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Newark Bay Study Area
NBSA-00083

and Hunter, 1973; 1979). Metal accumulation in sediments has been linked to specific local sources such as discharges from smelters (Cu, Pb and Ni), metal-based industries (e.g., Zn, Cr and Cd from electroplating), paint and dye formulators (Cd, Cr, Cu, Pb, Hg, Se and Zn), petroleum refineries (As and Pb), as well as effluents from chemical manufacturing plants (Williams et al., 1978; Forstner, 1990). In Newark Bay, New Jersey, numerous studies have associated these sources and others such as municipal wastewater and treatment plant effluents, dustfall, precipitation, urban runoff, combined sewer outfalls and emissions from automobiles and other combustion sources with the presence of metals in sediments and biota (Mytelka et al., 1973; Whipple et al., 1976; Wilber and Hunter, 1973; 1979; Meyerson et al., 1981; NOAA, 1982; NRC, 1989; Granier et al., 1990; USEPA, 1992).

Newark Bay is an enclosed estuary located in the heavily industrialized and densely populated New York City, New York/Newark, New Jersey metropolitan area. Port Newark and Port Elizabeth, located along the western bank, are two of the largest shipping ports in the world (Meyerson et al., 1981). Newark Bay is included within the New York/New Jersey (NY/NJ) Harbor Estuary, which has been cited as one of the most chemically polluted estuaries in the United States (NOAA, 1984a,b; NOAA, 1988). Numerous studies examining the distributions of heavy metals in surficial sediments have been conducted in the Passaic River, Hackensack River, Newark Bay, the Arthur Kill and the Kill van Kull (Suszkowski, 1978; Meyerson et al., 1981; USEPA, 1982; NOAA, 1984a,b; Goeller, 1989; HMDC, 1989). Elevated concentrations of several metals have been found in the edible tissues of striped bass, bluefish, winter flounder, white perch, American eel, blue crab and lobster (Ellis et al., 1980; Sabounjian and Galluzzi, 1980; O'Connor and Moese, 1984; Santoro and Koepp, 1986; HMDC, 1989).

The present study was undertaken as a screening-level assessment to determine the range of trace metal concentrations in surficial sediments and to examine the potential hazard to aquatic biota resulting from exposure to these compounds. The concentrations of As, Cd, Cu, Hg, Ni, Pb, Zn and 16 other trace elements were determined in surficial sediments collected from the Passaic River and other tributaries of Newark Bay and from two areas within the Hackensack Meadowlands. The concentrations of metals designated by the U.S. Environmental Protection Agency (USEPA) as toxic to aquatic biota (USEPA, 1989), including As, Cd, Cu, Hg, Ni, Pb and Zn, were compared to results reported in previous investigations. The potential for adverse effects to fish and shellfish was evaluated based on comparisons to available benchmark sediment quality criteria and toxicity guidelines. In the absence of sediment criteria specific to New Jersey waterways, sampling results were compared to values derived from several proposed approaches. Sediment management guidelines proposed by the Ontario Ministry of the Environment using the Screening Level Concentration (SLC) approach (Persaud et al., 1991), Washington State Marine Sediment Quality Standards derived for Puget Sound using a combination of the Apparent Effects Threshold (AET) and Equilibrium Partitioning (EqP) methodologies (WADOE, 1991) and preliminary values developed by the California State Water Resources Control Board (CSWRCB, 1990) based on the AET approach were used for comparative purposes. Sampling results also were compared to median- and lowest-observed sediment toxic effect values derived by the National Oceanic and Atmospheric Administration (NOAA) from a compilation of the results of acute and chronic bioassays in several aquatic species (NOAA, 1991). Although many of these values are considered site-specific and are not intended for use as regulatory guidelines, they provide useful benchmarks for assessing the potential toxicity of contaminated sediments.

2. Methods

Eighteen surficial sediment samples were collected in February, 1990 at locations where deposition and accumulation of sediments were visually evident (Fig. 1). Sampling locations included eleven sites along the Passaic River and two sites in the Hackensack River. Five sites were located in

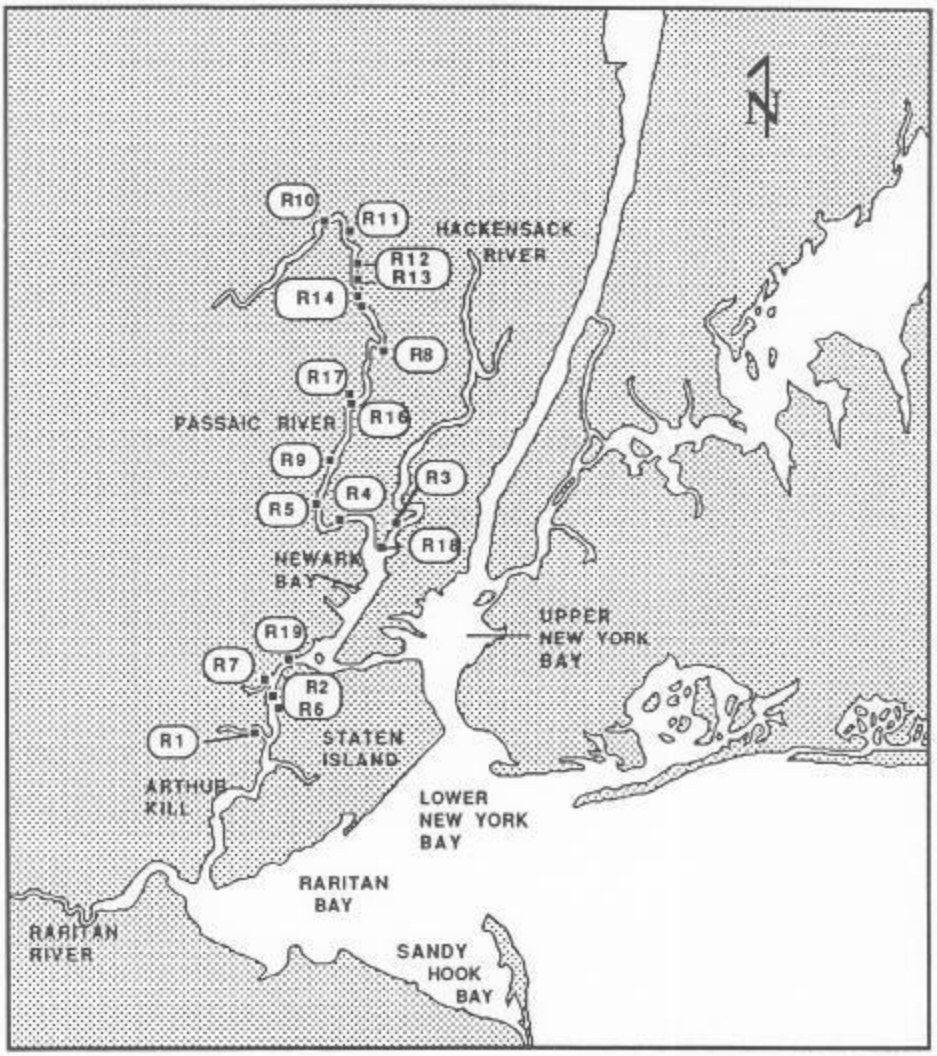


Fig. 1. Location of surficial sediment samples within the Passaic River, Hackensack River, and the Arthur Kill

the Arthur Kill, the Elizabeth River and the Rahway River. Sediments at each location were collected using a petite Ponar Grab sampler. Samples were taken from the center of each grab sample using an acid-cleaned stainless steel scoop and transferred to precleaned, amber glass containers. Samples were stored at 4°C until laboratory analysis.

In October and November of 1991, 35 additional surface sediment samples were collected from two wetland areas located along the western bank of the Hackensack River. Specifically, 27 samples were collected from the Hackensack Meadowlands (Area I), located near the western spur of the New Jersey Turnpike and bounded by the Belleville Turnpike and the AmTrak railway (Fig. 2). An additional eight samples were collected from a marsh area (Area II) located east of the New Jersey Turn-

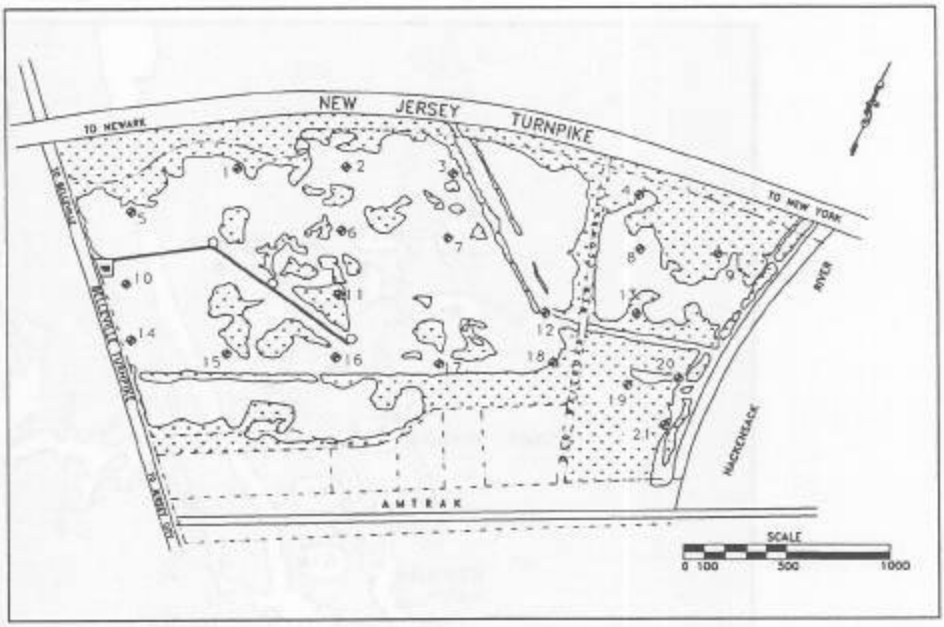


Fig. 2. Sampling locations in Area I.

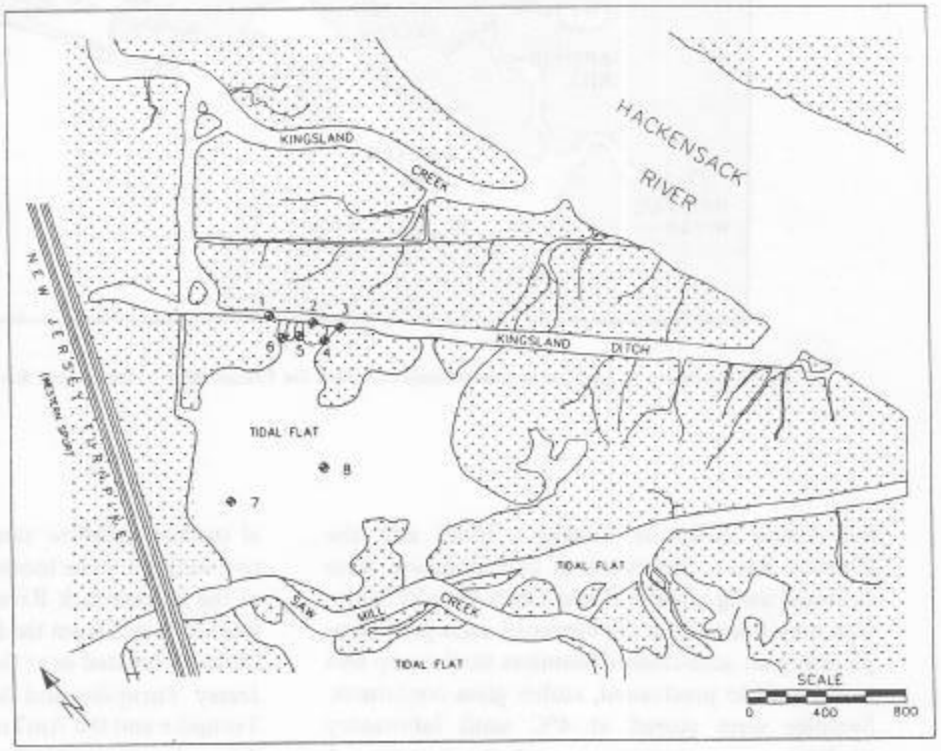


Fig. 3. Sample locations in Area II.

pike Western spur near Kingsland Creek (Fig. 3). Both Areas I and II were determined to have relatively few direct industrial discharges and were selected to evaluate metal levels resulting primarily from runoff and other non-point sources. Sediments were collected at each location using a Lamont dredge. Samples were transferred to precleaned, teflon-lined glass containers and stored at 4°C until laboratory analysis.

Surficial sediments were acid-digested and analyzed for Al, As, An, Ba, Be, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Se, Si, Th, V and Zn by Twin City Testing Corporation (St. Paul, MN) using graphite furnace atomic adsorption spectroscopy in accordance with USEPA Methods 6010, 2040, 7060, 7740 and 7840 (USEPA, 1986). Mercury concentrations were determined using a manual cold vapor technique in accordance with USEPA Method 245.5 (USEPA, 1983). Cyanide concentrations were determined spectrophotometrically in accordance with USEPA Method 335.2 (USEPA, 1983). Surficial sediments collected from Hackensack Meadowland Areas I and II were analyzed by Accutest Laboratory (Dayton, Hew Jersey) for Ca, Cu, K, Mg and Na in accordance with ICP protocols and for Pb using graphite furnace atomic adsorption spectroscopy in accordance with USEPA Method 6010. The limits of detection for all trace metal analyses ranged from 0.1 to 5.0 mg/kg (dry weight basis).

3. Results

3.1. Trace metal concentration

The concentrations of trace metals measured in surficial sediments are summarized in Table 1. In general, metal levels were highest in the Arthur Kill, followed by the Passaic River and the Hackensack River. Sediments collected from the tidal portions of the Passaic River below the Dundee Dam (sampling stations R4, R5, R8, R9, R16 and R17) contained higher metal concentrations than sediments collected from sites above the Dundee Dam (R10–R14). The highest Cd concentrations were measured in the Ironbound section of the Passaic River, a heavily industrialized area located in Newark, New Jersey below the Jackson Street bridge (R5; 29 mg/kg and R4; 14 mg/kg) and in the Arthur Kill on the northwest side of Prall's Island (R6; 15 mg/kg). The highest Cu concentrations were found in the Passaic River upstream of two paint formulating plants (R5; 760 mg/kg) and at the confluence of the Arthur Kill and Morses Creek (R7; 750 mg/kg) in an area adjacent to several petroleum refineries. The highest Pb concentrations were found in the Arthur Kill (R7; 2500 mg/kg) and the Passaic River just below the hydroelectric station at the Dundee Dam (R14; 910 mg/kg) and below the Jackson Street bridge (R5; 800 mg/kg). The highest Hg concentrations were measured in the Passaic River (R5; 9.8 mg/kg), the Arthur Kill (R1; 6.2 mg/kg), and the Hackensack River (R3; 4.4 mg/kg). The highest Ni and Zn concentrations were measured in the Passaic River (R5 and R4) and in the Rahway River (R1). The highest sediment concentrations of As were found in the Rahway River adjacent to a chemical manufacturing plant (R1; 58 mg/kg) located near the confluence with the Arthur Kill and in the Hackensack River adjacent to a coal-fired power plant (R3; 49 mg/kg). Arsenic concentrations in the Passaic River ranged from 1.9 to 33 mg/kg, with the highest concentrations measured at the confluences with the Third River (R17; 33 mg/kg) and Goffle Brook (R10; 25 mg/kg).

Trace metal concentrations measured in surficial sediments collected from the Hackensack Meadowlands are presented in Table 2. Copper concentrations in Area I ranged from 37 to 283 mg/kg, with a mean concentration of 116 mg/kg; Pb concentrations ranged from 121 to 704 mg/kg, with a mean concentration of 275 mg/kg. In Area II, Pb and Cu concentrations were substantially lower; Pb levels ranged from 25 to 130 mg/kg, with a mean concentration of 58 mg/kg and Cu concentrations ranged from 17 to 100 mg/kg, with a mean concentration of 42 mg/kg. Sediment concentrations of Ca, K, Mg and Na did not differ significantly between the two wetland areas, but were higher than those found in the Passaic River, Hackensack River and Arthur Kill.

3.2. Hazard assessment

To quantify the relative hazard to aquatic biota posed by the presence of As, Cd, Cu, Hg, Ni, Pb and Zn in surficial sediments, hazard indices were calculated by dividing the mean concentrations

Table 1
Concentrations (mg/kg, dry wt.) of trace metal in surficial sediments collected from the Passaic River, Hackensack River and Arthur Kill

Sample Location	Al	At	As	Ba	Be	Cd	Ca	Co	Cr	Cy	Fe
Passaic River											
R4	14 000	[0.2][a]	7.5	150	0.75	14	5 100	13	270	0.29	19 000
R5	18 000	[0.2]	14	240	0.88	29	6 600	38	760	1.1	20 000
R8	9 300	[0.2]	5	170	0.71	9.1	5 100	11	110	0.46	16 000
R9	8 800	[0.2]	8.2	160	[0.5]	8.9	6 500	8.7	190	0.52	13 000
R10	3 800	[5.0]	25	45	[0.5]	5.6	3 500	8.7	70	[0.2]	21 000
R11	2 500	[5.0]	7.3	23	[0.5]	1.6	3 900	3.6	22	[0.2]	6 500
R12	4 800	[0.5]	13	35	[0.5]	2.5	2 200	7.2	42	[0.2]	9 000
R13	4 200	[5.0]	11	33	[0.5]	2.2	1 800	6.2	22	[0.2]	8 400
R14	5 200	[0.2]	1.9	80	[0.5]	5.5	6 300	8.6	82	0.29	14 000
R16	14 000	[0.2]	9.8	220	0.7	11	5 400	12	170	0.4	16 000
R17	11 000	[5.0]	33	180	0.8	8	4 300	9.3	190	[0.2]	16 000
Median	8 800	—	10	150	0.50	8.0	5 100	8.7	110	0.43	16 000
Mean + S.D.	8 691 ± 5 084	—	12 ± 9	121 ± 80	0.62 ± 0.15	9 ± 8	4 609 ± 1 644	11 ± 9	175 ± 210	0.37 ± 0.3	14 445 ± 4 831
Hackensack River											
R3	14 000	[5.0]	49	130	1	8.8	9 000	14	200	[0.2]	20 000
R18	990	[0.2]	10	95	0.59	9.1	2 500	11	190	0.27	15 000

Table 1 (*continued*)

Sample Location	Al	At	As	Ba	Be	Cd	Ca	Co	Cu	Cn	Fe
Arthur Kill											
R1	15 000	[0.5]	58	180	1.1	11	4 600	14	400	2.9	21 000
R2	13 000	[0.2]	1.4	40	0.71	12	1 700	16	86	[0.1]	27 000
R6	1 700	[0.2]	23	250	1	15	7 200	16	430	0.44	25 000
R7	8 400	[0.2]	29	190	0.52	8.1	2 100	10	750	0.38	15 000
R19	1 300	[0.2]	8.5	140	0.7	12	5 600	12	290	1.5	18 000
Median	8 400	—	23	180	0.71	12	4 600	14	400	0.97	21 000
Mean ± S.D.	7 880 ± 6 298	—	24 ± 22	160 ± 78	0.81 ± 0.24	12 ± 2	4 240 ± 2 333	14 ± 3	391 ± 242	1.3 ± 1.2	21 200 ± 4 919
All waterways											
Median	8 600	—	11	145	0.73	9.0	4 850	11	190	0.44	16 000
Mean ± S.D.	8 333 ± 5 454	—	17 ± 16	131 ± 75	0.79 ± 0.17	10 ± 6	4 633 ± 2 075	12 ± 7	237 ± 222	0.78 ± 0.8	16 661 ± 5 429

	Pb	Mn	Mg	Hg	Ni	K	Se	Si	Na	Th	Vn	Zn
Passaic River												
R4	320	330	5 800	2.2	38	2 000	[1.5]	5.4	2 900	0.25	29	560
R5	800	250	5 400	9.8	230	2 000	[1.5]	11	1 800	0.39	55	1 900
R8	280	570	3 100	0.34	25	630	[1.5]	2.2	300	[0.2]	97	340
R9	360	310	3 300	1.1	38	830	[1.5]	1.4	370	[0.2]	25	440
R10	120	380	2 300	0.15	0.15	207	[0.4]	[0.5]	210	15	4.1	120
R11	64	99	2 400	0.22	6.2	140	[0.4]	[0.5]	96	[5.0]	6	110
R12	66	190	1 900	0.5	11	290	[0.4]	[0.5]	240	[5.0]	9.4	150

Table 1 (*continued*)

Sample	Pb	Mn	Mg	Hg	Ni	K	Se	Si	Na	Th	Vn	Zn
R13	94	110	1 600	0.34	13	260	[0.4]	[0.5]	230	[0.4]	110	110
R14	910	190	2 900	0.18	47	320	[1.5]	[0.5]	410	[0.2]	26	240
R16	470	690	3 400	1	38	1 100	[1.5]	[0.5]	400	[0.2]	48	470
R17	450	600	2 800	1.2	33	670	[0.4]	[0.5]	310	[0.4]	37	440
Median	320	310	2 900	0.50	33	630	—	3.8	310	0.39	29	340
Mean ± S.D.	358 ± 288	338 ± 202	3 173 ± 1 327	2 ± 3	44 ± 64	768 ± 676	—	5 ± 4.4	661 ± 876	5.2 ± 8.5	41 ± 35	444 ± 510
Hackensack River												
R3	150	430	7 800	4.4	34	2 600	[0.4]	[0.5]	6 500	16	25	300
R18	140	200	4 600	1.8	25	1 900	[1.5]	2.1	4 000	0.25	21	260
Arthur Kill												
R1	220	310	8 100	6.2	42	2 700	0.59	[0.5]	16 000	17	29	460
R2	72	220	6 400	[0.1]	22	3 400	[1.5]	[0.5]	14 000	[0.2]	27	83
R6	230	440	8 500	2.8	38	4 100	[1.5]	4.6	12 000	0.24	40	390
R7	2500	150	4 100	1.5	31	1 800	3.4	[0.5]	5 000	[0.2]	33	340
R19	340	250	6 100	1.1	35	2 700	[1.5]	3.8	5 400	0.2	32	400
Median	230	250	6 400	2.2	35	2 700	2.0	4.2	12 000	0.24	32	390
Mean ± S.D.	672 ± 1 026	274 ± 109	6 640 ± 1 760	2.9 ± 2.3	34 ± 8	2 940 ± 862	1.8 ± 2	4.2±0.6	10 480±5 025	5.8 ± 10	32 ± 5	335 ± 147
All waterways												
Median	255	280	3 750	1.10	34	1 450	2.0	3.8	1 105	0.32	29	340
Mean ± S.D.	421 ± 571	318 ± 171	4 472 ± 2 212	2.1 ± 2.6	39 ± 49	1 536 ± 1 216	2 ± 2	4 ± 3	3 898 ± 5 130	6 ± 8	36 ± 28	395 ± 403

[a]Brackets indicate that the sample was below the detection limit; the value shown represents the limit of detection.
[b]All values less than the limit of detection.

Table 2
Trace metal concentrations (mg/kg dry wt.) in surficial sediments collected from two wetland areas along the Hackensack River

Sample Location[a]	Ca	Cu	Pb	Mg	K	Na
Meadowlands Area I						
1A	n/a[b]	n/a	130	n/a	n/a	n/a
1B	3 900	37	121	7 460	2 310	55 100
2A[c]	n/a	n/a	165	n/a	n/a	n/a
2B	6 700	74	240	12 000	3 500	76 000
3A	6 020	52	138	12 500	4 160	93 500
4A	5 200	220	410	10 000	3 700	61 000
5A	n/a	n/a	280	n/a	n/a	n/a
5B	5 000	82	170	10 000	3 200	73 000
6A	4 400	64	134	10 500	3 340	75 300
7A	4 400	41	123	9 240	2 990	68 100
8A	5 180	119	417	8 950	3 560	46 600
9A	3 730	126	217	8 470	4 820	26 400
10A	5 600	215	322	7 330	2 670	36 300
11A	2 830	150	116	5 400	1 720	39 200
12A	4 710	77	183	7 200	2 840	32 200
13A	3 870	106	389	6 650	2 990	29 600
14A	8 500	283	704	10 000	3 740	46 600
15A	n/a	n/a	430	n/a	n/a	n/a
15B	7 700	140	330	12 000	3 800	66 000
16A	n/a	n/a	310	n/a	n/a	n/a
16B	5 900	99	270	9 000	2 800	51 000
17A	n/a	n/a	190	n/a	n/a	n/a
17B	5 900	98	210	9 900	3 600	58 000
18A	6 100	124	300	9 140	3 430	43 300
19A	5 300	68	340	9 300	3 300	51 000
20A	5 210	162	487	7 900	3 270	22 000
21A	4 400	110	290	300	2 700	33 000
Median	5 200	106	270	140	3 300	51 000
Mean	5 264	116	275	9 059	3 259	51 581
±S.D.	±1,330	±63	±138	±1,839	±661	±18,996
Meadowlands Area I						
1A	5 600	100	130	9 00	3 800	11 000
2A	7 200	17	25	8 300	4 400	6 800
3A	4 200	18	30	3 800	1 800	3 200
4A	3 000	37	52	5 900	2 500	6 200
5A	2 600	20	31	7 600	4 100	7 500
6A	2 300	20	33	5 900	3 000	5 800
7A	2 500	81	100	5 100	2 400	5 800
8A[c]	8 050	46	65	7 300	3 250	17 500
Median	3 600	29	43	6 600	3 125	6 500
Mean	4 431	42	58	6 625	3 156	7 975
±S.D.	±2263	±32	±38	±1760	±905	±4422

[a]Samples designated 'A' and 'B' were collected in October or November of 1991 respectively.
[b]n/a indicates that the sample was not analyzed for this parameter.
[c]Concentrations represent the mean of two replicate analyses.

found in each waterway by various sediment quality criteria and guideline values (Table 3). Since each benchmark sediment quality value was determined on the basis of effects observed during sediment toxicity testing, a ratio of 1.0 or greater was assumed to indicate a sediment metal concentration with the potential to pose an adverse effect on benthic biota.

Based on comparisons to sediment quality guidelines and toxicity values, metal concentrations in surficial sediments are of greatest concern in the Arthur Kill, followed by the Passaic River and the Hackensack River. Cadmium, Pb and Hg concentrations in sediments exceeded their respective sediment quality benchmark values most frequently. In Areas I and II of the Hackensack Meadowlands, hazard indices calculated for Cu were lower than those estimated in other waterways, but still exceeded Canadian Lowest and Severe Effect Levels and NOAA ER-L toxicity values. In the case of Pb, however, hazard indices calculated for Area I were among the highest estimated anywhere in the Newark Bay estuary.

Mean sediment-bound Cd, Cu, Hg, Ni, Pb and Zn concentrations exceeded Canadian Lowest Effect Levels (Persaud et al., 1991) and NOAA ER-L values in the Passaic River, Hackensack River, Arthur Kill and Hackensack Meadowlands, with few exceptions (Table 3). Mean As concentrations in sediments were below the NOAA ER-L value in all three waterways. Nickel concentrations in surficial sediments were higher than its benchmark value in the Arthur Kill and the Passaic River. The concentrations of Cd, Cu, Pb and Hg were generally 10-fold higher or greater than their respective Canadian guideline values in all waterways. The concentrations of Ni, Zn and As were 2–5-fold higher than their respective Canadian guideline values. Since the Lowest Effect Level is defined as the threshold for metal toxicity in freshwater organisms (Persaud et al., 1991), the sensitivity of aquatic biota in an estuarine system such as Newark Bay could be different due to differences in sediment and water chemistry. However, adverse effects have been observed in both marine and freshwater species at concentrations similar to those derived by Persaud et al. (1991) (NOAA, 1991).

Mean concentrations of Cd and Hg were 2–7-fold higher than WADOE (1991) marine sediment quality criteria. The concentrations of Cu and Pb in the Arthur Kill and Zn in the Passaic River were slightly higher than their benchmark values. The WADOE criteria correspond to a level of sediment quality in the marine environment that is not likely to result in adverse effects, including acute or chronic toxicity to biological resources or significant health risk to humans (WADOE, 1991).

The mean concentrations of Cd, Cu, Pb, Hg and Ni in the Hackensack River, Passaic River and Arthur Kill exceeded one or more of three California AET values. The amphipod and bivalve AET values were derived from short-term bioassays and are considered to be sensitive indicators of toxicity; while, the benthic AET addresses effects on macroinvertebrates based on results from a combination of both short-term and long-term toxicity tests (CSWRCB, 1990). Mean sediment concentrations of Cu, Pb, Hg and Zn were 5-fold or more higher than their respective California Bivalve AET values. Cadmium sediment levels were 15–20-fold higher than the California Bivalve AET throughout Newark Bay. Mercury concentrations were 2–5-fold higher than the California Amphipod and Benthic AET values.

4. Discussion

The degradation of ecological conditions in Newark Bay and its major tributaries due to chemical contamination has been recognized for more than a century (NOAA, 1984b; Esser, 1988). Although extensive research has not been conducted to correlate sediment contamination with observed impacts to biota, several reviews have suggested that the level of metal contamination in sediments in the estuary is associated with declines in fish populations, lower species diversity and various infectious and non-infectious diseases (NJMSC 1987; Moser, 1990). A recent review of available data on the distribution of benthic species in the estuary suggests that the Arthur Kill, Newark Bay and Hackensack River are unable to support the expected populations of amphipods, possibly as a result of elevated concentrations of trace metals and organic chemicals in water and

Table 3
Ratio of the mean As, Cd, Cu, Pb, Hg, Ni and Zn concentrations (mg/kg dry wt.) in surficial sediments from Newark Bay, New Jersey to benchmark sediment quality criteria and guidelines and NOAA toxic effects values

	NOAA[a]		WADOE marine[b] Sediment quality criteria	Ontario, Canada[c]		California[d]		
	ER-L	ER-M		Lowest effect level	Severe effect level	Amphipod AET	Bivalve AET	Benthic AET
Arsenic	*33*	*85*	*57*	*6*	*33*	*>72*	*70*	*70*
Arthur Kill	0.7	0.3	0.4	4.0	0.7	0.3	0.3	0.3
Hackensack River	0.4	0.3	0.5	4.9	0.9	0.4	0.4	0.4
Passaic River	0.9	0.1	0.2	2.1	0.4	0.2	0.2	0.2
Cadmium	*5*	*9*	*5.1*	*0.6*	*10*	*>32*	*0.57*	*8.9*
Arthur Kill	2.3	1.3	2.3	19.4	0.4	0.4	20.4	1.3
Hackensack River	1.8	1.0	1.8	14.9	0.3	0.3	15.7	1.0
Passaic River	1.8	1.0	1.7	14.8	0.3	0.3	15.5	1.0
Copper	*70*	*390*	*390*	*16*	*110*	*>690*	*66*	*310*
Arthur Kill	5.6	1.0	1.0	24.5	3.6	0.6	5.9	1.3
Hackensack River	2.8	0.5	0.5	12.2	1.8	0.3	3.0	0.6
Hackensack Area I	1.7	0.3	0.3	7.3	1.1	0.2	1.8	0.4
Hackensack Area II	0.6	0.1	0.1	2.6	0.4	0.1	0.6	0.1
Passaic River	2.5	0.4	0.4	11.0	1.6	0.3	2.7	0.6

TABLE 3 (*continued*)

Lead	*35*	*110*	*450*	*31*	*250*	*>340*	*71*	*150*
Arthur Kill	19.2	6.1	1.5	21.7	2.7	2.0	9.5	4.5
Hackensack River	4.1	1.3	0.3	4.7	0.6	0.4	2.0	1.0
Hackensack Area I	7.8	2.5	0.6	8.9	1.1	0.8	3.9	1.8
Hackensack Area II	1.7	0.5	0.1	1.9	0.2	0.2	0.8	0.4
Passaic River	10.2	3.3	0.8	11.5	1.4	1.1	5.0	2.4
Mercury	*0.15*	*1.3*	*0.41*	*0.2*	*2*	*1.2*	*0.51*	*0.51*
Arthur Kill	19.3	2.2	7.1	14.5	1.5	2.4	5.7	5.7
Hackensack River	20.7	2.4	7.6	15.5	1.6	2.6	6.1	6.1
Passaic River	10.3	1.2	3.8	7.7	0.8	1.3	3.0	3.0
Nickel	*30*	*50*	*n/a*	*16*	*75*	*>170*	*>170*	*>170*
Arthur Kill	1.1	0.7	—	2.1	0.4	0.2	0.2	0.2
Hackensack River	1.0	0.6	—	1.8	0.4	0.2	0.2	0.2
Passaic River	1.5	0.9	—	2.7	0.6	0.3	0.3	0.3
Zinc	*120*	*270*	*410*	*120*	*820*	*>870*	*150*	*340*
Arthur Kill	2.8	1.2	0.8	2.8	0.4	0.4	2.2	1.0
Hackensack River	2.3	1.0	0.7	2.3	0.3	0.3	1.9	0.8
Passaic River	3.7	1.6	1.1	3.7	0.5	0.5	3.0	1.3

Note: Hazard indices were calculated as the ratio of the mean concentration in sediment to the benchmark sediment quality value. A ratio greater than one indicates the presence of metals at concentrations that may pose a threat to aquatic biota.

[a]NOAA (1991a).

[b]WADOE (1991).

[c]Persaud et al. (1991).

[d]CSWRCB (1990).

[e]n/a indicates that a sediment quality guideline or criteria was not available.

sediment (Cristini, 1991). Several species of fish and shellfish collected from the region have been found to exhibit gross pathological abnormalities that have typically been associated with metal contamination (Ellis et al., 1980; Greig et al., 1982; Goeller, 1989; Cristini, 1991). Fin erosion of unknown etiology has been observed in bottom fish collected from the NY/NJ Harbor Estuary (O'Connor et al., 1986). Other diseases associated with environmental degradation have been reported in several aquatic species, including lymphocystis, ulcers and microsporidiosis in finfish and shell disease among anthropods (Cali, 1988).

In general, elevated metal concentrations have historically been found in the Hackensack River north of Berry's Creek Canal and its tributaries, in the Ironbound section of the Passaic River, in Newark Bay and at the confluence of the Arthur Kill and Morses Creek (Suszkowski, 1978; Ellis et al., 1980; Meyerson et al., 1981; Goeller, 1989; HMDC, 1989). Trace metal concentrations at two sites in the Hackensack River were comparable to levels measured in earlier studies (Suszkowski, 1978; Meyerson et al., 1981; Goeller, 1989). Arsenic, Hg and Ni concentrations in the Passaic River were higher than those reported by Suszkowski (1978). Cadmium, Pb and Zn concentrations in sediments collected from Kearny Point in Newark Bay (R18) were considerably higher than those reported by Meyerson et al. (1981) at approximately the same location; however, the concentration of Hg measured at station R18 was approximately one-half the level reported by Meyerson et al. (1981). Sediment concentrations of Cd and Ni reported by the USEPA (1982) in the Arthur Kill were similar to recent measurements.

The issue of the appropriate measure of sediment quality is being actively and intensely debated in the scientific literature, with five major approaches under consideration in the United States (Chapman, 1989; Giesy and Hoke, 1990). During this period of intense, critical examination of the regulatory implications of an appropriate national sediment management strategy, metal contaminated sediments in urban estuaries such as Newark Bay continue to pose unacceptable ecological risks. We believe that it is useful to assess sediment quality conditions through comparisons to as many different sediment quality approaches as possible, ascertain whether a consensus on hazard can be reached on the basis of different numerical criteria and then define a course of action for further investigation. Because of the apparent weaknesses of each method alone (Chapman, 1989; Giesy and Hoke, 1990), an assessment of sediment quality based upon a consensus of multiple approaches would have more credibility than judgements based upon only one approach.

While it is difficult to accurately determine specific sources of As, Cd, Cu, Hg, Ni, Pb and Zn based on the data reported in this study, several potentially toxic hot spots in sediments can be ascertained by comparing sampling data (Table 1) to their respective sediment quality values (Table 3). For example, in the Passaic River at stations R4, R5, R8, R16 and R17, the concentrations of Cd, Cu, Hg, Ni, Pb and Zn in sediments exceeded NOAA ER-L values, Canadian Lowest Effect Levels and, except for Ni, California Bivalve and Benthic AET values. In the Hackensack River, sediment-bound Cd and Hg at stations R3 and R18 exceeded nearly all sediment quality values; As, Cu, Pb and Zn were 2–3-fold higher than NOAA ER-L, NOAA ER-M, Canadian Lowest Effect Levels, or California Bivalve AET values. The high concentrations at these locations may be due to the historical presence of scrap metal yards, tanneries and paint and pigment manufacturers, as well as combined sewer outfalls and a municipal wastewater treatment plant at Kearny Point (HydroQual, 1991). The distribution of contaminated sediments in the Passaic River may be due, in part, to turbulent conditions generated by the hydroelectric system at the Dundee Dam, as well as discharges from contaminated storm sewer overflows during periods of heavy rain. Concentrations measured in the Hackensack wetlands areas, where relatively few direct industrial inputs are evident, most likely represent inputs from atmospheric deposition, non-point source runoff from urban areas and automobile traffic from the nearby highways and rail lines. These sediments may reflect the emissions of Pb from automobiles prior to regulations limiting the level of Pb in gasoline. Elevated metal concentrations in surficial

sediments in the upper Arthur Kill may be associated with the presence of several petroleum refining facilities located in the Bayway, New Jersey industrial complex. The presence of Cd, Cu, Pb, Hg and Zn in sediments from stations R6 and R7, located in the Arthur Kill channel and station R 19, located in the Elizabeth River, may pose a significant hazard to biota. Interestingly, metal concentrations in sediments at station R2 were not as high as those in sediments located immediately downstream at station R6. All seven toxic metals measured at station R1, located on the Rahway River, exceeded their respective sediment quality values. Although sediment characteristics, tidal currents, dredging activities and sediment depositional patterns are likely to influence the distribution of sediment bound materials (NOAA, 1984; Munns and Rubinstein, 1990), the relatively high concentrations found in these areas warrant further investigation.

The results of this study indicate that the presence of several metals, particularly Cd, Hg and Pb, in surficial sediments may pose a threat to aquatic biota in the Passaic River and elsewhere in Newark Bay. Sediment concentrations generally exceeded benchmark sediment quality criteria and guidelines, indicating a potential for significant adverse effects to aquatic biota. Efforts to reduce metal contamination of sediments in Newark Bay and its major tributaries will be difficult due to the numerous contributing sources (Wilburand Hunter, 1973; 1979; Meyerson et al., 1981). Consequently, the presence of metals in surface sediments must be considered a potentially significant factor in the overall environmental quality of the Newark Bay estuary. Spiked sediment toxicity tests and bioaccumulation bioassays are needed to more fully characterize the ecological hazard posed by metal contamination. Recent studies have shown that metal speciation has a significant affect on the bioavailablity and subsequent toxicity of trace metals in sediments (Luoma and Carter, 1991; Di Toro et al., 1992). Sediment characteristics such as pH, redox potential, organic content and the presence of acid volatile sulfides are determinants of the bioavailability of many metals and their potential ecological risks (McIntosh, 1991; Di Toro et al., 1992). Although site-specific sediment toxicity bioassays would be required to evaluate the affects that these factors might have on biota, the results of comparisons to various sediment quality benchmark values indicate that site-specific conditions in the Passaic River, Hackensack River and the Arthur Kill warrant further study.

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