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Evaluation of the Significance of Waterway Sediment-Associated Contaminants on Water Quality at the Dredged Material Disposal Site

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ABSTRACT: During the past few years, considerable interest has developed concerning the significance of chemical contaminants associated with dredged sediments. Research has been done on the factors influencing the release of contaminants from waterway sediments and the toxicity of these sediments to various forms of aquatic life. This study has shown that the only two compounds which are released in potentially significant amounts to affect water quality at the disposal site are manganese and ammonia. The other compounds studied including heavy metals, chlorinated hydrocarbon pesticides, polychlorinated biphenyls (PCBs), and aquatic plant nutrients are either not released, released in insignificant amounts, or taken up as a result of mixing the sediments with the overlying waters under conditions which simulate typical dredging and dredged material disposal.

Bioassays conducted of the elutriates of the sediments with the sediments present show that, in general, large concentrations of contaminants can be present in dredged sediments which would have little or no effect on water quality at an in-water disposal site. These results show that the bulk chemical criteria that have been used frequently by pollution control agencies to establish the method of dredged material disposal are not a technically valid approach for determining the significance of contaminants associated with natural water particulate matter. In fact, in some instances, the methods of dredged material disposal which have been adopted because of excessive concentrations of contaminants based on bulk chemical criteria may have been more detrimental to environmental quality than the previously used methods of dredged material disposal.

KEY WORDS: water analysis, toxicology, dredging, bioassay, elutriate test, sediments, water quality

The U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency (EPA) are currently in the process of developing dredged

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material disposal criteria for open water disposal of dredged sediments. Part of this effort has been devoted to development of a leaching test (elutriate test, [*1–4*])[2] that could be used to evaluate the release of chemical contaminants from the dredged sediments in the disposal site water column. This paper presents some of the results of the studies using the elutriate test to assess the release of contaminants from waterway sediments taken from selected locations across the United States. Particular attention is given in this paper to the use of bioassays to assess potential toxicity of contaminants released from dredged sediments in the disposal site water column. The discussions presented in this paper represent a condensation of the results and discussion presented in a report by the authors [*5*].

Literature Review

Comprehensive discussions of the literature on the significance of sediment-associated contaminants in affecting water quality in association with dredging and dredged material disposal have been prepared by Lee and Plumb [*6*] and Lee et al [*5,7–10*]. A review of the literature in this area shows that sediment-associated contaminants, in general, tend to be much less available to affect water quality and aquatic ecosystems than their corresponding dissolved species. In some instances, sediments have been used to detoxify contaminants present in natural water systems. It has become clear that bulk chemical criteria, such as those formerly used by the USEPA [*11*], do not provide a valid base for estimating the significance of sediment-associated contaminants for affecting water quality at the dredged material disposal site. However, there are examples of contaminants associated with natural water sediments having an adverse effect on water quality. It therefore becomes important in dredging and dredged material disposal to develop procedures which can be used to determine the conditions under which sediment-associated contaminants could have a significant adverse effect on water quality at the dredged material disposal site.

The elutriate test is designed to simulate the release of contaminants in association with hydraulic dredging operations. Previous studies on this test [*6–10*] have shown that it has considerable merit in predicting the release of contaminants in open water disposal of hydraulically dredged sediments. The study reported in this paper is part of an ongoing study on the potential merit of the elutriate test in predicting contaminant release upon open water disposal of hydraulically dredged sediments.

The main thrust of the overall study was the measurement of chemical species released from U.S. waterway sediments under various conditions of the elutriate test. In order to evaluate the reliability of the chemical

[2]The italic numbers in brackets refer to the list of references appended to this paper.

measurements in determining all chemical species that could cause toxicity at the dredged material disposal site water column, a bioassay of a modified elutriate solution was conducted. These bioassays provide valuable data for assessing the elutriate test's reliability in measuring potentially significant amounts of contaminants in dredged sediments for the disposal site water column.

This paper presents the results of some of the bioassays of modified elutriate test waters performed on sediments from various U.S. waterways.

Procedures

The marine bioassays were conducted with *Palaemonetes pugio* obtained from Gulf Specimen Company, Panacea, Florida. The experimental procedure consisted of adding a known volume of sediment to a known volume of a standard synthetic ocean water [*11*], running the modified elutriate test, and assaying for toxicity of the elutriate waters in the presence of the dredged sediments. All bioassays were static, and the test organisms were not fed during the test period. The chemical characteristics of the bioassay elutriate waters were determined at the end of the hour settling period. Immediately following the 1-h settling period, ten young adult grass shrimp were added to each test chamber. Selection of test organisms was based upon a random selection of young adults ranging from 15 to 20 mm in length. All test and control tanks were maintained at 20°C (±1°C) in a controlled-temperature room unless field conditions warranted the use of some other temperature. The bioassays were run on a 14-h light/10-h dark regime. Two replicates were run simultaneously for both the test tanks and controls.

The freshwater bioassays, using first instar *Daphnia magna,* were conducted in a manner similar to the marine tests, except that dredging site water was used as the test solution and the bioassays were conducted in 200-ml aliquots of the 1-h settled elutriate water. This solution was not filtered or centrifuged. It contained any solids present in the elutriate solution after the 1-h settling. All other test conditions and procedures were the same as the marine tests.

The elutriate test procedure involved the use of either a 5 or 20 percent elutriate. The 20 percent elutriates were prepared by mixing one volume of sediment with four volumes of the test water using compressed air agitation for a 30-min period. The 5 percent elutriates were prepared by mixing one volume of sediment with 19 volumes of test water. This was followed by a 1-h quiescent settling.

The marine bioassay was initiated by the introduction of the grass shrimp into this solution. The freshwater bioassays were treated in an identical manner except that, at the end of the 1-h settling period, the supernatant

was siphoned off and placed in various test vessels for the bioassay test. The *Daphnia* were added to the decanted supernatant.

These elutriate procedures are similar but not identical to the elutriate test developed by the USEPA and the U.S. Army Corps of Engineers [*1–4*]. The principal difference between the elutriate test procedures used in this study and those used by the USEPA and U.S. Army Corps of Engineers is that the standard elutriate test involves filtration after the 1-h settling period to remove any suspended particulate matter that did not settle. It is felt that the modified elutriate test used in this study is a more severe test in that there is opportunity for release of the contaminants over the four-day test period from any suspended sediment present at the time of decantation for the freshwater test and from all of the sediment used for the marine test.

Sediments tested in this study were Duwamish River, Seattle, Washington; Los Angeles Harbor; Rhode Island offshore dredged material disposal site and sediment samples collected from selected Connecticut harbors; Mississippi River near St. Paul; James River near Richmond, Virginia; and Bailey's Creek near Hopewell, Virginia. The results of the bioassays conducted on these sediments are presented next. The results are part of a study evaluating the reliability of the elutriate test as a technique for estimating the release of contaminants during open water dredged material disposal. The other parts of this study are presented in a report by Lee et al [*7,10*].

Results

Duwamish River, Seattle, Washington

Sediments from the Duwamish River located in Seattle, Washington, were subjected to a modified elutriate test using *P. pugio* as the test organism. Table 1 presents the total heavy metal composition of the Duwamish River sediments collected on 16 Feb. 1976. Some of these same sediments were used for bioassay tests. The results of the heavy metal analyses for the bioassay elutriates utilizing Duwamish River Site 3 sediments are presented in Table 2. Examination of this table compared to Table 1 shows that a relatively small amount of the heavy metals present in the sediments are released in the elutriate leaching test, and the only two elements which show potentially significant release are iron and manganese.

Small releases of copper occurred in the bioassay elutriate water. There appears to be one anomalous result in the cadmium data where the Test Solution A under the 5 percent sediment of the total elutriate volume is 34 μg/litre cadmium. All others showed 2 to 6 μg/litre, which are in the

TABLE 1—*Total heavy metal composition, mg/kg.*

Sampling Location	Mn		Cr		Cd		Ni	
	$\bar{X}$[a]	SD[a]	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Duwamish River Sediments								
Site 1	493	57	11.2	1.8	<0.5	...[b]	15.0	0
Site 2	572	10	18.4	0.7	<0.5	...	15.0	3.5
Site 3	558	54	15.3	2.0	<0.5	...	17.5	0
New England Sediments								
Newport	306	3	19.9	0.4	<0.5	...	9.5	3.2
Stamford	451	43	86.0	6.7	2.8	0.1	37.8	9.1
Norwalk (North)	480	9	67.5	5.9	4.1	0.2	43.1	4.8
Norwalk (South)	369	68	73.9	22.2	3.5	0.6	37.8	6.7
Los Angeles Sediments								
Los Angeles Buoy A-7	382	7	47.6	2.7	3.0	0	30.5	0

[a]$\bar{X}$ = mean. SD = standard deviation. Mean and standard deviation calculated from du-
[b]Not determined.

TABLE 2—*Heavy metals in bioassay elutriate waters, Duwamish River sediments, Seattle, Washington (Site 3).*

Element	Control[a]		Sediment Percentages[a], %			
			5		20	
	A	B	A	B	A	B
Cd	3.1	3.3	34	2.6	6.1	6.1
Cu	13.3	14.8	21.3	19.8	71.6	34.3
Cr	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Fe	11	13	8506	9772	22 177	23 038
Mn	49	29	2430	2177	6 962	6 354
Ni	11.9	13.9	15.1	14.7	21.5	13.9
Pb	47.8	49.3	12.9	12.9	33.6	14.0
Zn	76	141	94	82	188	106
Hg	0.06	0.06	0.001	<0.001	0.096	0.13

[a]A and B are replicates. Concentrations in μg/litre.

range of the controls. The concentrations of lead decreased as a result of elutriation.

Table 3 presents the results of the bioassay test using 5 and 20 percent sediment of the total elutriate volume. Only one grass shrimp died in the 96-h test period, indicating little or no toxicity from these sediments to

Pb		Zn		Cu		Fe		Hg		As	
$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
13.0	1.7	68.6	1.6	22.5	2.8	15 581	44	0.058	0.004	1.8	0
17.7	8.3	73.6	1.9	42.0	2.1	16 079	88	0.085	0.007	1.7	0
27.1	1.7	71.9	6.2	42.8	6.0	15 892	220	0.050	0.007	1.3	0
<1	...	55.3	3.0	12.2	0.7	8 847	293	0.026	0	2.8	0.3
122.9	13.8	339.5	52.6	217.8	23.6	9 531	64	0.162	0.004	1.0	0.3
276.9	11.0	635.7	8.6	223.7	6.0	9 414	178	0.309	0.030	3.4	0.5
196.9	35.9	567.3	6.6	254.5	50.2	9 387	344	0.379	0.010	0.9	0.1
41.3	8.3	222.9	0.3	147	9.8	17 478	946	0.147	0.007	12.8	0

plicate analyses.

this organism within this period of time. Table 4 presents the characteristics of the bioassay test water used in this part of the study. Of potential concern is the 4 to 5 mg/litre ammonium nitrogen present in the 20 percent elutriate test.

Because of space limitations, the complete data for the characteristics of the bioassay test waters (elutriate) and the mortality of the test organisms will not be presented in this report. Data of the type presented in Tables 1 to 4 are available for each of the sites studied. This is being presented in a report by Lee et al [5]. Only a summary of these results is presented in this paper.

Upper Mississippi River, St. Paul

A set of sediment samples were taken from the upper Mississippi River in Pool 2, just below Minneapolis-St. Paul. This region of the river is generally considered to be one of the most polluted. The pollution is the result of the discharge of municipal and industrial wastes from these two municipalities. The particular location where the samples were collected is the one that is most severely impacted with low dissolved oxygen arising from the biochemical oxygen demand (BOD) discharge to the river. The bioassays conducted on these sediments utilized *D. magna* (acclimatized to 20°C) as the test organism. In addition to conducting a modified elutriate test bioassay, samples of water obtained from the discharge pipe of the hydraulic dredging operation were also utilized. The test water used in

TABLE 3—*Mortality of* P. pugio *during 96-h acute bioassay of Duwamish River (Site 3), Seattle, Washington.*

	Number of Organisms Alive					
			Sediment of Total Elutriate Volume, %			
	Control		5		20	
Time, h	A[a]	B[a]	A	B	A	B
0	10	10	10	10	10	10
12	10	10	9	10	10	10
24	10	10	9	10	10	10
36	10	10	9	10	10	10
48	10	10	9	10	10	10
60	10	10	9	10	10	10
72	10	10	9	10	10	10
84	10	10	9	10	10	10
96	10	10	9	10	10	10

[a]A and B are replicates.

TABLE 4—*Physical and chemical characteristics of the elutriate test bioassay*[a] *for Seattle, Washington sediments (Site 3).*

Sample	Temperature, °C	pH	Dissolved Oxygen, mg/litre	Salinity, parts per thousand	Total Ammonium as N, mg/litre	Turbidity, NTU[c]
Control A[b]	21.0	8.1	7.0	29.0	0.14	0.4
Control B[b]	21.0	8.1	7.0	29.0	0.12	0.5
5% A	21.0	7.3	4.3	28.5	1.65	74.0
5% B	21.0	7.0	3.8	28.7	1.42	68.0
20% A	21.0	7.0	2.0	28.2	5.29	78.0
20% B	21.0	7.2	1.1	28.3	4.41	84.0

[a]Measurements taken at the end of the 1-h settling period.
[b]A and B are replicates.
[c]NTU = nephelometric turbidity units.

these tests was obtained upstream of the dredging site in Pool 2. The characteristics of the Mississippi River water and the dredge discharge water and characteristics of the elutriate waters are presented by Lee et al [5].

There was no toxicity to *D. magna* over a 96-h test period for either the elutriate waters or the dredge discharge water. Soluble heavy metal analyses of the bioassay waters for these samples showed release of iron and manganese in relatively large amounts and small releases of zinc, lead, nickel,

copper, and cadmium. However, the concentrations of toxic forms of these elements in the elutriate waters was insufficient to be adverse to *D. magna* during this period. In addition to heavy metals, these solutions also contained from 1 to 6 mg/litre NH_4^+-N. The sum of all of these contaminants, other unmeasured contaminants, and the synergistic effects of all contaminants present in the system was such that they did not create any toxicity to *Daphnia* over this test period. It is probable that no acute toxicity would be expected from dredging operations conducted in the upper Mississippi River at this location.

Rhode Island and Connecticut

Sediments were collected from three different areas in southern New England in November 1975. These areas included the offshore dredged material disposal site near Narragansett, Rhode Island, commonly called the Newport, Rhode Island disposal site. Also, one set of samples from Stamford Harbor, Connecticut and two sets of samples from Norwalk River, Connecticut were collected. All of these sediments were analyzed for the total heavy metal content, the release of heavy metals and other contaminants during the modified elutriate test and their toxicity to *P. pugio*. Table 1 presents the results of the heavy metal analyses for these sediments. Examination of Table 1 shows that the Newport site generally has lower concentrations of various heavy metals than the other two sites. This is to be expected in that the Newport site is an offshore disposal site, used approximately six years ago by the Corps of Engineers for disposal of dredged sediments. The Stamford Harbor and Norwalk River sites represent areas which are receiving municipal and industrial wastes and land runoff. The Norwalk North and Norwalk South sites are two different sampling locations in the Norwalk River located within a couple of miles of each other.

The results of the bioassay using *P. pugio* for the Newport sediments show that there was no toxicity over the 96-h test period. The characteristics of this bioassay test solution are presented by Lee et al [5]. Approximately 1 mg/litre ammonium was present in the 20 percent elutriate solution while the cadmium content of the test water decreased as a result of the elutriate test. Similar results were found for copper, manganese, nickel, lead, and zinc. The only metal which showed any release during the modified elutriate test was iron.

A similar set of data for the Stamford Harbor sediments shows that only one grass shrimp died in the 20 percent elutriate over the 96-h period. Approximately 2 to 4 mg/litre ammonium nitrogen was present in the elutriate tests. There was a slight decrease in cadmium during the elutriation procedure. The other heavy metals showed little or no change or a

slight increase, except for iron which showed up to 2200 μg/litre increase for the 20 percent elutriate of these sediments.

The Norwalk River North and South site bioassays and elutriate data showed no toxicity to *P. pugio* during the 96-h test period for the North site, and one grass shrimp in the two replicate test systems using 20 percent sediment of the total elutriate volume died after 36 h of exposure to the South site sediments. Ammonium content of the two sediment elutriates ranged from 7 to slightly over 11 mg/litre ammonium as N. The North site sediments showed no change in cadmium or nickel during the elutriate test while there appears to have been a slight decrease in cadmium and nickel content of the South site sediment elutriates. Copper showed a slight increase in the North site while the South site sediments showed no change to a slight decrease. There was readily measurable iron release in the South site sediments. Iron measurements were not made on the North site sediments. Manganese was released for both sediments. There were insignificant changes in the other heavy metals measured for both these sediment elutriates.

Again, with this set of data taken from a variety of harbors and disposal sites along the southern New England coast, it has been found that sediments contain large amounts of heavy metals, some of which are released during the elutriate tests; however, essentially no toxicity was found to *P. pugio* over a 96-h period when exposed to a 1 to 19 or 1 to 4 sediment-water mixture.

Los Angeles Harbor

Samples from the Los Angeles Harbor sediments were collected on 9 July 1975. The total heavy metal content of these sediments is shown in Table 1. These sediments have approximately the same general concentration of heavy metals as the other sediments that were investigated in this study. The toxicity of these sediments, however, is considerably greater than any of the other sediments that have been investigated as part of this phase of the study. While only a single sample of the 20 percent elutriate was run, over half of the grass shrimp died in a 96-h period. For the 5 percent elutriate, 20 to 30 percent of the grass shrimp died during the 96-h period. These results indicate a somewhat greater toxicity of these sediments to this organism than found in the other sediments that have been tested.

Examination of the characteristics of the elutriate water shows that the 20 percent elutriate has approximately 22 mg/litre ammonium nitrogen while the two 5 percent elutriates have 9 and 12 mg/litre ammonium nitrogen. The heavy metals released during the elutriate tests were copper, iron, nickel, lead, and zinc. Manganese appeared to decrease for these sediments. This is an unusual pattern for this metal. It cannot be ascertained from the information available whether the increased toxicity of

these sediments to *P. pugio* is related to the somewhat greater release of heavy metals, higher ammonia, or some other unmeasured constituents.

James River and Bailey's Creek

A set of samples was collected in July 1976, from Bailey's Creek and the James River. The Bailey's Creek samples were taken about one mile downstream from the Hopewell domestic wastewater treatment plant. This plant received the Kepone discharged by a manufacturing firm located in Hopewell, Virginia which resulted in the widespread contamination of the James River and Chesapeake Bay with this compound. Sampling was also done of water discharged from a pipeline dredge that was operating near Windmill Point on the James River. This location is several miles below the point where Bailey's Creek enters the river. The sediments in this area would be expected to be contaminated with Kepone and a wide variety of other contaminants from municipal and industrial wastes of the area which include pulp and paper wastes and petrochemicals. It was impossible to sample the dredge discharge water directly because of submerged discharge. Samples were taken immediately adjacent to the discharge. There was some dilution due to the initial mixing that occurs upon the entry of the discharge water into the river.

The bioassays were conducted with *D. magna* since this is a freshwater system. In this case, the *Daphnia* were acclimatized to 25°C since this was the temperature found at the disposal site. The bioassays on the elutriate on the Bailey's Creek samples were run with the James River water taken near Windmill Point. This water was not contaminated with any discharge from recent dredging operations. The characteristics of the James River water and nonsettled discharge water are presented in Lee et al [5]. The dredged discharge water showed no toxicity to *Daphnia* in 96 h. The Bailey's Creek sediments, however, showed some toxicity to *Daphnia* for both the 5 and 20 percent sediment of the total elutriate volume. Slightly greater toxicity was demonstrated for Replicate B for the 5 percent sediment than with either A or B for the 20 percent sediment. These results indicate some toxicity to *D. magna* from these sediments from Bailey's Creek. The ammonia content of these samples ranged from 1 to 5 mg/litre as N while the elutriates on the Bailey's Creek sediments showed slight releases of cadmium and readily measurable increases of copper, chromium, iron, manganese, nickel, lead, and zinc. The dredge discharge water taken from the James River, however, showed no significant change in the cadmium content, and readily measurable release of copper, iron, manganese, lead, zinc, and nickel.

One of the reasons why the dredged discharge water and the elutriates from the James River sediments showed increased concentrations of many

of the heavy metals is that these sediments contained large amounts of particulate matter that would readily pass through a 0.45-μm pore size filter. A filtrate was milky in appearance, indicating that large amounts of particulate matter were present in the samples that would not readily settle in the modified elutriate test that is used for bioassay solutions. A true elutriate of these sediments, that is, treated in such a way as to remove the particulate matter, would likely show much lower concentrations of many of these heavy metals than those found.

Tests on Other Sediment Samples

In addition to the sediments reported in this paper, elutriate-type bioassays on sediments from Ashtabula Harbor, Lake Erie; Bridgeport Harbor, Connecticut; Corpus Christi Harbor, Texas City Channel, Houston Ship Channel near Morgan's Point, Galveston Bay Entrance Channel, Texas; and San Francisco Bay near Mare Island and Rodeo Flats have been investigated. The results of these studies have been reported by Lee et al [*7*] and Lee, Lopez, and Mariani [*9*]. Also, ongoing studies using sediments from Mobile Bay, Alabama, several sites in the New York-New Jersey area, and Apalachicola, Florida have been completed. All of these studies show that, for freshwater sites using *D. magna* and marine sites using *P. pugio*, in general, little or no toxicity was found in a 96-h bioassay of modified elutriate test water. In some instances, as many as half of the grass shrimp would die in a 96-h period. However, this situation was rare, and, in most of these tests, from zero to 20 percent of the grass shrimp died during the test period. The lack of toxicity noted with the Ashtabula Harbor, Lake Erie sediments, is supported by the observation that *Daphnia* reproduced during the test period.

Overall Evaluation

From the results of these tests, it may be concluded that the typical open water dredged material disposal operation involving dumping of dredged sediments should have little or no acute toxicity to aquatic life in the disposal site water column. This conclusion is based on the rapid dilution that occurs at the disposal site water column, coupled with the fact that relatively small amounts of contaminants present in the water sediments tested were available to be acutely toxic to aquatic life over much longer periods of time than the typical exposure that would occur in open water disposal operations. Most open water disposal operations will involve a dilution of many thousandfold within a few hours of the time of disposal [*7*]. Further, it is unlikely that any chronic toxicity would be found from open water disposal involving dumping operations to water

column organisms because of the intermittent nature of the disposal operation.

The results of these studies clearly demonstrate that chemical contaminants associated with natural water sediments taken from both fresh and marine waters throughout the United States in general are largely unavailable to be adverse to aquatic life in the water column during typical open water disposal of dredged material.

Hazard Evaluation of Sediment-Associated Contaminants

Increasing impetus will be given in the near future to evaluating the significance of sediment-associated contaminants. Section 404 guidelines for Public Law 92-500 [*3*] governing the disposal of dredged material require that applicable water quality standards be used to judge the significance of contaminants associated with dredged sediments at the edge of a mixing zone. A similar approach has been proposed for disposal of dredged sediments in marine waters [*4*]. While inappropriate for most dredged material disposal operations, it is likely that attempts will be made to utilize the USEPA "Quality Criteria for Water" [*12*] as a basis for judging the significance of the presence of chemical contaminants at the edge of a mixing zone for a dredged material disposal site. As discussed by Lee [*13*], the inappropriateness of the July 1976 USEPA "Quality Criteria for Water" [*12*] stems from the fact that these criteria were developed for chronic exposure situations utilizing readily available forms of the chemical contaminants. The dredged material disposal operation, on the other hand, consists primarily of contaminants present in a particulate form where a substantial part of the contaminants is not available to affect water quality. Further, the time of exposure for concentrations in excess of proposed water quality criteria is generally such that it is virtually impossible to obtain an exposure similar to that used in the bioassay tests which serve as a basis for establishing the USEPA criteria.

The development of meaningful dredged material disposal criteria provides considerable impetus for development of a reasonable approach for interpretation of the significance of sediment bioassay test results. As noted in other sections of this paper, some sediments will show toxicity to aquatic organisms. For example, two to three grass shrimp will die in a four-day exposure period when the sediments and water are mixed in a one to four volumetric ratio. The important question that must be resolved is, what is the significance of these results? Should results of this type be of concern in a dredged material disposal-dredging operation? First, it is obvious that the toxicity encountered is not in any way related to the bulk chemical content of these sediments. If it were, all organisms would die in a very short period of time, based on the presence of relatively large amounts of many different contaminants which are acutely toxic to

aquatic life at the bulk concentrations present in the test system. These bioassays clearly demonstrate the lack of validity of bulk chemical criteria for judging the significance of contaminants associated with dredged sediments.

With respect to open water dredged material disposal, the toxicity associated with the deposition of contaminated sediments at the designated disposal site is of limited concern. Studies currently underway on behalf of the Corps of Engineers as part of the dredged material disposal research program are showing that there are changes in the numbers and types of benthic and epibenthic organisms present in the dredged material disposal site. Further, the disposal operations, even though conducted with sediments derived from waters which are classically considered grossly polluted, do not create a biological desert at the disposal site. What is generally observed is a change in the numbers and types of organisms. Even the deposition of clean sand causes a change in the numbers and types of organisms present at a disposal site because of the physical effects of the matrix on the organisms and their habitat.

The toxicity effects should focus on the conditions that prevail at the edge of the deposition area, not on the dredged material disposal mound. Since the disposal mound represents an area which has been set aside for disposal operations, it is analogous to a landfill site in terrestrial disposal of contaminants in that one would expect to find toxicity at the disposal site. However, the concern is whether the materials that are transported from the disposal site have a significant adverse effect on water quality. This should be measured outside the designated disposal area. Such an approach requires some understanding of the rate and conditions of transport that prevail at the edge of the designated disposal area. The conditions that prevail there are usually significantly different from those present in the disposal mound immediately after disposal. For example, the concentrations of sediment-associated contaminants should, in general, be considerably less than those present in the sediments that were originally dredged, due to dilution. Further, for many contaminants, the characteristic of the environment at the edge of the disposal site should generally be one in which the contaminant would be likely to be less available to affect water quality.

Another factor that must be considered in interpreting bioassay results designed to evaluate the significance of contaminated sediment disposal in natural water systems is that the sediments at the edge of the designated deposition zone are probably moving with the currents of the area and therefore, long-term chronic exposure by benthic organisms that inhabit a specific area may be difficult to achieve. In the case of water column effects, it is virtually impossible in typical dredging operations for organisms in the water column associated with the dredged material disposal site to receive chronic exposure of contaminants arising from the dumping

of dredged sediments in open waters. The intermittent nature of most dredged material disposal operations makes it unlikely that most contaminants will be present in the water column in sufficient concentrations and in a sufficient area to cause chronic exposure to planktonic and nektonic organisms. The planktonic organisms would encounter the same rapid dispersion as the suspended sediment that is not immediately settled upon disposal and any solutes released from the disposal operation. The nektonic (free swimming) organisms, in addition to dilution and dispersion, have the ability to swim in and out of the area. The interpretation of bioassays directed toward water column effects must focus on the proper time concentration relationships that would exist at a particular disposal site and type of operation.

The federal regulations for disposal of dredged sediments [*2,3*] currently call for an evaluation of the concentrations of contaminants at the edge of a mixing zone using appropriate water quality criteria. As discussed previously, quality criteria for water [*12*] developed by the USEPA are in general inappropriate for judging the significance of contaminants associated with dredged material disposal at the edge of the mixing zone. The basis for their inappropriateness is that these criteria are, in general, based on chronic exposure to the most readily available forms of the contaminants in laboratory situations. As noted before, it is virtually impossible to achieve a chronic exposure situation in normal dredged material disposal in open waters. Second, many of the contaminants present at the edge of the mixing zone will be in a particulate form and will probably be in what might be considered the most unavailable form that would normally be encountered. Therefore, finding a concentration of contaminants at the edge of a mixing zone which exceeds the USEPA "Quality Criteria for Water" released in July 1976, should not be interpreted as being representative of an adverse environmental impact. Further, any acute bioassays conducted to judge the significance of the contaminants at the edge of the mixing zone should be interpreted in terms of the time-concentration relationship that will be encountered in a particular disposal operation.

The effects of the bioaccumulation of contaminants from dredged sediments are different than toxicity effects. For bioaccumulation, where the concern is the impact on higher trophic level organisms or man, emphasis should be placed on accumulation in organisms at or near the dredged material disposal site which results in excessive concentrations in higher forms of aquatic life. The interest should not be restricted to mere measurement of some transfer from the sediment or sediment-associated water to a form of aquatic life. There are many situations in which you can readily detect some transfer. However, as with toxicity problems, bioaccumulation problems are related to concentrations.

Almost all aquatic and terrestrial organisms have some readily measur-

able concentration of chlorinated hydrocarbon pesticides present within them. The mere presence is not the reason for concern; it is presence in sufficient concentrations to make the use of fish and other aquatic life unsuitable for food either to man or fish-eating birds that is of concern.

Interpretation of bioaccumulation bioassays must consider the fact that fish, shrimp, crab, lobster, or many other normally used food species rarely accumulate sufficient concentrations of contaminants to render the food unsuitable for human use or hazardous to other forms of aquatic life, even though many of these organisms live in sediments with elevated concentrations of chlorinated hydrocarbon pesticides, polychlorinated biphenyls (PCBs) and heavy metals.

With respect to dredged material disposal, one of the best ways to screen for potential bioaccumulation problems is to collect organisms from the disposal site and examine their tissue content for the contaminants of concern. If the tissue content is less than the known critical levels, then bioaccumulation problems generally can be ruled out from all other sources of contaminants. If, however, the concentrations in organisms in the region of the dredged material disposal site exceed the critical levels, then further studies are necessary to ascertain whether these excessive concentrations are derived from dredged material disposal or from other sources. It is important to emphasize that the study of the concentrations of contaminants present in the organisms should take place over about a one-year period in which particular attention is given to reproductive cycles, molting, and sex of the organisms, since these have all been shown to be significant in determining the significance of bioaccumulation within aquatic organisms.

One of the methods that is sometimes utilized to assess bioaccumulation in solids is the activation of the elements present in the solid phase by nuclear bombardment. Such an approach greatly increases the sensitivity of detecting transfer from the solids to the organism for certain of the elements that are readily activated. However, rarely is this approach appropriate for real-world situations in that, if the bioaccumulation cannot be measured with normally used analytical procedures, then the potential for it to be of any major significance in affecting water or food quality is small.

A factor that should be considered in any bioaccumulation studies is the ability of many organisms to depurate the excessive concentrations of contaminants once the source of the elevated concentrations has been removed. Several studies have shown that the concentrations of contaminants in aquatic organisms will increase in association with dredging. However, within a month or more after the dredging has ceased, the levels within the organisms are back to predredging concentrations. It may be necessary to control the taking of certain organisms at or near dredged material disposal sites during certain times of the year in order to allow

the organisms to adjust to normal body burden for contaminants of concern to man when the organism is utilized as food.

The time-concentration relationships of importance in properly evaluating the hazards associated with dredged material disposal should also be considered with natural phenomena such as the conditions that are considered with storms or high currents arising from tides which cause suspension of sediment materials. It is possible that the magnitude of sediment-associated contaminants released during a storm could be significant in terms of a readily measured amount, yet since the duration of the storm is relatively short, the overall significance to water quality could be small. It is important in considering dredged material disposal operations to examine the relative magnitude of releases from dredging operations compared to other human activities such as shipping (where the boat propellers stir up the sediments), as well as storms, high tides, high river discharges, etc. In many situations, if there is a release of contaminants as a result of sediment suspension, the relative amount of release from natural or other man-derived activities would completely overshadow any release associated with highly localized, relatively short-term effects accompanying the dredging.

Evaluation of the environmental hazards associated with dredged material disposal in natural waters should include an evaluation of the environmental hazards associated with alternate methods of disposal. As discussed by Lee [*7,14*], many of the alternate methods of disposal that have been adopted as a more "environmentally safe" method of disposal arising from the use of bulk chemical criteria may actually be more environmentally harmful than the previously used, often less expensive, open water disposal. A much better mechanism than exists today must be developed for evaluating the related environmental hazards of alternate methods of dredged material disposal where the primary concern is the presence of potentially significant amounts of chemical contaminants in the dredged sediments.

Conclusions

Recent changes in the criteria governing dredged material disposal provide the opportunity for a more realistic assessment of the significance of sediment-associated contaminants than has generally been possible in the past. However, a number of problem areas remain, the most important of which is the development of the appropriate water quality criteria for use at the edge of a mixing zone associated with open water dredged material disposal. Further, any meaningful hazard evaluation for dredged sediment-associated contaminants must include an evaluation of the potential environmental impact of alternate methods of disposal.

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References

[1] *Federal Register,* Vol. 38, No. 94, U.S. Environmental Protection Agency, 1973, pp. 12872–12877.

[2] *Federal Register*, Vol. 38, No. 198, U.S. Environmental Protection Agency, 1973, pp. 28610–28621.

[3] *Federal Register,* Vol. 40, No. 173, U.S. Environmental Protection Agency, 5 Sept. 1975, pp. 41292–41298.

[4] *Federal Register,* Vol. 41, No. 125, U.S. Environmental Protection Agency, 28 June 1976, pp. 26644–26667.

[5] Lee, G. F., Lanza, G. R., and Mariani, G. M., "Significance of Sediment-Associated Contaminants in Water Quality Evaluation," Occasional Paper No. 11, Center for Environmental Studies, University of Texas-Dallas, Nov. 1976.

[6] Lee, G. F. and Plumb, R. H., "Literature Review on Research Study for the Development of Dredged Material Disposal Criteria," U.S. Army Corps of Engineers Dredged Material Research Program, Vicksburg, Miss., June 1974.

[7] Lee, G. F., Piwoni, M., Lopez, J., Mariani, G., Richardson, J., Homer, D., and Saleh, F., "Research Study for the Development of Dredged Material Disposal Criteria," U.S. Army Corps of Engineers Dredged Material Research Program, Vicksburg, Miss., Nov. 1975.

[8] Lee, G. F., Lopez, J. M., and Piwoni, M. D., *Proceedings*, ASCE Specialty Conference on Dredging and Its Environmental Effects, American Society of Civil Engineers, 1976, pp. 253–288.

[9] Lee, G. F., Lopez, J. M., and Mariani, G., "Leaching and Bioassay Studies on the Significance of Heavy Metals in Dredged Sediments," presented at International Conference on Heavy Metals in the Environment, Toronto, Canada, Oct. 1975, in press.

[10] Lee, G. F., McDonald, C., Saleh, F., Bandyopadhyay, P., Butler, J., Homer, D., Jones, A., Lopez, J., Mariani, G., Piwoni, M., and Nicar, M., "The Development of Criteria for Dredged Material Disposal," report to Dredged Material Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1977.

[11] *Methods for Acute Toxicity Tests with Fish, Macroinvertebrates and Amphibians,* Ecological Research Series, EPA-660/13-75-009, U.S. Environmental Protection Agency, 1975, p. 18.

[12] "Quality Criteria for Water," EPA-440/9-76-033, U.S. Environmental Protection Agency, Washington, D.C., July 1976.

[13] Lee, G. F., *Federal Register,* Vol. 40, No. 173, 1975, pp. 41292–41298. Mimeo available from Center for Environmental Studies, University of Texas-Dallas.

[*14*] Lee, G. F., "Significance of Chemical Contaminants in Dredged Sediments on Estuarine Water Quality," report submitted to U.S. Environmental Protection Agency, to be published in *Proceedings,* Estuarine Pollution Workshop, Pensacola, Feb. 1975. Mimeo available from Center for Environmental Studies, University of Texas-Dallas.