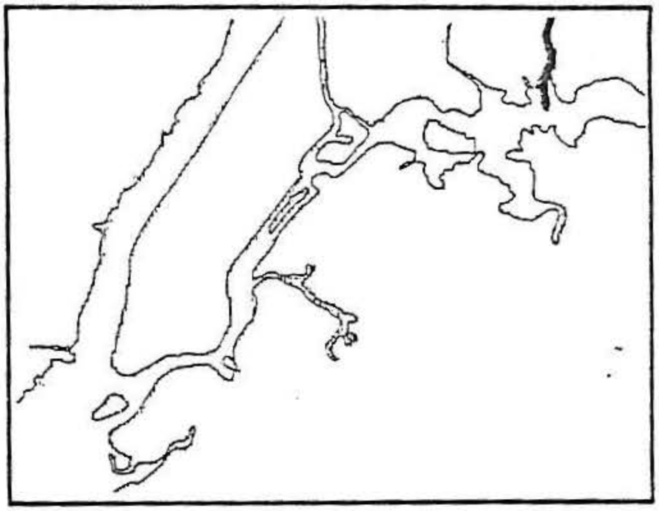
SHCH -Sandy Hook Channel



SHTR -Shooters Is. Channels



SPUR -East River Spur Channel



WCHST -Westchester Creek

Table A-1

Annual Federal Maintenance Dredging ($10^3 yd^3$)

Project	15-yr Avg Annual	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
RB	912	755	740	1728	615	1471	1223	1186	1539		819	2870	177	321	243	
AMB	834	522		247						1111	1501	1238	1844	2100	2319	1630
BRRH	704		382	385	1399		1678	25	404	350	1368	1879	594	650	1296	148
HRWE	594	468	900	713	729	1181	521	840	493	397	1451	860			357	
HRBW	423		910	791	1584		521						267	2273		
RR	318	185	1057	199		104	205	270	204		999	1541				
SHCH	256	64		654	503		469	434	243		188	188		626	471	
BMLK	217	400	650			271	1086				275	225			247	
NB	212			255	128		73	146	290	588				821	880	
UB	162						499		609		26	78			1224	
SHB	136	276	78				556	563	563							
MSCH	129	1158						777								
SHTR	111		335			550	60			726						
PAS	78						263	158				231	525			
AK	71							1066								
WCHST	62	274				85			135							441
JAMB	30							31				277			141	
BRX	26	84						94								219
HCK	24											355				
FLSH	19								279							
ER	15	202										28				
HRLM	13			10					179							
SPUR	11											122				41
NTWN	9						104			36						
ECHST	3									49						

Table A-2

Annual Private Dredging ($10^3 yd^3$)

Project	5-yr Avg Annual	1976	1977	1978	1979	1980
HRBW	601	664	660	977	366	338
AK	195	140	278	38	286	234
NTML	150			752		
KK	114	30	72	80	79	307
GWB	78		43	78		253
NB	72			235		127
BKLNY	56			66	141	71
PAS	39	126	24		18	25
BMLK	35				175	
HCK	34	20	2	95		52
RB	18		66	24		
BRRH	15			31	45	
UB	9		45			
NTWN	4			.5	12	5
SPUR	3		17			
JAMB	3			1	12	
HRWE	2			11		
SHB	2		5	2		3
ER	.8		4			
HRLM	.5					2
ECHST	.1		.6			

Table A-3

Federal New Work Dredging

Location	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
NB					1374	625	2424	2009							
UB			204	1324	259	3297	3363								
GRVS							1734	1108		833	291				
KK	660	302	158								197				
RR		104													
SHTR														18	

Table A-4

Average Percent Fines for Dredged Material

Project	Number of Samples	(%) Mean	Std. Dev.	95% Confidence
Hudson River - Battery to Weehawkin	12	81.1	16.7	10.6
Raritan Bay	10	45.3	22.4	16.0
Ambrose Channel		- ND -		
Bay Ridge - Red Hook	11	57.9	26.2	17.6
Hudson River - Weehawkin to Edgewater	19	86.9	7.4	3.6
Raritan River	4	66.8	25.7	40.9
Newark Bay	4	91.5	9.6	15.4
Arthur Kill	18	52.7	30.8	15.3
Sandy Hook Channel		- ND -		
Buttermilk Channel	11	38.6	21.9	14.7
Upper Bay	6	33.2	29.4	30.9
Navy Terminal	1	46.0	0	0
Sandy Hook Bay	2	80.5	14.8	133.4
Main Ship Channel		- ND -		
Passaic River	10	83.9	11.5	8.3
Kill van Kull	23	56.6	29.0	12.5
Shooter's Island	9	52.6	34.0	26.1
Gowanus Bay	5	47.2	33.7	41.8
Westchester Ck.	5	90.8	9.5	11.8
Hackensack R.	2	76.5	12.0	108.0
Brooklyn Navy Yd.	3	91.3	3.5	8.7
Jamaica Bay		- ND -		
Bronx River	6	79.5	10.6	11.2
Flushing Bay	2	85.5	10.6	95.3
East River	2	87.0	8.5	76.2
Spur Channel	6	81.6	16.5	17.3
Harlem River	1	13.0	0	0
Newtown Ck.	12	49.2	22.0	14.0
Eastchester Ck.	7	30.4	24.3	22.4
Hudson R. - above Edgewater	6	77.0	28.4	29.8
Coney Is. Channel		- ND -		
Gravesand Bay	4	20.3	7.0	11.2
Little Neck		- ND -		

Table A-5

Water Content of Dredged Material (Percent by mass)

Project	# of Samples	Mean
Hudson River-Battery to Weehawkin	- ND -	
Raritan Bay	13	58.7
Ambrose Channel	- ND -	
Bay Ridge-Reb Hook	8	51.2
Hudson River-Weehawkin to Edgewater	11	51.2
Raritan River	9	58.0
Newark Bay	3	46.6
Arthur Kill	7	53.0
Sandy Hook Channel	4	15.6
Buttermilk Channel	- ND -	
Upper Bay	6	60.3
Navy Terminal	- ND -	
Sandy Hook Bay	2	48.1
Main Ship Channel	2	48.8
Passaic River	9	55.1
Kill van Kull	1	46.3
Shooter's Island	2	35.7
Gowanus Bay	- ND -	
Westchester Ck.	5	59.8
Hackensack R.	2	34.6
Brooklyn Navy Yd.	- ND -	
Jamaica Bay	- ND -	
Bronx River	- ND -	
Flushing Bay	- ND -	
East River	- ND -	
Spur Channel	- ND -	
Harlem River	- ND -	
Newtown Ck.	12	64.5
Eastchester Ck.	7	47.6
Hudson R. - above Edgewater	- ND -	
Coney Is. Channel	- ND -	
Gravesand Bay	4	38.4
Little Neck	- ND -	

Table A-6

Bulk PCB Levels

Project	Number of Samples	(ppm) Mean	Std. Dev.	95% Confidence
Hudson River-Battery to Weehawkin	1	4.80	0	0
Raritan Bay		- ND -		
Ambrose Channel		- ND -		
Bay Ridge-Red Hook	8	<0.1	ND	ND
Hudson River-Weehawkin to Edgewater	23	0.223	0.186	0.081
Raritan River	7	0.2	ND	ND
Newark Bay	3	<0.1	ND	ND
Arthur Kill	42	0.468	0.429	0.130
Sandy Hook Channel	4	<0.1	ND	ND
Buttermilk Channel		- ND -		
Upper Bay	6	<0.1	ND	ND
Navy Terminal	3	0.017	0.012	0.029
Sandy Hook Bay		- ND -		
Main Ship Channel	2	<0.1	ND	ND
Passaic River	9	0.2	ND	ND
Kill van Kull	1	<0.1	ND	ND
Shooter's Island	1	0.900	0	0
Gowanus Bay	6	0.052	0.038	0.040
Westchester Ck.	5	0.6	ND	ND
Hackensack R.	2	<0.1	ND	ND
Brooklyn Navy Yd.		- ND -		
Jamaica Bay		- ND -		
Bronx River		- ND -		
Flushing Bay		- ND -		
East River		- ND -		
Spur Channel		- ND -		
Harlem River		- ND -		
Newtown Ck.	12	0.7	ND	ND
Eastchester Ck.	7	0.186	0.121	0.112
Hudson R.-above Edgewater		- ND -		
Coney Is. Channel		- ND -		
Gravesend Bay		- ND -		
Little Neck		- ND -		

Table A-7

Bulk Mercury Levels

Project	Number of Samples	(ppm) Mean	Std. Dev.	95% Confidence
Hudson River-Batter to Weehawkin	10	2.3	ND	ND
Raritan Bay	24	1.8	ND	ND
Ambrose Channel			- ND -	
Bay Ridge-Red Hook	8	3.1	ND	ND
Hudson River-Weehawkin to Edgewater	23	0.700	0.259	0.112
Raritan River	7	2.2	ND	ND
Newark Bay	79	4.229	2.513	0.554
Arthur Kill	51	2.180	1.474	0.404
Sandy Hook Channel	4	0.03	ND	ND
Buttermilk Channel	2	2.2	ND	ND
Upper Bay	3	1.233	0.153	0.379
Navy Terminal	3	0.767	0.058	0.143
Sandy Hook Bay	2	0.3	ND	ND
Main Ship Channel	2	1.9	ND	ND
Passaic River	7	11.214	9.177	8.487
Kill van Kull	3	4.333	1.155	2.869
Shooter's Island	23	9.296	4.238	1.833
Gowanus Bay	7	1.143	0.341	0.315
Westchester Ck.	5	3.3	ND	ND
Hackensack R.	3	3.767	3.412	8.477
Brooklyn Navy Yd.			- ND -	
Jamaica Bay			- ND -	
Bronx River			- ND -	
Flushing Bay			- ND -	
East River			- ND -	
Spur Channel			- ND -	
Harlem River			- ND -	
Newtown Ck.	12	5.1	ND	ND
Eastchester Ck.	7	1.086	0.797	0.737
Hudson R.- above Edgewater			- ND -	
Coney Is. Channel			- ND -	
Gravesend Bay	3	0.933	0.473	1.174
Little Neck			- ND -	

Table A-8

Bulk Cadmium Levels

Project	Number of Samples	(ppm) Mean	Std. Dev.	95% Confidence
Hudson River-Battery to Weehawkin	10	5.4	ND	ND
Raritan Bay	54	3.494	1.614	0.430
Ambrose Channel	11	2.200	1.362	0.915
Bay Ridge-Red Hook	8	4.8	ND	ND
Hudson River-Weehawkin to Edgewater	23	1.174	0.384	0.166
Raritan River	7	2.6	ND	ND
Newark Bay	79	8.558	5.851	1.290
Arthur Kill	55	4.176	3.206	0.847
Sandy Hook Channel	4	0.18	ND	ND
Buttermilk Channel	2	6.1	ND	ND
Upper Bay	3	1.633	0.929	2.308
Navy Terminal	5	1.900	1.699	2.109
Sandy Hook Bay	12	3.942	1.917	1.218
Main Ship Channel	8	3.275	3.265	2.730
Passaic River	7	11.841	5.238	4.844
Kill van Kull	3	8.333	1.155	2.869
Shooter's Island	23	18.765	8.448	3.654
Gowanus Bay	7	3.586	1.087	1.005
Westchester Ck.	5	7.8	ND	ND
Hackensack R.	3	6.600	3.857	9.583
Brooklyn Navy Yd.		- ND -		
Jamaica Bay	1	1.000	0	0
Bronx River		- ND -		
Flushing Bay		- ND -		
East River		- ND -		
Spur Channel		- ND -		
Harlem River		- ND -		
Newtown Ck.	12	94.4	ND	ND
Eastchester Ck.	7	2.714	1.505	1.392
Hudson R.-above Edgewater		- ND -		
Coney Is. Channel		- ND -		
Gravesend Bay	3	2.100	1.389	3.451
Little Neck		- ND -		

Table A-9

Bulk Arsenic Levels

Project	Number of Samples	(ppm) Mean	Std. Dev.	95% Confidence
Hudson River-Battery to Weehawkin	10	1.0	ND	ND
Raritan Bay	24	9.9	ND	ND
Ambrose Channel		- ND =		
Bay Ridge-Red Hook	8	6.8	ND	ND
Hudson River-Weehawkin to Edgewater	11	4.1	ND	ND
Raritan River	7	31.1	ND	ND
Newark Bay	81	5.566	ND	ND
Arthur Kill	7	19.6	ND	ND
Sandy Hook Channel	4	2.2	ND	ND
Buttermilk Channel	2	1.9	ND	ND
Upper Bay	6	10.383	ND	ND
Navy Terminal		- ND -		
Sandy Hook Bay	2	11.4	ND	ND
Main Ship Channel	2	6.3	ND	ND
Passaic River	9	7.8	ND	ND
Kill van Kull	1	30.8	ND	ND
Shooter's Island	18	10.189	11.293	5.617
Gowanus Bay	1	0.2	0.0	0.0
Westchester Ck.	5	9.8	ND	ND
Hackensack R.	2	20.4	ND	ND
Brooklyn Navy Yd.		- ND -		
Jamaica Bay		- ND -		
Bronx River		- ND -		
Flushing Bay		- ND -		
East River		- ND -		
Spur Channel		- ND -		
Harlem River		- ND -		
Newtown Ck.	12	42.1	ND	ND
Eastchester Ck.	7	7.243	4.424	4.092
Hudson R. - above Edgewater		- ND -		
Coney Is. Channel		- ND -		
Gravesand Bay	4	7.2	ND	ND
Little Neck		- ND -		

Table A-10

Bulk Lead Levels

Project	Number of Samples	(ppm) Mean	Std. Dev.	95% Confidence
Hudson River-Battery to Weehawkin	10	230.4	ND	ND
Raritan Bay	76	148.5	ND	ND
Ambrose Channel	11	25.3	16.4	11.0
Bay Ridge-Red Hook	8	234.2	ND	ND
Hudson River-Weehawkin to Edgewater	23	63.1	23.8	10.3
Raritan River	7	160.6	ND	ND
Newark Bay	94	267.7	ND	ND
Arthur Kill	55	192.8	429.3	113.4
Sandy Hook Channel	4	4.4	ND	ND
Buttermilk Channel	2	238.5	ND	ND
Upper Bay	6	76.5	ND	ND
Navy Terminal	5	92.7	68.2	84.7
Sandy Hook Bay	12	132.5	70.2	44.6
Main Ship Channel	8	43.0	22.0	18.4
Passaic River	9	477.8	ND	ND
Kill van Kull	3	367.6	140.8	350.0
Shooter's Island	23	400.4	129.4	55.9
Gowanus Bay	7	108.6	34.2	31.7
Westchester Ck.	5	623.7	ND	ND
Hackensack R.	3	238.0	71.0	176.4
Brooklyn Navy Yd.		- ND -		
Jamaica Bay	1	6.0	0.0	0.0
Bronx River		- ND -		
Flushing Bay		- ND -		
East River		- ND -		
Spur Channel		- ND -		
Harlem River		- ND -		
Newtown Ck.	12	865.9	ND	ND
Eastchester Ck.	7	263.2	140.5	129.9
Hudson R.-above Edgewater		- ND -		
Coney Is. Channel		- ND -		
Gravesend Bay	4	111.6	ND	ND
Little Neck		- ND -		

Table A-11

Mercury Levels for the Elutriate Test

Project	Number of Tests	(ppb) Mean	Std. Dev.	95% Confidence
Hudson River - Battery to Weehawkin	2	0.350	0.212	1.906
Raritan Bay	2	0.200	0	0
Ambrose Channel	1	0.200	0	0
Bay Ridge - Red Hook	3	0.173	0.142	0.353
Hudson River - Weehawkin to Edgewater	4	0.225	0.050	0.080
Raritan River	2	0.200	0	0
Newark Bay	3	0.200	0	0
Arthur Kill	10	0.212	0.089	0.063
Sandy Hook Channel			- ND -	
Buttermilk Channel	2	0.365	0.233	2.096
Upper Bay	2	0.365	0.233	2.096
Navy Terminal			- ND -	
Sandy Hook Bay	2	0.200	0	0
Main Ship Channel			- ND -	
Passaic River	3	0.233	0.058	0.143
Kill van Kull	9	0.189	0.076	0.058
Shooter's Island	1	0.300	0	0
Gowanus Bay	2	0.315	0.163	1.461
Westchester Ck.	1	0.200	0	0
Hackensack R.			- ND -	
Brooklyn Navy Yd.	2	0.250	0.071	0.635
Jamaica Bay			- ND -	
Bronx River	1	0.200	0	0
Flushing Bay	2	0.200	0	0
East River	1	0.370	0	0
Spur Channel	1	0.800	0	0
Harlem River	1	0.200	0	0
Newtown Ck.	4	0.275	0.150	0.239
Eastchester Ck.			- ND -	
Hudson R. - above Edgewater	3	0.367	0.208	0.517
Coney Is. Channel			- ND -	
Gravesend Bay	1	0.200	0	0
Little Neck			- ND -	

Table A-12

Cadmium Levels for the Elutriate Test

Project	Number of Tests	(ppb) Mean	Std. Dev.	95% Confidence
Hudson River - Battery to Weehawkin	2	0.200	0.141	1.271
Raritan Bay	2	0.240	0.198	1.779
Ambrose Channel	1	0.270	0	0
Bay Ridge - Red Hook	3	0.190	0.115	0.287
Hudson River-Weehawkin to Edgewater	4	0.242	0.165	0.263
Raritan River	2	0.235	0.021	0.191
Newark Bay	3	0.177	0.133	0.330
Arthur Kill	10	0.332	0.364	0.261
Sandy Hook Channel			- ND -	
Buttermilk Channel	2	<0.100	0	0
Upper Bay	2	0.450	0.495	4.447
Navy Terminal			- ND -	
Sandy Hook Bay	2	0.325	0.064	0.572
Main Ship Channel			- ND -	
Passaic River	3	0.233	0.231	0.574
Kill van Kull	9	0.737	1.518	1.167
Shooter's Island	2	0.330	0	0
Gowanus Bay	2	<0.100	0	0
Westchester Ck.			- ND -	
Hackensack R.			- ND -	
Brooklyn Navy Yd.	2	2.950	0.311	2.795
Jamaica Bay			- ND -	
Bronx River	1	0.540	0	0
Flushing Bay	2	0.100	0	0
East River	1	0.300	0	0
Spur Channel	1	1.500	0	0
Harlem River	1	0.400	0	0
Newtown Ck.	4	0.617	0.405	0.644
Eastchester Ck.			- ND -	
Hudson R. - above Edgewater	3	1.080	0.570	1.417
Coney Is. Channel			- ND -	
Gravesend Bay	1	0.260	0	0
Little Neck			- ND -	

Table A-13

PCB Levels for the Elutriate Test

Project	Number of Samples	(ppb) Mean	Std. Dev.	95% Confidence
Hudson River - Battery to Weehawkin	2	<0.1	0	0
Raritan Bay	2	0.055	0.064	0.572
Ambrose Channel	1	<0.1	0	0
Bay Ridge - Red Hook	3	0.103	0.095	0.236
Hudson River - Weehawkin to Edgewater	4	0.08	0.091	0.144
Raritan River	2	<0.1	0	0
Newark Bay	3	0.04	0.052	0.129
Arthur Kill	10	0.06	0.045	0.032
Sandy Hook Channel		- ND -		
Buttermilk Channel	2	0.055	0.064	0.572
Upper Bay	2	0.170	0.226	2.033
Navy Terminal		- ND -		
Sandy Hook Bay	2	<0.1	0	0
Main Ship Channel		- ND -		
Passaic River	3	0.09	0.075	0.188
Kill van Kull	9	0.124	0.034	0.026
Shooter's Island	1	0.270	0	0
Gowanus Bay	2	0.150	0.071	0.635
Westchester Ck.	1	<0.1	0	0
Hackensack R.		- ND -		
Brooklyn Navy Yd.	2	0.165	0.021	0.191
Jamaica Bay		- ND -		
Bronx River	1	<0.1	0	0
Flushing Bay	2	<0.1	0	0
East River	2	<0.1	0	0
Spur Channel	1	0.46	0	0
Harlem River	1	<0.1	0	0
Newtown Ck.	4	<0.1	0	0
Eastchester Ck.		- ND -		
Hudson R. - above Edgewater	3	0.153	0.092	0.229
Coney Is. Channel		- ND -		
Gravesend Bay	1	<0.1	0	0
Little Neck		- ND -		

Sources of Dredging Data (Tables B1 to B3)

1) U.S. Army Corps of Enginers, New York District, Unpublished data
2) Conner et al., 1979
3) U.S. Army Corps of Engineers 1976 through 1979

Sources of Bulk Contaminant Levels (Tables B4 to B8)

1) U.S. Army Corps of Engineers, New York District, Water Quality Section, Unpublished data
2) Conner et al., 1979
3) Meyerson et al., 1981
4) Koons and Thomas, 1979
5) Olsen et al., 1978
6) Williams et al, 1978
7) Suszkowski, 1978
8) Greig and McGrath, 1977
9) Bopp, 1979

Sources of Particle Size and Elutriate Levels (Tables B9 to B12)

1) U.S. Army Corps of Engineers, New York District Water Quality Section, Unpublished data

Appendix B

Waterway Name - Bay Ridge-Red Hook Channels

Waterway Description - Bay Ridge Channel runs east from anchorage channel starting at the Narrows, and joins Red Hook Channel, ending at Buttermilk Channel just south of Governors Island. Together, they provide primary access to the Brooklyn waterfront.

Waterway Dimensions - Bay Ridge Channel is 40' deep and ranges from 1,200'-1,750' wide. Red Hook Channel is also 40' deep and 1,200' wide to the junction of but Termilk Channel. In the entrance to Gowanus Creek, the width narrows to 500'. Total length is 4 miles

Tidal Range - Tidal range is 4.7' with an extreme range of 14.8' (MLW).

Major use and facilities - These channels provide primary terminal access to the Brooklyn Waterfront, serving such facilities as the Port Authority's Erie Basin Terminal, Todd Shipyards, Bush & Military Ocean Terminals, Hellenic Lines, and the Owls Head Sewage Plant

Tons Landed (1960-1978 Yearly Average) - 4.0 million tons

Tons Through (1960-1978 yearly average) - 3.7 million tons

Passengers (1960-1978 yearly average) - 1.3 million

Main Commodity Group (1978) - Waste & Scrap Material 37% (.85 million tons)

Second Commodity Group (1978) - Food & kindred products 16% (.37 million tons)

Third Commodity Group (1978) - Petroleum Products 12% (.3 million tons)

Inbound Vessel Movements (1978) - 8,760

Outbound Vessel Movements (1978) - 8,611

Movements by Vessel Draft - Over 96% of the incoming vessels had drafts of 18' and less, of which the greatest number (78%) were tugs and towboats. The remaining vessels were either passenger & dry cargo ships or tankers.

Federal Maintenance Dredging (1966-1080) - 704,000 Cubic Yards per year

Private Dredging Activities (1976-1980) - 15,000 Cubic Yards per year

Combined Dredging Activities - 119,000 Cubic Yards per year

Bioassay/Bioaccumulation tests and results - 6 reported tests with no failures (BR002-1980)

Waterway Name - Bronx River

Waterway Description - The Bronx River Empties into a shallow bay in the north shore of the East River 11 miles by water northeast of the Battery.

Water Dimensions - The project provides for a channel 10' deep and 100'-200' wide, extending from deep water in the East River to East 172nd Street in the Bronx. The length of the navigable portion is 2.6 miles.

Tidal Range - Tidal range is 6.9' with an extreme range of 19.5' (MLW).

Major use and facilities - The Bronx River has 2 facilities used by party fishing vessels, and one facility each for the shipment of scrap metal and sand, stone and gravel.

Tons Landed (1960-1978 yearly average) - .5 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) - .1 million

Main Commodity Group (1978) - Sand, Gravel & Crushed Rock 68% (.2 million tons)

Second Commodity Group (1978) - Iron & steel scrap 32% (.1 million tons)

Third Commodity Group (1978) -

Inbound Vessel Movements (1978) - 2,104

Outbound Vessel Movements (1978) - 2,100

Movements by vessel draft - Nearly 72% of all vessel movements were due to passenger and dry cargo ships with drafts of 7' and less (1,504). Tugboats and barges made up the remainder with the majority having drafts between 10'-13'.

Federal Maintenance Dredging (1966-1980) - 26,000 cubic years per year

Private Dredging Activities (1976-1080) -

Combined Dredging Activities - 26,000 cubic years per year

Bioassay/Bioaccumulation Tests and Results - 1 reported test.
No failures

Waterway Name - Brooklyn Navy Yard (Wallabout Channel)

Waterway Description - Wallabout Channel is a tidal branch of the East River, about 2.5 miles by water northeast of the Battery. It is located on the east side of the river immediately east of the Brooklyn Navy Yard.

Waterway Dimensions - The project provides for a channel 20' deep, between 230'-350' wide, extending from the East River the inner end of the causeway at Clinton Avenue for a total length of about 2000'.

Tidal Range - Tidal range is approximately 4.4' with an extreme range between 10'-15' (MLW).

Major Use and Facilities - The former Brooklyn Navy Yard is found at the entrance to Wallabout Bay, but is no longer operating. Two dry dock and vessel repair facilities operate within Wallabout Basin.

Tons Landed (1960-1978 yearly average) - N/A

Tons Through (1960-1978 yearly average) - N/A

Passengers (1960-1978 yearly average) - N/A

Main Commodity Group (1978) - N/A

Third Commodity Group (1978) - N/A

Inbound Vessel Movements (1978) - 3

Outbound Vessel Movements (1978) - 3

Movements by Vessel Draft - One tugboat and two tankers with drafts of 13' and less were reported to have used Wallabout Channel in 1978

Federal Maintenance Dredging (1966-1980) -

Private Dredging Activities (1976-1980) - 56,000 Cubic Yards per year

Combined Dredging Activities - 56,000 Cubic Yards per year

Bioassay/Bioaccumulation Tests and Results - 3 tests reported with no failures.

Waterway Name - Buttermilk Channel

Waterway Description - Buttermilk Channel lies between Governors Island and Brooklyn, and connects deep water in the Upper Bay with the East River. Together with Bay Ridge & Red Hook Channels, they form an easterly channel along the Brooklyn waterfront.

Waterway Dimensions - A Channel 40' deep and 1000'-500' wide along the easterly half, and 35' deep and 500' wide along the westerly half is provided, with suitable widening at the junctions with the East River and Red Hook & Anchorage Channels. Length is 2.3 mil.

Tidal Range - Tidal range is 4.4' with an extreme range of 14.4' (MLW).

Major Use and Facilities - Buttermilk Channel serves the Governors Is. Coast Guard Base, the Port Authority's Brooklyn Marine Terminal, and 5 general cargo & container facilities. It's also used as a cut-off between anchorage and East River Channels.

Tons Landed (1960-1978 yearly average) - 1.9 million tons

Tons Through (1960-1978 yearly average) - .9 million tons

Passengers (1960-1978 yearly average) - .001 million

Main Commodity Group (1978) - Food & kindred products 22% (.3 million tons)

Second Commodity Group (1978) - Petroleum products 18% (.27 million tons)

Third Commodity Group (1978) - Farm products 9% (.1 million tons)

Inbound Vessel Movements (1978) - 7,182

Outbound Vessel Movements (1978) - 7,370

Movements by Vessel Draft - Over 70% of the incoming vessel movements were due to tugs and towboats of 18' and less draft. The incoming passenger and dry cargo had drafts ranging from less than 18' to 37'. Most incoming tankers (98%) had drafts of 18' and less.

Federal Maintenance Dredging (1966-1980) - 217,000 cubic yards per year

Private Dredging Activities (1976-1980) - 35,000 cubic yards per year

Combined Dredging Activities - 252,000 cubic years per year

Bioassay/Bioaccumulation Tests and Results - 4 tests reported with no failures (BM000-1979)

Waterway Name - Eastchester Creek

Waterway Description - Eastchester Creek, also known as Hutchinson River, is a small tidal stream emptying into East Chester Bay, an indentation in the north shore of Long Island Sound immediately north of Throgs Neck, about 21 miles northeast of the Battery.

Waterway Dimensions - A channel about 8' deep and between 70'-150' wide extends from Long Island Sound to a point about 300' above the Fulton Avenue Bridge. Total length is about 5 miles.

Tidal Range - Tidal range is 7.3' with an extreme range of 19.3' (MLW).

Major Use and Facilities - There are 8 facilities used for the handling of petroleum products from barge and small tank vessels. There are also 3 facilit deal with sand, stone and gravel. (Code ES000-ES900)

Tons Landed (1960-1978 yearly average) - 1.9 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) -

Main Commodity Group (1978) - Petroleum & coal products 79% (1.3 million tons)

Second Commodity Group (1978) - Sand, gravel & crushed rock 20% (.3 million tons)

Third Commodity Group (1978) - Iron and steel scrap 1% (.01 million tons)

Inbound Vessel Movements (1978) - 2,220

Movements by Vessel Draft - Over 84% of the incoming vessels had drafts between 8'-10', which is the maximum depth of the channel.

Federal Maintenance Dredging (1966-1980) - 3,000 cubic yards per year

Combined Dredging Activities - 3,100 cubic yards per year

Bioassay/Bioaccumulation tests and results - 1 reported test. Passed. (ES000-1978)

Waterway Name - East River Channel System

Waterway Description - The East River is a tidal strait about 14 miles long. It connects deep water at Governors Is. in the upper bay with Long Island Sound at Throgs Neck, separating Long Island from the mainland.

Waterway Dimensions - Depth: 40' from upper bay to Brooklyn Navy Yard; 35' above Brooklyn Navy Yard. Width: 1000' wide in the 40' section and 550'-1000' wide in the 35' section.

Tidal Range - From 4.4' at the Battery to 7.1' at Throgs Neck; extreme tide ranges from 14.4' to 19.3' (MLW), respectively.

Major Use and Facilities - The East River provides the major link between New York Harbor, the Hudson River and Long Island Sound. Along the waterway are 6 major petroleum terminals, 2 steamship lines, and at least 3 major cargo terminals. (see listings ER000-ER905)

Tons Landed (1960-1978 yearly average) - 20.4 million tons

Tons Through (1960-1978 yearly average) - 29.6 million tons

Passengers (1960-1978 yearly average) - 22.6 million tons

Main Commodity Group (1978) - Petroleum & coal products 76% (12.3 million tons)

Second Commodity Group (1978) - Waste & scrap materials 13% (2 million tons)

Third Commodity Group (1978) - Farm products 3% (.4 million tons)

Inbound Vessel Movements (1978) - 25,785

Outbound Vessel Movements (1978) - 26,023

Movements by Vessel Draft - of the 1,405 inbound tankers, only 125 (9%) had drafts of 34' and greater, while 1,232 (88%) tankers had drafts of 18' and less. Of the 9,740 inbound passenger and dry cargo ships, 9,323 (96%) had drafts of 18' and less.

Federal Maintenance Dredging (1966-1980) - 15,000 cubic yards per year

Private Dredging Activities (1976-1980) - 1,000 cubic yards per year

Combined Dredging Activities - 16,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 5 reported tests with 2 failures (ER905-1979, 1980)

Waterway Name - East River Spur Channel

Waterway Description - The East River Spur Channel is a recent modification to the East River Channel system and provides for the South Brother Island Channel leading to Astoria waterfront, passing between South Brother and Rikers Islands towards the south

Waterway Dimensions - The channel is 35' deep and 400' wide with a turning basin at the head of the channel. Length is about 1 mile.

Tidal Range - Tidal range varies from 4.4' at the Battery to 7.1' at Throgs Neck with extreme raf 14.4' and 19.3' respectively (MLW).

Major Use and Facilities - The East River Spur Channel provides access from the East River to the Astoria waterfront for 2 petroleum receiving facilities, and for the shipment of sludge from the Bowery Bay Water Pollution Control Plant.

Tons Landed (1960-1978 yearly average) - not available

Tons Through (1960-1978 yearly average) - N/A

Passengers (1960-1978 yearly average) - N/A

Main Commodity Group (1978) - Petroleum products

Second Commodity Group (1978) -

Third Commodity Group (1978) -

Inbound Vessel Movements (1978) - N/A

Outbound Vessel Movements (1978) - N/A

Movements by Vessel Draft - N/A

Federal Maintenance Dredging (1966-1980) - 11,000 cubic yards per year

Private Dredging Activities (1978-1980) - 3,000 cubic yards per year

Combined Dredging Activities - 14,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 1 test reported with no failure.

Waterway Name - Flushing Bay and Creek

Waterway Description - Flushing Bay is located on the north shore of Long Island, approximately 12 miles by water northeast of the Battery. Flushing bay is 2 miles long and Flushing Creek 1 mile.

Waterway Dimensions - Depth is 15' in the Bay Channel and a width of 300' from the East River to the maneuvering area (1.8 miles). The Creek Channel is also 15' deep and varies between 170'-200' wide (1.1 mile)

Tidal Range - Tidal range is 6.8' with an extreme range of 18.4' (MLW).

Major Use and Facilities - There are 9 facilities specializing in the receipt of sand, stone and brick type cargoes along Flushing Bay and Creek, as well as 3 for the receipt of petroleum products by barge. There are also some recreational boat facilities in the bay

Tons Landed (1960-1978 yearly average) - 2.2 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) -

Main Commodity Group (1978) - Petroleum & Coal products 39% (.7 million tons)

Second Commodity Group (1978) - Sand, gravel & crushed rock 37% (.7 million tons)

Third Commodity Group (1978) - Waste & scrap 21% (.4 million tons)

Inbound Vessel Movements (1978) - 2,418

Outbound Vessel Movements (1978) - 2,540

Movements by Vessel Draft - Dry cargo barges and tugboats comprised nearly 88% of the vessel movements. of the tankers, nearly 50% had drafts between 12'-15'.

Federal Maintenance Dredging (1966-1980) - 19,000 cubic yards per year

Private Dredging Activities (1976-1980) -

Combined Dredging Activities - 19,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 2 tests reported. No failures

Waterway Name - Gowanus Bay and Creek

Waterway Description - Gowanus Creek is a small tidal waterway in Brooklyn extending northeasterly about 1.5 miles from the north end of Bay Ridge Channel.

Waterway Dimensions - A main channel of 30' depth and between 200'-500' wide funs from Bay Ridge Channel to the Vicinity of Sigourney Street. The Channel reduces to a depth of 18' and width of 100' around the Hamilton Ave. Bridge. Total length is about 0.8 miles

Tidal Range - Tidal range is approximately 4.7' with an extreme range of 14.8' (MLW).

Major Use and Facilities - At least 9 facilities dealing in the receipt and shipment of general cargo are found along this waterway. A large dry dock and vessel repair facility is located here. Petroleum, as well as sand and gravel facilities make use of Gowanus Bay

Tons Landed (1960-1978 yearly average) - 3.5 million tons

Tons Through (1960-1978 yearly average) - .5 million tons

Passengers (1960-1978 yearly average) -

Main Commodity Group (1978) - Petroleum & coal products 78% (2.5 million tons)

Second Commodity Group (1978) - Sand, gravel & crushed rock 7% (.2 million tons)

Third Commodity Group (1978) - Food & kindred products 4% (.1 million tons)

Inbound Vessel Movements (1978) - 5,307

Outbound Vessel Movements (1978) - 5,169

Movements by Vessel Draft - Over 96% of the incoming vessels had drafts of 18' and less with most of those being tugs and towboats. A fairly large number of self-propelled tankers (37), however, had drafts between 33'-35'.

Federal Maintenance Dredging (1966-1980) -

Private Dredging Activities - 78,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 4 reported tests with 2 failures (GB000-1979, GB904-1980)

Waterway Name - Hackensack River

Waterway Description - The Hackensack River extends from the northeastern portion of Newark Bay for a navigable distance of more than 16 miles

Waterway Dimensions - from the junction with the Newark Bay Channel, a 30' deep and 300' wide channel runs northeast up the Hackensack River for 4 miles to a sm all turning basin, then narrows and shallows to 12' deep for an additional 12.5 miles.

Tidal Range - Tidal range is approximately 4.9', with an extreme tidal range of about 14.4' (MLW).

Major Use and Facilities - The receipt of petroleum products by barge (at least 21 facilities), and of sand, stone & gravel (7 facilities) dominate the waterfront usage of the river. There is also a large shipbreaking and scrap metal facility along the shore.

Tons Landed (1960-1978 yearly average) - 4.3 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) -

Main Commodity Group (1978) - Petroleum & coal products 45% (1.2 million tons)

Second Commodity Group (1978) - Sand, gravel & crushed rock 24% (.7 million tons)

Third Commodity Group (1978) - Coal & lignite 22% (.6 million tons)

Inbound Vessel Movements (1978) - 3,229

Outbound Vessel Movements (1978) - 3,235

Movements by Vessel Draft - with the exception of only 3 vessels, all incoming vessels had drafts of 18' and less. Tankers and tanker barges comprised only 27% of the total reported vessel movements, with dry cargo vessels and tugboats making up the remainder.

Federal Maintenance Dredging (1966-1980) - 24,000 cubic yards per year

Private Dredging Activities (1976-1980) - 34,000 cubic yards per year

Combined Dredging Activities - 58,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 2 reported tests with no failures

Waterway Name - Harlem River

Waterway Description - The Harlem River leads northward from the east River, between Manhattan and the Bronx, and connects with the Hudson River through the Spuyten Duyvil Creek.

Waterway Dimensions - The existing project provides for a channel 15" deep and generally 400' wide from the East River to the Hudson River, a distance of approximately 8 miles.

Tidal Range - Tidal range varies from 4.9' at East River junction to 3.9' at Spuyten Duyvil. Extreme ranges are 15.1' and 14.1' (MLW) respectively.

Major Use and Facilities - There are 3 facilities that deal with the receipt of petroleum and coal products along the Harlem River and 1 that handles the receipt of sand, gravel and crushed rocks. High tidal velocities make navigation along the river difficult.

Tons Landed (1960-1978 yearly average) - .9 million tons

Tons Through (1960-1978 yearly average) - .001 million tons

Passengers (1960-1978 yearly average) -

Main Commodity Group (1978) - Petroleum & coat products 54% (.2 million tons)

Second Commodity Group (1978) - Sand, gravel & crushed rock 46% (.18 million tons)

Third Commodity Group (1978) -

Inbound Vessel Movements (1978) - 675

Outbound Vessel Movements (1978) - 685

Movements by Vessel Draft - of the 107 inbound tankers, 82 (77%) had drafts of 12' and less. All the incoming dry cargo vessels (169) had drafts of 12' and less. Of the 399 tugboat or towboats, 398 had drafts of 12' and less.

Federal Maintenance Dredging (1966-1980) - 13,000 cubic yards per year

Private Dredging Activities (1976-1980) - less than 500 cubic yards per year

Combined Dredging Activities - 13,500 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - No reported tests

Waterway Name - Hudson River-Combined Sections

Waterway Description - The Hudson River separating New York from New Jersey empties into the upper bay at the Battery. The channel included in the federal maintenance project extends from deep water in the upper bay to a point along the edgwater waterfront.

Waterway Dimensions - A channel 45' deep and 2000' wide runs from the upper bay to west 59 St. (Manhattan). From there northward, the Weehawken-Edgewater Channel (32' deep, 550'-750' wide) runs along the Jersey shore.

Tidal Range - Tidal range is 4.4' with an extreme range of 14.4' (MLW).

Major Use and Facilities - Some of the major facilities located along the Hudson River include the passenger ship terminal, Dept. of Sanitation piers, coffee & sugar processing facilities, dry docks & ship repair facilities, and the container facility at Port Seatrain.

Tons Landed (1960-1978 yearly average) - Battery-Edgewater 10.9 million tons Edgewater-Tarrytown 1.3 million tons

Tons Through (1960-1978 yearly average) - Battery-Edgewater 21.4 million tons Edgewater-Tarrytown 20.6 million tons

Passengers (1960-1978 yearly average) - Battery-Edgewater 6.2 million Edgewater-Tarrytown .6 million

Main Commodity Group (1978) - Bat-Edge-waste & scrap 28% (1.2 mi. tons) Edge-Tarry-petroleum prd 71% (.4 m tons)

Second Commodity Group (1978) - Bat-Edge-petroluem prd 25% (1.1 m. Tons) Edge-Tarry-waster & scrap 19% (.1 m. tons)

Third Commodity Group (1978) - Bat-Edge-food & kindred prd - 14% (.6 m. tons) Edge-Tarry-food & kindred - 10% (.06 m. tons)

Inbound Vessel Movements (1978) - Battery-Edgewater 24,889

Outbound Vessel Movements (1978) - Battery-Edgewater 24,065

Movements by Vessel Draft - Although nearly 98% of all incoming traffic had drafts of 18' and less, including almost all the tanker traffic by barge, drafts reported for the passenger and dry cargo ships ranged from 18'-38'. over 100 ships had drafts of 30' and more.

Federal Maintenance Dredging (1966-1980) - Battery-Weehawken (423,000 cu.yd/yr) Weehawken-Edgewater (594,000 cu.yd/yr)

Private Dredging Activities (1976-1980) - Battery-Weehawken (601,000 cu.yd/yr)
Weehawken-Edgewater (2,000 cu./yd/yr)

Combined Dredging Activities - Battery-Weehawken (1,024,000 cu.yd/yr) Weehawken-Edgewater (596,000 cu.yd/yr)

Bioassay/Bioaccumulation Tests and Results - B-W (13 reported tests, 2 failures-BW901-1979, BW918-1980) W-E (3 tests, 0 failures)

Waterway Name - Jamaica Bay

Waterway Description - Jamaica Bay is located along the south shore of Long Island, and has its entrance about 17 miles by water southeast of the Battery.

Waterway Dimensions - The Jamaica Bay Channel System is composed of a series of channels and turning basins ranging in depth from 12'-20' and in width from 200'-1000'. The total length of the channel system is 19.7 miles.

Tidal Range - Tidal range is 4.9' with an extreme range of 13.7' (MLW).

Major Use and Facilities - The receipt of petroleum products and aviation fuel used at Kennedy International Airport is handled by at least 17 facilities throughout the Bay. Floyd Bennett Field and the fishing vessels from Sheepshead Bay also use the channels.

Tons Landed (1960-1978 yearly average) - 4.9 million tons for Jamaica Bay 2.3 million tons for East Rockaway

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) - .45 million for Jamaica Bay .13 million for East Rockaway

Main Commodity Group (1978) - Petroleum products 81% (5.9 million tons) Jamaica Bay

Second Commodity Group (1978) - Waste & scrap materials 15% (1.1 million tons) Jamaica Bay

Third Commodity Group (1978) - Sand, gravel & crushed rock 4% (.3 million tons) Jamaica Bay

Inbound Vessel Movements (1978) - 14,624 Jamaica Bay

Outbound Vessel Movements (1978) - 14,666 Jamaica Bay

Movements by Vessel Draft - Nearly 74% of the incoming vessel movements were by passenger and dry cargo vessels with drafts of 12' and less. Over 95% of the 1,600 incoming tankers had drafts of 13' and less. For East Rockaway, nearly all ships had drafts between 6'-14

Federal Maintenance Dredging (1966-1980) - 30,000 cubic yards per year

Private Dredging Activities (1976-1980) - 3,000 cubic yards per year

Combined Dredging Activities -33,000 cubic yards per year

Bioassay/Bioaccumultation Tests and Results - No reported tests

Waterway Name - Lower Entrance Channels

Waterway Description - The lower entrance channel system of New York Harbor is made up to Ambrose Channel, Sandy Hook Channel (East Section), Sandy Hook (Bayside Channel), and the main ship channel (Chapel Hill Channel).

Waterway Dimensions _ Ambrose-45' deep, 2000' wide, 10.2 miles long; Sandy Hook (east) - 35' deep, 800' wide, 3.4 miles long; Bayside- 35' deep, 800' wide, 3.7 miles long; main ship- 30' deep, 1000' wide, 5.3 miles long.

Tidal Range - Mean tidal range is 4.7' with an extreme range of 14.8' (MLW).

Major Use and Facilities - These channels provide access to New York Harbor from the south.

Tons Landed (1960-1978 yearly average) -

Tons Through (1960-1978 yearly average) - 106.5 million tons

Passengers (1960-1978 yearly average) - .7 million

Main Commodity Group (1978) -

Second Commodity Group (1978) -

Third Commodity Group (1978) -

Inbound Vessel Movements (1978) - 13,628

Outbound Vessel Movements (1978) - 18,537

Movements by Vessel Draft - over 500 vessels with drafts of 40' and greater used the lower entrance channels. By far, the greatest number of deep draft vessel were large, self-propelled tankers, with most of the passenger & dry cargo ships having drafts less than 30'

Federal Maintenance dredging (1966-1980) - Ambrose - (834,000) Sandy Hook Channels - (256,000) main ship channel - (129,000)

Private Dredging Activities (1976-1980) -

Combined Dredging Activities - Ambrose (834,000) Sandy Hook Channels 256,000) main ship (129,000 cu.yd/yr)

Bioassay/Bioaccumulation Tests and Results - No reported tests

Waterway Name - Newark Bay

Waterway Description - Newark Bay lies to the north of Staten Island and is reached by either the Arthur Kill or the Kill Van Kull. From the northern end of Newark Bay extend the Hackensack and Passaic Rivers.

Waterway Dimensions - The main Newark Bay Channel is 35' deep and between 500'-1000' wide. There are branch channels and a pierhead channel leading to Port Newark and Port Elizabeth on the western shore. Total length of all Newark Bay channels is about 10 miles

Tidal Range - Tidal range is 4.9' with an extreme range of about 14.4' (MLW).

Major Use and Facilities - Newark Bay, with the Port Authority's facilities at Port Newark and Port Elizabeth handling large volumes of containerized and general cargo, along with the Texaco Bayonne Terminal, is a major center for New York's oceanborne commerce.

Tons Landed (1960-1978 yearly average) - 14 million tons

Tons Through (1960-1978 yearly average) - 12.7 million tons

Passengers (1960-1978 yearly average) - 1,800

Main Commodity Group (1978) - Petroleum & coal products 35% (6.2 million tons)

Second Commodity Group (1978) - Food & kindred products 12% (2.1 million tons)

Third Commodity Group (1978) - Miscellaneous commodities 9% (1.5 million tons)

Inbound Vessel Movements (1978) - 14,754

Outbound Vessel Movements (1978) - 14,734

Movements by Vessel Draft - Over 300 ships with drafts of 30' and greater entered Newark Bay. These were generally large, self-propelled tankers and dry cargo ships. At least 9 ships with reported drafts of 37' used the Bay.

Federal Maintenance Dredging (1966-1980) - 212,000 cubic yards per year

Private Dredging Activities (1976-1980) - 72,000 cubic yards per year

Combined Dredging Activities - 284,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 8 reported tests with 2 failures (NB000-1978, 1979)

Waterway Name - Newtown Creek

Waterway Description - Newtown Creek, a tidal arm of the East River, forms a portion of the boundary between Brooklyn and Queens. The entrance is on the east bank, approximately 3.6 miles above the Battery.

Waterway Dimensions - Depth: 20' in main channel; 12'-20' from East River to south end of turning basin; balance ranges from 9'-16'. Width varies from 75'-150'. Length is 5.6 miles.

Tidal Range - Tidal range at Belmont Island (North entrance to Newtown Creek) is 4.2' with an extreme range of 10.7' (MLW).

Major Use and Facilities - At least 12 facilities used for the receipt and shipment of petroleum products by barge are located along the waterway. Additionally, at least 3 facilities specialize in the shipment and receipt of waste materials. (Codes NT000-NT905)

Tons Landed (1960-1978 yearly average) - 5.8 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) -

Main Commodity Group (1978) - Petroleum & coal products 60% (2.5 million tons)

Second Commodity Group (1978) - Waste & scrap materials 25% (1.1 million m tons)

Third Commodity Group (1978) - Sand, gravel & crushed rock 13% (.5 million tons)

Inbound Vessel Movements (1978) - 5,782

Outbound Vessel Movements (1978) - 5,763

Movements by Vessel Draft - Mostly tankers, tugboats and dry cargo ships with 92% having drafts of 12' and less.

Federal Maintenance Dredging (1966-1980) - 9,000 cubic yards per year

Private Dredging Activities (1976-1980) - 4,000 cubic yards per year

Combined Dredging Activities - 13,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 7 reported tests with 3 failures (NT000-1978, NT001-1978, 1979)

Waterway Name - New York & New Jersey Channels

Waterway Description - These channels extend from deep water northwest of Sandy Hook, through lower N.Y. Bay, to Perth Amboy, and then through Arthur Kill, Lower Newark Bay, and the Kill Van Kull to deep water in upper New York Bay.

Waterway Dimensions - The main channel is 37' deep in rock, 35' in soft material with widths ranging from 500'-1400'. Two secondary channels (south of Shooters Is. & the Raritan River cut-off) are maintained under the existing project. Total length is 31 miles.

Tidal Range - Mean tidal range is approximately 5.0' with an extreme range of 14.6' (MLW).

Major Use and Facilities - At least 18 major petroleum terminals line the banks of the NY & NJ channels. In addition to providing access to the major port facilities in Newark Bay, the Howland Hook Containership Terminal is served by these channels.

Tons Landed (1960-1978 yearly average) - 92.9 million tons

Tons Through (1960-1978 yearly average) - 28 million tons

Passengers (1960-1978 yearly average) - .1 million

Main Commodity Group (1978) - Petroleum & coal products 68% (72.9 million tons)

Second Commodity Group (1978) - Crude petroleum 21% (22.5 million tons)

Third Commodity Group (1978) - Waste & scrap materials 4% (3.9 million tons)

Inbound Vessel Movements (1978) - 63,015

Outbound Vessel Movements (1978) - 673,171

Movements by Vessel Draft - Tankers dominated the deep draft vessel movements with ships ranging in draft from 45' to 18' and less. Over 230 tankers had drafts of 40' and greater. In general though, nearly 97% of all reported vessel traffic had drafts of 18' and less

Federal Maintenance Dredging (1966-1980) - Raritan Bay (912,000) Arthur Kill (71,000) Shooters Island (111,000 cu.yd/yr)

Private Dredging Activities (1976-1980) - Raritan Bay (18,000) Arthur Kill (195,000) Kill Van Kull (114,000 cu.yd/yr)

Combined Dredging Activities - Raritan Bay (930,000) Arthur Kill (266,000) Kill Van Kull (114,000) Shooter (111,000)

Bioassay/Bioaccumulation Tests and Results - A.K(20 tests, 4 fail) K.K(19 tests, 5 fail) R.B(6 tests, pass) SHTR(6 tests, 4 fail)

Notes - Failures-Arthur Kill(AK920-1979, AK918,AK921,AK925-1980) Kill Van Kull (KK000-1979,KK907,KK912,KK913-1980) Shooters Island (SI000-1978,SI001-1978,1979)

Waterway Name - Passaic River

Waterway Description - The Passaic River extends from the northwestern portion of Newark Bay for a distance of about 15 miles. Along its banks are the towns of Kearny and Newark.

Waterway Dimensions _ The Passaic River Channel runs for 2.5 miles from the junction with the Newark Bay Channel at a depth of 30' and a width of 300'. It then begins to shallow progressively to 20', 16', and 10' for another 13 miles.

Tidal Range - Tidal range is 4.9', with an extreme range of about 14.4' (MLW).

Major Use and Facilities - Petroleum facilities (23) including a number of large refineries and oil terminals are by far the dominant users of the Passaic River Channel. A small number (5) of facilities deal with the receipt of sand, stone & gravel.

Tons Landed (1960-1978 yearly average) - 8.9 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) - .004 million

Main Commodity Group (1978) - petroleum products 87% (6.4 million tons)

Second Commodity Group (1978) - Sand, gravel & crushed rock 5% (.4 million tons)

Third Commodity Group (1978) - Waste and scrap materials 2% (.2 million tons)

Inbound Vessel Movements (1978) - 5,531

Outbound Vessel Movements (1978) - 5,488

Movements by Vessel Draft - Over 83% of all incoming vessels had drafts of 12' and less. Tanker traffic ranged in draft from 34'-12' and less, with at least 14 incoming tankers having drafts of greater than 30'.

Federal Maintenance Dredging (1966-1980) - 78,000 cubic yards per year

Private Dredging Activities (1976-1980) - 39,000 cubic yards per year

Combined Dredging Activities - 117,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 10 reported tests with 4 failures (PS000-1978, 1980, PS902-1978, PS903-1980)

Waterway Name - Raritan River

Waterway Description - The Raritan River Channel leads west from Sandy Hook Channel in Raritan Bay up the river for nearly 6 miles, a southerly spur runs along the south shore for .6 miles, terminating at the Titanium Company, Inc. in Sayreville, NJ

Waterway Dimensions - There channels have a maximum depth of 25' and range between 200'-300' wide. A shallower channel, 10'-15' deep and 100'-200' wide runs to the Delaware and Raritan Canal entrance at New Brunswick, about 13.8 miles.

Tidal Range - Tidal range is 5.1' at Perth Amboy with an extreme range of 15.6' (MLW).

Major Use and Facilities - At least 4 facilities dealing in the receipt of petroleum products, including the Amerada Hess Terminal and 2 power plants are located along the banks of the river. Two facilities deal with sand & gravel, and 1 with liquid chemical products

Tons Landed (1960-1978 yearly average) - 7.6 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) -

Main Commodity Group (1978) - Petroleum & coal products 55% (3.1 million tons)

Second Commodity Group (1978) - Waste & scrap materials 36% (2 million tons)

Third Commodity Group (1978) - Chemical products 8% (.5 million tons)

Inbound Vessel Movements (1978) - 3,155

Outbound Vessel Movements (1978) - 3,199

Movements by Vessel Draft - Over 55% of the traffic on the Raritan River was by tugs and towboats, of which 83% had drafts of 12' and less. Tankers comprised 72% of the remaining traffic with drafts ranging from 12'-25'. Non self-propelled tankers were most numerous.

Federal Maintenance Dredging (1966-1980) - 318,000 cubic yards per year

Private Dredging Activities (1976-1980) - 16,000 cubic yards per year

Combined Dredging Activities -334,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 5 reported tests with 2 failures (RR000-1978, RR001-1978)

Waterway Name - Upper New York Bay

Waterway Description - The upper bay extends southerly from the junction of the Hudson and East Rivers 5.5 miles to the Narrows. It includes the Anchorage & NY/NJ pierhead channels, as well as the Red Hook Flats and Liberty Island anchorages.

Waterway Dimensions - The project depths for the upper bay system is as follows: Anchorage Channel-45' deep, 5.7 miles: NY/NJ pierhead channel-20' deep, 3 miles: Red Hook flats anchorage-35'-45' deep, 928 acres: Liberty Island anchorage-20' deep, 160 acres.

Tidal Range - Mean tidal range is 4.7', with an extreme range of 14.8' (MLW).

Major Use and Facilities - The upper bay comprises the major approach channels and anchorage facilities for vessels entering New York Harbor. It also includes an oil receiving facility and the State Island Ferry Terminal.

Tons Landed (1960-1978 yearly average) - 20.3 million tons

Tons Through (1960-1978 yearly average) - 123.9 million tons

Passengers (1960-1978 yearly average) - 25.8 million

Main Commodity Group (1978) - Petroleum products 75% (30.9 million tons)

Second Commodity Group (1978) - Crude Petroleum 20% (8.3 million tons)

Third Commodity Group (1978) - Iron & steel scrap 3% (1.1 million tons)

Inbound Vessel Movements (1978) - 105,093

Outbound Vessel Movements (1978) - 84,378

Movements by Vessel Draft - Although 92% of all incoming vessels had drafts of 18;' and less, greater than 1,600 vessels had drafts between 35'-45'. By and large, self propelled tankers made up the largest portion of the deep draft vessels.

Federal Maintenance Dredging (1966-1980) - 162,000 cubic yards per year

Private Dredging Activities (1976-1980) - 9,000 cubic yards per year

Combined Dredging Activities - 171,000 cubic yards per year

Bioassay/Bioaccumulation Tests and Results - 4 reported tests with no failures.

Waterway Name - Westchester Creek

Waterway Description - Westchester Creek is a tidal stream flowing into the East River from the north at a point 14 miles by water northeast of the Battery.

Waterway Dimensions - A channel 12' deep and 100' wide is provided for a length of 2000' through the estuary. The remaining channel varies from 60'-80' wide with three turning basins along its length. The total length of the project is 2.6 miles.

Tidal Range - Tidal range is 7.0' with an extreme range of 19.3' (MLW).

Major Use and Facilities - There are 3 facilities that are used for the receipt of petroleum products by barge, and 1 that handles the shipment of scrap metal by barge. There is also a wharf used to dock small vessels. (Code WD000)

Tons Landed (1960-1978 yearly average) - .8 million tons

Tons Through (1960-1978 yearly average) -

Passengers (1960-1978 yearly average) - .03 million

Main Commodity Group (1978) - Petroleum products 95% (.6 million tons)

Second Commodity Group (1978) - Sand, gravel & crushed rock 5% (.03 million tons)

Third Commodity Group (1978) -

Inbound Vessel Movements (1978) - 589

Outbound Vessel Movements (1978) - 597

Movements by Vessel Draft - Over 95% of the incoming vessels were tankers, tanker barges and their accompanying tugs and towboats. Only 7 vessels had drafts greater than 13', but the remaining vessels were fairly evenly distributed over th range 6'-13'.

Federal Maintenance Dredging (1966-1980) - 62,000 cubic yards per year

Private Dredging Activities (1976-1980) -

Combined Dredging Activities - 62,000 cubic yards per year

Bioassay/Bioaccumulation tests and results - 2 reported tests. No failures.