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Toxicity of U.S. Waterway Sediments with Particular Reference to the New York Harbor Area

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ABSTRACT: A study was conducted in the mid- to late-1970s on the toxicity of elutriate test mixtures of water and sediment from U.S. harbors and waterways to grass shrimp or daphnia. While for many waterway sediments, 20 to 30% mortality was found after 96-h exposure, those of the New York harbor area showed somewhat greater toxicity. The specific cause of the mortalities was not investigated at that time. It is known that the sediments contained a wide variety of chemical contaminants which, if available to the organisms, could be toxic to them. More than 30 chemical parameters, including heavy metals and chlorinated hydrocarbon pesticides, were measured in the sediments; of the parameters measured, only ammonia was released in sufficient amounts to potentially cause acute lethality in the test waters associated with the sediments. Recent review of the data showed that there is a relationship between the concentration of ammonia in the sediment/water mixtures (elutriates) test and the mortality of grass shrimp in the tests. Furthermore, the concentrations that appeared to cause about 50% mortality of the grass shrimp in the 96-h exposure were about the level of 96-h LC50 to grass shrimp for ammonia.

KEY WORDS: sediment, toxicity, ammonia, dredged sediment

The sediments in waterways in urban and industrialized areas contain a variety of chemical contaminants that could have adverse impacts on the aquatic organisms in these waters. One of the most urbanized and industrialized areas of the country is the New York/New Jersey harbor area (Fig. 1). This area receives approximately12 million m^3 per day of industrial and domestic wastewaters [1]; the sediments provide a sink for many of the chemical contaminants. Nonetheless, the toxicity of the sediments in this area and their impacts on water quality have not been well studied or systematically reviewed. The primary concern in the Hudson/Raritan Estuary-New York Harbor area is still the maintenance of dissolved oxygen in the water. In fact, the recently completed use-attainability studies conducted by the New Jersey Department of Environmental Protection (NJ DEP) and the New York Department of Environmental Conservation (NY DEC) did not even consider toxics in these waters, but instead restricted discussion to the problems of dissolved oxygen and coliforms [2,3], which are currently of primary concern in the beneficial uses of these waters. As the problems with low dissolved oxygen and coliforms are remedied, as is being done, the impact of toxics will come to the forefront. There are areas in this system, such as the Arthur Kill, which contain water that itself has been found to be toxic to aquatic organisms when used as control water in toxicity tests.[2] Lee [4] reported that there are several heavy metals such

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[2]Buzby, M., Director Industrial and Laboratory Operation,. Rahway Valley Sewerage Authority, Rahway. NJ, personal communication to G. Fred Lee, 1986.

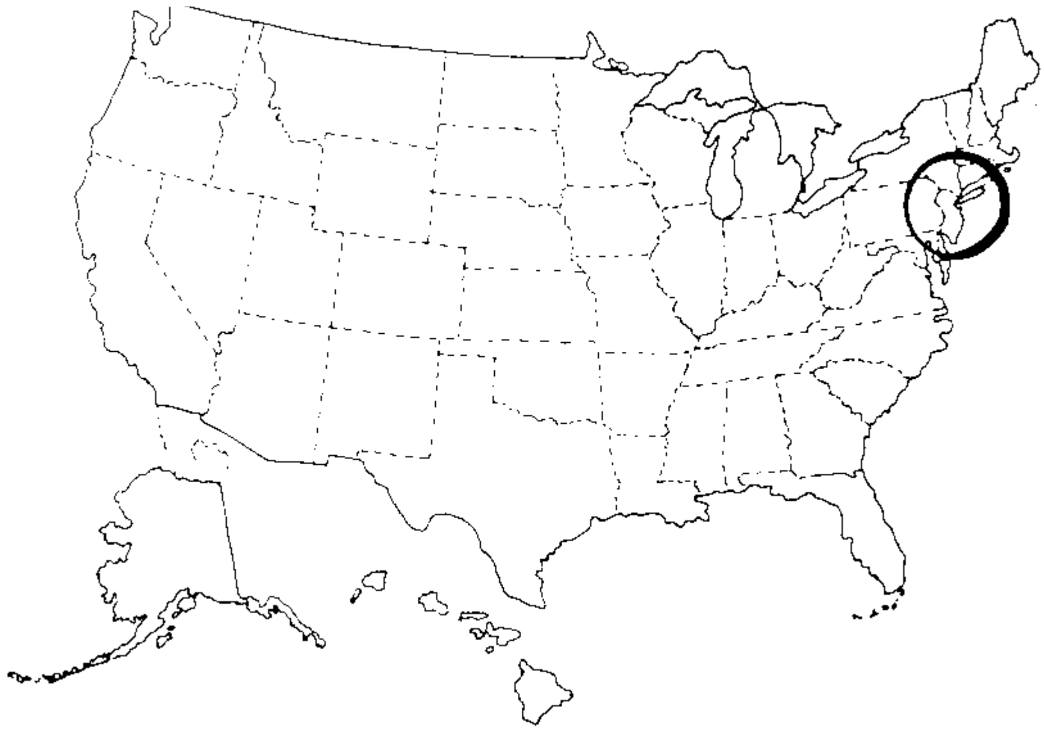

FIG. 1—*New York Harbor area highlighted.*

as copper and zinc in the waters of the New York-New Jersey harbors and waterways that would be chronically toxic to aquatic life based on the U.S. Environmental Protection Agency (EPA) water quality criteria of July 1985 [5]. The source of the toxicity and the significance of this finding to water quality in this area have yet to be evaluated.

The work reported herein developed from an on-going effort on the assessment of sediment toxicity, how it may be determined, and the significance of laboratory results to the management of water quality. The focus of this work is on the sediments of the New York and New Jersey coastal waterways, reviewing what is known about the toxicity of these sediments, and also adapting and developing methods for this toxicity evaluation. The study is directed toward water quality management —the protection of the designated beneficial uses of the waters of the systems—and will eventually proceed to evaluating the toxic components of the sediment and the sources of the toxicity. It is important in the discussion and development of so-called sediment criteria that focus be maintained on the impact. That is, the existence of certain chemicals in a sediment does not indicate, a priori, that there is a problem.

Problem Definition

There is concern about the potential toxicity of waterway sediments in general, and the Hudson/Raritan Estuary sediments in particular, from several points of view. First, on the order of 9 million wet tons of sediment (more than 10 million m^3) of sediments dredged from this area annually are dumped in the New York Bight at the Mud Dump Site, about 11 km off-shore from Sandy Hook, NJ [6]. There is concern that the release of toxic contaminants from these sediments could adversely affect the benthic and pelagic organisms of the Bight waters. Second, certain of the fisheries in the Hudson/Raritan Estuary have been adversely affected because of the excessive body burdens of PCBs in the fish. Most noted is the restriction on fishing striped bass in these waters. It is unclear at this time from what source(s) these fish are acquiring the PCBs; the sediments could be an important source. Third, there is concern about the impact of the exposure of fish passing through the Hudson/

Raritan Estuary to sediments and waters of the area containing potentially toxic concentrations of chemical contaminants. A related concern arises when we consider that this estuary serves as a spawning-stock area for fish of the open waters of the Bight and the Atlantic coastal waters of the United States. There may be chronic, early life-stage toxicity associated with these waters and sediments. There is also concern that exposure of these organisms while they are in the estuary may contaminate the open-water fishery.

There is another factor associated with these concerns, and important to the interpretation of the potential toxicity of the Hudson/Raritan Estuary sediments. That is, despite the toxicity of the waters and potential toxicity of the sediments, there is a large fishery supported in these waters. However, there is need to understand the characteristics of the fishery that could exist were it not for the presence of the chemicals that could be acutely or chronically toxic to aquatic life. In making this assessment, the relative significance of the sediments and current discharges as sources of contaminants will be an important issue for developing management approaches.

Procedures

There are several procedures by which the toxicity of sediments has been assessed. One is a short-term screening toxicity test procedure developed and evaluated through the U.S. Army Corps of Engineers (COE) Dredged Material Research Program (DMRP) [7,8]. This procedure began with the elutriation of the sediment —the mixing of typically four parts sediment with one part water for 30 min with vigorous aeration to maintain oxic conditions, followed by one hour quiescent settling. For testing on marine systems, the test organisms, grass shrimp (*Palaemonetes pugio*), were added to the settled sediment water system, and mortality observed for 96 h or longer.

The New York District of the Corps of Engineers (COE) and U.S. EPA Region II use the more comprehensive testing scheme developed by the U.S. EPA and COE [9] in which the sediments are elutriated without controlling the redox condition, and the settled elutriate is separated into three "phases" and tested separately. Tests using three species of organisms were prescribed for each of the three phases: the liquid phase (the supernatant from the settled test after filtration through a 0.45-μ pure-size membrane filter), the suspended particulate phase (the unfiltered supernatant from the settled test), and the solid phase (the settled solids). Toxicity tests are conducted on dilutions 0, 10, 50, and 100%) of the liquid phase and suspended particulate phase using each of three species of organisms. For the liquid phase testing, *Mysidopsis bahia, Skeletonema costatum,* and *Menidia menidia* are tested; for the suspended solid phase, *Acatia tonsa, Mysidopsis bahia,* and *Menidia menidia* are tested. The dilution corresponding to 50% mortality of the test organisms is then computed. For the solid phase testing, a 10-day flow-through test is run on the settled elutriated sediment in which 15 mm of the solid phase is placed atop 30 mm of a reference sediment. The percent survival of the test organisms (P. *pugio, Merceneria merceneria* and Nereis birens) after the 10 days is noted; the survivors are purged (exposed to clean dilution water) for 24 h and analyzed for mercury, cadmium, PCBs, DDT, and petroleum hydrocarbons.

These test procedures have been developed for the assessment of the release of chemical contaminants and the toxicity of the contaminants released after they have been mixed with water. The development of these procedures was prompted by the fact that factors other than the total concentration of chemicals in the sediments control the release of contaminants from them such as the amount of mixing, redox conditions, presence of iron, and so forth [7, 8, 10, 11]. Testing for the toxicity of sediments as they lie in waterways will require modification of the elutriate procedure because of differences in mixing, although considerable mixing of bottom sediment with overlying waters is likely to occur with wind/storm-induced mixing of the water, as well as with ship traffic and the activities of organisms in the sediments.

Results and Discussion

The authors and their associates [8, 11, 12] evaluated the toxicity to grass shrimp and *Daphnia magma* (for freshwater systems) of the elutriates from dredged sediments from about 25 waterways around the United States. Included in this study was the collection of sediment and water from the Perth Amboy Channel and Anchorage in New Jersey, and Bay Ridge Channel in New York for elutriation and toxicity testing using the short-term screening procedure (Fig. 2). As shown in Table 1 the toxicity associated with these sediments was among the highest of the sediments tested with this procedure. Table 1 also shows that the sediments from a number of other waterways also show appreciable toxicity in the elutriate toxicity tests. The first series of tests on the sediments from the Perth Amboy Channel showed such high toxicity that an additional set of samples was collected from this channel for testing. The mortality found after 96-h exposure to the second set of samples, while less than that from the first set, was still as much as 40%; some additional toxicity, up to 50 to 60%, was found with continued exposure (Table 2).

Associated with the toxicity testing on the dredged sediments shown in Table 1, about 30 chemical parameters were measured in the sediments, water, and elutriate for each of the test systems [12]. Table 3 presents the bulk chemical analyses for heavy metals in the New York Harbor sediments evaluated by the authors [8, 12]. Jones

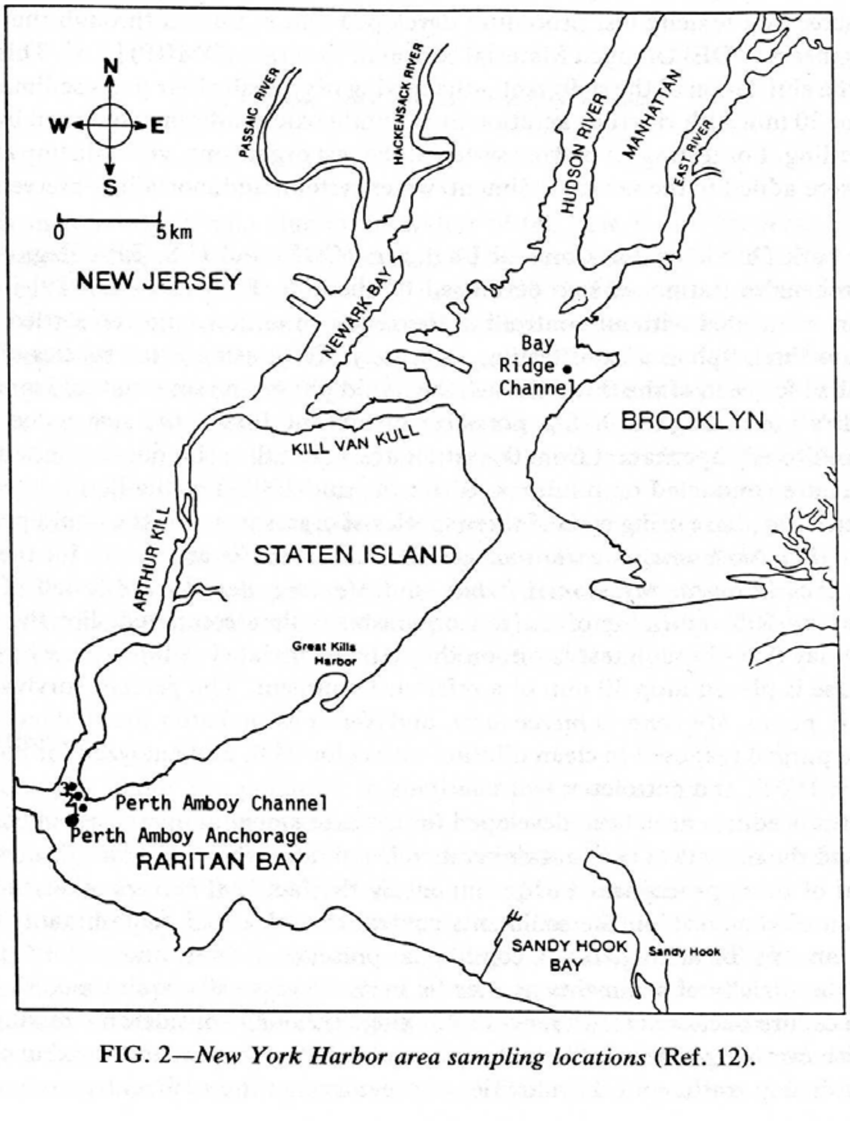

FIG. 2—*New York Harbor area sampling locations* (Ref. 12).

TABLE 1—*Summary of acute toxicity for selected U.S. waterway sediments Ref. (9).*

	Percent Surviving[a] at 96 h—Sediment Percentage					
	5%		10%		20%	
Sediment Location	(A B)[b]	$\bar{X}$	(A B)	$\bar{X}$	(A B)	$\bar{X}$
Mobile Bay, AL		100		...		100
San Francisco Bay, CA						
Rodeo Flats	(90,100)	95	(70,70)	70	(60,80)	70
Mare Island	(100,90)	95	(80,90)	85	(80,80)	80
Oakland Inner Harbor		100		...		100
Los Angeles Harbor, CA						
Buoy A-7 (Site 1)	(70,80)	75		...	(40,...)	40
Buoy C-2 (Site 2)	(90,100)	95		...	(90,100)	95
Bridgeport, CT	(80,70)	75	(50,40)	45		...
Norwalk River, CT						
North Site		100		...		100
South Site		100		...	(90,90)	90
Stamford, CT						
West Branch		100		...	(90,100)	95
Apalachicola, FL						
Site 1		100		...	(80,100)	90
Site 5	(90,90)	90		...	(80,80)	80
Menominee River, MI		100		...	(40,30)	35
Upper Mississippi River, St. Paul, MN		100		...		100
Hudson River, NY						
Foundry Cove—*P. pugio*		...		...	(100,90)	95
—*D. magna*		...		...	(90,80)	85
New York-New Jersey Harbors						
Perth Amboy Anchorage	(80,70)	75		...	(80,70)	75
Perth Amboy Channel	(60,80)	70		...	(40,40)	40
Bay Ridge Channel	(100,50)	75		...	(100,90)	95
Perth Amboy Channel—Site 1		...		...	(90,80,90)	87
—Site 2		...		...	(60,60,60)	60
—Site 3		...		...	(80,80,90)	83
Ashtabula Harbor, Lake Erie, OH	Reproduction occurred		Reproduction occurred			100
Newport, RI						
Offshore		100		...		100
Corpus Christi, TX						
Site 3	(90,80)	85	(80,100)	90	(90,90)	90
Houston Ship Channel, TX						
Site 2		100		...	(90,90)	90
Site 3		100		...		100
Morgan's Point, TX	(90,90)	90	(80,80)	80	(70,60)	65
Port Lavaca, TX		100		100		100
Galveston Bay Entrance Channel, TX						
Buoy 1	(90,90)	90		100	(90,80)	85
Buoy 9		...		100		...
Buoy 11		100		100	(90,90)	90
Texas City Channel, TX						
Site 1		100		100		80
Site 2	(90,90)	90	(90,90)	90	(80,80)	80
Site 3	(90,90)	90	(90,90)	90	(80,80)	80
Site 4	(80,100)	90	(90,70)	80	(90,80)	85
Site 5		100		100		100
Site 6		100		100	(90,100)	95
Bailey Creek, VA (4/76)		100		...	(80,100)	90

TABLE 1—*(Continued).*

Sediment Location	Percent Surviving[a] at 96 h—Sediment Percentage					
	5%		10%		20%	
	(A B)[b]	$\bar{X}$	(A B)	$\bar{X}$	(A B)	$\bar{X}$
Bailey Creek, VA (7/76)	(80,60)	70		...	(80,100)	90
James River, VA	(90,60)	75		...	(80,100)	90
Near Windmill Point dredge discharge		...		...		100
Duwamish River, Seattle, WA	(100,90)	95		...		100

[a]Freshwater—*Daphnia magna*, Marine water—*Palaemonetes pugio*.
[b]A and B are replicate bioassays.

TABLE 2—*Response of* P. pugio *to Perth Amboy Channel elutriates as a function of time (Ref. 12).*

Time, hr	Number of *P. pugio* Living											
	Controls			Site 1			Site 2			Site 3		
	A	B	C	A	B	C	A	B	C	A	B	C
0	10	10	10	10	10	10	10	10	10	10	10	10
12	10	10	10	10	10	10	10	10	10	10	10	10
24	10	10	10	10	10	10	10	10	10	10	10	10
36	10	10	10	10	10	10	10	10	10	10	10	10
48	10	10	10	10	10	10	10	9	10	10	10	10
60	10	10	10	10	10	10	9	9	8	10	10	10
72	10	10	10	9	8	10	9	8	7	9	10	10
84	10	10	10	9	8	10	7	8	6	9	10	10
96	10	10	10	8	8	9	6	6	6	9	8	9
120	10	10	10	8	8	9	6	6	6	9	8	9
144	10	10	10	8	8	9	6	6	6	9	8	9
168	10	10	10	8	8	9	6	6	6	9	8	8
192	10	10	10	8	8	9	5	6	6	9	8	8
216	10	10	10	8	7	8	5	6	5	9	8	8
240	10	10	10	7	7	8	5	6	5	8	8	8
264	10	10	10	7	7	8	5	6	5	8	8	8
288	10	10	10	7	7	8	5	6	5	8	7	8
312	10	10	10	7	7	8	5	6	5	8	7	8
336	10	10	10	7	7	8	5	5	5	8	7	8
360	10	10	10	7	7	8	5	5	5	8	7	8
384	9	10	10	7	7	8	5	5	4	8	7	8

NOTE: Organisms were fed after 96-h exposure time with live *Artemia nauplii*. All bioassays used 20% sediment of total elutriate volume. A, B, and C are replicates.

et al. [11] calculated that if all of the contaminants present in dredged sediments were available to affect the organisms in the toxicity tests, the mortality would have been considerably higher. There was no realistic relationship between the sediment concentration of the various heavy metals and chlorinated hydrocarbon pesticides measured and the mortality found in the elutriate toxicity tests for the more than 250 elutriate tests run during the study on sediments from about 25 locations around the United States. This is an important conclusion because it means that bulk chemical analysis of sediment is not a reliable indication of the potential impacts of

TABLE 3—*Heavy metal concentration: New York Harbor Area sediments (concentrations in mg/kg)* [2].

Sample Designation	Manganese		Cadmium		Chromium		Zinc		Nickel		Lead		Copper		Iron[a]		Mercury		Arsenic	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Perth Amboy Channel	99	72[a]	1.7	0.6	18	17	140	127	11.6	9.1	8.9	0.3	380	39	14	5	3.44	0	15.1	12.6
Perth Amboy Anchorage	245	111	3.3	2.5	69	33	97	94	30	20	84	67	487	102	15	7	4.77	0.18	57.5	17.9
Bay Ridge Channel	183	126	6.9	3.4	3.2	2.9[a]	103	95	2.5	0.7	48	67	257	128	16	10	2.21	0.07	<5	0

NOTE: Mean and standard deviation calculated from triplicate analyses, except for mercury and arsenic, which were calculated from duplicate analyses.

[a] g/kg

the sediments on water quality and aquatic life.

Elutriate toxicity testing as prescribed by the U.S. EPA/ COE [9] is required as part of the permit application process for dredging with open water disposal in the New York Bight; recently the requirement for liquid phase toxicity testing was rescinded [13]. Suszkowski and Mansky [14] summarized the data on the toxicity shown in these tests; these summaries are shown in Figs. 3 and 4. The summaries of the tests on the suspended particulate phase (unfiltered elutriate, Fig. 3) and the liquid phase (filtered elutriate, Fig. 4) show that there is a substantial proportion of the area sediments tested in which 50% kill is effected by a few percent of the elutriate. The interpretation of these results in terms of their implications for the suitability of these sediments for open water disposal may be different from their interpretation in terms of the potential toxicity of these sediments as they lie in the waterway, undredged.

The data from the records of public hearings concerning dredging of particular locations under the jurisdiction of the New York District of the COE were examined by the authors for information concerning the toxicity of specific waterway sediments. The test results for five sites, Passaic River, a site off Staten Island, two sites in the Hudson River, and Sandy Hook Bay are presented in Table 4. The COE has its own procedure for evaluating the toxicity data relative to its assessment of the potential impact of the sediments on disposal-site water quality. Neither that assessment procedure nor the results of that assessment was the subject of the authors' review of the data; rather the data were examined to glean information about the potential for the sediments in the area to cause

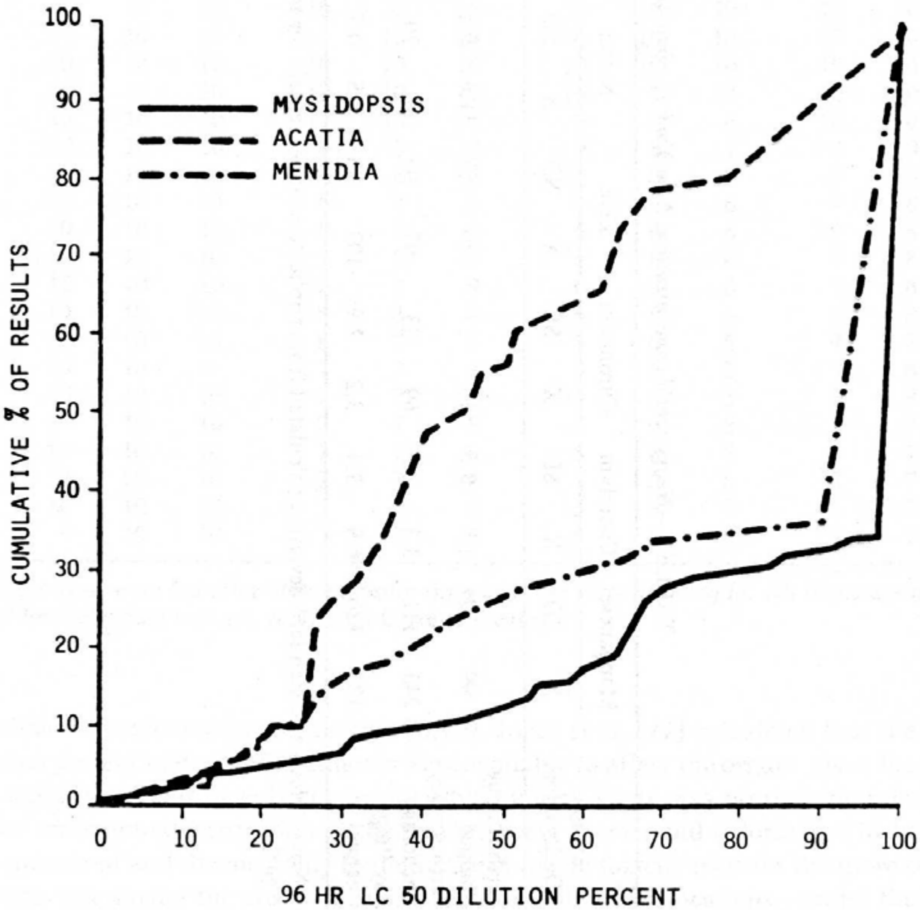

FIG. 3—*Results for suspended particulate phase bioassays after Suszkowski and Mansky* (Ref. 14).

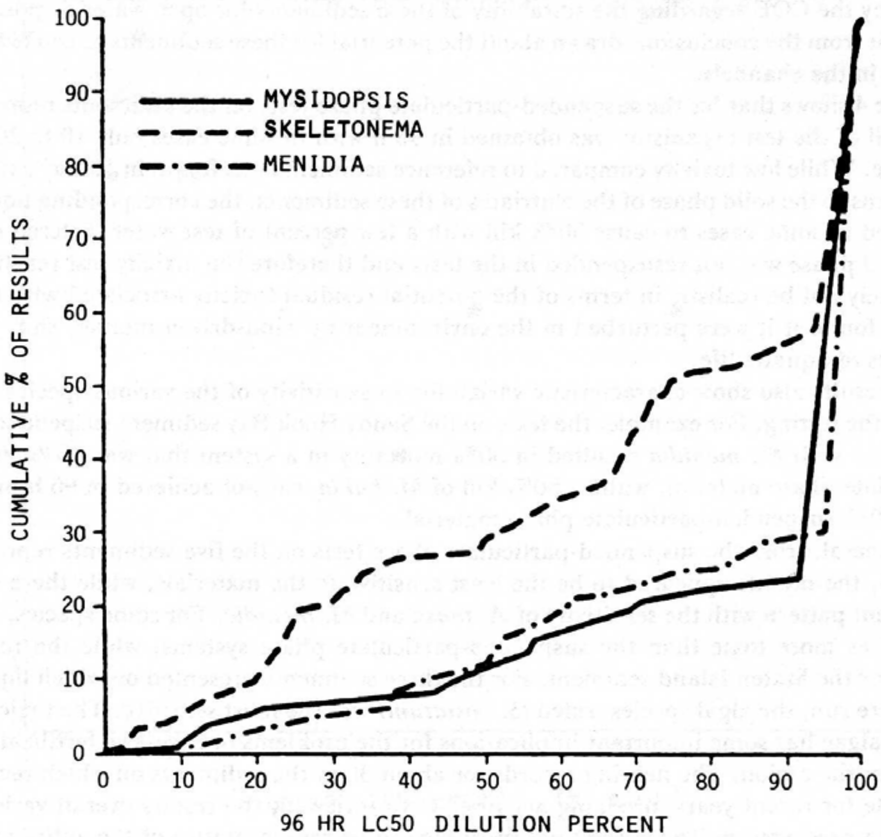

FIG. 4—*Results for liquid phase bioassays after Suszkowski and Mansky* (Ref. 14).

TABLE 4—*Examples of sediment toxicity data—Corps of Engineers.*

	Passaic River	Staten Island	Hudson River	Hudson River	Sandy Hook Bay
	Suspended Particulate 96-h LC50, % Dilution				
A. tonsa	32	32	17	8	60
M. bahia	100	53	28	33	>100
M. menidia	32	44	12	28	35
	Solid Phase (% Survival)				
P. pugio	94	94	92	92	93
M. mercenaria	98	100	98	94	98
N. virens	95	95	96	89	96
	Liquid Phase (96-h EC50/LC50), % Dilution				
S. costatum	...	15	...	2	14
M. bahia	...	>100	...	33	>100
M. menidia	...	>100	...	28	35

Note: (...) = test not conducted

toxicity in the waterway. Therefore the conclusions drawn by the COE regarding the suitability of these sediments for open water disposal may be different from the conclusions drawn about the potential for these sediments to cause toxicity as they lie in the channels.

Table 4 shows that for the suspended-particulate phase tests on the sediments represented, a 50% kill of the test organisms was obtained in 96 h with in some cases only 10 to 20% of the elutriate. While low toxicity compared to reference sediments was found in 10-day exposures of organisms to the solid phase of the elutriates of these sediments, the corresponding liquid phase appeared in some cases to cause 50% kill with a few percent of test water (filtered elutriate). The solid phase was not resuspended in the tests and therefore the toxicity test results for that phase may not be realistic in terms of the potential residual toxicity associated with them that may be found if it were perturbed in the environment by wind-driven mixing, ship traffic or activities of aquatic life.

The results also show characteristic site variability insensitivity of the various species of organisms in the testing. For example, the tests on the Sandy Hook Bay sediment suspended-particulate phase with *M. menidia* resulted in 50% mortality in a system that was 35% suspended-particulate phase material, while a 50% kill of *M. bahia* was not achieved in 96 h in a system with 100% suspended-particulate phase material.

In general, from the suspended-particulate phase tests on the five sediments represented in Table 4, the mysids appeared to be the least sensitive to the materials. while there was not a consistent pattern with the sensitivity of *A. tonsa* and *M. menidia.* For some species, the liquid phase was more toxic than the suspended-particulate phase systems, while the reverse was found for the Staten Island sediment. For the three sediments presented on which liquid phase tests were run, the algal species tested (*S. costatum*) was the most sensitive. The toxicity potential for algae has some important implications for the problems of excessive fertilization of the waters of the region. The hearing records for about 30 of the sediments on which records were available for recent years' dredging activities were reviewed; the results overall varied highly. The data presented in Table 4 are not presumed to be representative of the entire region. but rather were selected to illustrate the types of information found.

It is apparent from the bulk sediment analyses of the Perth Amboy and Bay Ridge sediments shown in Table 3 (as well as the other sediments evaluated by the authors and their associates [8, 11, 12]) that there was no relationship between the bulk concentrations of heavy metals, chlorinated hydrocarbon pesticides, or other parameters measured and the toxicity found in elutriate toxicity tests. They also found that of all the chemical contaminants measured in the sediments and elutriate, only ammonia was released in the elutriate test in potentially significant amounts. The heavy metals and other potentially toxic constituents measured were not released in amounts that would be expected to be toxic. These test results were in keeping with the finding that these constituents were also not released during actual dredged sediment disposal operations monitored during their study in conjunction with the elutriate testing.

Because ammonia was released, the mortality found in the New York/ New Jersey elutriate toxicity tests was plotted as a function of the un-ionized ammonia concentration found in each of the respective elutriate tests. The relationship that emerged is presented in Fig. 5. This figure clearly shows that there is a decrease in the survival of the test organisms after 96-h exposure with an increasing concentration of un-ionized ammonia measured in the test system. Further, the concentration of un-ionized ammonia found in those systems in which the 96-h survival was about 50% was on the order of 0.3 to 0.5 mg N/L. While there are few published data on the toxicity of ammonia to grass shrimp, work under way at the U.S. EPA Narragansett Laboratory indicates that the 96-h LC50 for grass shrimp exposed to ammonia is on the order of a few tenths of a mg/L as NH_3.[3] Hall et al. [15] indicated that the 96-h LC50 of ammonia for grass shrimp was < 0.97 mg/L. While these results are not conclusive, the toxicity exhibited by the Perth Amboy and Bay Ridge sediments may be due to the release of ammonia, with little or no effect of the myriad other potentially toxic chemicals in the sediments.

[3] Hanson, D., U.S. EPA Narragansett. Laboratory, personal communication to G. Fred Lee, 1986.

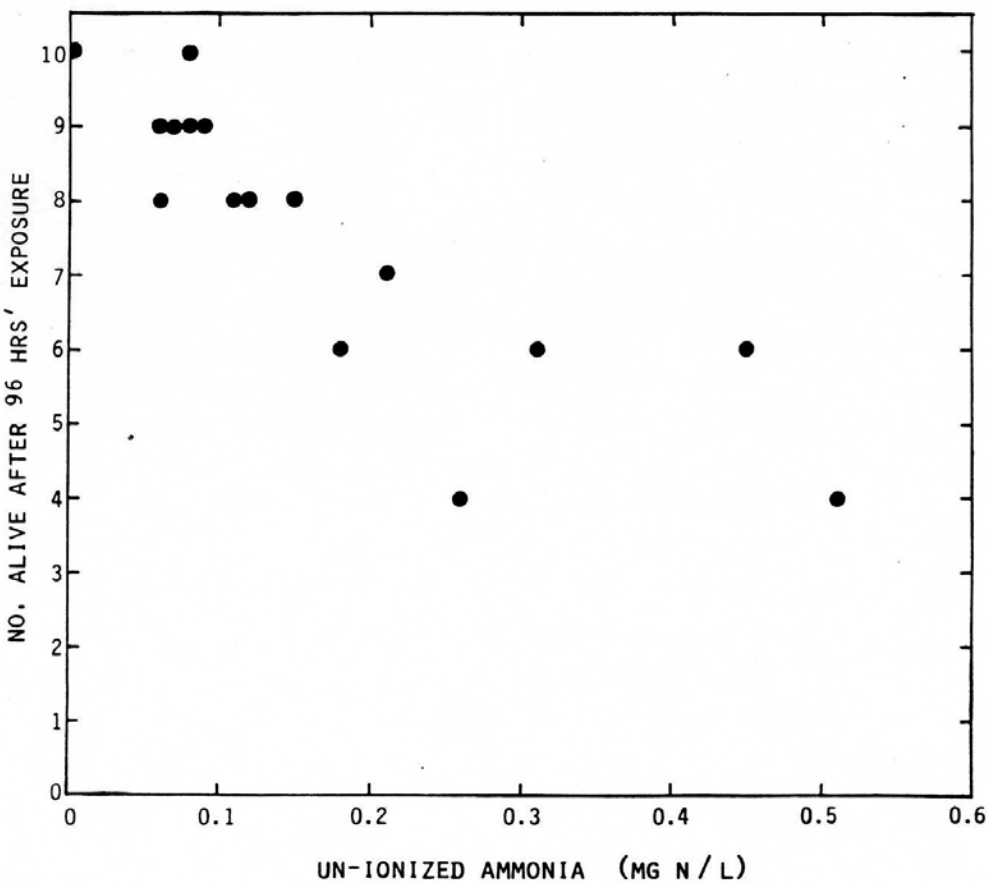

FIG. 5—*Survival of grass shrimp in elutriate toxicity tests as a function of elutriate ammonia concentration—New York Harbor sediments (Source of data* (Ref. 12)*).*

Implications for Water Quality Management

The results of this investigation have some important implications for the management of toxicity in aquatic systems. First, the sediments of many U.S. waterways show toxicity to aquatic life in elutriate toxicity tests. Under certain conditions associated with storms, ship passage, and so forth in which sediments are mixed into the water-column, there is the potential for acute toxicity to aquatic life. Of greatest concern is the ammonia released from the sediments under conditions of vigorous mixing of the sediments with the overlying waters. However, it should be noted the conditions of the tests conducted by the authors as well as by the COE New York District reported herein use a l:4 mixture of sediments with water under a confined, 4-day continuous-exposure situation. These test conditions are designed to mimic the worst-case conditions that could occur during open-water disposal of hydraulically dredged sediments, rather than the toxicity of the sediments as they lie in a waterway. It is unlikely that conditions of this type would prevail for substantial amounts of time in significant parts of any waterway following a storm or other event which would stir the sediments into the overlying water. Furthermore, as discussed by the authors [8], these conditions are not likely to exist in open water dumping of hydraulically or mechanically dredged sediments because of the rapid dilution that occurs.

Dredged sediment disposal operations that involve the open water pipeline disposal of hydraulically dredged sediments may result in somewhat longer exposure of water-column organisms to contaminants released inasmuch as material is typically discharged in one location for several hours or more before the point of discharge is moved. For most chemical contaminants that could be released, principally ammonia, the dilution that would occur at the point of discharge would likely preclude the exposure of water-column organisms for sufficient durations to be adversely affected. However, for open-water pipeline disposal operations, there is a possibility of low dissolved-oxygen conditions existing long enough to be adverse to some forms of aquatic life that could not escape the vicinity of the discharge.

On the other hand, it is conceivable that the overflow from a so-called on-land "confined" disposal site for dredged sediments could be toxic to aquatic life in the vicinity of the area in which the confined disposal overflow enters the water. In this type of operation, the discharge is typically continuous and extended. Therefore, there could be significant toxicity to organisms that remain in the area of the discharge. Again, the most likely candidate for causing such toxicity would be the ammonia released from the sediments; there may also be problems of low dissolved oxygen in the area of the discharge as well. It is important in any evaluation of the potential toxicity of dredged sediment to consider the mixing that occurs between the discharge waters and the waters receiving the discharge.

While there is normally little potential for acute or chronic toxicity to water-column aquatic organisms associated with open water disposal of dredged sediments because of the dilution associated with the disposal operations and the dilution of any contaminants released from the redeposited sediments in the overlying waters, there is a potential for acute and chronic toxicity to epibenthic and especially benthic organisms that recolonize the redeposited dredged sediments. Site-specific studies would have to be conducted to determine if this was of importance at a particular location.

It appears that there is limited potential for acute aquatic-life toxicity associated with storms because of their duration and the dilution that would be readily available for the ammonia or other contaminants released during the storm. However, it is likely that there could be toxicity at the sediment/water interface. While there may be acute toxicity in this area, it is more likely to be a chronic impact on benthic or epibenthic organisms. Toxicity tests are needed to provide insight into the potential chronic toxicity of the sediments, such as modifications of the embryo-larval tests developed by Birge, Black, and coworkers [16]. The significance of this potential toxicity to aquatic life-related beneficial uses of waterways is an area that needs investigation. It is possible that this potential for toxicity is not manifested to a significant extent. This is because of the relatively limited flux of contaminants such as ammonia from the sediments to the waters immediately above the sediments as compared to the rate at which these waters mix with overlying waters. It is likely that under most situations the water-column mixing, even down to the sediment/water interface, is sufficient to preclude any significant amount of aquatic-life toxicity, even at the sediment/water interface. This is especially true in estuarine systems because of tide-induced currents.

Laboratory tests have significant limitations in mimicking crucial aspects of field conditions such as the mixing of the sediments with overlying waters at the sediment/water interface, and the amount and rate of dilution that occurs with the overlying waters at the site. It appears that caged-organism studies in areas in which laboratory tests of the type discussed herein show appreciable toxicity to aquatic life should be conducted to ascertain whether the toxicity manifested in laboratory elutriate toxicity tests actually occurs in the field. The key to translating laboratory results to field situations is gaining an understanding of the degree of mixing that occurs between the interstitial waters and the waters at the sediment/water interface, as well as the mixing of the sediment/water interface waters with the overlying waters. Lee [10] discussed the role of mixing in influencing how contaminants in sediments impact overlying water quality.

It is also unclear how the results of the type of testing of toxicity in sediments discussed in this paper relate to toxicity to truly benthic organisms, that is, those living within the sediments.

Since ammonia is likely to be the principal toxicant of concern. and since significantly elevated concentrations of ammonia can be derived from natural sources because of the conversion of organic nitrogen to ammonia in the sediments, it is likely that many truly benthic organisms have evolved to tolerate elevated concentrations of ammonia. It may be that even in highly contaminated systems, such as those found in the Hudson/Raritan Estuary sediments, the toxicity of the sediments is caused by ammonia from "natural"sources such as the mineralization of algae. This would have significant implications for the management of sediment toxicity and the control of potential sources of chemical contaminants in the sediments. It is unlikely that ammonia discharged from municipal or industrial sources contributes to the significantly elevated levels of ammonia in the sediments. Ammonia in general shows relatively low affinity for sediments and therefore would not be derived directly from the water-column. Instead, it would arise from the mineralization of particulate organic nitrogen discharges or of algae and other organisms whose remains accumulate within the sediments. It would be of interest to examine the relationship between the trophic state of water-bodies, that is, algal biomass development, and the toxicity of the sediments to aquatic life in an elutriate toxicity test. It is possible that the areal loading of aquatic plant nutrients (nitrogen and phosphorus) to a water-body could play a major role in the sediment-associated toxicity in screening elutriate toxicity tests. This could be another consequence of the excessive fertilization of a water bodv.

The Hudson/Raritan Estuary is somewhat unique compared to many other water-bodies because of the large amounts of raw sewage that are still being discharged to these waters at this time. According to the NY DEC [3] in the summer of 1985 more than 200 mgd of raw sewage were discharged to the Hudson River Estuary from the city of New York. The city of New York is developing treatment works to provide primary treatment for its domestic wastewaters; during the past winter it has reduced the amount of raw sewage discharged directly to the Hudson/Raritan system about 100 mgd. NY DEC [3] also indicated that there is in excess of 500 mgd of combined sewer overflows to the Hudson/Raritan Estuary from New York and New Jersey sources. The raw sewage and CSOs added to this estuary would be expected to contribute large amounts of particulate organic nitrogen, which would be mineralized to ammonia in the sediments. The potential role of this organic nitrogen in contributing to the elevated elutriate test toxicity found for the Hudson/Raritan sediments as compared to the toxicity found for other U.S. waterway sediments is unknown, but is likely to be significant.

The U.S. EPA criteria and standards branch is attempting to develop sediment-based criteria.[4] The basic approach being used is to attempt to relate the concentrations of contaminants in sediments to water-quality impacts. According to Zarba,[4]attempts are being made to normalize these concentrations based on various factors such as organic carbon and so forth. Based on the work done by the authors and others on the relationships between bulk chemical analysis of sediments with or without normalization, the release of contaminants from sediments under various conditions, and the toxicity associated with the elutriates of the sediment, such criteria will have limited utility in predicting the potential impacts of contaminants present in sediments on the beneficial uses of a particular water-body.

Another area that needs attention in any water pollution control program directed toward control of toxicity in sediments is the relationship between sediment toxicity to a particular organism as measured in a particular test and the significance of this toxicity in affecting the beneficial uses of the overlying waters for propagation of fish and other aquatic life of interest to the public. It is possible that a sediment in a particular test may show appreciable toxicity to a particular organism, yet in field conditions there may be little or no adverse impact on the aquatic life-related beneficial uses of the water-body. The relationship between sediment toxicity as measured in a certain type of test and the impairment of beneficial uses of interest to the public, such as the amount of harvestable fish, shellfish, and other aquatic organisms, is an area that should receive a high priority

[4]Zarha, C., U.S. EPA, Washington. DC, personal communication and discussions at Pellston Conference, "The Role of Suspended and Settled Sediments in Regulating the Fate and Effects of Chemicals in the Aquatic Environment," Florissant, CO, August 1984.

for research funding. Any attempts to use sediment-based criteria for developing water pollution control programs must be considered highly speculative in terms of predicting the benefits that may be derived from limiting the discharge of contaminants from a particular source or sources that became associated with the sediments.

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