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Distribution of Inorganic Compounds in Sediments from Three Waterways in Northern New Jersey

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Recently, a screening-level study of surficial sediments within Newark Bay, New Jersey was conducted to determine the spatial distribution of trace metals throughout the watershed (Bonnevie et al. 1992). The results of the analysis indicated that concentrations of trace metals exist within the estuary at levels potentially posing serious ecological hazards to fish and benthic invertebrates. Based on the results of that study, a more extensive sediment sampling effort was conducted to more specifically identify areas with high metal contamination relative to potential sources. The focus of this study was to further quantify the spatial distribution of metals within the watershed and to more closely examine the ecological hazard at specific locations. In addition, vertical distributions were examined in sediment cores and the activities of the radionuclides ^{210}Pb and ^{137}Cs were measured within the cores to provide approximate dates of deposition. From this information, it may be possible to identify possible current and historical sources of contamination and areas in which further toxicological testing should be conducted.

MATERIALS AND METHODS

Thirty-one 10- and 20-ft sediment cores were collected during November and December of 1991 at locations throughout the Arthur Kill, Hackensack River, Kill van Kull, and the Passaic River (Fig. 1). Sampling stations were located outside of shipping channels in stable depositional reaches to minimize the impacts associated with dredging activities and ship traffic in an effort to obtain undisturbed sedimentation profiles. At all stations, except A3, P1, P2, and P3, cores were collected using a Model 1400 Vibracore unit with either a 10 ft or 20 ft stainless steel core barrel with a Lexan liner. At stations A3, P1, P2, and P3, a smaller vibracore unit equipped with a 10 ft, unlined, aluminum core barrel was utilized. Prior to core collection, all field sampling and sample processing equipment, aluminum core barrels, and Lexan liners were rinsed with acetone and hexane (50:50), analyte-free trichloroethylene, and analyte-free deionized water. Core barrels and liners were sealed with aluminum foil until the commencement of field sampling. Field and rinsate blanks were utilized to verify the levels, if any, of residual contamination. Sediment samples were collected from the intact Lexan liner or aluminum core tube at predetermined depths for chemical (2 in thickness) and radionuclide (1 in thickness) analysis. The outermost layer of sediment was discarded to minimize vertical mixing. Samples were transferred to pre-cleaned

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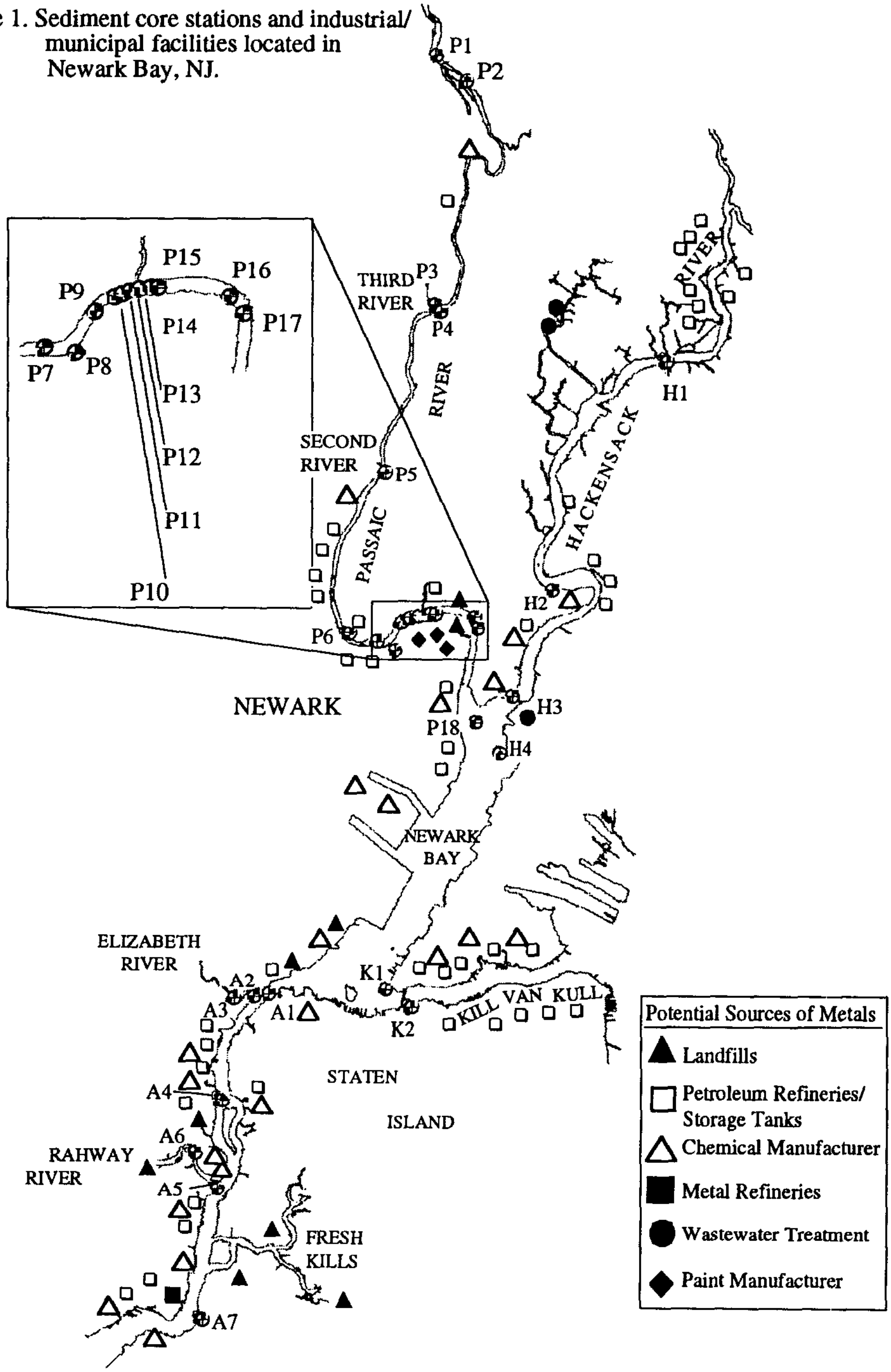
Figure 1. Sediment core stations and industrial/ municipal facilities located in Newark Bay, NJ.



glass containers, sealed, and maintained at 4°C prior to analysis in accordance with USEPA Contract Laboratory Program requirements.

Sediments were analyzed for Target Analyte List (TAL) metals by S-Cubed Laboratory (San Diego, CA) according to the USEPA Contract Laboratory Program (CLP) Statement of Work for Inorganic Analysis, Multi-Media, Multi-Concentration (ILM02.0) methods. Sediments were digested using a total dissolution. A portion of non-homogenized sample was analyzed for mercury by cold vapor atomic absorption spectroscopy. The remaining sample was homogenized and analyzed for the other TAL metals and cyanide. Graphite furnace atomic absorption spectroscopy (GFAA) was used to determine the concentrations of arsenic, thallium, and selenium. The concentrations of cyanide were determined spectrophotometrically. Inductively coupled plasma emission spectroscopy (ICP) was used for all other TAL analyses except for lead. Lead was analyzed by ICP for most samples; however, for those samples with low lead analyte levels GFAA methods were used. Recoveries were determined from matrix spikes. Analytical methods were calibrated using standard reference materials. Radiochemistry samples were analyzed for ^{210}Pb and ^{137}Cs radioisotopes by Teledyne Isotopes (Westwood, NJ). The radioisotope ^{210}Pb was measured by radiochemical separation and beta assay for ^{210}Bi product, while gamma spectral analysis was used to determine ^{137}Cs activity.

RESULTS AND DISCUSSION

Metal accumulation in sediments has been linked to specific sources such as discharges from smelters (Cu, Pb, and Ni), metal-based industries (e.g., Zn and Cd from electroplating), paint and dye formulators (Cd, Cu, Pb, Hg, and Zn), petroleum refineries (Pb), as well as effluents from chemical manufacturing (Forstner 1990). Metals in aquatic environments also occur as the result of a variety of nonpoint sources such as emissions from automobiles, dustfall, precipitation, combined sewer outfalls (CSOs), municipal wastewater treatment plant effluents, and stormwater runoff (Mytelka et al. 1973; Whipple et al. 1976; Meyerson et al. 1981; NOAA 1982; Granier et al. 1990; USEPA 1992). Many of these potential sources have been identified within the Newark Bay region (Fig. 1).

Of the twenty-three metals analyzed, seven (As, Cd, Cu, Pb, Hg, Ni, Zn) were selected for closer examination in this analysis. The concentrations of these seven metals are summarized in Table 1. Lead and Zn were the most frequently detected throughout the study area, generally found in more than 70 percent of all samples (Table 1). Copper, Pb, and Zn results in several samples were rejected due to interferences, therefore the actual detection frequencies of these metals are likely to be higher than reported here. The concentrations of all metals tended to be highest in the Passaic River and in the Arthur Kill, similar to the previously reported results (Bonnevie et al. 1992).

Metal concentrations measured at stations in the lower Passaic River and the Arthur Kill are presented in Tables 2 and 3, respectively. The highest concentrations of Pb, Cu, and Ni were found at Station A5, located adjacent to two large chemical manufacturers (Fig. 1), while Zn concentrations were highest (10,200 mg/kg) at the northwest corner of Prall's Island (A4) in the Arthur Kill. Elevated metal

Table 1. Summary of inorganics measured in Northern New Jersey sediments[a]

	Arthur Kill (n=21)			Hackensack River (n=12)		
Chemical	Frequency (%)	Range (mg/kg)	Median (mg/kg)	Frequency (%)	Range (mg/kg)	Median (mg/kg)
Arsenic	76	3.7 - 294	43.7	83	8.4 - 11.9	24.1
Cadmium	71	1.9 - 23.2	11.2	58	1.5 - 6.5	2.5
Copper	100	3 - 3850	419	58	7 - 328	170
Lead	100	7.3 - 3000	423	100	9.4 - 541	149.5
Mercury	62	0.96 - 22.1	7.4	67	0.38 - 9.3	7.6
Nickel	62	20.4 - 269	64.4	92	16.6 - 76.6	40.5
Zinc	100	10.2 - 10200	768	100	28.1 - 506	328

	Passaic River (n=84)			Kill van Kull (n=6)		
Chemical	Frequency (%)	Range (mg/kg)	Median (mg/kg)	Frequency (%)	Range (mg/kg)	Median (mg/kg)
Arsenic	92	0.72 - 233	10.2	50	15.4 - 32.6	23.8
Cadmium	65	0.38 - 45.4	6.3	67	0.72 - 10.3	3.35
Copper	80	4.4 - 1390	151	100	8.4 - 378	121.15
Lead	77	4.4 - 2200	391	100	16.4 - 395	168.55
Mercury	69	0.46 - 29.6	7.5	67	2.2 - 13	6.05
Nickel	100	6.4 - 185	34.2	100	13 - 87.4	44.2
Zinc	80	15 - 1960	393.5	100	37.2 - 713	250.5

	Total (n=134)		
Chemical	Frequency (%)	Range (mg/kg)	Median (mg/kg)
Arsenic	78	0.72 - 294	14.5
Cadmium	65	0.38 - 45.4	6.45
Copper	82	3 - 3850	186
Lead	84	4.4 - 3000	350.5
Mercury	68	0.38 - 29.6	7.5
Nickel	93	6.4 - 269	40.9
Zinc	90	10.2 - 10200	394

a. Summary statistics are based on detectable concentrations only. Concentrations measured at all depths are included in each calculation.

concentrations in sediments in the upper Arthur Kill (A1-A4) are likely associated with the presence of several large petroleum refining facilities located in the Bayway, NJ industrial complex (Fig. 1), while sediments along the lower portion (A5-A7) are likely impacted by the presence of numerous landfills, scrap-metal yards, and smelters (Fig. 1). The Fresh Kills landfill, for example, located on Staten Island near station A7, was established in 1948 and is one of the largest landfills in the world (Suflita et al. 1992).

In the lower Passaic River, metal concentrations were highest in the lower reaches at stations P10 through P18 (Table 2). Elevated metal levels are likely due to several well-established tanneries, scrap-metal yards, and paint manufacturers (Fig. 1). The Roanoke Street sewer outfall located downstream of P17 has been identified as the area's most contaminated sewer discharge (PVSC 1970). This area has also historically been impacted by discharges from the Brown Street sewer (PVSC 1970). Stations P10 to P17 are located on the Passaic River in an area with the highest sedimentation rates south of the Dundee Dam (IT 1986). Station P2, located on the upper Passaic River just below the dam, contained elevated levels of Cu and Pb. Sedimentation rates estimated for the area above the dam are low, implying that the dam is not a barrier to downstream sediment transport. Elevated metal concentrations are likely due to contributions from upstream industrial and municipal sources.

To evaluate the toxic potency of metal-contaminated sediments, hazard indices for each waterway were derived from comparisons of average metal concentrations in surficial samples (0-2 in) to bench-mark sediment toxicity values derived by the

Table 2. Metals concentrations (mg/kg dry wt.) in lower Passaic River sediments

	Depth (in)	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
P10	0	R[a]	7	265	425	4.6	52.8	740
	18	R	10	338	534	10.1	75.9	944
	38	R	19.5	489	823	14.6	83.3	1350
	92	R	35	666	777	18.7	104	1520
	146	R	7.2	875	907	13.6	140	1760
	188	R	(0.33)[b]	13.9	13.4	(0.16)	21.6	55.6
	224	R	(0.33)	19.2	8.9	(0.17)	22.5	60
P11	0	13.2	7.2	R	350	5.1	49.6	R
	18	15.8	13.4	R	755	9	98	R
	38	18.8	18.7	R	800	10.3	84	R
	92	47.4	45.4	R	868	25.1	103	R
	146	67.3	33.7	R	814	29.6	104	R
	188	21.5	0.84	R	99.6	2.2	22.9	R
	200	5	(0.35)	R	19.3	0.49	24.2	R
P12	0	15	13.7	R	840	6.5	118	R
	18	15.7	12.2	R	747	12.7	93.1	R
	38	8	19	R	675	12.4	90.7	R
	62	33.6	7.6	613	813	10.6	76.6	1430
	92	23.5	3.5	408	518	9.6	50.3	843
	146	9.4	0.6	103	151	2.7	17.4	193
	166	1.6	(0.34)	14.6	9.6	(0.17)	8.7	31.9
	178	1.6	(0.34)	17.5	12.2	(0.17)	16.1	39.6
P13	0	10	6.1	243	400	5.3	49.7	608
	18	14.5	8.2	280	552	6.8	64.8	695
	38	30	15.9	506	707	12.5	77.2	1080
	92	49.6	3	349	365	8.1	62.7	658
	146	215	8.7	1390	1650	10.8	132	1900
	188	(1)	(0.35)	9.6	7.8	(0.18)	12.8	28.3
	212	(1.1)	(0.35)	9.5	R	(0.18)	8.8	22.9
P14	0	12.3	(0.54)	26.4	31.3	(0.17)	16.8	76.6
	18	74.6	2.7	448	1040	12.5	53.6	853
	38	11.1	0.38	55.5	61.6	1.4	11.4	130
	92	(1)	(0.35)	6.4	R	(0.17)	6.4	15
	146	14.8	12.5	345	837	(0.31)	80.6	1090
	188	17.2	4.6	510	728	13.8	57.7	1250
	230	2.1	(0.35)	11.2	17.3	0.46	10.6	55.9
P15	0	12.2	7.7	255	391	5.9	52.9	729
	18	7.9	6.2	192	482	9.4	44.8	515
	38	18.8	13.8	421	810	16.9	76.1	1140
	92	52.3	31.2	690	755	16.8	98.8	1530
	146	35.5	5.5	845	1160	18.3	184	1450
	188	2	(0.38)	15.4	12.9	(0.18)	9.5	29
	216	(1.1)	(0.36)	7.3	R	(0.18)	10.5	20.7
P16	0	11.5	4.7	184	R	5	42.4	494
	18	16.1	11.9	364	R	7.4	65.9	847
	38	20.9	19.5	444	R	10.9	93.1	1670
	92	233	6.4	1040	R	27.1	185	1960
	146	22.2	0.5	61.7	R	0.59	15.4	100
	194	0.81	(0.37)	5.9	R	0.78	7.4	16.6
	216	0.72	(0.37)	15.6	R	(0.18)	18.4	41

a. "R" indicates that sample was rejected due to analytical interferences.

b. Numbers in parentheses indicate detection limit.

Table 3. Metals concentrations (mg/kg dry wt.) in Arthur Kill sediments

	Depth (in)	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
A1	0	18.8	6.8	264	532	3.9	45.7	906
	8	(3.5)[a]	(0.35)	9.8	18.1	(0.18)	28.6	60.1
	18	4.8	(0.35)	8.6	14.9	(0.17)	25.3	54.9
A2	0	R[b]	(0.72)	89.7	138	3.9	45.9	204
	8	R	19.8	497	864	5	136	995
	18	R	21.9	660	684	14.1	113	911
A3	0	3.7	1.9	61.2	117	0.96	20.4	151
	18	(1)	(0.35)	3	7.3	(0.18)	(3.7)	10.2
	38	13.7	(0.58)	15.4	28.2	(0.29)	33.2	90
A4	0	18.4	7.3	321	408	2	130	1890
	18	101	23.2	419	750	5.9	50.4	10200
	38	11.5	(0.62)	17.7	23.4	(0.31)	30.2	116
A5	0	52.7	9.6	500	351	R	74	904
	18	294	19.4	3850	3000	R	269	2650
	38	118	11.2	2660	1170	R	185	1910
A6	0	29.8	5.4	347	472	8.2	50	554
	18	35.5	9.8	510	423	14.4	59.9	610
	38	51.9	13.7	631	654	22.1	69.7	768
A7	0	60.9	5.7	586	356	7.4	68.9	607
	18	70.9	18.4	1350	532	17.8	115	945
	38	190	15.5	1320	545	12.3	74.4	909

a. Numbers in parentheses indicate detection limit.

b. "R" indicates that sample was rejected due to analytical interferences.

National Oceanic and Atmospheric Administration (NOAA 1991) (Table 4). Similar to earlier findings (Bonnevie et al. 1992), all metals of concern exceeded their respective NOAA guideline values. Eight stations in the Arthur Kill (A4, A5, A7), Passaic River (P6, P10, P12, P15), and Hackensack River (H1) warrant further investigation based on exceedances of NOAA toxicity values. Mercury, Pb, and Zn pose the greatest potential aquatic hazards based on the magnitude of the calculated hazard indices and the number of stations that exceeded NOAA toxicity values.

Table 4. Summary of benchmark sediment quality criteria used for evaluating potential sediment toxicity

	Toxic Effects Values	
Metal	ER-L[a] (mg/kg) dry wt.	ER-M[b] (mg/kg) dry wt.
Arsenic	33	85
Cadmium	5	9
Copper	70	390
Lead	35	110
Mercury	0.15	1.3
Nickel	30	50
Zinc	120	270

Source: NOAA 1991

a. Effects Range - Low. Represents the 10th percentile of concentrations at which adverse affects were observed in bioassays reviewed.

b. Effects Range - Median. Represents the 50th percentile of concentrations at which adverse affects were observed in bioassays reviewed.

The vertical distributions of the metals were examined to investigate historical changes in anthropogenic contributions to bottom sediments. In general, metal concentrations found at depth were higher than at the surface (Tables 2 and 3). Concentrations in samples collected from the top twenty inches of sediment did not differ significantly from the mean; elevated metal concentrations were typically measured in samples collected from depths greater than 24 in. Despite the occurrence of metals in surficial sediments at potentially toxic concentrations, results suggest that more recent inputs have declined relative to historical discharges. This may be difficult to discern, however,

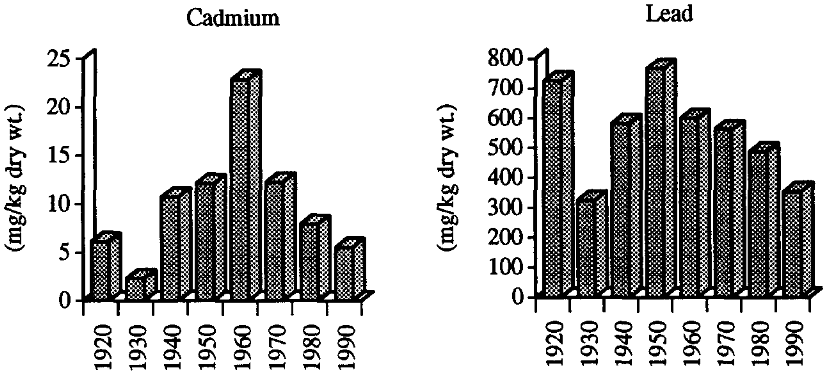


Figure 2. Cadmium and lead concentrations according to decade of deposition

since the high sedimentation rates in the lower Passaic River and elsewhere suggest that elevated metal concentrations are indicative of contributions from upstream, as well as local, sources.

Radiochemistry results support sedimentation rates ranging from 0.23 (A6) to 3.5 (P10) in/year in the three waterways. Sediment cores from the lower Passaic River were found to have the highest depositional rates in the watershed (2.8 - 3.5 in/year), confirming those reported in a previous investigation (IT 1986). This area has not been dredged by the U.S. Army Corps of Engineers since before 1950 (IT 1986); based on these high sedimentation rates, nearly 8 ft of sediment has accumulated since that period.

Using the sedimentation rates calculated from radioisotope measurements, pollution profiles of sediment cores indicate elevated concentrations of several metals prior to 1950 and decreased levels since the 1960s. The results for Pb and Cd are presented in Fig. 2 to illustrate the observed trends. In general, metal concentrations increased after the 1920s, peaking in the 1950s and the 1960s. Concentrations in sediments have gradually declined since the 1970s (Fig. 2). Cadmium concentrations appear to have peaked during the 1960s, while the highest concentrations of Cu, Pb, Hg, Ni, and Zn appear to have occurred during the 1950s. These profiles closely match the industrial history of the region. Although the Newark region has been heavily populated for over a hundred years, its most intense industrial expansion occurred during the rapid economic expansion associated with World War II (Cunningham 1966a,b). Industries related to the war effort, including paint and pigment formulators, metal plating, and ship building, are likely to have contributed significant amounts of trace metals to the estuary during this period. In addition, the historical presence of scrap metal yards, tanneries, and paint and pigment manufacturers have undoubtedly impacted the environmental quality of the area (Meyers 1945; Cunningham 1966b). The gradual decline after the 1960s may reflect increased regulations of waste discharges, as well as improvements in the structure and functioning of combined sewer outfalls (CSOs) and other waste treatment facilities (ISC 1988).

The results of this investigation demonstrate that the presence of toxic metals in surficial and buried sediments must be considered a significant factor in the overall environmental quality of Newark Bay and its major tributaries. Although inputs appear to have declined relative to historical sources, metal concentrations in bottom sediments from the Passaic River and the Arthur Kill indicate on-going contributions. Data from sediment cores collected from the lower Passaic River indicate that this reach is heavily contaminated, in part due to a relatively high depositional environment and the accumulation of metal-laden sediments from local and upstream industrial and municipal sources. Additional research will be necessary to identify these potential sources and to evaluate their contribution to trace metal pollution in these waterways.

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