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AN EVALUATION OF THE STANDARD ELUTRIATE TEST AS AN ESTIMATOR OF CONTAMINANT RELEASE AT THE POINT OF DREDGING

by

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Release of contaminants during dredged material disposal operations has long been the subject of environmental concern. The potential release of pollutants during the dredging process has, in recent years, come under the scrutiny of Federal and State regulatory agencies. The mechanical action of a dredging operation causes resuspension of sediment particles and release of soluble contaminants to the water column. A predredging test is essential to estimate the amount of soluble release at or near the point of dredging to ascertain potential water quality impact. The Standard Elutriate Test has proven to be a good estimator of soluble contaminant release for dredged material disposal operations. The processes involved at the point of dredging are similar to those involved with open-water disposal of dredged material.

This research is an evaluation of the Standard Elutriate Test as an estimator of soluble contaminant release at the point of dredging. Data and field studies were
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conducted by the US Army Engineer Waterways Experiment Station at four sites in the United States. A direct comparison was made between chemical concentrations in the test elutriate from sediment samples taken prior to dredging and corresponding concentrations in water samples taken at or near the point of dredging as sediment was being dredged.

The Standard Elutriate Test satisfactorily predicted the release of soluble contaminants at or near the point of dredging at all four sites in this study. However, results indicated that the elutriate test appears to overestimate the release of organic materials, nutrients, and some heavy metals (mercury, manganese, iron, and chromium).

Appendix A summarizes the data, and Appendix B outlines a statistical analysis that provided predictive equations which can be used to estimate the upper bound value that a constituent concentration will approach based on elutriate test data and a specified confidence level.

PREFACE

The study described herein was performed by Drs. Daniel D. Ludwig and Joseph H. Sherrard of the Virginia Polytechnic Institute (VPI), Blacksburg, VA, and MAJ Roger A. Amende, Fort Benjamin Harrison, US Army Corps of Engineers, while assigned to the VPI. The study and report were conducted under Contract No. DACW39-87-M-0329 for the US Army Engineer Waterways Experiment Station (WES) as part of the Improvement of Operations and Maintenance Techniques (IOMT) research program, Work Unit No. 32433, Contaminant Release Control During Dredging. The IOMT Program is sponsored by the Headquarters, US Army Corps of Engineers (USACE), with overall program management assigned to the WES Hydraulics Laboratory (HL). This specific work unit was further assigned to the WES Environmental Laboratory (EL).

The contract was monitored by Drs. Michael R. Palermo and Robert N. Havis of the Environmental Engineering Division (EED), EL, under the direct supervision of Dr. Raymond L. Montgomery, Chief, EED, and the general supervision of Dr. John Harrison, Chief, EL. The IOMT Program Manager was Mr. E. Clark McNair, Jr., of the HL. Messrs. James L. Gottesman and Charles Hummer were the USACE Technical Monitors.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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

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

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres

AN EVALUATION OF THE STANDARD ELUTRIATE TEST AS AN ESTIMATOR OF CONTAMINANT RELEASE AT THE POINT OF DREDGING

PART I: INTRODUCTION

Background

1. While release of contaminants during dredged material disposal operations has long been the subject of environmental concern for some projects, the potential release of pollutants during the dredging process has recently come under the scrutiny of Federal and State regulatory agencies. Maintenance of shipping channels may require the removal of sediments suspected to contain high concentrations of contaminants. During any dredging operation, sediments become resuspended to varying degrees according to sediment type, hydrologic conditions, type of dredging equipment used, and operational procedures employed. Contaminants may be released in soluble form directly to the water column, or they may remain adsorbed to the fine resuspended sediment particles. The primary mode of environmental impact is from the soluble fraction since dissolved forms of pollutants are more available for aquatic biota uptake than those which remain adsorbed to sediment particles. Dissolved contaminants disperse into the surrounding water column from sediment interstitial water and through desorption from sediment particles (Environmental Effects Laboratory 1976; Fulk, Gruber, and Wullschleger 1975). Therefore, a predredging test is essential to estimate the potential release of contaminants by the agitation of bottom sediments during dredging operations (Lee and Plumb 1974, Engler 1980).

2. The Standard Elutriate Test was jointly developed by the US Army Corps of Engineers (CE) and the US Environmental Protection Agency (EPA) to monitor the soluble release of contaminants into the water column during open-water disposal operations. "Elutriate" means to purify, separate, or remove by washing. As used in this test procedure, it is the centrifuged/filtered clear liquid containing the soluble fraction of the sample sediment. The validity of the Standard Elutriate Test as a predictor of dissolved release during disposal operation was demonstrated through extensive laboratory and field studies during the Dredged Material Research Program (DMRP) conducted by

the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, from 1973 to 1978 (Herner & Company 1980).

3. Recent studies under the CE Improvement of Operations and Maintenance Techniques (IOMT) research program have been directed toward the development of methods to predict the potential degree of sediment resuspension and contaminant release during dredging operations. During the early stages of the IOMT studies, researchers recognized that the processes involved with potential contaminant release at the point of dredging were similar to those involved during open-water disposal of dredged material. Consequently, a preliminary investigation was initiated to determine the applicability of the elutriate test to estimate release at the point of dredging. Field studies conducted for this investigation included collection of predredging sediment samples and water samples taken during dredging to determine concentrations of contaminants released to the water column during the dredging operation.

Objectives

4. The overall objective of this study was to make an evaluation of the usefulness of the Standard Elutriate Test for estimating the release of contaminants at or near the the point of dredging. To meet this objective, the following tasks were performed:

- *a.* Literature was reviewed in order to confirm the logic of using the Standard Elutriate Test, or a modified version of it, to estimate potential release at the point of dredging.
- *b.* Data from field studies and laboratory reports provided by WES was sorted and categorized and a method for analysis was determined.
- *c.* Conclusions and recommendations were developed for further studies to answer the question, "Is the Standard Elutriate Test a good predredging estimator of contaminant release?".

Approach

5. WES collected field data and performed laboratory analyses from four dredging sites to evaluate the potential for release of contaminants during dredging. A summary of the collected data is included in Appendix A. Protocol for data collection at each site was established based upon the contaminant of concern at the site, thus causing some inconsistency among data for

the four sites. Collected data included predredging sediment samples, water samples taken at various depths and distances from the operating dredge, plus a variety of site parameters including dredge equipment type, location, dates of sampling, sediment characterization, current, and salinity. The water column samples analyzed for chemical concentrations and used for comparison to elutriate test data were collected as near to the point of dredging as safety would allow (about 50 ft* for clamshell operations). The James River water column samples were obtained from a dredge head sampling apparatus.

6. The approach used for this evaluation was to make a direct comparison between the elutriate test data and the water column samples analysis for each site. The primary hypothesis for comparative evaluation was that the elutriate value for each constituent should approximate (within one order of magnitude) the actual constituent concentration found at or near the point of dredging as determined by water samples collected during the dredging operation. A secondary hypothesis was that the Standard Elutriate Test is a conservative estimator of the amount of soluble release. Hence, contaminant concentrations in the elutriate may be more than one order of magnitude greater than the water column contaminant concentration, but not vice versa.

7. Concern about evaluating the correlation between contaminant concentrations of the elutriate and water column samples by means of statistical analysis was addressed. Rather than using an order-of-magnitude comparison, the respective elutriate and water column concentrations would be evaluated by employing analysis of variance (ANOVA). However, in view of the limited number of samples available (usually three or four) for both the elutriate and water column (bottom within 50 ft), this approach was deemed impractical.

8. Appendix B is a statistical development of a predictive equation. The equation, adjustable to preselected probability-of-occurrence levels, will estimate the upper bound constituent concentration in the water column at or near the point of dredging based on elutriate test data from the site.

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

PART II: LITERATURE REVIEW

9. Various references quote annual dredging quantities in the United States to be between 280 to 380 million cubic yards (Chen et al. 1976, Brannon 1978, Edgar and Engler 1984). While approximately 90 percent of this amount is considered to be "clean" (Francingues et al. 1985), the remaining 10 percent poses potential water quality problems at two locations: the dredging site and the disposal site (Lee and Plumb 1974). Research literature and implementation guidance (Environmental Effects Laboratory 1976, EPA/CE 1972) are readily available for the management and control of disposal operations, but potential problems that can occur in the water column at the dredging site from disturbances of sediments have only recently been studied.

10. Although the surface layer of sediment is generally assumed to be in dynamic equilibrium with the overlying water (Keeley and Engler 1974), a number of investigators (Fulk, Gruber, and Wullschleger 1975; Keeley and Engler 1974; Lee et al. 1975) report that physical disturbances of contaminated sediment may release some of the contaminants to the water column through dispersal of the interstitial pore water and from desorption of constituents from the resuspended sediment particles. Two investigations (Lee and Plumb 1974, Engler 1980) recommended the development of a predredging test to evaluate the potential impact from disturbances of the bottom prior to the start of a dredging operation.

11. The EPA recognized that any test for contaminant release should be quick, simple, and reliable (EPA 1979). Bulk sediment analysis was investigated as a test, but researchers (Lee and Plumb 1974, Allen and Hardy 1980) did not find this method to be a technically sound approach for predicting the soluble release to the water column. They concluded that bulk analysis only reveals the composition of the sediment, not the potential desorption of contaminants.

12. Bioassay is another testing method, accepted by the EPA (Federal Register, 11 Jan 1977) for measuring potential water quality impact. Although bioassay is the preferred method for assessing long range environmental effects to the biota, this process has been dismissed as an estimator of soluble contaminant release for several reasons. Specifically, the reasons for rejecting this test are: variability of investigative techniques (EPA/CE 1972), lack of indication of the true effects from contaminated sediment, and

because it is based upon acute toxicity and utilizes mortality as an end point (Allen and Hardy 1980).

13. A third approach for determining the potential impact to water quality as a consequence of dredging is the comparison of site water samples with the elutriate from mixtures of dredged material and water (Lee et al. 1975). This approach was used in the development of the Standard Elutriate Test by EPA and the CE. The validity of the test as a means of predicting the impact of disposal of dredged material has been demonstrated by extensive laboratory and field studies under the DMRP conducted by WES (Herner and Company 1980).

14. The Standard Elutriate Test is an empirical test (Lee and Plumb 1974, and US EPA 1979) that compares the chemical analysis of the elutriate from a sediment/disposal water mixture to a similar analysis of the disposal site water. Test results which exceed set standards cause the sediment to be classified as being contaminated and requiring further testing and/or special disposal techniques. Two key areas for refining the Standard Elutriate Test are the application of the data and the testing procedures. Because the test is empirical, two references (Lee and Plumb 1974, and US EPA 1979) suggest development of correction coefficients to adjust elutriate test data to more closely simulate concentrations actually found in water samples.

15. Potential concerns with test procedures include: pH changes, salinity, mixing methods, contact time, and solid-liquid ratio (US EPA 1979). In this regard, the original elutriate test, as published in the Federal Register (16 May 1973 and 15 Oct 1973) by the EPA, was modified by a later article (11 Jan 1977). Specifically, forced air agitation of the sediment/water mix was added to correct a potential reduced pH problem that arises when the Standard Elutriate Test turns anaerobic due to sediment oxygen demand. Reduced pH increases the solubility of many chemical forms and adversely affects the test results. Some investigators (Bender et al. 1984, Huggett, Nichols, and Bender 1980; Stroebel, Croonenberghs, and Huggett 1981) dismiss salinity as a potential problem area. Another report (Karickoff, Brown, and Scott 1979) concluded that salinity played only a minor role in the release of contaminants from a sediment.

16. One group (Bender et al. 1984) conducted limited factorial experiments concerning contact times and solid/liquid ratios. This study, sponsored by WES and conducted by the Virginia Institute of Marine Science (VIMS),

consisted of analysis of field samples in addition to a laboratory study designed to evaluate the elutriate test as a means of predicting contaminant release during dredging. The VIMS study compared the Standard Elutriate Test to modifications which would simplify analytical procedures or more realistically represent environmental conditions. Accordingly, a limited laboratory program was undertaken to investigate the effects of short agitation time and lower sediment-to-liquid ratios. Bender et al. (1984) reasoned that the 30-min agitation time and 1:4 ratio of sediment to water by volume in the standard test was selected to represent agitation and concentrations present in open-water disposal operations. The time available for initial agitation during the action of resuspension due to the operating dredge was considered to be substantially less than 30 min, and the sediment-to-water ratio was found to be much lower than the ratio used for the Standard Elutriate Test.

17. Conclusions from the VIMS study included a recommendation to modify the standard test to reduce the sediment volume to 1 percent and agitation time to 5 min for sediments that contain only contaminants of low water solubility. The reduced sediment ratio and agitation time showed promise in more accurately estimating the release of total Kjeldahl nitrogen (TKN) and total phosphorus, although phosphorus concentrations were still overestimated. Changes in mixing time and sediment ratio for estimation of the release of metals did not show any significant change in the accuracy of the estimation.

18. Jones and Lee (1978) found that the Standard Elutriate Test predicted release of heavy metals and ammonia within an order of magnitude of concentrations found in the field and would generally indicate phosphorus and chlorinated hydrocarbon levels. Additional references (Lee and Plumb 1974, Brannon 1978, Burks and Engler 1978) also cite a tendency for the Standard Elutriate Test to overestimate the chemical releases experienced at disposal sites, thus yielding conservative predictions of contaminant release.

PART III: METHODS AND PROCEDURES

19. Dredged material evaluation procedures must consider the potential environmental harm caused by changes in water quality due to the release of available chemical species present in bottom sediments (Keeley and Engler 1974). The primary water quality impact associated with sediment resuspension occurs from the soluble constituents of the interstitial water and the easily desorbed chemical species from sediment particles. The Standard Elutriate Test was developed jointly by the EPA and the CE as a means of predicting the release of soluble constituents to the water column during disposal operations (EPA/CE 1972). Consequently, the purpose of this investigation was to evaluate the usefulness of an elutriate test for estimating the release of contaminants at or near the point of dredging.

Standard Elutriate Test Procedure

20. The Standard Elutriate Test procedures used for this investigation (illustrated in Figure 1) specify that 20 percent by volume of undisturbed bottom sediments from the dredging site be mixed with 80 percent by volume of water from the dredging site. This mixture is then vigorously agitated by mechanical shaking and release of compressed air through a diffuser tube for 30 min (EPA/CE 1972). The infusion of oxygen into the system during mixing is used to offset any potential oxygen demand exerted by the sediments. Reduction in dissolved oxygen causes a drop in pH that may result in the release of chemical forms that do not normally occur at the dredging site. The addition of oxygen has also been shown to increase the reproducibility of the test (Lee et al. 1975).

21. The mixed system is allowed to settle for 1 hr, after which the supernatant is collected, centrifuged, or filtered through a 0.45-μm filter, and then analyzed. Chemical analysis of the supernatant (elutriate) from the bottom sediment samples is then compared with a corresponding analysis of water samples taken while dredging. Water samples undergo laboratory analyses for total dissolved fractions with the dissolved fraction being centrifuged or filtered through a 0.45-μm filter prior to analysis.

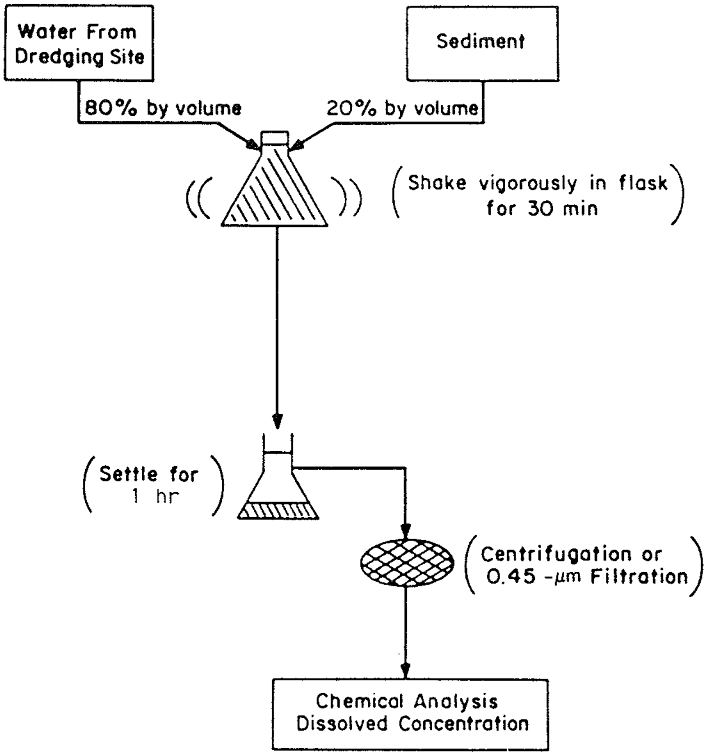

Figure 1. Standard Elutriate Test

Description of Field Sites

22. Field data and samples for laboratory analysis were obtained over a 4-year time span at four sites: Black Rock Harbor near Bridgeport, Connecticut; the Calumet River in Chicago, Illinois; the Duwamish Waterway in Seattle, Washington; and the James River near Jamestown, Virginia.

23. These investigations were conducted as satellite studies by CE District offices during maintenance dredging operations. Although all field sample collection procedures and laboratory analyses methods were accomplished in accordance with required procedures (EPA 1979), the constituents studied varied from site to site based upon the contaminant of concern at a specific site.

Black Rock Harbor, Connecticut

24. Field studies were conducted on 2 May and 5-6 May 1983 at Bridgeport, Connecticut, during maintenance dredging of Black Rock Harbor (Figure 2). The sediments were dark to black in color and were classified as

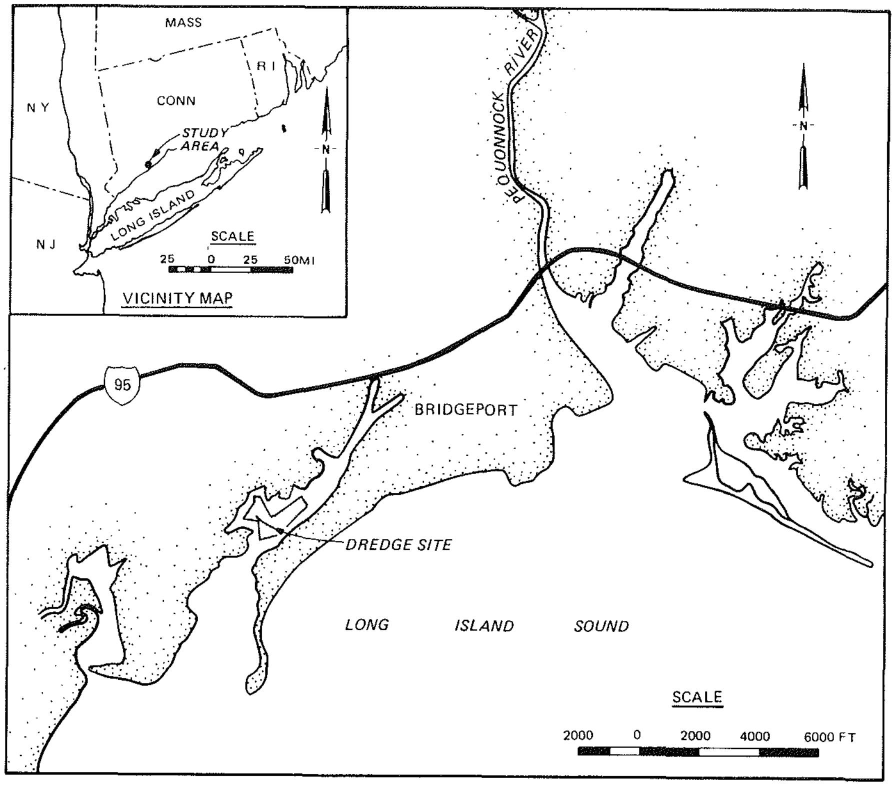

Figure 2. Site location map for the Black Rock Harbor dredging project

sandy organic clay. Known contaminants included polychlorinated biphenyls (PCBs) and petroleum products. Average salinity was 18 ppt and any current was tide induced. A 10-cu-yd standard open clamshell bucket was used to remove the sandy organic clay sediments at a depth of approximately 20 ft.

25. Sediment sample collection was conducted on 2 May with water sample collections on 5 and 6 May. Dredging procedure was to excavate a 55- by 30-ft section 3 to 4 ft deep, drag the bottom with the bucket to smooth the cut, and move to the next section. A total of 27 water samples were collected at bottom, mid-depth, and surface at ranges of 30, 80, and 130 ft from the dredge. The three repetitions of water column samples collected near the bottom and 30 ft from dredging operations were considered representative of evaluations at or near the dredgehead for this evaluation.

Calumet River, Illinois

26. The Calumet River is a navigation channel serving the City of Chicago (Figure 3). Samples were collected 20-23 August 1985 during an ongoing maintenance dredging operation near the northern bank of Turning Basin

Figure 3. Location map of Calumet River clamshell demonstration

Number 5. A 10-cu-yd standard open clamshell bucket was used to remove the the soft organic clay/silt sediments. The dredge would cut an approximate 100-ft width, smooth the bottom by dragging the bucket, and then move ahead.

27. Elutriate test sediment samples were collected on 20 August, and water column samples were collected during dredging operations on 22-23 August. Water column samples were collected from near surface (5 ft below surface), mid-depth (15 ft), and near bottom (27 ft). Sampling stations were established at points 200 and 300 ft upstream of the dredge as well as at the point of dredging and 50, 200, 300, 600, and 800 ft downstream from the dredging site. Low stream velocities were recorded during sampling with the maximum of 0.2 fps. Sediment samples for conducting the elutriate test were taken in accordance with the Implementation Manual (EPA/CE 1972). Near-bottom samples collected at a distance of 50 ft were considered representative of conditions at or near the dredgehead for this evaluation.

Duwamish River, Washington

28. The CE Seattle District contracted maintenance dredging of the upper Duwamish River (Figure 4) in a heavy industrial and commercial area. The sandy clayey silt sediments were known to be contaminated with heavy metals and chlorinated hydrocarbons. Currents averaged 0.7 fps, and the average salinity was 14 ppt.

29. A standard open clamshell bucket was used for dredging, and overflow of sediment from the disposal barges was disallowed in order to minimize suspended solids concentrations in the adjacent water column. Two sets of sediment samples were collected, with one sample taken 2 days earlier and the other taken 30 min before the commencement of dredging operations. Dredging commenced on 26 March 1984, with water column samples collected from depths of 5, 15, and 30 ft and distances of 100, 150, 200, 225, and 300 ft from the point of dredging. Samples were analyzed for selected heavy metals and PCBs. Samples collected at a depth of 30 ft from the deck of the dredge were considered representative of conditions at or near the dredgehead for this evaluation.

James River, Virginia

30. Sampling for this study was conducted by VIMS under contract with WES and in conjunction with a dredging project by the CE Norfolk District (Bender et al. 1984). The purpose of the James River demonstration was to remove a layer of contaminated sediment at near in-situ density while

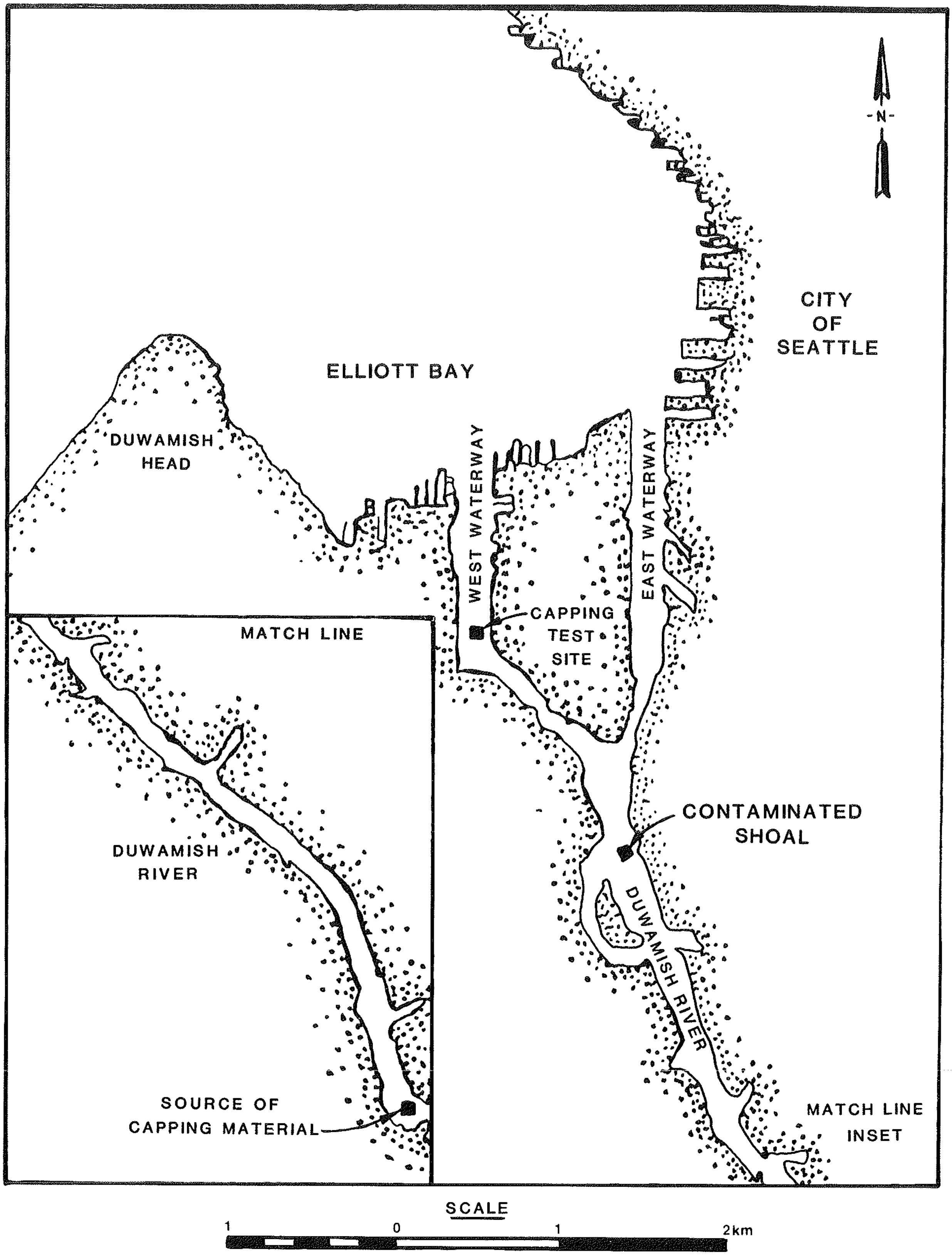

Figure 4. Location map of Duwamish River dredging project

minimizing resuspension at the dredgehead. All information used in this investigation was extracted from the final report to WES (Bender et al. 1984). The silty clay sediment samples were collected in March 1982 from a dredging site near the Jamestown Ferry Pier, James River, Virginia (Figure 5). Twenty-five sediment samples were obtained, pooled into two groups, and homogenized before use in the elutriate test. Water samples were taken during dredging operations on 17 and 24 June 1982.

31. Water column samples were taken at near-bottom depth in close proximity to the dredging activity since the sampling apparatus was attached to the cutterhead mechanism of the dredge. A 5-ft-diam cutterhead was used during this phase of the dredging operation. Currents ranged from 0.5 to 2.3 fps, and salinity was reported at <0.1 ppt. Samples taken from the cutterhead sampling apparatus were considered representative of conditions at the cutterhead for this analysis.

Lake City, Minnesota

32. Data from samples taken at a fifth dredging site were considered for use in this investigation. Sediment and water samples were taken during dredging tests in 1984 on Lake Pepin near Lake City, Minnesota. The objective of that study was to compare sediment resuspension of an enclosed or "watertight" clamshell bucket with that caused by a standard clamshell. Unfortunately, shaping of riprap on a nearby breakwater using a backhoe caused high levels of suspended sediment in the vicinity of the clamshell test. Since those levels were well above background levels, the data were considered invalid for use in this study.

Sampling Procedure

33. Sediment samples for the elutriate test were collected from the sites prior to dredging activities. A minimum of three sampling stations per dredging area were used to ensure reliable characterization of the sediment. The collection, mixing, and analysis of each sample was in accordance with procedures outline for the Standard Elutriate Test (EPA/CE 1972).

34. A major consideration concerning water sample collection was the selection of sampling stations. In most of the field studies, the opportunity to collect field samples in close proximity to the operating dredge was limited by safety and logistical constraints. Ideally, the closer the sample can

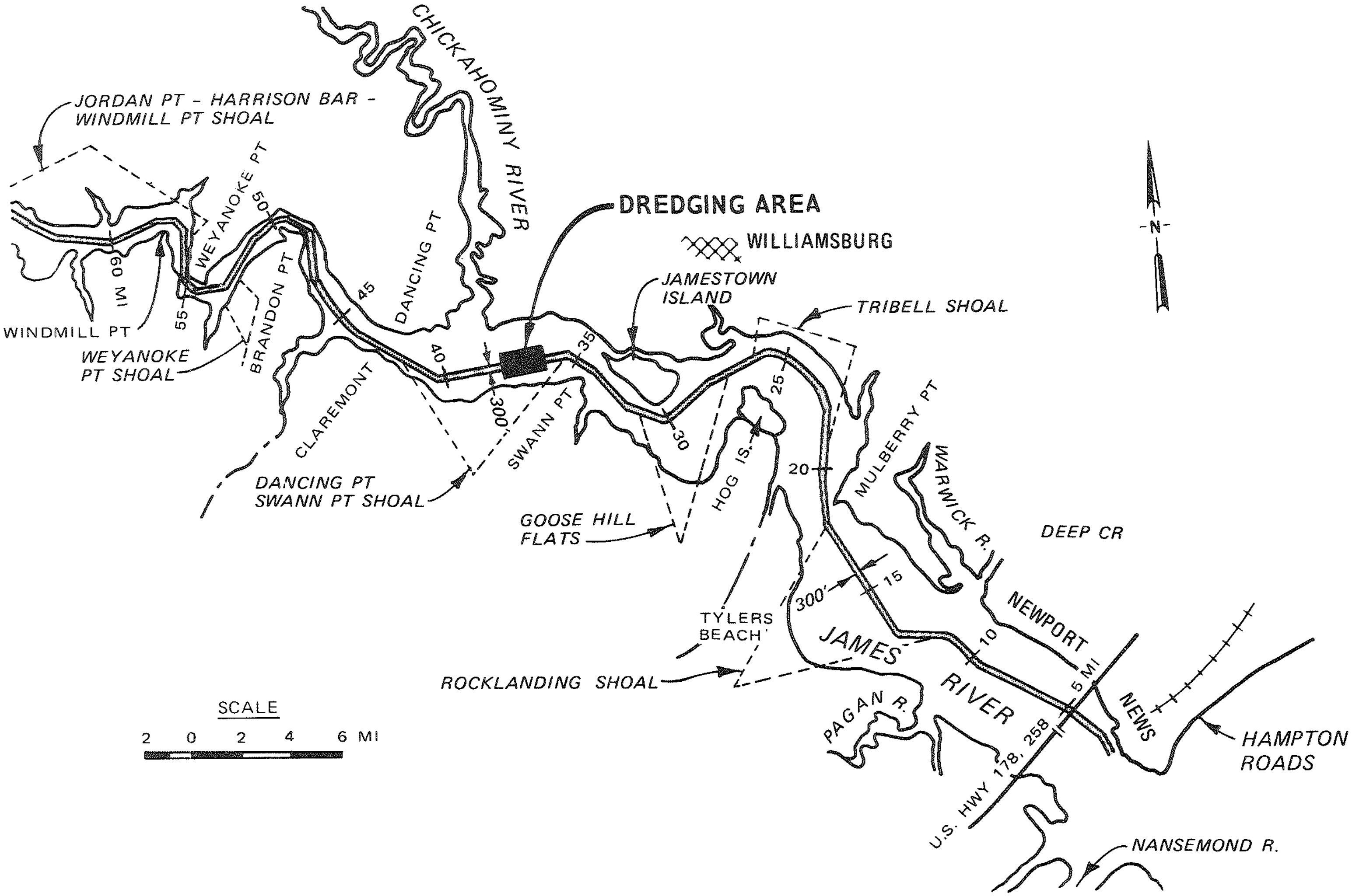

Figure 5. James River demonstration area

be taken to the operating mechanism (cutterhead, clamshell bucket, or suction head), the more it will be representative of the elutriate test procedure. Barnard (1978) has shown that turbidity caused by the dredging operation decreases rapidly with increasing distance. Correspondingly, McLellan et al. (1988) indicate that primary resuspension of dredged sediments remains closely associated with the bottom region. Therefore, to most closely simulate the conditions expected at or near the point of dredging, only data from bottom sampling sites 50 ft or nearer to the point of dredging were used for comparison with the predredging sediment elutriate data. Various investigators (Chen et al. 1976, Burks and Engler 1978, US Army Engineer District, St. Paul 1985; and Hayes, McLellan, and Truitt 1986) report findings of reduced suspended solids, decreased turbidity, and near background water quality within a few hundred feet of a dredging operation.

PART IV: DISCUSSION AND SITE COMPARISONS

Discussion

35. Evaluation of the Standard Elutriate Test was based on a direct comparison of data from laboratory analysis of field water samples and predredging sediment elutriates. Fundamentally, the evaluation sought to establish whether constituent values determined from the Standard Elutriate Test would estimate the actual concentration determined from field water samples collected during the dredging operation.

36. This investigation was based upon the hypotheses that the elutriate test would predict within an order of magnitude (Jones and Lee 1978) the concentrations found during field water sampling. A secondary expectation, based on the elutriate test being conservative (Lee and Plumb 1974, Brannon 1978, Burks and Engler 1978), was that elutriate values could be greater than one order of magnitude higher than water column sample values. Values that were within the same order of magnitude, or when elutriate values exceeded the water sample concentrations by greater than an order of magnitude, were considered to validate the hypothesis.

37. Some findings of the laboratories conducting the chemical analyses reflect values that are at or below the maxi-minimum detectable (measurable) limit for a particular constituent. In the direct comparison portion of this evaluation, the average constituent concentration is based upon use of the detection limit value for any constituent sample where less than the minimum value was recorded. For the statistical analysis in Appendix B, data recorded at or below the minimum detectable limit were excluded.

Site Comparisons

Black Rock Harbor

38. Tables A1 and A2 in Appendix A comprise a listing of the laboratory analyses conducted on elutriate and water column samples collected on 2-6 May 1983. Three replicas of sediment samples for elutriate tests were collected on 2 May prior to the commencement of dredging. The water column samples were collected during dredging operations on 5 and 6 May at a point approximately 30 ft from the operating cutterhead and 5 ft above the bottom.

39. Table 1 and Figure 6 compare the average constituent concentrations from water column sample analysis with predredging sediment elutriate test data. They indicate that the sediment elutriate test chemical concentrations are higher or equal to dredge site water column chemical concentrations for 12 out of 15 constituent samples. The three constituents (copper, iron, and PCB 1242) that had higher water column sample concentrations are still within the same order of magnitude as the elutriate test value and therefore confirm the hypothesis.

40. Constituents having equal values for both the water analysis and the elutriate test (cadmium and arsenic) reflect findings of less than the minimum detectable concentration limit. No quantitative conclusions can be drawn from these constituents; however, qualitatively the Standard Elutriate Test does typify what was found from water analysis. For this site, comparison of the data indicates that the elutriate test is a good estimator of contaminant release during dredging operations.

Calumet River

41. Table A3 summarizes the chemical analyses of elutriates from four bottom sediment samples collected on 20 August 1985. Correspondingly, Table A4 depicts the analyses of six water column samples collected at a depth of approximately 27 ft and as close to the operating dredge as safety would allow.

42. Comparison of chemical constituent concentrations found in the elutriates and water column samples is shown in both Table 2 and Figure 7. Concentrations of five of the constituents (copper, cadmium, chromium, nickel, and PCB) were within the minimum detectable limit for both elutriate and water column samples. Hence, the field data and the elutriate test show no release of these chemicals. Of the remaining nine constituents, eight had elutriate test values that were higher than the corresponding water concentrations. Zinc was the exception displaying a higher concentration in the water column than in the sediment elutriate. However, the difference between 0.024 and 0.015 is within one order of magnitude and thus not significant for this hypothesis evaluation.

43. Overall for the Calumet River data, the elutriate test again predicted the release of contaminants upon resuspension by the dredging operation. However, values estimated by the Standard Elutriate Test for five of the constituents (mercury, manganese, iron, TKN, and NH_3) were more than

Table 1

Black Rock Harbor Comparison of Average Concentrations

Constituent	Water Column Analysis Avg of Three, ppm	Elutriate Test Avg of Three, ppm
Cd	<0.001	<0.001*
Zn	0.026	0.03
Pb	0.003	0.005
Cu	0.009	0.002
Hg	0.0001	0.0004
As	<0.01	<0.01*
Cr	0.0012	0.013
Mn	0.119	0.245
Fe	0.6	0.43
Ni	0.012	0.039
T-Phosphorus	0.016	3.02
NH_3	4.71	18.1
PCB 1242	0.0053	0.002
PCB 1254	<0.00002*	0.00018
PCB 1260	<0.00002*	0.00006

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* Detection limit.

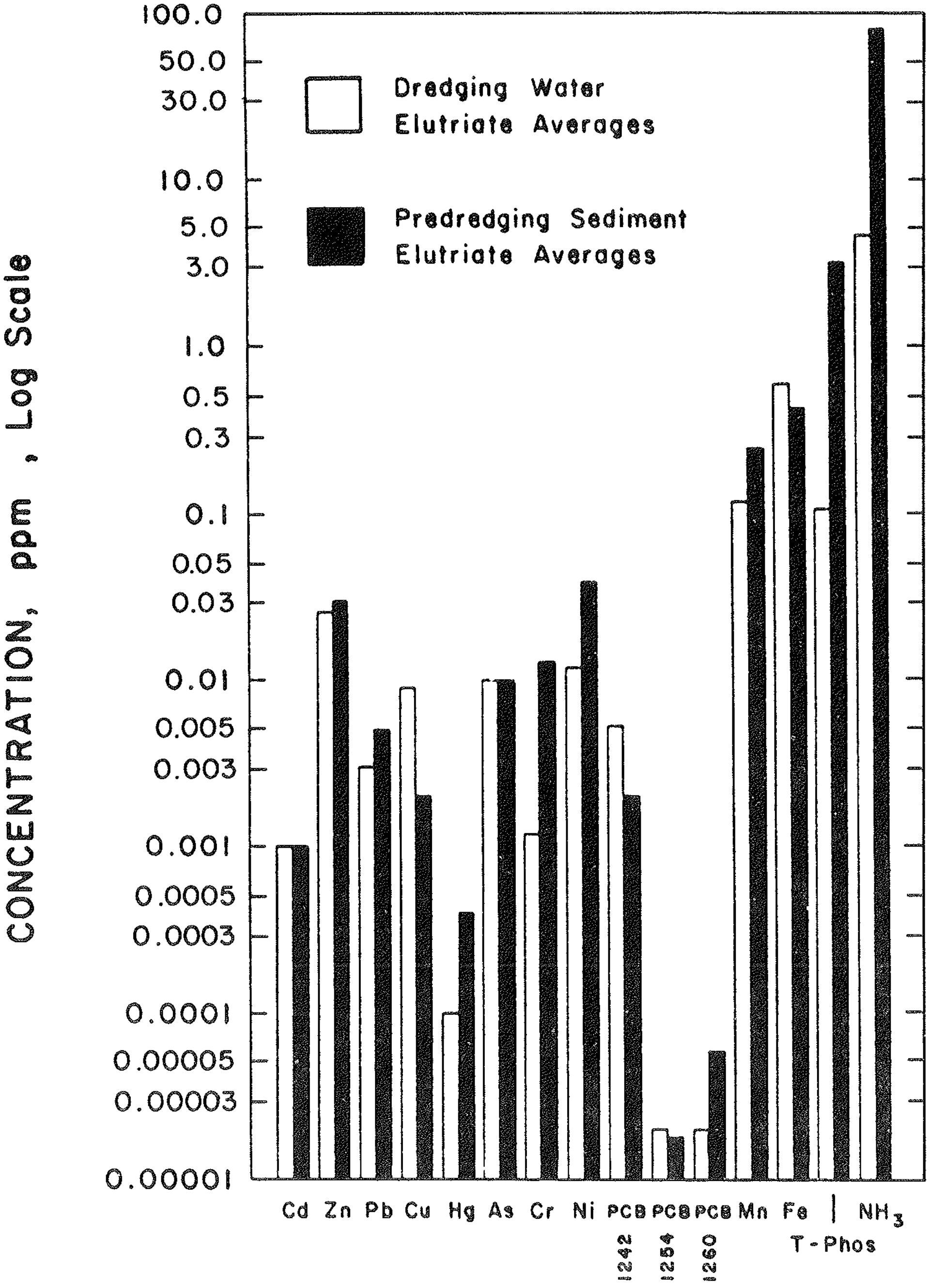

Figure 6. Black Rock Harbor comparison of average constituent concentration

Table 2

Calumet River Comparison of Average Constituent Concentrations

Constituent	Water Column Analysis Avg of Six, ppm	Elutriate Test Avg of Four, ppm
Cd	<0.01	<0.01*
Zn	0.03	0.02
Pb	<0.01	0.015
Cu	<0.01	<0.01*
Hg	<0.0001	0.1
As	<0.001	0.007
Cr	<0.01	<0.01*
Mn	<0.01	0.7
Fe	0.11	2.75
Ni	<0.01	<0.01
T-Phosphorus	0.025	0.075
TKN	0.25	22.3
NH_3	0.5	25.89
PCB	<0.0001	<0.0001*

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* Detection limit.

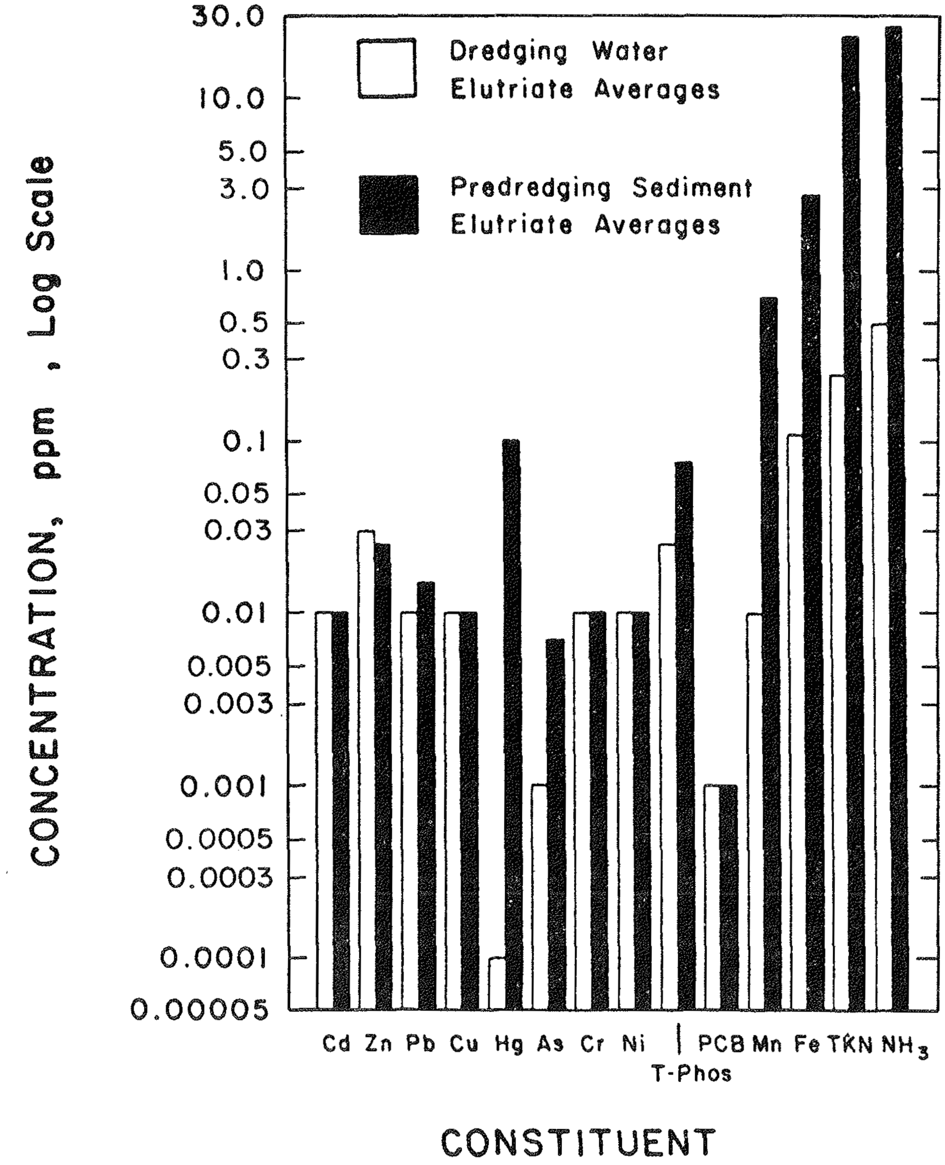

Figure 7. Calumet River comparison of average constituent concentration

one order of magnitude greater than the level found in the dredge water. In the elutriate, mercury was four orders of magnitude greater while the other four constituents were approximately two orders of magnitude greater than concentrations found in the water column samples. These overpredicting results indicate that the elutriate test may be very conservative with respect to some chemical constituents.

Duwamish Waterway

44. Table A5 reflects the chemical analyses performed on four samples collected on 24 and 25 March 1984 at the center of the proposed dredging site. Bottom water samples collected on 26 March for this comparison are analyzed in Table A6.

45. Comparison of the average constituent concentrations in Table 3 and Figure 8 indicates that sediment elutriate values closely estimated corresponding water column analysis concentrations. Two of the three constituents evaluated at this site had water column concentrations that were higher than the elutriate test value, but both were within the same order of magnitude. Although the results of the comparison for the Duwamish Waterway data were not as conservative as was determined with the previous two sites, the data validate the established hypothesis regarding the use of the elutriate test.

Table 3

Duwamish Waterway Comparison of Average Constituent Concentrations

Constituent	Water Column Analysis Avg of Three, ppm	Elutriate Test Avg of Four, ppm
Zn	0.024	0.015
Pb	0.007	0.005
Cu	0.002	0.005

46. Dredging operations on the Duwamish Waterway were carefully executed in an attempt to minimize resuspension both during clamshell operation and by limiting overflow of the disposal barge. Operators were able to limit the suspended solids concentrations to a maximum of seven times the background level. A limit such as this (seven times the background level) may represent

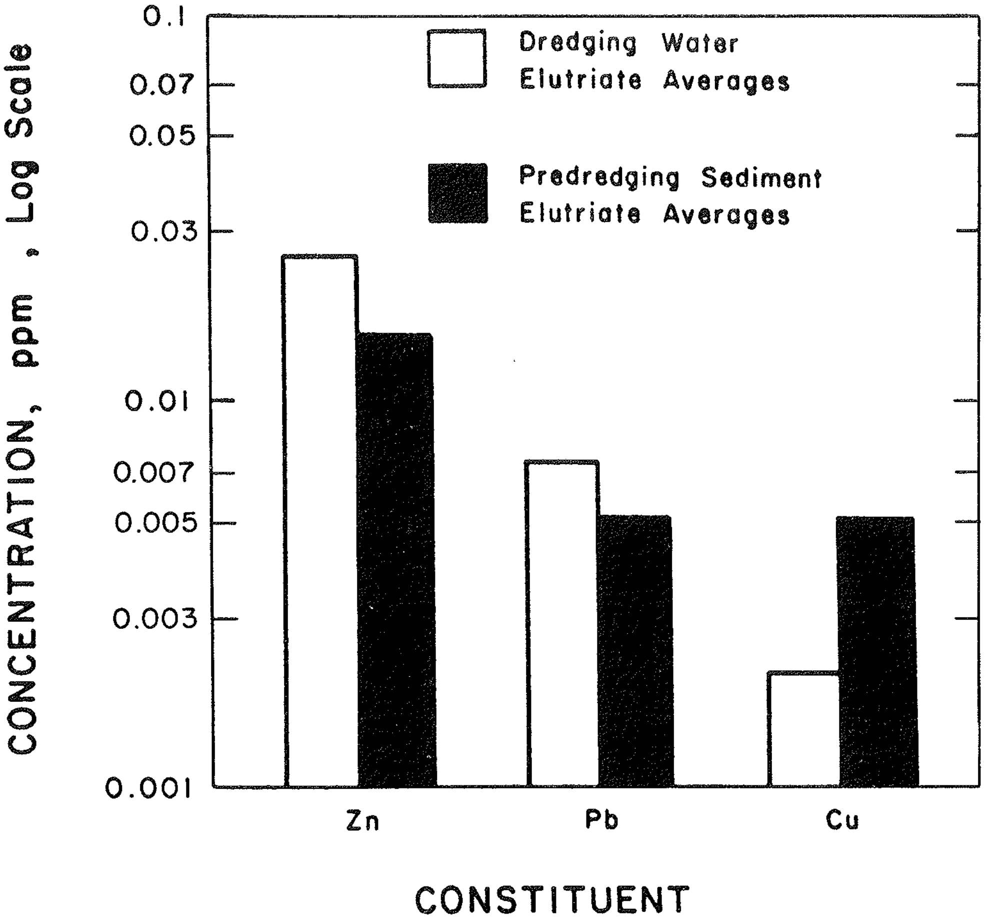

Figure 8. Duwamish Waterway comparison of average constituent concentration

a target level for other dredging operations. Moreover, these results suggest that the elutriate test could possibly be employed to reflect an expected level of suspended solids when dredging commences at a given site.

James River

47. Data depicted in Tables A7 and A8 were extracted from a study (Bender et al. 1984) sponsored by WES and conducted by the VIMS. Comparison of the data as displayed in Table 4 and Figure 9 indicates the elutriate test values were equal or higher for five of the six constituents studied, and the sixth (lead) was within an order of magnitude of the water analysis concentration. The TKN value estimated by the Standard Elutriate Test was approximately 19 times that found for the water column analysis, thus supporting the conclusion of the VIMS study that the elutriate test may overestimate concentrations.

Table 4

James River Comparison of Average Constituent Concentrations

Constituent	Water Column Analysis Avg of Three, ppm	Elutriate Test Avg of Four, ppm
Cd	0.0024	0.0024
Zn	0.0016	0.0023
Pb	0.009	0.007
Cu	0.011	0.018
T-Phosphorus	0.01	0.05
TKN	0.27	5.2

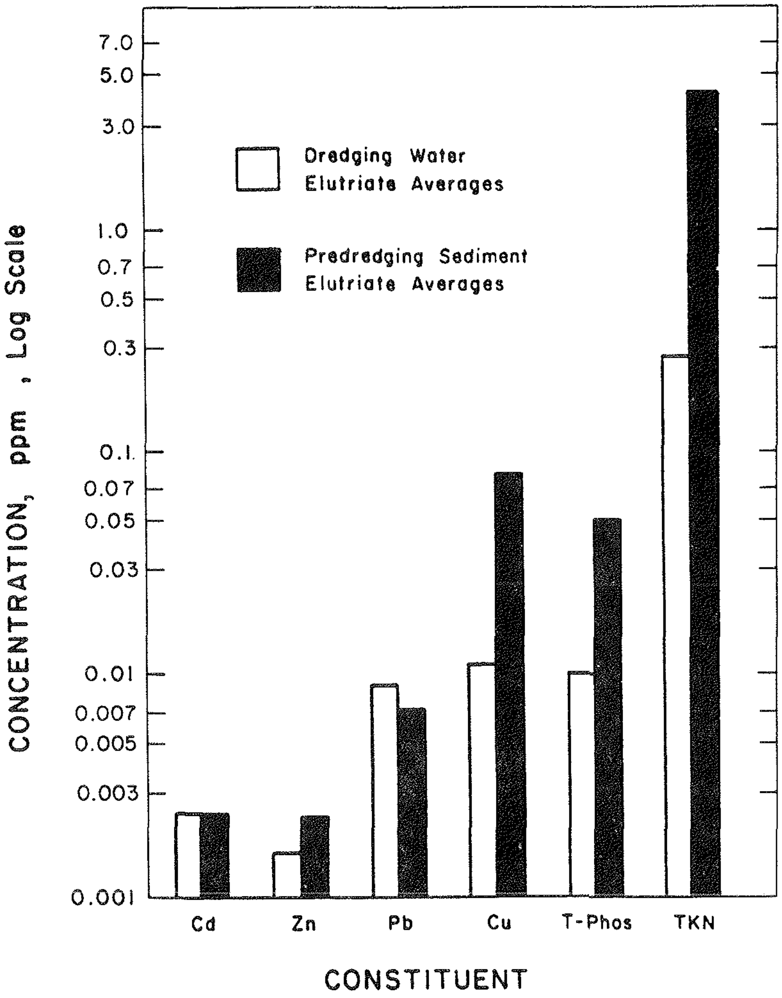

Figure 9. James River comparison of average constituent concentration

PART V: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

48. The hypothesis for this evaluation of the Standard Elutriate Test stated that an elutriate test would estimate within one order of magnitude the constituent concentration found by water column analysis at or near the point of dredging. A secondary hypothesis was that the elutriate test would overestimate soluble constituent release. Therefore, any elutriate values beyond one order of magnitude above initial dredge site water concentration would be higher than the corresponding value during dredging.

49. Table 5 is a summary of 38 chemical constituent comparisons evaluated in the course of this study. Based upon these data, the Standard Elutriate Test satisfactorily predicted the release of contaminants at or near the point of dredging by validating the hypothesis within one order of magnitude in 74 percent of the comparisons. Restated, recorded chemical concentrations in the sediment elutriate were at the same level or within one order of magnitude of the corresponding concentration in the water column sample in 74 percent of the tests. The remaining 26 percent of the comparisons met the secondary expectations of this investigation by showing that the test overestimated the expected release of some constituents; i.e., the Standard Elutriate Test is a conservative indicator of expected dredge contaminant release.

Table 5

Summary of Comparison Date From the Four Sites

Site	Constituents That Validate Primary Hypothesis (Within One Order of Magnitude)	Constituents That Validate Secondary Hypothesis (Greater Than One Order of Magnitude)	Invalid
Black Rock	11	4	0
Calumet	9	5	0
Duwamish	8	0	0
James River	5	1	0
TOTAL	28	10	0

Conclusions

50. Based upon analysis of the data provided for this investigation, the following conclusions are drawn:

- a. The elutriate test satisfactorily predicted, within one order of magnitude, the release of contaminants at the point of dredging for the four sites evaluated. Predictions were generally conservative.
- b. The results of this investigation indicated that no special adjustments of the Standard Elutriate Test are required, although the test does appear to be especially conservative in estimating the release of organic compounds and some heavy metals (mercury, manganese, iron, and chromium).

Recommendations

51. Although the Standard Elutriate Test works reasonably well, additional studies may improve the ability of the test to more accurately estimate the release of soluble contaminants. From the conclusions of this investigation and background research, the following recommendations for further studies are offered:

- a. Modifications to the elutriate test should be evaluated to predict both dissolved and particle-associated contaminant concentrations at the point of dredging. The process for contaminant release at the dredge site would be better simulated by a laboratory testing procedure which compensates for variations between dredge types.
- b. Studies should be conducted of the solids/liquids ratio and sediment water aeration time in elutriate test procedures to better represent field conditions and to reduce the tendency of the elutriate test to overestimate soluble contaminant release.

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APPENDIX A: SUMMARY OF AVAILABLE DATA

Table A1

Black Rock Harbor Sediment Elutriate Test Data

Constituent	Sample 1 ppm	Sample 2 ppm	Sample 3 ppm	Average ppm
Cd	<0.001	<0.001	<0.001	<0.001*
Zn	0.05	<0.02	<0.02	0.03
Pb	0.006	0.005	0.005	0.005
Cu	0.002	0.002	0.002	0.002
Hg	0.00077	0.00034	0.0001	0.0004
As	<0.01	<0.01	<0.01	<0.01*
Cr	0.016	0.008	0.015	0.013
Mn	0.234	0.232	0.27	0.245
Fe	0.4	0.4	0.5	0.43
Ni	0.033	0.036	0.047	0.039
T-Phosphorus	3.05	2.85	3.15	3.02
NH_3	17.4	15.1	21.8	18.1
PCB 1242	0.0023	0.0015	0.0022	0.002
PCB 1254	0.00023	0.0002	0.00012	0.00018
PCB 1260	0.00009	0.00005	0.00004	0.00006

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* Detection limit.

Table A2

Black Rock Harbor Water Column Analysis (Bottom Samples Within 50 ft of Dredge)

Constituent	Sample 1 ppm	Sample 2 ppm	Sample 3 ppm	Average ppm
Cd	<0.001	<0.001	0.001	<0.001*
Zn	0.04	<0.02	<0.02	0.026
Pb	0.005	0.003	<0.002	0.003
Cu	0.022	<0.002	<0.002	0.009
Hg	0.0004	0.00019	0.00011	0.00011
As	<0.01	<0.01	<0.01	<0.01*
Cr	0.007	0.02	0.008	<0.012
Mn	0.094	0.132	0.131	0.119
Fe	0.4	0.7	0.7	0.6
Ni	0.019	0.007	0.01	0.012
T-Phosphorus	0.05	1.15	0.97	1.06
NH_3	2.72	6.5	4.9	4.71
PCB 1242	0.00085	0.0087	0.0018	0.0053
PCB 1254	<0.00002	<0.00002	<0.00002	<0.00002*
PCB 1260	<0.00002	<0.00002	<0.00002	<0.00002*

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* Detection limit.

Table A3

Calumet River Sediment Elutriate Test Data

Constituent	Sample 1 ppm	Sample 2 ppm	Sample 3 ppm	Sample 4 ppm	Average ppm
Cd	<0.01	<0.01	<0.01	<0.01	<0.01*
Zn	0.02	0.02	0.02	0.02	0.02
Pb	0.02	0.01	0.01	0.02	0.015
Cu	<0.01	<0.01	<0.01	<0.01	<0.01*
Hg	<0.1	<0.1	<0.1	<0.1	<0.1*
As	<0.007	<0.007	<0.007	<0.007	<0.007*
Cr	<0.01	<0.01	<0.01	<0.01	<0.01*
Mn	0.98	0.89	0.89	0.1	0.7
Fe	3	2.5	2	3	2.75
Ni	0.01	0.01	0.01	0.01	0.01
T-Phosphorus	0.09	0.07	0.08	0.06	0.075
TKN	23	22	22	22	22.3
NH_3	25	26	26	26	25.89
PCB	<0.001	<0.001	<0.001	<0.001	<0.001*

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* Detection limit.

Table A4

Calumet River Water Column Analysis (Bottom Samples Within 50 ft of Dredge)

Constituent	Sample 1 ppm	Sample 2 ppm	Sample 3 ppm	Sample 4 ppm	Sample 5 ppm	Sample 6 ppm	Average ppm
Cd	0.01*	0.01	0.01	0.01	0.01	0.01	0.01
Zn	0.03	0.04	0.05	0.02	0.010	0.03	0.03
Pb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01*
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01*
Hg	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001*
As	<0.001	0.0040	<0.001	<0.001	<0.001	<0.001	<0.001*
Cr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01*
Mn	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01*
Fe	0.13	0.15	1.6	0.1	0.05	0.07	0.11
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01*
T-Phosphorus	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025*
TKN	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5*
NH_3	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5*
PCB	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001*

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* Detection limit.

Table A5

Duwamish Waterway Sediment Elutriate Test Data

Constituent	Sample 1 ppm	Sample 2 ppm	Sample 3 ppm	Sample 4 ppm	Average ppm
Zn	0.019	0.016	0.013	0.013	0.015
Pb	0.005	0.005	<0.005	<0.005	<0.005
Cu	<0.005	<0.005	<0.005	<0.005	<0.005*

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* Detection limit.

Table A6

Duwamish Waterway Water Column Analysis (Bottom Samples Within (50 ft of Dredge)

Constituent	Sample 1 ppm	Sample 2 ppm	Sample 3 ppm	Average ppm
Zn	0.016	0.041	0.016	0.024
Pb	<0.005	0.010	0.005	0.007
Cu	<0.002	<0.002	<0.002	<0.002*

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* Detection limit.

Table A7

James River Elutriate Test Data*

Constituent	Sample 1 ppm	Sample 2 ppm	Sample 3 ppm	Sample 4 ppm	Average ppm
Cd	0.0024	0.0027	0.0018	0.0025	0.0024
Zn	0.0023	0.0015	0.0023	0.0029	0.0023
Pb	0.007	0.14	0.004	0.0031	0.007
Cu	0.018	0.013	0.019	0.022	0.018
T-Phosphorus					0.05**
TKN					5.2**

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* Table 7, High Composite Figures in Bender et al. (1984).
** Individual sample concentrations not available.

Table A8

James River Water Column Analysis*

Constituent	Sample 1 ppb	Sample 2 ppb	Average ppb
Cd	0.0024	0.0023	0.0024
Zn	0.0016	0.0015	0.0016
Pb	0.0090	0.0080	0.0085
Cu	0.0110	0.0100	0.0105
T-Phosphorus			0.0100**
TKN			0.2700**

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* Bender et al. (1984).
** Individual sample concentrations not available.

APPENDIX B: STATISTICAL ANALYSIS METHODS

1. A statistical analysis for this investigation was conducted by members of the Department of Statistics at Virginia Polytechnic Institute and State University, Blacksburg, Virginia. The analysis process consisted of the following steps: data transformation, estimation of variances, and development of correction coefficients. Data were analyzed to develop a correction coefficient (k value) to predict the upper-value concentration of various constituents based upon values determined from a predredging elutriate test.

2. Initial analysis of the data showed that low concentration samples had small variances, whereas high numeric value samples had large variances. To improve the mean-to-variance relationship, logarithmic (Napierian) transformation was applied only to the water column values and not to the elutriate data.

3. The second step was to estimate the variance assuming a normal distribution. Some constituents exhibited zero variance because the minimum detectable limit was recorded for all sampling observations. Those constituents were eliminated from further analysis because they did not provide any information. One water sample from the three taken for polychlorinated biphenyl (PCB) 1242 determination at the Black Rock Harbor site was also purged from the data base because it was deemed to be inaccurate by being two orders of magnitude lower than the other two samples at the site.

4. All samples (bottom depth and <50 ft from the point of dredging) from the four sites were lumped together for computation of one k value. Still, the number of observations was relatively small, and the goal of one k value to cover all constituents proved to be unrealistic. Categories of constituents were determined based upon similar mean values, and the pooled estimator of variance (weighted arithmetic mean of variances) was used to determine the category variance.

5. The last step in the statistical analysis was to develop k for each of the constituent categories. The k value equals the standard deviation times a standardized variable (or z score, where z represents the probability that the predicted water sample concentration will exceed the actual field water sample value). For this investigation, levels of significance were preselected at 0.05, 0.1, 0.15, and 0.2 to provide 80, 85, 90, or 95 percent confidence, respectively, that the predicted concentration would be no higher than the upper bound value found in the field water sample.

Statistical Analysis Results

6. The primary goal of the statistical analysis was to develop a method to predict the upper bound which a constituent concentration might approach based on a preselected confidence level (probability of occurrence). Table B1 represents the estimated variances (pooled), and Table B2 shows the correction coefficients from the data used in this investigation.

7. The following predictive equation was developed to describe the upper bound of constituent concentration to be expected at the site of dredging:

$$PUB = AETV * e^{k/n} \tag{B1}$$

where

PUB = predicted upper bound; highest value expected for a water sample concentration based on a selected confidence interval.

AETV = average elutriate test value; the average concentration of a constituent as determined from Standard Elutriate Testing of predredging bottom sediments.

n = Number of sediment samples used to establish AETV.

Recommendation for Further Study

8. It is recommended that additional testing be conducted to increase the number of samples available for statistical analysis, specifically for computation of variance. This would allow for the correction coefficients to be better defined and the predictive equation to be more indicative of the release experienced at or near the point of dredging.

Table B1

Pooled Variances for Constituent Categories from Black Rock Harbor, Calumet River, Duwamish River, and James River

Constituent Category	Variance, Sp^2
Metals (minus Fe)	0.2
Fe	2.0
NH_3	0.2
PCBs (all)	1.2
Phosphates (Ortho and Total)	3.1 ± 2.5

Table B2

Values of k for the Constituent Categories Based Upon Selected Confidence Intervals

	Confidence Interval			
Constituent Category	80%	85%	90%	95%
Metals (minus Fe)	0.37	0.5	0.6	0.7
Fe	1.2	1.5	1.8	2.3
NH_3	0.37	0.5	0.6	0.7
PCBs (all)	0.9	1.2	1.4	1.8
Phosphates (Orthos and Total)	1.5	1.8	2.2	2.9