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Magnitude and Extent of Trace Metal Contamination in Hudson River Estuary Surficial Bottom Sediment

By

Fatemeh Ashkan

A dissertation submitted to the Graduate Faculty in Earth and Environmental
Sciences in partial fulfillment of the requirement for the degree of Doctor of
Philosophy, The City University of New York

2000

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This manuscript has been read and accepted for the Graduate Faculty in Earth and Environmental Sciences in satisfaction of the dissertation requirement for the degree of Doctor in Philosophy.

5-1-00

Date

William H. Harris

Chair of Examining Committee

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Date

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The City University of New York

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Abstract

Magnitude and Extent of Trace Metal Contamination in Hudson River Estuary Surficial Bottom Sediment

By: Fatemeh Ashkan

Advisor: Professor William H. Harris

Bottom sediment samples were taken from 97 stations along 33 cross-river transects, spaced approximately one kilometer apart, and extending from the Battery, New York (km 0) north to Haverstraw Bay (km 67). The sampling program was conducted in summer, 1997 (maximum density stratification) and fall, 1998 (near isothermal water column). The resultant longitudinal and cross-river environmental gradients show simultaneous increases and/ or decreases in trace metal concentrations (Ag, Cd, Cr, Cu, Ni, Pb, Zn, and V) throughout the study area with substantial increases down river in the vicinity of NJ/NY Water Pollution Control Plants (WPCPs). Trace metal concentrations were found to be greater than those of sediment quality guidelines established for bioassay toxicity. Sewage-derived carbohydrates in bottom sediments (as cellulose and hemi-cellulose) form a major portion of total organic carbon (TCH: TOC = 131 – 451). Ag is found to be the most pervasive contaminant followed by Pb and Cr. The results of bivariate analysis (Spearman-Rho non-parametric pairwise correlation) indicated good correlations, at 95% confidence limit, between the studied metals. The trace metal concentrations were higher along the NJ shore, where sediments are finer. NY shore was found to be 4x sandier than the NJ shore. Sediment particle size, proximity to present locations of NY/NJ WPCPs, and river hydrodynamics were found to be the main factors controlling spatial distribution of trace metals analyzed in Hudson River Estuary surficial bottom sediments. This study has established a baseline data set (summer of 1997) for

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environmentally available concentration distributions of selected trace metals, which may be useful in (a) future studies of correlates of benthic species richness and dominance (population density), and (b) may ultimately lead to more effective estuarine ecosystem management or restoration alternatives.

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Chapter 1: Introduction

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1. 1. Background and Objectives

During the past few decades, the Hudson estuary's ecosystem has been highly altered, primarily due to practices requiring the use of the estuary's waterways in the highly urbanized area of New York and New Jersey. The estuary's waterways have been used as an inexpensive and convenient means of transport for commercial goods and for receiving contaminated domestic and industrial wastes. Each year, maritime-related activity generates about $14 billion in regional economic activity, 190,000 jobs, $4.5 billion in wages and salaries, and $500 million in regional taxes (Birgeles, 1993). However, the discharges of contaminated wastes into the estuary from Water Pollution Control Plants (WPCPs), combined sewer overflows (CSO) during storm events, urban runoff, accidental spills, and industrial discharges have degraded the quality of estuarine water and bottom sediments, resulting in a decline in fish population and diversity and, thus, several health advisories (Clark, 1990). For example, a general advisory has been extended to bluefish and American eel, which are also contaminated with PCBs. The New York State Department of Health (DOH) recommends only eating one meal of bluefish and American eel per week and no consumption of striped bass from New York marine waters. The hepatopancreas (mustard, liver or tomalley) of Blue Crabs should never be eaten due to PCB and heavy metal contaminations (Clark, 1990).

In 1988, the estuary received an estimated 6.8 million gallons per day of untreated sewage, primarily from Manhattan, Staten Island, and Brooklyn (Gottholm *et al.*, 1993). This high rate of polluted waste discharged into the estuary had dropped below 1.0 million gallons per day by 1992, due to better source control, such as upgrading the fourteen WPCPs in New York and a few in New Jersey that discharge into the estuary. The improvements have led to

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a significant reduction in the level of harmful bacteria (fecal coliform), ammonia, and an increase in dissolved oxygen throughout the estuary (Brosnan *et al.*, 1994). It is important to note, however, that the level of toxic heavy metal concentrations in water and sediment within the estuary did not improve simultaneously. One reason for such a delay is that water treatment plants are not designed to "treat" water but rather to remove total suspended solids (TSS), biological oxygen demand (BOD), acids, and bacteria (Clark, 1990). Compared to a faster recovery rate of water, the estuary's bottom sediments have been recovering at a much slower pace.

Previous studies indicate high concentrations of potentially toxic trace metals (Ag, Cd, Cu, Ni, Pb, and Zn) in Hudson River estuarine bottom sediments and water (Williams *et al.*, 1978; Klinkhammer and Bender, 1981; Olsen *et al.*, 1984; Bopp and Simpson. 1989; Squibb *et al.*, 1991; NOAA, 1995). These studies showed that (1) sediment contamination by metals has been related to the industrial and municipal wastewaters discharged over the past few decades into the estuary (Muller *et al.*, 1982; Dujardin *et al.*, 1991; NOAA, 1995) and (2) fine-grained sediment particles are good adsorbent or repositories for metals.

These studies, however, have generally examined either a limited area of the estuary in some detail or a larger area in less detail than the present study. Thus, they do not offer a comprehensive picture of the magnitude and extent of metals in surficial bottom sediments (the benthic habitat) over a larger area. The present study, following the 1992- improvement of source controls at municipal WPCPs, focuses on the spatial variation of trace metal contamination including Ag, Cd, Cr, Cu, Ni, Pb, Zn, and V, as well as Mn and %Fe, Total Organic Carbon (%TOC), and Total Carbohydrate (%TCH) in surficial bottom sediments of the lower Hudson Estuary.

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The main objectives of this study are:

- To establish a baseline data set for environmentally available concentration distributions of selected trace metals, which may (a) be useful in future studies of correlates of benthic species richness and dominance (population density); and (b) ultimately lead to more effective estuarine ecosystem management or restoration alternatives;
- To determine how the sediment trace metal contaminant concentrations compare to sediment quality guidelines (ERL/ERM) of Long and Morgan (1990);
- To demonstrate the interrelationship between sediment geochemistry (% Total Organic Carbon, % Total Carbohydrates and grain size analysis) and trace metal contaminant concentrations;
- To indicate the possible sources of trace metal contamination in surficial bottom sediment of the study area;
- To analyze the statistical significance of trace metal correlations in surficial bottom sediment of the study area.

1. 2. Study Area

The study area extends from the Battery (km 0) to Haverstraw Bay, approximately 67 kilometers north (**Fig. 1**). It is customary to measure locations along the Hudson River in statute miles north (+) and south (-) of the Battery, which is located at the southern tip of Manhattan Island.

The Hudson Estuary is classified as a partially mixed estuary (Abood, 1974) and is tidal as far upstream as the Green Island Dam at Troy, N. Y. at RM 154 (km 248), with a mean tidal amplitude of approximately 1 meter (Cooper *et al.*, 1988). Salt intrusion (0.01 ppt

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isohaline) ranges from RM 25 (*ca.* km 15.5, south of the GWB) during the winter to RM 65 (*ca.* km 104.6, north of Newburgh Bridge or Poughkeepsie) during periods of low flow, particularly in the late summer. Bottom salinity in the lower estuary is typically 2 to 4 ppt greater than surface salinity. Precipitation is fairly uniform throughout the year except during spring, when snowmelt results in a major increase in freshwater discharge. Typically, about 50 – 70% of the fresh water to the Hudson River comes from above the Green Island Dam. Down river, there are no major tributaries entering the Hudson south of RM 90 (*ca.* km 145), and in addition, groundwater input is believed to be small (Garvey, 1990). Freshwater replacement time in the estuary is on the order of 6 – 12 weeks during the low discharge months and only 1 – 2 weeks during high runoff events (Clarke *et al.*, 1992). There are 11 Water Pollution Control Plants (WPCPs) around the study area, from the Battery (km 0) to Haverstraw Bay, approximately 67 km upstream (**Table 1**). All kinds of contaminated wastewaters pass through these WPCPs before entering the river.

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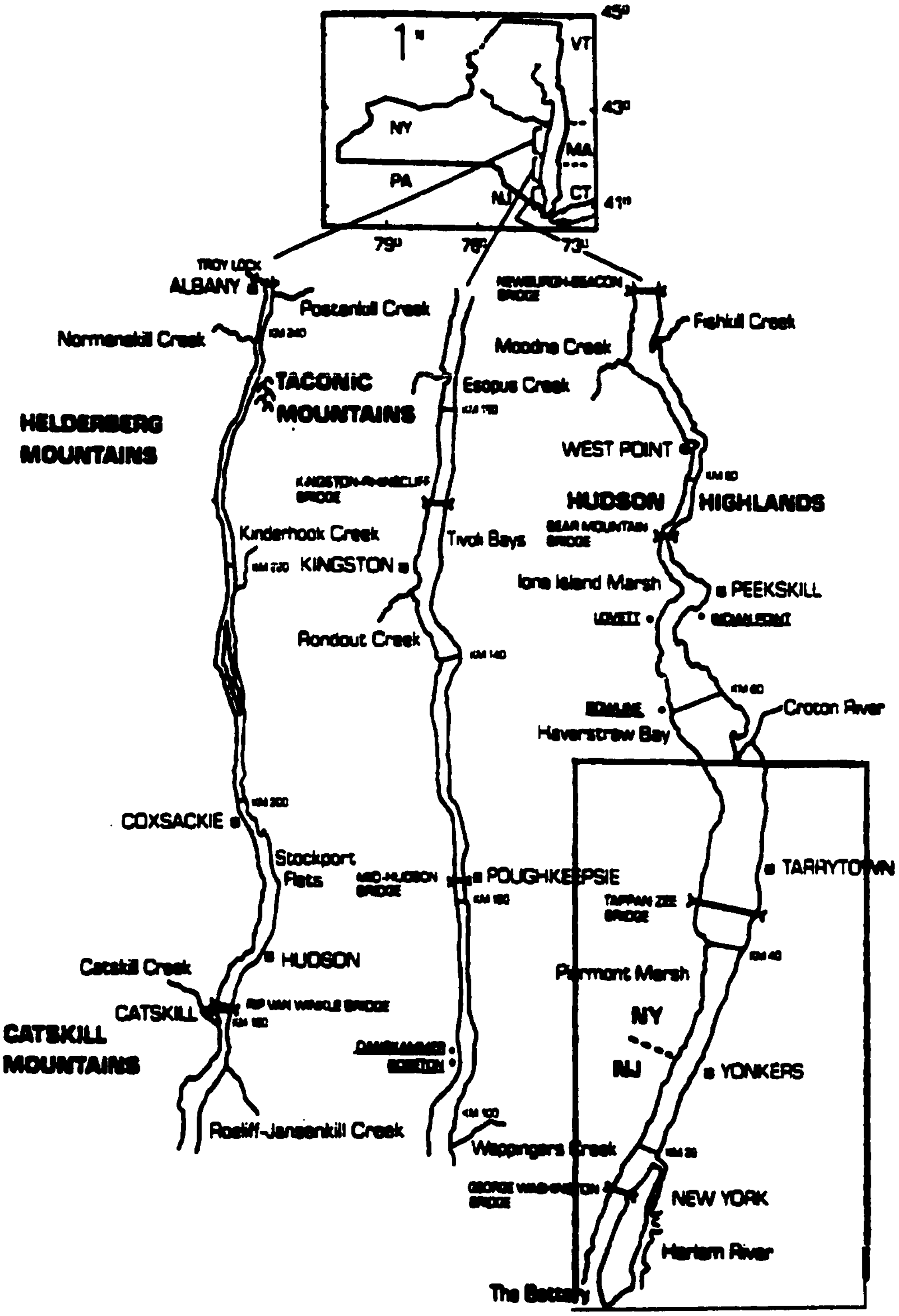

Figure 1. Geographic features of the Hudson River Watershed (Cooper *et al.*, 1988, figure 3, p.13). Rectangle shows the location of the study area

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Table 1. NY/NJ Water Pollution Control Plants discharging into the study area. Data are based on ISC report

WPCPs	latitude (degrees)	Longitude (degrees)	Receiving Water Classification	Type of Treatment	Design Flow (MGD)	Flow Average (MGD)	Date of last upgrade (+) /construction
Stony Point WTP	41.2225	73.9661	A	Secondary	1.0	1.0	1985+
Haverstraw J. R. STP	41.2147	73.9586	A	Secondary	8.0	5.2	1989+
Ossining SD WWTP	41.1539	73.8700	A	Secondary	7.0	5.4	1981
Rockland Co. SD #1	41.0419	73.9403	A	Secondary	26	21.1	1995+
Orangetown SD #2 STP	41.0417	73.8917	A	Secondary	12.75	9.6	1996+
Yonkers Joint WTP	40.9183	73.9106	A	Secondary	93.5	92	1988+
Edgewater	NA	NA	B-1	Secondary	6	3.4	1989+
North River	40.82528	73.9575	B-1	Secondary	170	140.7	1986-1991*
North Bergen	40.7911	73.9997	B-1	Secondary	2.9	2.9	1991+
North Hudson Sewage Authority							
River Road (West New York)	40.7878	74.0008	B-1	Secondary	10	6.8	1992+
Adames Street (Hoboken)	40.7531	74.0194	B-1	Secondary	24	11.8	1994+

* upgrade was phased out over time due to construction

\+ year of major addition or reconstruction

A and B refers to Class of water defined by Interstate Sanitation Commission to indicate water quality

Class A: water contains >5 mg/l dissolved oxygen

Class B: water contains 3 - 5 mg/l of dissolved oxygen

MGD: Millions of gallons per day

1.3. Geomorphologic and Geological Settings of the Hudson River Watershed

The Hudson River originates from a small lake called the Lake-of-Clouds on the southwest slope of Mount Marcy in the eastern Adirondacks Mountains. From its source the river flows in a generally southward direction for 507 km to its mouth at the Battery (km 0), the southern tip of Manhattan Island, where it empties into the Upper Bay of the New York Harbor. The Hudson River watershed covers some 34,526 km^2 (13,336 mi^2) of the northern and eastern parts of New York, along with small areas in Vermont, Massachusetts, Connecticut, and New Jersey. Three mountain ranges (the Adirondacks on the north, the Catskills on the west and southwest, and the Taconic on the east) border the Hudson River Watershed (**Fig. 1**).

From Troy to the Hudson Highlands, the river is relatively narrow with a mean depth of 8 meters, and flows through the valley section of the Appalachian Ridge and Valley province, which is underlain in this area by gently folded and tilted siltstones, shales, and carbonate rocks (Sanders, 1974). From here southward (from south of Newburgh), the river flows through highly metamorphic and igneous rocks of the Hudson Highland Gorge. This 16-km stretch of the river is the deepest (53 m) and narrowest (450 m). Upon emerging from the Hudson Highlands Gorge, the river becomes wider and shallower at Haverstraw Bay. From Croton Point southward, the river again narrows and deepens (10 m), and flows along the boundary between the Newark Basin to the west and the Manhattan Prong to the east (**Fig. 2**).

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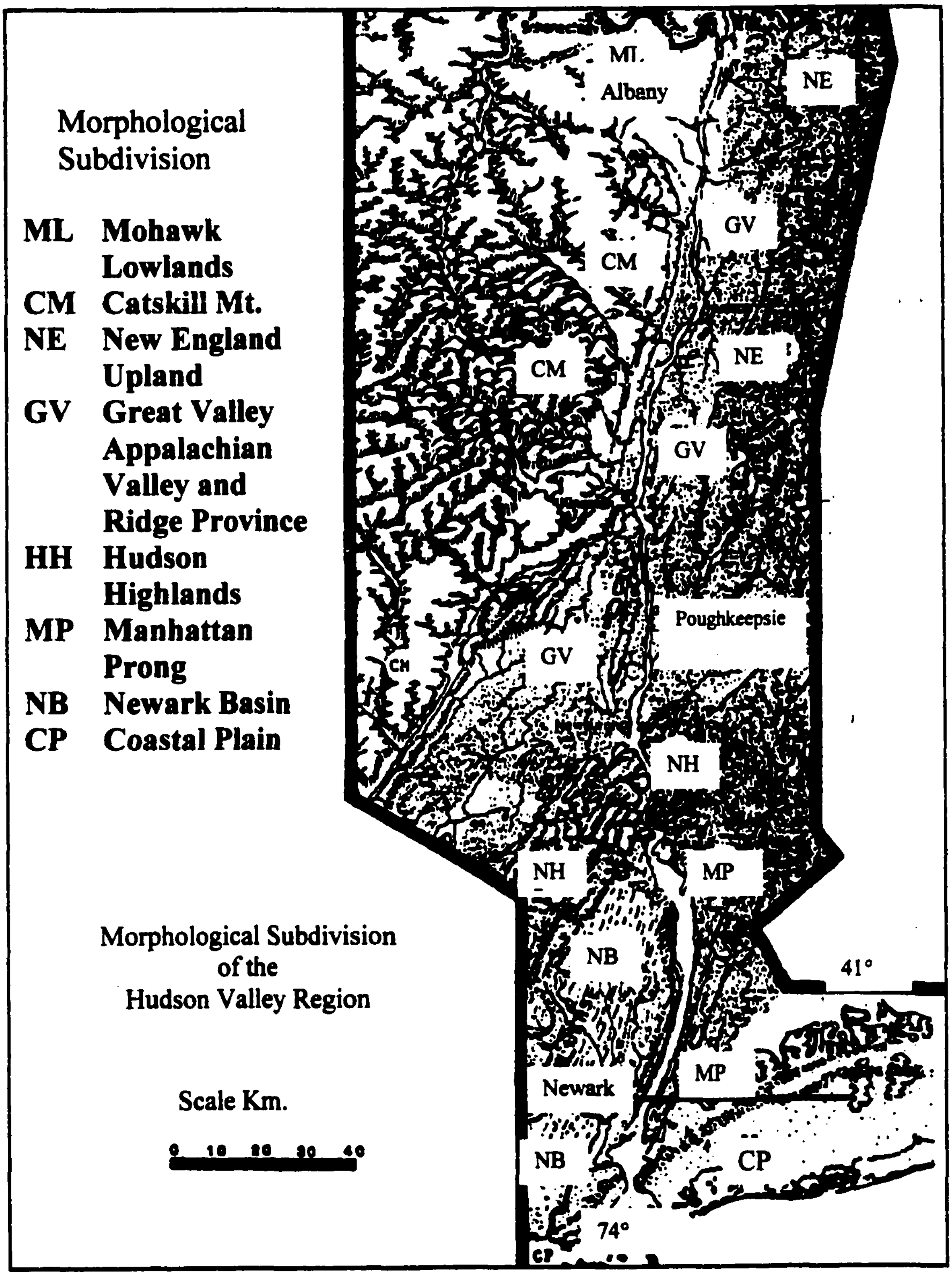

Figure 2. Morphological division of the Hudson Valley region. (Coch, 1986, figure 2, p. 98)

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It is believed that during the Miocene Epoch (24 – 5 m.y. ago), the ancestral Hudson River flowed through the Hudson Highlands to Piermont, where it breached the Palisades at a low point called Sparkill Gap to run across northeastern New Jersey. There, it joined the Atlantic Ocean, perhaps through what is now Raritan Bay or Delaware Bay. By the Pliocene Epoch (5 – 1.6 m.y. ago), the river was flowing along what is today the western margin of the Hackensack Meadows, crossing the Palisades at Bayonne, New Jersey, joining the Atlantic Ocean through the Upper Bay (Lovegreen, 1974). During the Pleistocene glaciations (1.6 – 0.01 m.y. ago), however, glacial erosion deepened the Hudson Highlands Gorge, causing the melt-water to be impounded between the terminal moraines and the melting ice front during interglacial periods. Sedimentary evidence of such pro-glacial lakes, such as the Glacial Lake Hudson between the New York Highlands and The Narrows in the Hudson Valley, has been provided by Newman *et al.*, (1969); Lovegreen (1974) has provided such evidence for the Newark Lowlands.

During post-Wisconsinian time, when glacial deposits blocked the river's westward flow through Sparkill Gap, the river was forced to carve its present valley in the weak rocks of the Newark Lowlands, between the resistant rocks of the Palisades to the west and the equally resistant metamorphic rocks of the Manhattan Prong to the east (Lovegreen, 1974). With the rise of sea level in post-Wisconsinian time, saline water intruded into the river, converting its lower portion into a tidally controlled estuary. Using foraminifers as a stratigraphic and paleoecologic tool for investigations of the late Pleistocene Epoch, Weiss (1974) showed that the Hudson River estuarine condition was established well before 12,000 B.P. South of the Battery, the river leaves its rocky channel and flows into the Upper Bay of New York Harbor on the Coastal Plain. The

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Coastal Plain in the New York area is the surface of Pleistocene glacial deposits overlying Cenozoic and Cretaceous sediments. The Harbor Hill Moraine is now breached at the Narrows.

Information on the subsurface stratigraphy and geology of the Hudson Basin (**Fig.3**) became available from seismic reflection studies (Worzel and Drake, 1959), records of borings made prior to the construction of bridges and channels (Newman *et al.*, 1969; Lovegreen, 1974), and shallow exploratory borings (Weiss, 1974; Bekuniewicz and Fray, 1979). These studies suggest that the Hudson River channel has cut into its bedrock, and is filled with till, lacustrine (glacial lake) sediments, and organic silts (Newman *et al.*, 1969). The Hudson River in the study area flows along the boundary between two major geologically different provinces, Newark Basin to the west and the Manhattan Prong of the New England Uplands to the east. To the east, are the highly metamorphosed Protrozoic to Lower Paleozoic rocks of the Manhattan Prong, which widens northeastward into the crystalline terrain of New England. Southward from New York City, the rocks of the Manhattan Prong plunge unconformably under the Mesozoic rocks of the Newark Group in New Jersey.

Rocks making up the Manhattan Prong are classically divided into three major stratigraphic units: the Fordham Gneiss, Inwood Marble, and Manhattan Schist (Merrill, 1890). This metamorphic "basement complex" resulted from two major orogenic events: (1) The Greenville Orogeny (lasting about 700 million years and dated at 1100 Ma) and (2) the Appalachian Cycle, beginning about 570 Ma and ending at 260 Ma. The Appalachian Cycle included three orogenic episodes: The Taconic (450 Ma), Acadian (365 Ma), and Appalachian Terminal (*ca.* 260 Ma) periods. Southeast of the Hudson

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Highlands, the Greenville rocks consist of Fordham Gneiss, which is best exposed in Westchester County and The Bronx. The Inwood Marble is best exposed in Inwood Park, at the north end of Manhattan, and the Manhattan Schist in Manhattan. The Inwood and Manhattan Schist formations (Cambro – Ordovician rocks) unconformably overlie the Fordham Gneiss.

The bedrock stratigraphy of NYC is best explained in the context of sequence stratigraphy. During Early Paleozoic time (Cambrian – Lower Ordovician) the present eastern part of North America formed a broad continental shelf near today's Tropical area. Shallow-water carbonates and clastic sediments (Sauk Sequence) accumulated on the shelf. Farther offshore, a succession of rocks stratigraphically equivalent to the shelf Sauk Sequence and part of the overlying Tippicanoe Sequence accumulated, that is, the shelf-to-slope transition Taconic Sequence of poorly bedded silt and turbidities (middle unit of the Manhattan Schist-∈–Om) and the deep-water shales, turbidites, and intercalated volcanic rocks (Hartland Terrane- ∈-Oh). During the Taconic orogeny, rocks of both the Shelf and Taconic sequences became folded and metamorphosed. Rocks making up the Sauk and Tippicanoe Sequences were metamorphosed (during the Appalachian Cycle) to form the Lowerre Quartzite, Inwood Marble, and the lower unit of the Manhattan Schist (∈-Om) in New York City. Later thrusting and long-distance transport of the Taconic Sequence over the rocks of Shelf Sequence led to further imbrication of the Shelf and Taconic Sequences. In southeastern New York, Cameron's Line and the St. Nicholas thrust faults mark the closure of the marginal ocean basin separating the Taconic arc from the North American mainland (Sanders and Merguerian, 1997).

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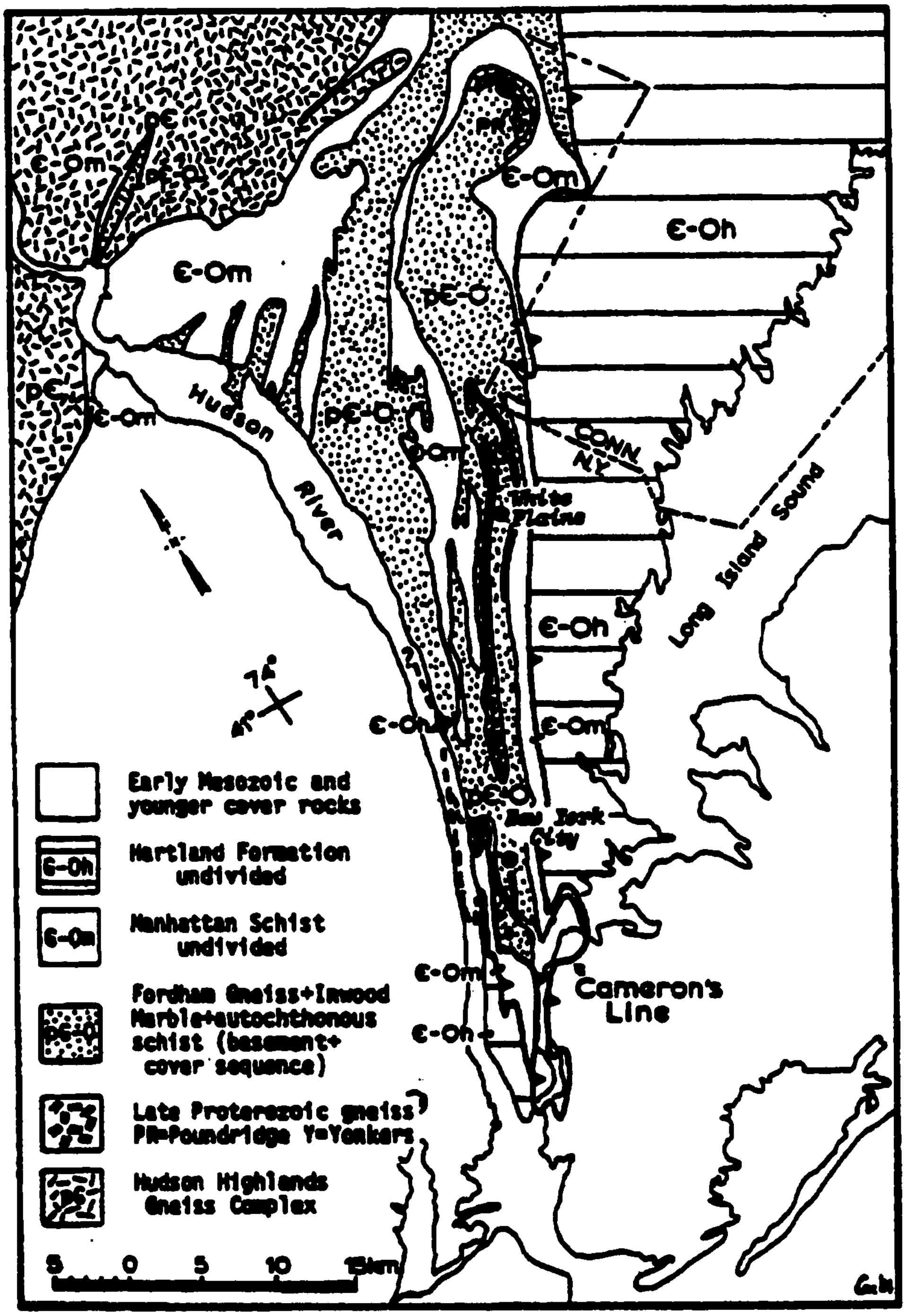

Figure 3. Simplified geologic map of the Manhattan Prong showing the distribution of metamorphic rocks ranging from Protrozoic to Early Paleozoic in age. (Sanders and Merguerian, 1997, figure 3, p. 55)

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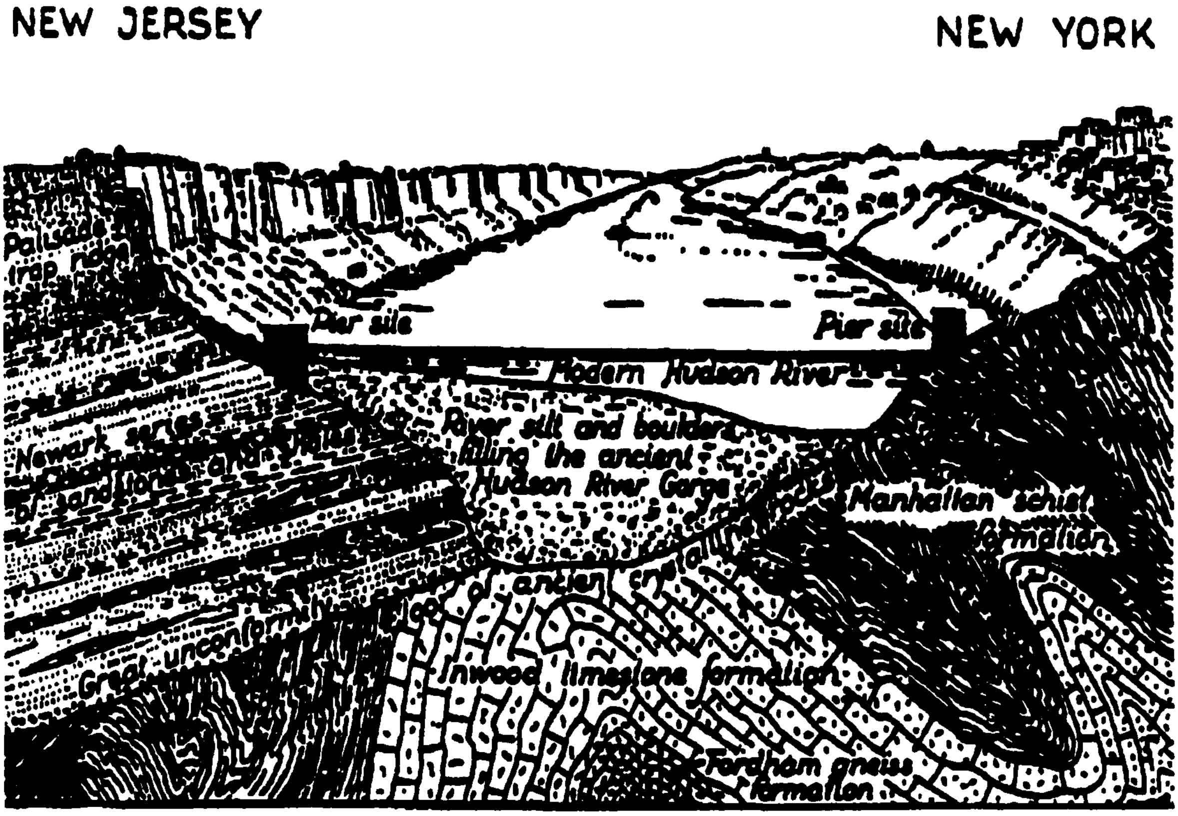

Figure 4. Interpretive geological section across the Hudson River in the vicinity of George Washington Bridge (Sanders and Merguerian, 1997, figure 4, p. 56)

On the west, the Hudson River is bounded by Newark Basin-filling strata dipping 10-15 degrees west, with the Palisades Sill making a sharp cliff along the Hudson River. Altitudes at the top of the Palisades ridge vary from 800 feet at High Tor (Haverstraw) to 300 feet at the George Washington Bridge, to sea level on Staten Island. Borings also disclose that the depth to bedrock beneath the river ranges from 350 feet at the George Washington Bridge to 950 feet at the Tappan Zee Bridge (Sanders and Merguerian, 1997). **Figure 4** shows a cross-sectional profile across the Hudson River at the George Washington Bridge. The Newark strata are entirely non-marine, fluvial and lake deposits,

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including, from the oldest to the youngest, Stockton Arkose, Lockatong Formation, and Brunswick Formation. The Newark strata unconformably overlie the "basement complex." The Palisades Sill intruded the Lockatong Fm. at a level about 400 m above the base of the Newark strata. The Palisades ridge extends for roughly 65 km along the west side of the Hudson River, from west of Haverstraw southwestward to Staten Island, where it passes beneath an intertidal salt marsh and continues southward into New Jersey and Pennsylvania within the Delaware subbasin (Sanders and Merguerian, 1997).

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Chapter 2: Field and Laboratory Methods

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2.1. Field Methods

2.1.1. Sampling Design

The sampling design was to replicate the survey of City University of New York studies in the 1970's. This original survey included a grid sampling design from the Battery to Haverstraw Bay, with transverse lines approximately one kilometer apart and some 60 stations to study the bivalve distribution in the Lower Hudson Estuary. Grid sampling is also the method of choice when estimating trends and patterns of contamination over space, especially for estimating the mean contamination when no trends or patterns of concentrations are known. Despite some degree of statistical bias, a grid sampling method provides a more uniform coverage than simple random sampling does for determining spatial variations in trace metal contaminants in a region-wide study.

To meet the objectives of this study, surficial bottom sediment samples were taken from 97 stations along 33 cross-river transects spaced approximately one kilometer apart, extending from The Battery, New York (km 0) to Haverstraw Bay (km 67). **Figure 5** shows the location of sampling stations in the study area. Cross-river transects are arranged with Transect 20 at the upstream end (Haverstraw Bay) and Transect 34 at the downstream end (Battery) of the study area. Each cross-river transect includes 2 to 5 sampling stations, depending on the width of the river. Each sampling station is designated by two symbols: a numeral indicating the transect number followed by a letter A, B, C, D, or E. Locations along the New Jersey shoreline are indicated by the letter A, the B locations in the mid- river position, and the C, D, and E locations are generally along the New York shoreline.

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The sampling program was conducted in the Summer of 1997 over a period of four days: on August 12-14, using the New Jersey Marine Science Consortium's 25-foot research vessel *Victoria*, and on September 4, using the Consortium's 55-foot research vessel *Lionel Walford*. Additional bottom samples were collected from the research vessel *Lionel Walford* on October 24, 1998. Station positions were fixed by a Trimble Navigation NavTracXL GPS and a NavGraphicXL GPS respectively, each with an accuracy of ± 50 feet (15 meters). Latitudes and longitudes were calculated for GPS-plotted positions from navigational charts of New York Harbor- Hudson River (89th Edition, NOAA, 1995b) and Hudson River- New York to Wappinger Creek (17th Edition, NOAA, 1996).

2.1.2. Sample Collection and Data Processing

Surficial bottom sediment samples were collected at each station using a Peterson or Smith-McIntyre grab sampler. The grab samples were accepted upon retrieval when (1) the jaws of the grab sampler were closed properly, and (2) the surface of the sediment was not significantly disturbed. All sediment sample collection and processing activities were conducted in accordance with U. S. EPA Environmental Monitoring and Assessment Program (EMAP) protocols (USEPA, 1993b). The EMAP field methods for chemistry sampling require that only the top 2 cm of sediment for each grab sample be collected for chemical analysis.

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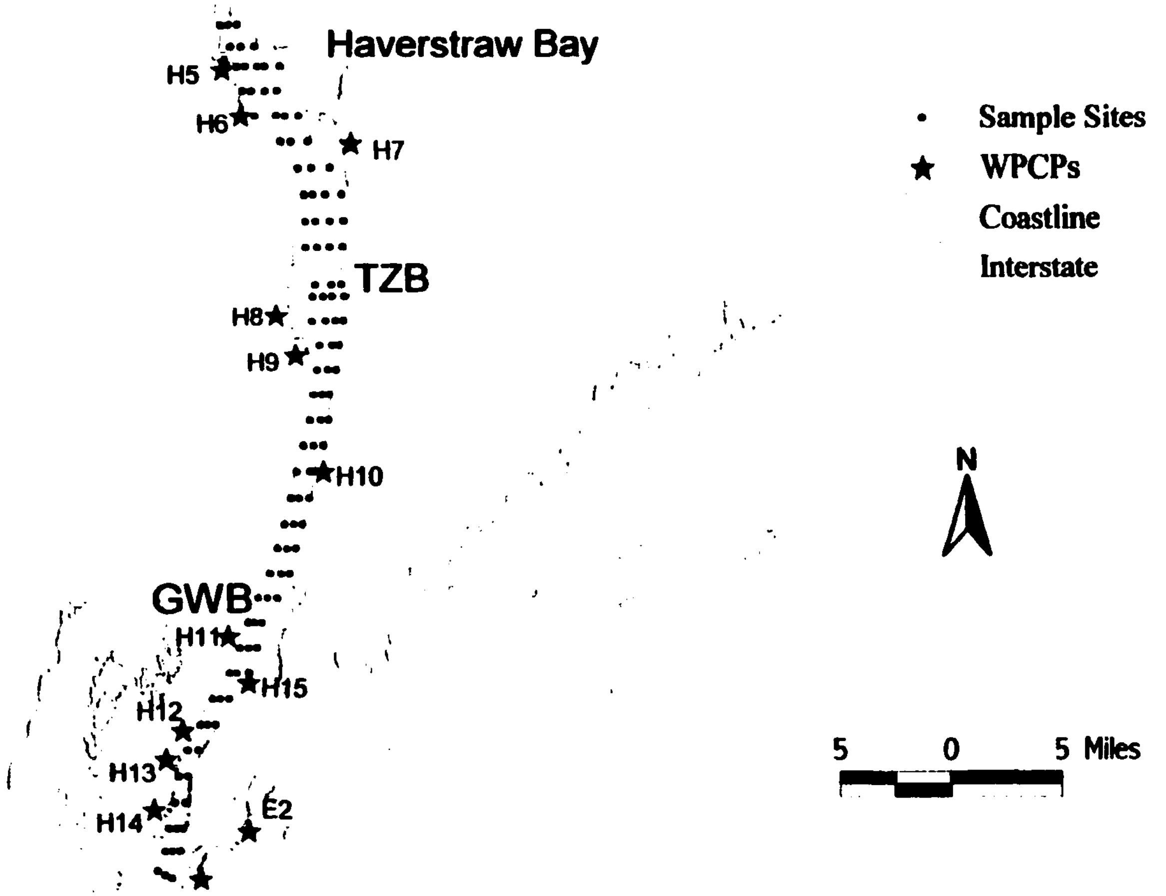

Location of Sediment Sampling Sites in Hudson River Estuary, Summer, 1997

Figure 5. Location of sampling sites in the study area : Battery (km 0) to Haverstraw Bay (km 60)

Upon retrieval, the grab sampler was placed over a stand, the jaws were opened, and the top 0.5 to 1 cm of sediment was spooned into a Whirl-Pack plastic (2-oz; 3 by 5 inches) sample bag. Immediately on collection, sediment samples were described in terms of their color and type (i.e., mostly gravelly, silty, sandy, and muddy) and the depth at which the grab was collected was recorded. To minimize the effects of chemical/ biological activity in the samples, the plastic bags containing sediment samples were then frozen stored on ice (shipboard ice chest) prior to laboratory analysis.

Water quality parameters (including percent dissolved oxygen, temperature, conductivity, pH, Eh, and salinity) were measured at each sampling site from within one foot of the water surface and one foot of the bottom with a Hydrolab Corp. Data Sonde 3, Model 100012, submersible water quality data logger or Hydrolab Corp. Scout 2 Water Quality System data probe Sonde. A summary of site-specific, water parameters, and sediment descriptions for 1997 sampling is presented in **Table 2**.

Eleven of the summer 1997 downriver stations with trace metal concentrations exceeding the ER-M values (see USEPA adopted sediment quality screening values in **chapter** 4, Sec. 4.3.) for at least one measured trace metal were selected for additional sampling. Sampling at these stations was conducted on October 24, 1998, from the New Jersey Marine Science Consortium's R/V *Lionel Wolford*. A Hydrolab Corp. Scout 2 Water Quality System was used to measure the water parameters pH, temperature, dissolved oxygen, salinity and water depth. A summery of site-specific, water parameters, and sediment descriptions for 1998 sampling is presented in **Table 3.**

The current velocities (knots) and directions (Flood and Ebb) at each sampling station, at the time of sampling, were computed based on daily current predictions at

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reference stations in the study area, reported in the NOS publication Tidal Current Tables – Atlantic Coast (**Appendix A**). The reference stations used are: The Narrows, Statue of Liberty, Hudson River Entrance (The Battery), Grant's Tomb, the George Washington Bridge, Sputen Duyvil, Riverdale, Mt. St. Vincent College, Dobbs Ferry, Tarrytown, Ossining, Haverstraw, and Peekskill.

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Table 2. Water Parameters and Sediment Descriptions at Sampling Sites from Lower Hudson Estuary, August – September 1997

Sites	LAT (deg)	LONG (deg)	WD (m)	Temp (S) (°C)	Temp (B) (°C)	Sal ppt (S)	Sal ppt (B)	% DO (S)	%DO (B)	% OS (S)	%OS (B)	pH (S)	pH (B)	Eh (S) mv	Eh (B) mv	Sediment Description
T34A	40.7019	74.0325	14.7	23.34	22.60	19.1	24.9	4.80	3.88	65.3	63.9	7.11	7.36	400	388	Gray silty mud, with a substantial amount of shell fragments, brick chips, and gravel pieces
T34B	40.7019	74.0267	18.3	23.87	23.38	17.7	23.1	5.21	4.27	68.6	55.8	7.27	7.30	360	366	Gray silty mud, with angular gravel pieces (~ 1 cm across), shell fragments.
T33A	40.7167	74.0292	11.7	22.94	22.75	23.0	25.7	5.19	4.36	68.6	59.3	7.45	7.51	359	363	Gray silty mud with some brick chips and gravel pieces
T33B	40.7167	74.0233	14.3	22.24	22.73	21.8	25.1	5.65	4.29	73.5	58.8	7.48	7.52	360	365	Gray silty mud with some brick chips and gravel pieces
T33C	40.7167	74.0183	10.7	21.61	22.59	22.5	25.7	5.34	4.42	67.5	59.8	7.48	7.51	351	360	Gray silty mud, a few shell fragments, gravel pieces
T32A	40.7333	74.0239	16.8	24.36	23.40	15.3	23.2	5.63	3.88	73.8	51.6	7.31	7.33	379	384	Gray silty mud, a few shell fragments, gravel pieces
T32B	40.7333	74.0153	19.4	24.25	22.94	15.5	23.8	5.71	3.85	74.8	51.5	7.30	7.33	367	376	Gray silty mud, with a few whole shells and shell fragments
T31A	40.7500	74.0200	14.3	22.48	22.59	18.9	19.3	5.37	4.83	67.5	64.1	7.03	7.08	353	357	Gray silty mud, shell fragments, and a few rounded gravel pieces
T31B	40.7500	74.0128	13.1	21.28	22.81	19.3	24.9	5.34	4.02	66.0	53.4	7.11	7.22	354	363	Gray silty mud, shell fragments, and a few rounded gravel pieces (~0.5 cm across)
T30A	40.7667	74.0122	16.5	24.53	23.69	13.8	21.6	6.03	4.08	78.4	54.3	7.31	7.34	366	372	Gray silty mud with a few shell fragments
T30B	40.7667	74.0036	17.0	24.69	23.56	14.0	20.2	5.96	4.21	80.3	56.3	7.32	7.34	366	374	Gray silty mud with only three shell fragments
T29B	40.7833	73.9953	17.4	19.67	22.50	19.6	25.4	5.43	3.96	65.6	53.2	7.21	7.32	369	370	Gray silty sand, shell fragments, wood pieces, and some brick fragments
T29C	40.7833	73.9883	8.8	21.03	22.90	18.9	22.1	5.45	4.54	68.5	66.6	7.29	7.27	356	357	Gray silty mud with some shell fragments

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Table 2. Water Parameters and Sediment Descriptions at Sampling Sites from Lower Hudson Estuary, Continued

Sites	LAT (deg)	LONG (deg)	WD (m)	Temp (S) (°C)	Temp (B) (°C)	Sal ppt (S)	Sal ppt (B)	% DO (S)	%DO (B)	% OS (S)	%OS (B)	pH (S)	pH (B)	Eh (S) mv	Eh (B) mv	Sediment Description
T28A	40.8000	73.9900	15.8	25.10	25.02	13.7	14.0	6.21	5.87	80.7	77.0	7.33	7.33	356	345	Gray silty mud, with a few small shell fragments
T28B	40.8000	73.9839	10.1	25.06	24.23	13.3	22.2	6.07	4.79	79.4	50.8	7.31	7.35	363	373	Gray silty mud with only two shell fragments
T28C	40.8000	73.9772	1.8	24.99	23.78	12.8	19.6	6.56	4.32	85.5	57.3	7.31	7.34	358	369	Gray silty mud, with a few shell fragments, brick chips
T27A	40.8167	73.9761	7.0	21.50	22.83	18.2	24.1	5.18	4.00	65.8	51.7	7.26	7.31	353	366	Gray silty mud, with a few shell fragments, brick chips
T27B	40.8167	73.9700	13.1	21.20	22.96	18.7	23.4	5.34	3.97	66.0	53.1	7.29	7.35	354	364	Gray silty mud, with a substantial amount of shell fragments, brick chips and gravel pieces
T27C	40.8167	73.9656	7.9	21.80	22.81	18.3	23.5	5.60	4.00	69.2	52.3	7.31	7.33	356	363	Gray silty mud, with a few shell fragments
T26A	40.8333	73.9669	4.6	25.19	24.75	12.5	15.6	6.16	5.17	80.7	67.5	7.33	7.34	362	364	Gray silty mud containing some shell fragments
T26B	40.8333	73.9594	25.9	25.34	23.98	12.4	20.0	6.43	4.26	83.0	56.3	7.32	7.33	360	371	Gray silty mud containing some shell fragments
T26C	40.8333	73.9525	6.1	25.26	24.45	13.3	18.1	6.35	4.83	84.3	63.2	7.32	7.33	354	362	Gray silty mud, with few shell fragments
T25A	40.8500	73.9583	5.5	22.14	22.96	17.0	22.0	5.42	4.04	68.3	52.0	7.32	7.34	354	365	Gray silty mud, with few shell fragments
T25B	40.8500	73.9539	11.9	21.42	22.98	19.0	23.1	5.47	3.95	69.0	52.0	7.34	7.39	394	380	Gray silty mud, with few shell fragments
T24A	40.8667	73.9492	5.8	25.67	24.88	11.5	16.0	6.42	5.26	85.9	69.4	7.33	7.34	343	336	Gray silty mud, with few shell fragments
T24B	40.8667	73.9425	10.1	25.41	24.14	11.8	18.9	6.64	4.45	86.9	60.2	7.32	7.34	346	359	Gray silty mud, with a few shell fragments
T24C	40.8667	73.9347	11.9	25.58	24.12	11.9	17.1	6.82	4.16	90.5	62.3	7.31	7.35	340	357	Light gray sandy silty mud, a few shell fragments
T23A	40.8833	73.9397	4.9	21.24	23.02	15.0	20.1	6.23	4.26	78.9	53.8	7.37	7.38	343	357	Gray sandy, with substantial shell fragments, brick chips and a few gravel pieces
T23B	40.8833	73.9303	10.1	22.10	23.20	17.8	20.9	5.82	4.06	74.4	53.6	7.43	7.46	366	370	Gray sand, with substantial shell fragments

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Table 2. Water Parameters and Sediment Descriptions at Sampling Sites from Lower Hudson Estuary, Continued

Sites	LAT (deg)	LONG (deg)	WD (m)	Temp (S) (°C)	Temp (B) (°C)	Sal ppt (S)	Sal ppt (B)	% DO (S)	%DO (B)	% OS (S)	%OS (B)	pH (S)	pH (B)	Eh (S) mv	Eh (B) mv	Sediment Description
T23C	40.8833	73.9236	11.3	22.62	23.29	16.4	20.9	5.74	4.06	72.1	53.6	7.43	7.45	365	370	Gray sand, with substantial shell fragments
T22A	40.9000	73.9322	3.7	25.90	25.82	10.7	11.3	6.88	6.30	89.3	81.9	7.32	7.33	338	340	Dark gray mud, with a few small shell fragments, sediment stinks
T22B	40.9000	73.9247	9.1	25.67	24.34	10.4	19.7	6.43	4.02	85.1	51.9	7.32	7.33	351	367	Gray silty mud, a few shells and gravel pieces (3-5 mm across)
T22C	40.9000	73.9175	14.0	25.64	24.20	11.8	18.8	6.56	4.21	89.0	54.5	7.32	7.34	350	354	Gray silty mud, with some shell fragments
T1A	40.9167	73.9253	6.4	23.25	23.41	14.2	18.2	6.71	4.56	85.5	57.5	7.38	7.42	330	350	Light gray silty mud, with a few shell fragments
T1B	40.9167	73.9192	14.3	22.45	23.21	16.0	17.8	5.95	4.81	74.6	61.9	7.41	7.44	340	353	Light gray silty mud, with a few shell fragments
T1C	40.9167	73.9125	13.4	22.53	23.38	15.0	18.0	5.65	4.41	71.5	58.0	7.41	7.44	360	359	Light gray silty mud, with a few shell fragments
T2A	40.9333	73.9208	3.7	25.77	25.25	9.7	14.2	6.74	5.02	90.5	64.1	7.33	7.34	348	360	Dark gray silty mud containing a few small shells, some twigs
T2B	40.9333	73.9142	13.7	25.66	24.09	10.6	19.3	6.15	4.11	87.0	55.2	7.33	7.36	338	356	Light gray silty mud containing some shell fragments
T2C	40.9333	73.9064	11.3	25.67	24.51	11.0	17.5	6.23	4.30	82.7	57.2	7.32	7.35	332	347	Gray silty mud, shell fragments, wood chips, gravel pieces
T3A	40.9500	73.9153	2.4	26.39	24.73	10.0	14.9	5.72	4.54	76.9	59.7	7.35	7.36	270	288	Gray mud with two shell fragments, smelling during crushing
T3B	40.9500	73.9042	13.7	26.50	24.53	9.6	17.6	6.30	4.18	87.1	55.1	7.36	7.37	260	293	Gray silty mud with three shell fragments
T3C	40.9500	73.9008	25.9	26.14	25.96	10.8	11.1	6.18	6.62	86.3	87.8	7.36	7.36	266	275	Gray muddy sand
T4A	40.9667	73.9078	5.8	25.81	24.97	9.3	14.7	6.94	4.88	91.0	63.0	7.33	7.34	341	339	Gray muddy sand, with a few hair strands
T4B	40.9667	73.9008	12.5	25.84	24.18	9.8	17.9	6.84	4.34	94.4	57.2	7.33	7.35	324	348	Gray silty mud, containing some shell fragments and gravel pieces
T4C	40.9667	73.8931	5.8	25.77	25.66	10.3	10.7	7.23	6.85	96.1	90.2	7.34	7.34	330	333	Gray silty mud, substantial amount of shell fragments

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Table 2. Water Parameters and Sediment Descriptions at Sampling Sites from Lower Hudson Estuary, Continued

Sites	LAT (deg)	LONG (deg)	WD (m)	Temp (S) (°C)	Temp (B) (°C)	Sal ppt (S)	Sal ppt (B)	% DO (S)	%DO (B)	% OS (S)	%OS (B)	pH (S)	pH (B)	Eh (S) mv	Eh (B) mv	Sediment Description
T5A	40.9833	73.9028	4.3	26.20	25.82	9.6	9.8	6.47	6.37	86.2	82.9	7.36	7.36	280	284	Gray mud with two shell fragments, smelling during crushing
T5B	40.9833	73.8942	14.3	26.11	24.69	9.0	15.8	6.09	4.31	82.8	56.6	7.34	7.37	280	304	Gray sandy mud with brick chips, shell fragments and fine gravel pieces
T5C	40.9833	73.8875	6.1	26.35	25.32	10.3	13.8	6.34	4.85	83.2	63.3	7.34	7.35	284	301	Gray silty mud with two shell fragments and onepiece of gravel
T6A	41.0000	73.8992	5.8	25.92	25.66	8.8	11.0	6.81	6.30	92.6	81.4	7.34	7.35	329	337	Gray silty mud, a few shell fragments
T6B	41.0000	73.8925	11.3	25.88	24.84	9.3	16.3	7.15	4.55	97.5	58.4	7.34	7.36	327	350	Gray silty mud, a few shell fragments and some gravel
T6C	41.0000	73.8867	4.6	25.84	24.88	10.4	14.7	6.68	4.76	87.2	61.8	7.33	7.35	331	346	Gray silty mud, with some shell fragments and a few pieces of paper
T7B	41.0167	73.8875	13.7	26.11	24.95	8.7	14.7	5.88	4.53	81.0	59.1	7.33	7.36	296	313	Gray silt, with lots of wood chips, shell fragments, brick pieces, angular gravel pieces
T7C	41.0167	73.8811	3.1	26.41	26.29	9.2	9.7	6.23	6.87	83.6	90.9	7.34	7.34	297	297	Gray sandy silty mud with a little gravel and a few wood chips
T8A	41.0333	73.8942	4.0	26.05	25.51	8.7	11.3	7.18	5.68	96.7	72.3	7.34	7.35	317	333	Gray silty mud
T8B	41.0333	73.8833	16.8	26.16	24.73	8.8	14.9	7.55	4.64	100.2	60.5	7.34	7.37	315	340	Gray silty mud, containing three shells and two gravel pieces
T8C	41.0333	73.8775	4.6	25.84	25.62	9.0	11.4	6.96	6.13	92.9	79.0	7.34	7.35	316	327	Gray silty mud containing some shells, a relatively construction material, wood chips
T9A	41.0500	73.9000	2.4	26.01	25.81	9.0	9.0	5.93	6.03	77.1	78.5	7.33	7.33	296	300	Gray sandy silty mud with a few shell fragments
T9B	41.0500	73.8883	4.9	25.92	25.53	8.3	9.9	5.88	5.39	78.5	69.7	7.33	7.34	295	304	Gray sandy mud with a substantial amount of construction material and shell fragments
T9C	41.0500	73.8800	11.6	26.50	25.19	8.1	13.3	6.96	4.83	90.4	63.3	7.32	7.35	294	311	Gray silty mud with a few shell fragments and a little gravel

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Table 2. Water Parameters and Sediment Descriptions at Sampling Sites from Lower Hudson Estuary, Continued

Sites	LAT (deg)	LONG (deg)	WD (m)	Temp (S) (°C)	Temp (B) (°C)	Sal ppt (S)	Sal ppt (B)	% DO (S)	%DO (B)	% OS (S)	%OS (B)	pH (S)	pH (B)	Eh (S) mv	Eh (B) mv	Sediment Description
T9D	41.0500	73.8733	1.8						Hydrolab has shut itself off.							Silty mud with one piece of gravel
T10A	41.0667	73.8992	2.7	24.88	25.06	8.4		6.25	6.50	79.5		7.30		333		Silty mud with one piece of gravel
T10B	41.0667	73.8900	3.7	24.18		9.0		8.75	11.30	86.9		7.30	7.31	328	336	Gray silty mud, with only two shell fragments
T10C	41.0667	73.8825	13.1						Hydrolab has shut itself off.							Gray silty mud, with a substantial amount of shell fragment and gravel
T11A	41.0750	73.8967	3.7	25.12	25.39	8.3	8.3	5.86	6.05	76.0	77.8	7.32	7.32	301	303	Gray silty mud with one big shell
T11B	41.0750	73.8825	13.4	25.66	24.89	8.1	13.2	7.04	4.73	92.7	61.5	7.32	7.35	294	314	Gray silty mud with a little gravel and wood chips
T11C	41.0750	73.8742	2.1						Hydrolab has shut itself off.							Gray muddy silt with only one gravel piece
T12A	41.1000	73.9042	2.7	24.40	25.08	8.5	8.5	6.97	6.34	85.4	80.7	7.31	7.32	322	322	Gray silty mud, with a few shell fragments
T12B	41.1000	73.8941	3.4	24.49	25.12	8.4	9.7	6.95	5.67	85.4	72.3	7.31	7.32	320	327	Gray silty mud, with about 80% shell fragments, a few pieces of brick, and some gravel
T12C	41.1000	73.8833	8.5	25.19	25.28	8.5	10.2	6.54	5.69	83.7	73.2	7.32	7.33	322	330	Gray muddy silt, with a few brick chips, shell fragments, wood chips
T12D	41.1000	73.8725	3.1	24.21	25.15	9.2	9.5	8.36	5.95	8.3	76.8	7.31	7.32	333	333	Gray silty mud, with only one piece of shell fragment
T13A	41.1167	73.9042	3.7	25.32	25.43	7.6	8.3	6.53	5.95	84.7	76.5	7.31	7.32	297	305	Gray sandy mud with pieces of iron staining, shell fragments
T13B	41.1167	73.8958	3.7	25.60	25.75	7.6	8.2	6.88	6.07	87.1	78.2	7.31	7.32	295	303	Gray sandy silty mud with a substantial amount of shells, pieces of woody tissue and gravel
T13C	41.1167	73.8833	7.6	25.10	25.04	7.6	11.6	6.19	4.91	80.7	63.3	7.31	7.32	294	310	Gray sandy silty mud with a substantial amount of shells and gravel
T13D	41.1167	73.8717	3.1	25.02	25.28	7.9	9.0	6.40	5.80	81.0	73.7	7.31	7.32	292	300	Gray sandy silty mud, shells, pieces of woody tissue and gravel

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Table 2. Water Parameters and Sediment Descriptions at Sampling Sites from Lower Hudson Estuary, Continued

Sites	LAT (deg)	LONG (deg)	WD (m)	Temp (S) (°C)	Temp (B) (°C)	Sal ppt (S)	Sal ppt (B)	% DO (S)	%DO (B)	% OS (S)	%OS (B)	pH (S)	pH (B)	Eh (S) mv	Eh (B) mv	Sediment Description
T14B	41.1333	73.8975	6.1	24.20	25.15	7.7	10.2	7.21	5.28	87.8	67.4	7.31	7.33	331	339	Gray muddy silt, with a few shell, wood, and gravel pieces
T14C	41.1333	73.8867	8.8	24.29	25.15	7.3	10.8	7.05	5.26	97.0	67.6	7.31	7.33	323	334	Gray muddy silt, with few shell, wood, and gravel pieces
T14D	41.1333	73.8725	2.7	24.82	25.23	7.3	7.5	6.80	6.43	85.0	81.4	7.32	7.32	323	325	Gray muddy silt, with a few shell, wood, and gravel pieces
T15A	41.1500	73.9094	3.1	25.38	25.49	6.6	6.9	6.54	5.95	81.3	75.5	7.30	7.31	296	303	Gray silty mud with a few shell fragments
T15B	41.1500	73.8983	9.5	25.26	25.13	6.9	12.0	6.71	4.84	85.7	62.7	7.30	7.33	295	312	Gray silty mud with a few pieces of twigs
T15C	41.1500	73.8825	2.7	24.99	25.34	7.8	8.1	6.30	5.67	80.1	71.9	7.31	7.31	295	302	Silty mud with one piece of gravel
T16A	41.1667	73.9231	9.1	25.02	25.54	6.7	7.5	6.46	5.85	80.5	74.8	7.32	7.33	335	313	Gray muddy silt, with a few angular pieces of gravel
T16B	41.1667	73.9158	12.8	25.26	25.45	6.8	9.3	6.50	5.16	81.4	66.4	7.32	7.34	333	340	Gray sandy mud with some construction material, shells, gravels
T16C	41.1667	73.9008	4.9	25.12	25.47	6.6	7.0	6.48	5.99	82.1	76.2	7.32	7.33	331	333	Gray muddy sand, shells, a few pieces of gravel
T17A	41.1833	73.9458	2.7	24.95	25.71	5.9	6.0	6.68	6.07	83.2	76.5	7.31	7.31	295	300	Gray muddy silt with one shell
T17B	41.1833	73.9275	8.8	25.21	25.32	6.5	9.8	6.78	4.77	84.3	61.9	7.30	7.32	293	307	Gray muddy silt with one shell
T17C	41.1833	73.9200	3.7	25.02	25.47	6.5	7.2	6.61	5.64	82.1	71.8	7.30	7.31	287	299	Gray sandy mud with several shell fragments, twigs, and brick chips
T17D	41.1833	73.9083	3.7	23.81	25.02	6.7	6.7	6.45	5.84	78.1	72.9	7.30	7.31	283	288	Gray silty mud with a few shells
T18A	41.2000	73.9553	3.1	25.84	26.01	6.1	6.3	6.23	5.72	80.1	73.3	7.32	7.33	307	310	Gray silty mud with a few shells
T18C	41.2000	73.9375	8.2	25.41	25.67	6.0	6.9	6.34	5.30	80.4	68.2	7.32	7.33	290	296	Gray silty mud with a few pieces of twigs
T18D	41.2000	73.9269	7.0						Hydrolab has shut itself off.							Gray silty mud, with a few shell fragments

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Table 2. Water Parameters and Sediment Descriptions at Sampling Sites from Lower Hudson Estuary, Continued

Sites	LAT (deg)	LONG (deg)	WD (m)	Temp (S) (°C)	Temp (B) (°C)	Sal ppt (S)	Sal ppt (B)	% DO (S)	%DO (B)	% OS (S)	%OS (B)	pH (S)	pH (B)	Eh (S) mv	Eh (B) mv	Sediment Description
T19A	41.2167	73.9611	7.0	25.60	25.75	5.9	7.9	6.08	5.45	76.3	69.6	7.31	7.32	327	333	Gray sandy mud with several shell fragments, twigs, and brick chips
T19B	41.2167	73.9542	9.1		25.40	5.9	8.3	6.46	5.38	78.7	68.9	7.31	7.33	323	329	Gray silty mud with a few pieces of twigs
T19D	41.2167	73.9375	4.3	24.21	25.15	6.2	6.7	6.51	5.90	79.9	74.6	7.30	7.31	297	305	Gray sandy silty mud with pieces of twigs and wood chips
T19E	41.2167	73.9242	3.1	24.42	25.13	6.4	6.5	6.60	5.81	81.2	73.2	7.30	7.31	282	295	Gray silty mud with one small shell fragment
T20A	41.2306	73.9667	5.4	25.38	25.84	5.2	5.5	5.92	5.75	75.5	72.7	7.33	7.33	282	288	Gray silty mud, a few shell fragments, a few angular gravel pieces
T20B	41.2306	73.9575	14.2	25.51	25.71	5.1	7.8	6.08	5.17	76.6	66.7	7.32	7.35	281	277	Gray silty mud, a few shell fragments, a few angular gravel pieces
T20C	41.2306	73.9458	5.1						Hydrolab has shut itself off.							Gray muddy silt, lots of shell fragments, gravel pieces, brick chips

Table 3. Water Parameters and Sediment Descriptions at Downriver Sites from the George Washington Bridge to the Battery, October 24, 1998

Sites	Latitude (degrees)	Longitude (degrees)		Time of Sampling EST	WD (m)	Temp. (°C)	Salinity (ppt)	%DO	%OS	pH	Sediment Description
25A	40.8500	73.9580	Surface	13:40	6.3	16.13	15.8	7.42	85.48	7.6	3-4 mm green over gray sandy mud
			Bottom	13:41		15.70	22.0	6.40	75.74	7.49	
26A	40.8330	73.9670	Surface	13:50	6.0	16.09	15.5	7.39	84.46	7.61	0.5 cm soupy green over black mud
			Bottom	13:52		15.62	22.8	6.35	75.24	7.5	
27C	40.8170	73.9660	Surface	12:26	16.3	15.82	15.3	7.45	84.28	7.64	2-3 mm green over soupy black mud
			Bottom	12:29		15.65	22.4	6.38	75.59	7.51	
28A	40.8000	73.9900	Surface	14:23	6.1	16.09	18.2	7.07	82.31	7.59	core sample: 7.5 cm green soupy over 2.5 cm green sticky mud, over 1cm.lack sticky mud.
			Bottom	14:25		15.18	24.4	6.31	74.76	7.54	
28C	40.8000	73.9770	Surface	12:11	12.7	15.92	16.0	7.19	82.17	7.62	2 mm green over sticky black mud
			Bottom	12:13		15.47	23.2	6.31	74.76		
29C	40.7830	73.9880	Surface	12:00	5.3	15.62	15.3	7.58	85.94	7.64	1 cm soupy green over black sticky mud
			Bottom	12:01		15.49	19.4	6.85	79.19	7.56	
30A	40.7670	74.0120	Surface	11:39	16.4	15.69	18.9	6.79	78.59	7.58	2.5 cm soupy green over sticky black mud
			Bottom	11:41		15.16	24.6	6.58	78.24	7.55	
31A	40.7500	74.0200	Surface	11:23	16.5	15.80	17.3	7.22	82.99	7.59	2.5 cm shelly mud
			Bottom	11:25		14.99	25.4	6.51	77.41	7.56	
32A	40.7330	74.0240	Surface	11:10	15.8	15.78	17.1	7.37	84.52	7.6	2.5 cm gravel over black sticky mud; 1 cm sample taken from below pebbles, 2.5-3.5 cm down the grab
			Bottom	11:14		14.75	26.0	6.57	77.75	7.56	
33A	40.7170	74.0290	Surface	10:34	10	15.80	17.6	7.23	82.63	7.58	< 0.5 cm green over black sticky silt
			Bottom	10:38		14.90	25.4	6.55	77.79	7.54	
34A	40.7020	74.0320	Surface	10:50	16.6	15.58	22.0	6.86	80.8	7.54	0.5 cm green over black silt
			Bottom	10:52		14.46	26.7	6.70	79.67	7.58	

%OS: Percent Oxygen Saturation
%DO: Percent Dissolved Oxygen

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2.2. Laboratory Methods

On arrival in the laboratory, thawed sediment samples were oven dried at 78°C and subsequently disaggregated using an agate mortar and pestle. These samples were then sieved through a 60-mesh nylon sieve to obtain a sediment fraction finer than 250-micrometers (find sand + silt + clay). This was done so as to facilitate comparison between this study and previous studies of Hudson River Estuary heavy metal concentrations in the finer than 250-micrometer size fraction (i.e., Williams *et al.*, 1978; NY City EPA, 1988; Adams *et al.*, 1998). The finer than 250- micrometers sediment samples were then statistically split into four sub-samples for trace metal analysis, grain size analysis, % total organic carbon (%TOC), and % total carbohydrate (TCH) analysis.

2.2.1. Trace Metal Analysis

One of the sample splits was analyzed by Activation Laboratories in Ancaster, Canada, for the trace metals Ag, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, and V in the sediment fraction using Inductively Coupled Plasma emission spectrophotometric analysis (ICP). The ICP method is based on the principle that each element, when heated to sufficient temperature, produces unique characteristic emission spectra whose intensity is proportional to the metal concentration in a solution of the element. The method requires that a 0.5 gram sediment sample be digested with aqua regia (0.6 ml concentrated HNO_3 and 1.8 ml concentrated HCl) at 95°C for 2 hours until the reaction stops. The digest is cooled and diluted to 10 ml with de-ionized water. The sample is then analyzed on a Thermo Jarrel Ash Enviro II ICP for a 30 - element suite. A matrix standard and blank are analyzed every 13 samples. **Table 4** shows a summary of the detection limits for ICP analysis.

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Table 4. Detection Limits of Elements by ICP Analysis

Analyte	Ag	Cd	Cr	Cu	Mn	Ni	Fe	Pb	Zn	V
Limit	0.2 ppm	0.5 ppm	1 ppm	1 ppm	2 ppm	2 ppm	0.01 %	2 ppm	1 ppm	2 ppm

2.2.2. Accuracy and Precision of the ICP Analytical Method

Instrumental precision (repeatability of analysis) was based on analysis of duplicate or triplicate samples. The analytical procedures (accuracy of procedures) were inter-calibrated by analysis of U.S.G.S. soil samples and of Canadian International Reference Material stream sediments. Standard reference materials used in this study are as follows: STSD-1 to STSD-4 represents typical stream sediments from various geochemical suites in Canada. STSD-1 is from Lavant Creek in Ontario. STSD-2 is a composite sample collected from British Columbia. STSD-3 and STSD-4 are each composite samples produced by mixing STSD-2 and STSD-1 in different proportions. GXR-1 is the USGS Jasperoid. GXR-2 and GXR-4 are USGS soil samples. GXR-6 is USGS Copper Mill-hand. The SRM Estuarine Sediment 1646 is provided by the U.S. National Bureau of Standards. Percent accuracy of metals analyzed using the standard reference material is shown in **Table 5**.

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Table 5. Percent Accuracy of Metals Analyzed Based on the Standard Reference Materials

Reference: STSD-1

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Ag	0.5	0.4	0.02	80.0	4.00
Cd	0.8	1	0.1	125.0	12.50
Cr	28	31	0.69	110.7	2.46
Cu	36	35	1.42	97.2	3.94
Fe	3.5	3.39	0.033	96.9	0.94
Ni	18	22	0.7	122.2	1.97
Pb	34	36	0.88	105.9	2.41
Zn	166	160	1.66	96.4	3.33
V	47	50	0.33	106.4	1.26

Reference: STSD-2

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Cd	0.8	0.9	0.06	112.5	7.50
Cr	50	57	0.94	114.0	1.88
Cu	43	43	1.42	100.0	3.30
Fe	4.1	3.96	0.03	96.6	0.73
Mn	720	857	6	119.0	0.83
Ni	47	57	0.75	121.3	0.00
Pb	66	67	2	101.5	0.00
Zn	216	216	3.38	100.0	0.00
V	58	58	0.33	100.0	0.00

Reference: STSD-3

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Ag	0.4	0.3	0.02	75.0	5.00
Cd	1	1.3	0.1	130.0	10.00
Cr	34	39	0.69	114.7	2.03
Cu	38	38	1.42	100.0	3.74
Fe	3.4	3.45	0.033	101.5	0.97
Mn	2630	3030	10	115.2	0.38
Ni	25	34	0.75	136.0	3.89
Pb	39	48	0.88	123.1	2.59
Zn	192	198	1.66	103.1	1.00
V	61	66	0.33	108.2	0.70

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Table 5. Percent Accuracy of Metals Analyzed Based on the Standard Reference Materials, continued.

Reference: STSD-4

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Ag	0.3	0.3	0.02	100.0	6.67
Cr	30	38	0.69	126.7	2.30
Cu	66	68	1	103.0	1.52
Fe	2.6	2.92	0.03	112.3	1.15
Mn	1200	1480	10	123.3	0.83
Ni	23	30	0.75	130.4	1.60
Pb	13	15	0.88	115.4	3.03
Zn	82	87	1.16	106.1	1.56
V	51	57	0.33	111.8	0.57

Reference: GXR-1

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Mn	853	928	6	108.8	0.70

Reference: GXR-2

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Ag	17	20.2	0.05	118.8	0.29
Cd	4.1	4.8	0.13	117.1	3.17
Cr	36	28	0.69	77.8	1.92
Cu	75	82	1	109.3	1.33
Fe	1.86	1.98	0.04	106.5	2.15
Ni	21	21	0.7	100.0	3.26
Zn	530	544	2.33	102.6	1.41
V	52	45	0.33	86.5	0.65

Reference: GXR - 4

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Fe	3.09	3.05	0.033	98.7	1.07
Zn	73	68	1.16	93.2	1.41

Reference: GXR - 6

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Cd	1	1.4	0.1	140.0	10.00
Cr	96	92	0.94	95.8	0.98
Cu	65	72	1	110.8	1.54

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Table 5. Percent Accuracy of Metals Analyzed Based on the Standard Reference Materials, continued.

Fe	5.58	5.7	0.04	102.2	0.72
Mn	1008	1280	10	127.0	0.99
Ni	27	29	0.7	107.4	3.00
Pb	101	116	1.33	114.9	2.26
Zn	118	112	1.66	94.9	0.86
V	186	177	0.33	95.2	0.54

Reference: Estuarine Sediment

Analyte	Certified Values (ug/g)	Analytical Values (ug/g)	Precision (+/-)	% Mean Accuracy*	+ / -
Cd	0.36 ± 0.07	0.3	0.06	86.6	17.32
Cu	18 ± 3	15	1.42	85.7	8.11
Mn	375 ± 20	241	7	64.4	1.87
Ni	32 ± 3	27	0.75	85.1	2.96
Pb	28.2 ± 1.8	26	0.88	92.6	4.04
Zn	138 ± 6	131	1.66	95.7	1.01

Mean Accuracy is determined as follows:
Accuracy = Average Sum of Errors ± slope of the regression line for each standard reference material
Error = Precision/ Certified Value
± values are the standard deviations of the mean values

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2.2.3. Percent Total Organic Carbon (%TOC)

The second finer than 250-micrometers sample split was analyzed for percent total organic carbon (%TOC) utilizing the analytical procedure of Walkley and Black (1934), as modified from Jackson (1958) by Gaudette *et al.*, (1974). This method determines the readily oxidizable organic carbon content of the sample through oxidation with potassium dichromate and concentrated sulfuric acid. The excess potassium dichromate is then back titrated with 0.5 N ferrous ammonium sulfate solution to a sharp one-drop endpoint, using 0.4% (w/v) diphenylamine in 83% sulfuric acid (v/v) as the indicator.

The required reagents:

85% phosphoric acid (H_3PO_4)

Solid sodium fluoride (NaF)

Concentrated sulfuric acid (H_2SO_4)

Standard 1 N potassium dichromate ($K_2Cr_2O_7$) solution:

Dissolve 49.4 g of $K_2Cr_2O_7$ in distilled water, dilute to one liter.

0.5 N ferrous ammonium sulfate solution:

Dissolve 196.1 g of ferrous ammonium sulfate [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$] in 800 ml of distilled water containing 20 ml concentrated H_2SO_4, dilute to one liter.

Diphenylamine indicator:

Dissolve approximately 0.5 g of reagent grade diphenylamine in 20 ml of distilled water and 100 ml of concentrated H_2SO_4.

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To insure statistical randomness, the less than 60 mesh (less than 250-micrometer) size fractions were divided into 2 replicate splits. From each of these a 0.2-0.5 gram portion was taken and placed in a 500 ml Erlenmeyer flask. Precisely 10 ml of 1N $K_2Cr_2O_7$ solution was added by burette to the sediment and the two were mixed by swirling the flask in order to ensure uniform wetting of the sediment grains. Then, 20 ml of concentrated H_2SO_4 was added by burette and mixed by gentle swirling of the flask for about one minute. Care was required to ensure complete mixing of the reagents with the sediment, while avoiding throwing sediment grains onto the side of the flask and out of contact with the reagents. The resulting mixture was allowed to stand for 30 minutes. A standardization blank without sediment was processed with each new batch of samples and treated identically so as to account for differences between reagent batches. After 30 minutes, the solutions were diluted to 200 ml volume with distilled water. Then, 10 ml of 85% H_3PO_4, 0.2 grams of sodium fluoride and 15 drops of acidified diphenylamine indicator were sequentially added to the sample flasks. The solutions were then back titrated with 0.5 N ferrous ammonium sulfate solution. The color of the solutions showed a progressive change from an opaque greenish brown to brownish green upon the addition of approximately 10 ml of ferrous solution. The color continued to shift as the titration proceeded to a bluish-black-gray; at this point the addition of 1-2 drops of ferrous solution shifted the color to a brilliant green, giving a sharp one-drop endpoint.

The method was set up on a production basis with nine samples analyzed at a time. To ensure analytical uniformity, two splits were run for each sample, plus a standardization blank analyzed for each batch of nine samples. In the table of data

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resulting from this analysis, the values for both the standardization blank and percent organic carbon are reported as average values. The %TOC is calculated as follows:

% Total Organic Carbon = 10 (1-T/S) [1.0 N (0.003) (100/W)]

Where:

T = ml ferrous ammonium solution used in sample titration

S = ml ferrous ammonium solution used in standardization blank titration

(The T/S factor will cancel out the effect of the ferrous solution normality)

0.003 = 12/4,000 = meq weight of carbon

1.0 N = normality of $K_2Cr_2O_7$ in ml

W = weight of sediment sample in grams

The relative standard deviation of the method based on replicate analysis of the samples is approximately 1.8%. Walkley and Black (1947) had indicated a lack of influence of $CaCO_3$ in the titrimetric method of organic carbon determination in soils.

2.2.4. Sediment Grain Size Analysis

Samples for grain size analysis were selected primarily on the basis of environmental gradients determined from ICP-trace metal analysis, and secondarily from the Hudson River sediment facies maps as drawn by Coch (1986). All together 44 samples were selected for grain size analysis. The selected samples (from the third split) were additionally wet sieved through a 230-mesh stainless steel sieve to determine the percent mud (silt, 62.5 to 3.9 microns + clay < 3.9 microns) as compared to percent sand finer than 250-micrometers (fine sand, 250 to 125 microns + very fine sand, 125 to 62.5 microns). Folk's (1980) standard procedure for wet sieving technique requires using an appropriate dispersant to prevent flocculation of clays during wet sieving. In this study, a dispersing solution of 0.02 N $Na_2 CO_3$ was used. The 230 mesh (62.5 - micron) screen

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that is reserved for wet sieving was dipped in dispersant to get the screen thoroughly wet on both sides. A sediment sample that was already well mixed in distilled water containing dispersant was poured onto the wet screen while holding it over a large pan. A fine jet of water containing dispersant was played to wash down the mud through the screen until the water running through was clear. The muddy water collected in the pan was then transferred into a beaker and dried at room temperature. The sand remaining on the screen was then transferred into a wide- mouth glass pan and dried also at room temperature. The resulting size fractions were then weighed and the percentage of mud (silt + clay; < 62.5 microns) and sand (250 to 62.5 microns) calculated for each.

2.2.5. Total Carbohydrate Analysis

The fourth finer than 250-micrometer sample split was analyzed for total carbohydrate (TCH) content, using the improved phenol-sulfuric acid method of Gerchakov and Hatcher (1972). This method requires the preparation of the following reagents, standards and blanks.

Phenol solution: 25 g of phenol (Sigma, ASC) was dissolved in 400 ml of distilled water and diluted to make 500 ml of solution.

Phenol correction blank: 2 ml distilled water, 2 ml phenol solution, 10 ml distilled water added consecutively to a culture tube.

Glucose stock solution: 10 mg of beta-D-glucose (97%, containing up to 3% α -anomer) was dissolved in 80 ml of distilled water and diluted to make 100 ml of stock solution. The resulting concentration is 100 ug/ml. Since the first run of sediment samples indicated a need for higher glucose concentrations, an additional glucose stock solution was prepared by adding 40 mg of beta – D- glucose to 100 ml of distilled water.

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The resulting concentration was 400 ug/ml. The beta-D-glucose was obtained from Sigma.

Glucose standards: Gerchakov and Hatcher's (1972) method of preparing glucose standards requires using eight 30 ml beakers to which were added 1, 2, 3, 4, 5, 8, 10, and 20 ml of glucose stock solution with enough distilled water to make a final volume of 20 ml. The resulting corresponding concentrations are as follows: 10, 20, 30, 40, 50, 80, 100, and 200 ug/2 ml. In the course of this experiment, it was found that using pipettes of smaller size for transferring glucose stock solution and bringing the final volume to 20 ml would increase the degree of relative errors in glucose concentrations in the standards. To reduce errors of such nature, the method was modified using 25 ml flasks. The resulting corresponding concentrations are as follows: 8, 16, 24, 32, 40, 64, 80, 160, 320, 480, and 640 ug/2ml.

Gerchakov and Hatcher's (1972) method requires three 2 ml aliquots of glucose standard to be taken from each beaker using a 5 ml glass hypodermic syringe and placed in a set of three 20 × 150 mm screw-top culture tubes (Corning Glass) with Teflon-lined screw caps, labeled A#, B#, and C#. The # in the subscript refers to the concentration /2 ml of particular standard solution. To the A-series were added consecutively 2 ml of phenol solution (1:20 w/v) and 10 ml of concentrated sulfuric acid. To the B-series were added consecutively 2 ml of distilled water and 10 ml of concentrated sulfuric acid. To the C-series were added consecutively 2 ml of phenol solution and 10 ml of distilled water. All additions to the culture tubes were made with good mixing from rapid delivery pipettes.

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Initial results and personal communication with Hatcher (September, 1999) indicated that the C culture tubes are not necessary in this experiment. Removal of the C culture tubes made the phenol correction for each standard unnecessary. In order to reduce the possible volumetric errors, 2-ml pipettes were used, rather than a glass syringe, in transferring stock solutions to A and B culture tubes.

The solutions were transferred to one-centimeter path length cuvettes and their absorbencies were measured at 485 nm (fixed wavelength) utilizing a Unikon 9410 double-beam UV/VIS recording spectrophotometer. When a number of cuvettes were available for use, the pair that had the least difference in absorbence values when filled with distilled water was utilized. Absorbence of the solutions from the A-tubes was measured against the corresponding solutions from the B-tubes on the previously auto-zeroed spectrophotometer. In this case, the A-tubes were placed in the front (sample) beam while the B-tubes were placed in the rear (reference) beam. Before each set of analyses, the spectrometer was auto-zeroed for water against water. To avoid a decrease in absorbence values, the standards were analyzed on the spectrometer the day after preparation. The following formula was used to compute the actual absorbencies of the standards:

$$\text{Abs}_{\text{standard}} = (\text{Abs}_A - \text{Abs}_B)$$

Using regression analysis, with the origin not set at zero, a graph of absorbency vs. concentration was prepared (Fig. 6). The non-zero y-intercept in the regression analysis is due to common errors of various kinds (volumetric error, weighing error, reagent sequence error, and time lapse in analysis).

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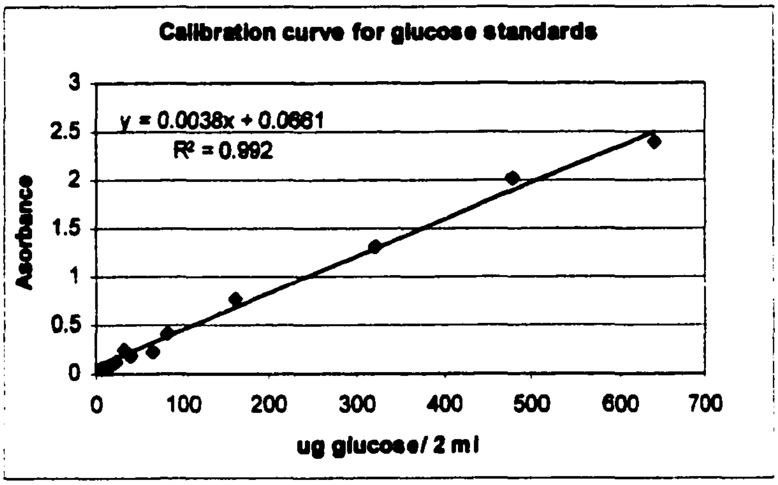
Figure 6. Calibration curve for glucose standards



It is reported that carbohydrates in sediments comprise about 10% of the total organic carbon (Artm'yev, 1969). Based on this relationship, particular sample weights were chosen for the TCH analysis. Sediment samples containing about 1000 ug of carbohydrates were used for the TCH analysis.

The computed amount of sediment was weighed into a 30 ml beaker, 20 ml distilled water added and the mixture was homogeneously agitated in an ultrasonic bath. Using a 15 ml capacity glass hypodermic syringe, three 2 ml aliquots were transferred to 20 × 150 mm screw top culture tubes labeled A, B, or C as described previously and immediately treated in a similar manner to the glucose standards. The sample sets A, B and C were centrifuged at 4500 RPM for 30 minutes, which resulted in the flotation of sedimentary debris. To prevent erroneous results in the spectrophotometric analysis, the solutions were transferred, using disposable Pasteur pipettes, from the culture tubes in which the centrifugation took place, thus leaving behind the floating particles.

Carbohydrate content (TCH) of the sediment samples was expressed in terms of glucose concentrations (which is actually not glucose but the product of reaction between

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glucose in the sediment and the added phenol) by comparing the measured absorbence values for the treated sediments with those of the glucose standards represented by the calibration curve (see **Fig. 6**). For the sediment samples, however, the C culture tubes were included since they, unlike in the standards, make a difference of about 3% in the total value of calculated TCH. The total absorbence for each treated sediment sample is obtained by measuring the absorbence of the A-series against the B-series on a previously auto-zeroed Unikon spectrophotometer, and of the C-series against the phenol blank on a previously auto-zeroed spectrophotometer. The total absorbence for each treated sediment sample is calculated as follows:

$\text{Abs}_{\text{sample}} = (\text{Abs}_{A} - \text{Abs}_{B}) - (\text{Abs}_{C} - \text{Abs}_{\text{Phenol Blank}})$

The relative standard deviation of the carbohydrate analysis is approximately 1.7%. The TCH analytical experiment was conducted in the Geochemistry Laboratory in the Geology Department and the Analytical Research Laboratory in the Chemistry Department at Brooklyn College, the City University of New York.

2.3. Statistical Methods

The results of chemical analysis of the eleven analytes Ag, Cd, Cr, Cu, Fe, Ni, Mn, Pb, Zn, V and %TOC in sediment samples were subjected to statistical analysis using the statistical software JMP IN –the student version of JMP, and JMP, developed by the SAS Institute (Sall and Lehman, 1996). Several statistical tests were performed, including tests for Normalcy, ANOVA (Analysis of Variance), Bivariate Analysis, Principal Components Analysis, and Cluster Analysis.

JMP uses the Shapiro-Wilk test to examine the distribution of data to see whether the data are normally distributed or not. ANOVA analysis is performed to test (a) the

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variance around the means and (2) to examine whether the differences among the group means are statistically significant. In this study, sampling sites were grouped into three longitudinal river locations: NY (New York), NJ (New Jersey), and MC (Mid- River). For river transects containing less than or more than three sampling sites, sites were assigned to river locations according to the water depth. There are 32 sampling sites in the NY group, 36 in the NJ group, and 30 in the MC (Mid-River) group. Bivariate Analysis is performed to see where the data points are located and where the distribution is dense and how the variables are correlated. Principal Components Analysis is performed to show the spatial distributions of correlated variables in a multidimensional plot.

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Chapter 3: Results

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To delineate the magnitude and extent of environmentally available trace metal contaminants in the Lower Hudson Estuary, 97 fine-grained (< 250 – micrometers: fine sand to clay) surficial bottom sediment samples were analyzed for environmentally recoverable Ag, Cd, Cr, Cu, Ni, Pb, Zi, V, Fe and Mg (ICP method), percent total organic carbon (%TOC), grain-size distributions, and percent total carbohydrate (%TCH). The choice of using finer sediment fractions for trace metal analysis was based on the following two criteria:

1. The much lower Cs-137 activities (radionuclide in atmospheric fallout from the nuclear weapon tests conducted in the early 1950's) in medium sands (180-250 µm) and coarser fractions than in the smaller size fractions as reported in Olson (1984). This finding indicates that trace metals are generally associated with finer sediment fractions, and
2. The possibility of comparing the results of this study (following the implementation of several programs by the New York City Department of Environmental Protection to reduce metals in the City's drinking water, sewage, and sludge) to those reported by others in the past where sediment type and/or time of sampling (possibly summer) are the same (Williams *et al.*, 1978; New York City EPA, 1988; Chillrud, 1996; Adams *et al.*, 1998).

3.1. Trace Metals

Trace metals concentrations (µg/g) in surficial bottom sediments for Ag, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, and V are reported in **Table 6**, where ± values are the standard deviation around the mean value in the sediment. Analytical precision and accuracy of

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the trace metal analyses, as determined, respectively by replicate sample analyses and analysis of standard reference materials are reported in **Chapter 2** (see **Table 5**, Sec. 2.2.2.) on Laboratory Methods.

Table 7 shows the result of trace metal analysis for eleven selected stations for both 1997 and 1998 sediment sampling. To determine the depth profile of trace metals, one experimental short core, about 11.43 cm. (4.5 inches), was taken from an undisturbed grab sample retrieved with a Smith McIntyre sampler at station 28A. This site is located north of North Bergen WPCP along the New Jersey shore. The downward core trace metals variation at site T28A is interesting. A decrease in Ag by 50%, Cd by 12%, Cr by 48%, Ni by 10%, Zn by 6%, and V by 24% is observed, suggesting less input of trace metals pollutants in the study area with time (the core was not dated). Pb and Cu, however, show increases by 40% and 8%, respectively, toward the surface.

Sample 34A was also analyzed for both the sediment size fraction greater than and less than 250 micrometers. The results show the extent to which the measured trace metals are associated with the "fines" less than 250 micrometers.

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Table 6. Trace Metals and Percent TOC Concentrations in Surficial Bottom Sediments in Lower Hudson Estuary, August-September 1997. Metal concentrations are in ppm. +/- values are the standard deviations around the mean value

Sites	Latitude (degrees)	Longitude (degrees)	TOC%	+/-	Ag	+/-	Cd	+/-	Cr	+/-	Cu	+/-	Fe%	+/-	Mn	+/-	Ni	+/-	Pb	+/-	Zn	+/-	V	+/-
20A	41.2306	73.9667	0.88	0.02	0.59	0.02	1.07	0.07	40	0.70	34	1.49	2.79	0.03	989	15.89	35	0.82	46	0.97	137	1.68	20	0.37
20B	41.2306	73.9575	1.91	0.09	1.31	0.05	1.90	0.12	74	0.95	63	1.05	3.73	0.03	1531	19.63	44	0.82	84	2.20	211	3.42	30	0.32
20C	41.2306	73.9458	2.02	0.00	1.42	0.05	2.13	0.12	73	0.95	67	1.05	3.54	0.03	1117	21.07	42	0.82	85	2.20	204	3.42	31	0.32
19A	41.2167	73.9611	1.98	0.04	1.54	0.05	1.42	0.12	71	0.95	65	1.05	3.71	0.03	1438	19.52	44	0.82	85	2.20	206	3.42	29	0.32
19B	41.2167	73.9542	1.93	0.03	1.19	0.05	1.90	0.12	64	0.95	58	1.05	3.41	0.03	1369	19.43	39	0.82	75	2.20	187	1.68	27	0.37
19D	41.2167	73.9375	1.36	0.03	0.71	0.02	1.54	0.12	45	0.70	40	1.49	2.71	0.03	836	15.71	33	0.77	51	0.97	144	1.68	21	0.37
19E	41.2167	73.9242	1.87	0.00	1.07	0.02	1.42	0.12	64	0.95	57	1.05	3.37	0.03	1670	19.79	40	0.82	76	2.20	189	1.68	28	0.37
18A	41.2000	73.9553	1.74	0.01	1.66	0.05	2.49	0.24	97	0.95	81	1.05	3.40	0.03	693	14.12	45	0.82	120	1.46	238	3.42	32	0.32
18B	41.2000	73.9492	1.36	0.01	1.07	0.02	1.42	0.12	56	0.95	47	1.49	2.95	0.03	838	15.71	39	0.82	64	2.20	160	1.68	25	0.37
18C	41.2000	73.9375	1.68	0.01	1.31	0.05	1.18	0.12	57	0.95	51	1.49	3.10	0.03	1152	21.11	36	0.82	63	2.20	169	1.68	24	0.37
18D	41.2000	73.9269	1.36	0.01	0.83	0.02	1.66	0.12	51	0.95	44	1.49	2.81	0.03	986	15.89	32	0.77	56	2.20	154	1.68	22	0.37
17A	41.1833	73.9458	2.18	0.03	2.02	0.05	1.66	0.12	92	0.95	82	1.05	3.97	0.03	2167	20.38	48	0.82	123	1.46	238	3.42	35	0.32
17B	41.1833	73.9275	1.27	0.02	0.95	0.02	1.42	0.12	50	0.70	40	1.49	2.79	0.03	902	15.79	35	0.82	57	2.20	153	1.68	23	0.37
17C	41.1833	73.9200	1.05	0.03	0.59	0.02	0.83	0.07	41	0.70	33	1.49	2.47	0.04	1254	21.23	28	0.77	51	0.97	134	1.68	20	0.37
17D	41.1833	73.9083	1.44	0.06	0.59	0.02	0.83	0.07	38	0.70	31	1.49	2.90	0.03	1158	21.12	32	0.77	41	0.97	116	1.68	23	0.37
16A	41.1667	73.9231	2.63	0.17	2.37	0.09	1.18	0.12	81	0.95	78	1.05	4.04	0.04	2769	21.09	47	0.82	105	2.20	227	3.42	34	0.32
16B	41.1667	73.9158	1.68	0.06	0.71	0.02	0.59	0.07	41	0.70	47	1.49	2.87	0.03	1064	21.01	33	0.77	50	0.97	140	1.68	23	0.37
16C	41.1667	73.9008	1.09	0.01	0.71	0.02	0.71	0.07	37	0.70	29	1.49	2.18	0.04	1140	21.10	26	0.77	47	0.97	113	1.68	20	0.37
15A	41.1500	73.9094	2.00	0.10	1.66	0.05	1.18	0.12	64	0.95	65	1.05	3.61	0.03	1369	19.43	40	0.82	92	2.20	192	1.68	36	0.32
15B	41.1500	73.8983	1.96	0.05	1.90	0.05	1.07	0.07	63	0.95	59	1.05	3.23	0.03	910	15.80	38	0.82	83	2.20	175	1.68	28	0.37
15C	41.1500	73.8825	1.90	0.02	1.66	0.05	1.18	0.12	65	0.95	59	1.05	3.34	0.03	1554	19.65	39	0.82	81	2.20	181	1.68	28	0.37
14B	41.1333	73.8975	1.87	0.40	1.54	0.05	1.30	0.12	62	0.95	52	1.49	3.76	0.03	1093	21.04	40	0.82	68	2.20	168	1.68	31	0.32
14C	41.1333	73.8867	1.91	0.20	1.66	0.05	1.30	0.12	58	0.95	52	1.49	3.01	0.03	779	14.22	36	0.82	76	2.20	162	1.68	27	0.37
14D	41.1333	73.8725	2.11	0.04	1.54	0.05	0.59	0.07	60	0.95	55	1.05	3.24	0.03	1427	19.50	37	0.82	75	2.20	162	1.68	28	0.37
13A	41.1167	73.9042	1.30	0.10	1.19	0.05	0.83	0.07	59	0.95	89	1.05	3.59	0.03	1173	21.13	37	0.82	67	2.20	156	1.68	26	0.37
13B	41.1167	73.8958	1.72	0.15	0.36	0.02	0.59	0.07	36	0.70	25	1.49	3.29	0.03	841	15.72	33	0.77	30	0.97	96	1.18	27	0.37
13C	41.1167	73.8833	1.73	0.22	1.78	0.05	0.71	0.07	57	0.95	52	1.49	2.94	0.03	909	15.80	33	0.77	72	2.20	159	1.68	25	0.37
13D	41.1167	73.8717	1.89	0.15	2.02	0.05	0.59	0.07	63	0.95	59	1.05	3.13	0.03	1311	19.37	34	0.82	80	2.20	167	1.68	28	0.37
12A	41.1000	73.9042	1.77	0.01	2.14	0.05	1.42	0.12	74	0.95	67	1.05	3.33	0.03	1020	15.93	39	0.82	92	2.20	186	1.68	32	0.32
12B	41.1000	73.8941	1.78	0.03	1.78	0.05	3.55	0.24	71	0.95	62	1.05	3.25	0.03	835	15.71	37	0.82	86	2.20	177	1.68	30	0.32
12C	41.1000	73.8833	1.45	0.01	1.90	0.05	0.83	0.07	60	0.95	102	1.05	3.08	0.03	807	14.26	35	0.82	80	2.20	166	1.68	29	0.32
12D	41.1000	73.8725	1.41	0.16	2.73	0.09	1.78	0.12	75	0.95	104	1.05	3.11	0.03	719	14.15	34	0.82	114	1.46	180	1.68	27	0.37
11A	41.0750	73.8967	2.22	0.04	2.49	0.09	1.07	0.07	73	0.95	68	1.05	3.72	0.03	1128	21.08	43	0.82	94	2.20	200	1.68	32	0.32
11B	41.0750	73.8825	2.06	0.01	1.90	0.05	1.54	0.12	70	0.95	66	1.05	3.52	0.03	875	15.76	42	0.82	89	2.20	196	1.68	31	0.32
11C	41.0750	73.8742	1.52	0.03	2.61	0.09	2.01	0.12	90	0.95	105	1.05	3.17	0.03	662	14.08	36	0.82	121	1.46	211	3.42	30	0.32
10A	41.0667	73.8992	1.24	0.01	1.31	0.05	0.71	0.07	48	0.70	43	1.49	2.87	0.03	877	15.76	32	0.77	58	2.20	141	1.68	22	0.37
10B	41.0667	73.8900	1.55	0.01	0.47	0.02	4.15	0.15	33	0.70	24	1.49	3.03	0.03	876	15.76	31	0.77	31	0.97	96	1.18	24	0.37

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Table 6. Trace Metals and Percent TOC Concentrations in Surficial Bottom Sediments in Lower Hudson Estuary, continued

Sites	Latitude (degrees)	Longitude (degrees)	TOC%	+/-	Ag	+/-	Cd	+/-	Cr	+/-	Cu	+/-	Fe%	+/-	Mn	+/-	Ni	+/-	Pb	+/-	Zn	+/-	V	+/-
10C	41.0667	73.8825	1.92	0.06	1.31	0.05	1.30	0.12	62	0.95	56	1.05	3.37	0.03	1012	15.92	40	0.82	78	2.20	183	1.68	28	0.37
9A	41.0500	73.9000	1.05	0.10	1.42	0.05	0.83	0.07	44	0.70	42	1.49	2.68	0.03	947	15.84	27	0.77	61	2.20	118	1.68	27	0.37
9B	41.0500	73.8883	1.38	0.08	1.54	0.05	0.83	0.07	52	0.95	50	1.49	2.97	0.03	916	15.81	30	0.77	66	2.20	145	1.68	27	0.37
9C	41.0500	73.8800	1.96	0.01	0.24	0.02	0.59	0.07	34	0.70	20	1.49	3.56	0.03	1152	21.11	36	0.82	24	0.97	93	1.18	31	0.32
9D	41.0500	73.8733	1.67	0.02	3.92	0.09	1.66	0.12	106	0.84	103	1.05	3.36	0.03	619	14.03	42	0.82	134	1.46	215	3.42	32	0.32
8A	41.0333	73.8942	1.31	0.02	0.83	0.02	0.59	0.07	42	0.70	35	1.49	2.96	0.03	1033	15.94	32	0.77	46	0.97	118	1.68	25	0.37
8B	41.0333	73.8833	1.76	0.01	0.24	0.02	0.59	0.07	29	0.70	19	1.49	3.18	0.03	1047	20.99	33	0.77	21	0.97	89	1.18	25	0.37
8C	41.0333	73.8775	1.50	0.01	0.95	0.02	1.18	0.12	41	0.70	36	1.49	3.09	0.03	863	15.74	33	0.77	45	0.97	114	1.68	26	0.37
7B	41.0167	73.8875	1.83	0.07	1.78	0.05	0.59	0.07	55	0.95	74	1.05	3.22	0.03	854	15.73	34	0.82	96	2.20	171	1.68	28	0.37
7C	41.0167	73.8811	1.21	0.03	1.66	0.05	1.30	0.12	50	0.70	52	1.49	2.60	0.03	558	16.15	33	0.77	75	2.20	138	1.68	24	0.37
6A	41.0000	73.8992	1.39	0.04	1.31	0.05	1.66	0.12	47	0.70	39	1.49	3.15	0.03	934	15.83	32	0.77	58	2.20	130	1.68	29	0.32
6B	41.0000	73.8925	1.70	0.08	1.31	0.05	0.71	0.07	50	0.70	43	1.49	3.25	0.03	1196	21.16	37	0.82	58	2.20	136	1.68	30	0.32
6C	41.0000	73.8867	1.99	0.01	3.80	0.09	1.90	0.12	73	0.95	84	1.05	3.17	0.03	872	15.75	37	0.82	103	2.20	188	1.68	31	0.32
5A	40.9833	73.9028	2.60	0.09	3.80	0.09	1.42	0.12	87	0.95	86	1.05	4.06	0.04	1623	19.74	46	0.82	114	1.46	227	3.42	38	0.32
5B	40.9833	73.8942	0.92	0.06	0.59	0.02	0.59	0.07	33	0.70	26	1.49	2.35	0.04	1169	12.24	25	0.77	45	0.97	108	1.68	20	0.37
5C	40.9833	73.8875	1.84	0.01	2.49	0.09	0.95	0.07	64	0.95	113	0.92	3.22	0.03	684	14.11	38	0.82	108	2.20	230	3.42	31	0.32
4A	40.9667	73.9078	2.14	0.04	3.20	0.09	0.83	0.07	74	0.95	77	1.05	3.56	0.03	1797	19.94	38	0.82	99	2.20	194	1.68	32	0.32
4B	40.9667	73.9008	1.83	0.29	0.47	0.02	1.90	0.12	34	0.70	25	1.49	2.90	0.03	838	15.71	31	0.77	31	0.97	97	1.18	23	0.37
4C	40.9667	73.8931	1.05	0.05	1.66	0.05	0.83	0.07	44	0.70	53	1.05	2.32	0.03	511	16.10	26	0.77	74	2.20	122	1.68	22	0.37
3A	40.9500	73.9153	2.84	0.11	4.27	0.09	1.30	0.12	92	0.95	93	1.05	4.12	0.04	1890	20.05	47	0.82	127	1.46	231	3.42	40	0.32
3B	40.9500	73.9042	1.70	0.04	0.24	0.02	3.79	0.02	36	0.70	21	1.49	3.73	0.03	1052	20.99	38	0.82	25	0.97	96	1.18	33	0.32
3C	40.9500	73.9008	1.19	0.07	1.78	0.05	0.95	0.07	44	0.70	50	1.49	2.41	0.04	555	16.15	27	0.77	63	2.20	131	1.68	21	0.37
2A	40.9333	73.9208	2.38	0.05	2.85	0.09	1.18	0.12	70	0.95	114	0.92	3.79	0.03	703	14.13	45	0.82	184	1.46	237	3.42	34	0.32
2B	40.9333	73.9142	1.55	0.02	0.24	0.02	0.95	0.07	30	0.70	15	1.49	3.22	0.03	938	15.83	32	0.77	19	0.97	79	1.18	28	0.37
2C	40.9333	73.9064	0.67	0.05	1.54	0.05	0.83	0.07	38	0.70	53	1.05	2.08	0.04	493	16.08	23	0.77	74	2.20	111	1.68	20	0.37
1A	40.9167	73.9253	2.49	0.03	4.04	0.09	1.07	0.07	84	0.95	87	1.05	3.82	0.03	1404	19.48	45	0.82	119	1.46	216	3.42	35	0.32
1B	40.9167	73.9192	2.08	0.03	2.02	0.05	0.95	0.07	64	0.95	57	1.05	3.45	0.03	882	15.76	42	0.82	75	2.20	184	1.68	31	0.32
1C	40.9167	73.9125	0.98	0.05	1.78	0.05	0.59	0.07	45	0.70	75	1.05	2.49	0.04	704	14.13	26	0.77	128	1.46	121	1.68	28	0.37
22A	40.9000	73.9322	2.61	0.09	4.27	0.09	1.42	0.12	90	0.95	95	1.05	3.96	0.03	2225	20.45	44	0.82	130	1.46	229	3.42	37	0.32
22B	40.9000	73.9247	1.48	0.03	0.83	0.02	0.59	0.07	39	0.70	40	1.49	3.13	0.03	1017	15.92	33	0.77	44	0.97	105	1.68	28	0.37
22C	40.9000	73.9175	1.63	0.03	2.14	0.05	1.66	0.12	59	0.95	60	1.05	3.14	0.03	772	14.21	37	0.82	81	2.20	170	1.68	27	0.37
23A	40.8833	73.9397	1.82	0.01	3.80	0.09	1.07	0.07	73	0.95	81	1.05	3.18	0.03	1346	19.41	36	0.82	98	2.20	183	1.68	28	0.37
23B	40.8833	73.9303	2.26	0.05	2.49	0.09	0.95	0.07	71	0.95	67	1.05	3.50	0.03	1154	21.11	40	0.82	92	2.20	195	1.68	31	0.32
23C	40.8833	73.9236	1.76	0.03	2.26	0.05	0.71	0.07	47	0.70	75	1.05	2.20	0.04	651	14.07	26	0.77	81	2.20	131	1.68	21	0.37
24A	40.8667	73.9492	2.54	0.06	3.68	0.09	2.13	0.12	80	0.95	83	1.05	3.65	0.03	1704	19.83	42	0.82	107	2.20	202	1.68	33	0.32
24B	40.8667	73.9425	2.03	0.18	4.15	0.09	0.95	0.07	77	0.95	80	1.05	3.41	0.03	1415	19.49	38	0.82	116	1.46	188	1.68	34	0.32
24C	40.8667	73.9347	1.06	0.02	1.78	0.05	0.83	0.07	49	0.70	63	1.05	2.54	0.03	748	14.18	28	0.77	89	2.20	134	1.68	25	0.37
25A	40.8500	73.9583	2.00	0.04	2.73	0.09	1.18	0.12	80	0.95	112	0.92	3.91	0.03	913	15.80	48	0.82	458	7.52	225	3.42	35	0.32
25B	40.8500	73.9539	2.39	0.13	4.27	0.09	0.95	0.07	90	0.95	94	1.05	3.88	0.03	1704	19.83	43	0.82	188	1.46	212	3.42	38	0.32
26A	40.8333	73.9669	2.99	0.04	5.22	0.06	0.95	0.07	102	0.84	106	0.92	4.16	0.04	2503	20.78	46	0.82	144	1.46	243	3.42	43	0.32

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Table 6. Trace Metals and Percent TOC Concentrations in Surficial Bottom Sediments in Lower Hudson Estuary, continued

Sites	Latitude (degrees)	Longitude (degrees)	TOC%	+/-	Ag	+/-	Cd	+/-	Cr	+/-	Cu	+/-	Fe%	+/-	Mn	+/-	Ni	+/-	Pb	+/-	Zn	+/-	V	+/-
26B	40.8333	73.9594	1.26	0.01	2.37	0.05	0.83	0.07	55	0.95	60	1.05	2.72	0.03	1047	20.99	27	0.77	79	2.20	144	1.68	25	0.37
26C	40.8333	73.9525	1.69	0.03	2.61	0.09	1.30	0.12	63	0.95	65	1.05	3.09	0.03	954	15.85	36	0.82	87	2.20	166	1.68	28	0.37
27A	40.8167	73.9761	2.80	0.09	4.63	0.09	0.59	0.07	89	0.95	95	1.05	3.62	0.03	2144	20.35	40	0.82	129	1.46	205	3.42	35	0.32
27B	40.8167	73.9700	1.29	0.04	2.02	0.05	0.59	0.07	44	0.70	48	1.49	2.05	0.04	1266	21.24	23	0.77	66	2.20	115	1.68	20	0.37
27C	40.8167	73.9656	2.93	0.01	10.80	0.06	5.33	0.15	166	0.84	268	0.92	3.31	0.03	461	16.04	47	0.82	385	7.52	418	2.36	40	0.32
28A	40.8000	73.9900	1.65	0.03	2.37	0.05	0.95	0.07	61	0.95	61	1.05	3.03	0.03	1010	15.92	35	0.82	78	2.20	161	1.68	28	0.37
28B	40.8000	73.9839	1.55	0.04	3.09	0.09	0.71	0.07	65	0.95	70	1.05	2.97	0.03	1276	19.32	33	0.77	96	2.20	166	1.68	28	0.37
28C	40.8000	73.9772	2.53	0.05	6.88	0.06	2.13	0.12	84	0.95	178	0.92	3.50	0.03	895	15.78	44	0.82	254	7.52	315	2.36	37	0.32
29B	40.7833	73.9953	1.40	0.04	3.09	0.09	0.95	0.07	61	0.95	74	1.05	2.65	0.03	901	15.79	28	0.77	97	2.20	153	1.68	27	0.37
29C	40.7833	73.9883	1.90	0.02	9.61	0.06	4.26	0.15	148	0.84	188	0.92	3.01	0.03	594	14.01	43	0.82	223	7.52	274	3.42	37	0.32
30A	40.7667	74.0122	2.39	0.02	6.41	0.06	3.08	0.24	139	0.84	145	0.92	3.32	0.03	807	14.25	44	0.82	180	1.46	255	3.42	35	0.32
30B	40.7667	74.0036	2.14	0.05	2.61	0.09	1.42	0.12	74	0.95	71	1.05	3.46	0.03	1276	19.32	39	0.82	98	2.20	194	1.68	32	0.32
31A	40.7500	74.0200	2.78	0.07	6.41	0.06	2.37	0.12	126	0.84	169	0.92	3.62	0.03	1015	15.92	48	0.82	239	7.52	333	2.36	40	0.32
31B	40.7500	74.0128	1.24	0.01	1.19	0.05	0.59	0.07	37	0.70	31	1.49	2.59	0.03	946	15.84	30	0.77	65	2.20	95	1.18	30	0.32
32A	40.7333	74.0239	2.18	0.01	5.10	0.06	3.55	0.15	105	0.84	171	0.92	3.17	0.03	593	14.00	64	0.82	266	7.52	397	2.36	35	0.32
32B	40.7333	74.0153	1.64	0.11	4.39	0.09	2.84	0.24	78	0.95	108	0.92	2.75	0.03	610	14.02	34	0.82	141	1.46	181	1.68	30	0.32
33A	40.7167	74.0292	2.33	0.05	3.32	0.09	1.66	0.12	80	0.95	84	1.05	3.36	0.03	952	15.85	42	0.82	140	1.46	225	3.42	34	0.32
33B	40.7167	74.0233	1.16	0.03	3.20	0.09	0.95	0.07	64	0.95	66	1.05	2.49	0.03	538	16.13	34	0.82	95	2.20	134	1.68	27	0.37
33C	40.7167	74.0183	1.36	0.03	3.20	0.09	1.18	0.12	64	0.95	74	1.05	2.44	0.04	534	16.13	31	0.77	129	1.46	162	1.68	26	0.37
34A	40.7019	74.0325	1.52	0.07	4.87	0.06	3.44	0.24	113	0.84	114	0.92	2.36	0.04	404	15.97	35	0.82	152	1.46	235	3.42	28	0.37
34B	40.7019	74.0267	1.89	0.19	2.73	0.09	0.71	0.07	71	0.95	63	1.05	2.95	0.03	718	14.15	35	0.82	83	2.20	147	1.68	33	0.32

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Table 7. Trace Metal Concentrations and %TOC in Surficial Bottom Sediment Samples: August, 1997 and October, 1998

1997	Lat	Long	WD	TOC	+/-	Ag	+/-	Cd	+/-	Cr	+/-	Cu	+/-	Fe%	+/-	Mn	+/-	Ni	+/-	Pb	+/-	Zn	+/-	V	+/-
	(deg)	(deg)	(m)	%																					
97-25A	40.8500	73.9583	5.48	2.00	0.04	2.73	0.09	1.18	0.12	80	0.95	112	0.92	3.91	0.03	913	15.80	48	0.82	458	7.52	225	3.42	35	0.32
97-26A	40.8333	73.9669	4.60	2.99	0.04	5.22	0.06	0.95	0.07	102	0.84	106	0.92	4.16	0.04	2503	20.78	46	0.82	144	1.46	243	3.42	43	0.32
97-27C	40.8167	73.9856	7.92	2.93	0.01	10.80	0.06	5.33	0.15	166	0.84	268	0.92	3.31	0.03	461	16.04	47	0.82	385	7.52	418	2.36	40	0.32
97-28A	40.8000	73.9900	15.84	1.65	0.03	2.37	0.05	0.95	0.07	61	0.95	61	1.05	3.03	0.03	1010	15.92	35	0.82	78	2.20	161	1.68	28	0.37
97-28C	40.8000	73.9772	15.60	2.53	0.05	6.88	0.06	2.13	0.12	84	0.95	178	0.92	3.50	0.03	895	15.78	44	0.82	254	7.52	315	2.36	37	0.32
97-29C	40.7833	73.9883	8.84	1.90	0.02	9.61	0.06	4.26	0.15	148	0.84	188	0.92	3.01	0.03	594	14.01	43	0.82	223	7.52	274	3.42	37	0.32
97-30A	40.7667	74.0122	16.45	2.39	0.02	6.41	0.06	3.08	0.24	139	0.84	145	0.92	3.32	0.03	807	14.25	44	0.82	180	1.46	255	3.42	35	0.32
97-31A	40.7500	74.0200	14.32	2.78	0.07	6.41	0.06	2.37	0.12	126	0.84	169	0.92	3.62	0.03	1015	15.92	48	0.82	239	7.52	333	2.36	40	0.32
97-32A	40.7333	74.0239	16.76	2.18	0.01	5.10	0.06	3.55	0.15	105	0.84	171	0.92	3.17	0.03	593	14.00	64	0.82	266	7.52	397	2.36	35	0.32
97-33A	40.7167	74.0294	11.68	2.33	0.05	3.32	0.09	1.66	0.12	80	0.95	84	1.05	3.36	0.03	952	15.85	42	0.82	140	1.46	225	3.42	34	0.32
97-34A	40.7019	74.0325	14.70	1.52	0.07	4.87	0.06	3.44	0.24	113	0.84	114	0.92	2.36	0.04	404	15.97	35	0.82	152	1.46	235	3.42	28	0.37
1998	**Lat**	**Long**	**WD**	**TOC**		**Ag**	**+/-**	**Cd**	**+/-**	**Cr**	**+/-**	**Cu**	**+/-**	**Fe%**	**+/-**	**Mn**	**+/-**	**Ni**	**+/-**	**Pb**	**+/-**	**Zn**	**+/-**	**V**	**+/-**
	(deg)	(deg)	(m)	%																					
98- 25A	40.8500	73.9580	6.30	ND		1.8	0.05	0.95	0.07	68	0.95	68	1.05	3.3	0.02	652	4.51	36	0.82	243	7.52	186	1.18	27	0.37
98- 26A	40.8330	73.9670	6.00	ND		6.2	0.06	1.3	0.12	135	0.84	125	0.92	3.8	0.02	826	6.57	45	0.82	136	1.46	243	3.42	36	0.32
98- 27C	40.8170	73.9660	16.30	ND		3.1	0.09	0.83	0.07	72	0.95	85	1.05	3.0	0.02	694	4.51	31	0.77	116	1.46	174	1.18	27	0.37
98- 28A-TOP	40.8000	73.9900	6.10	ND		2.6	0.09	0.83	0.07	55	0.95	116	0.92	2.7	0.02	377	7.44	35	0.82	183	1.46	231	3.42	25	0.37
98- 28A-MID	40.8000	73.9900	6.10	ND		3.0	0.09	0.59	0.07	71	0.95	70	1.05	3.0	0.02	819	6.57	32	0.77	96	2.20	166	1.18	27	0.37
98- 28A-BOT	40.8000	73.9900	6.10	ND		5.3	0.06	0.95	0.07	105	0.84	106	0.92	3.5	0.02	741	4.51	39	0.82	110	2.20	247	3.42	33	0.32
98- 28C	40.8000	73.9770	12.70	ND		5.5	0.06	0.95	0.07	107	0.84	105	1.05	3.6	0.02	901	6.57	38	0.82	110	2.20	212	3.42	32	0.32
98- 29C	40.7830	73.9880	5.30	ND		8.3	0.06	3.6	0.24	133	0.84	188	0.92	2.9	0.02	642	4.51	37	0.82	173	1.46	251	3.42	32	0.32
98- 30A	40.7670	74.0120	16.40	ND		4.7	0.09	-0.59	0.07	98	0.95	100	1.05	3.6	0.02	1495	10.83	36	0.82	114	1.46	203	3.42	33	0.32
98- 31A	40.7500	74.0200	16.50	ND		1.9	0.05	0.59	0.07	47	0.67	122	0.92	2.0	0.02	336	7.44	31	0.77	190	1.46	255	3.42	17	0.37
98- 32A	40.7330	74.0240	15.80	ND		0.36	0.02	-0.59	0.07	37	0.67	79	1.05	2.8	0.02	741	4.51	49	0.82	112	1.46	365	2.36	24	0.37
98- 33A	40.7170	74.0290	10.00	ND		3.8	0.09	0.71	0.07	79	0.95	88	1.05	2.7	0.02	564	4.51	31	0.77	113	1.46	202	1.18	24	0.37
98- 34A >0.25 mm size fraction	40.7020	74.0320	16.60	ND		1.7	0.05	0.95	0.07	34	0.67	38	1.49	1.7	0.02	314	7.44	17	0.77	46	0.97	93	1.68	15	0.37
98- 34A <0.25 mm size fraction	40.7020	74.0320	16.60	ND		5.0	0.06	1.5	0.12	100	0.95	112	0.92	2.7	0.02	440	7.44	34	0.82	123	1.46	204	3.42	29	0.37

Trace metal concentration is in ppm.by wt.. ND: not detected. +/- Standard deviation of the mean value.

3.1.1. Longitudinal River Section Along the New Jersey Shoreline — A sites

Figure 7 shows a longitudinal section for sites along the New Jersey shoreline in the study area. Trace metals with concentrations less than 100 ppm (Ag, Cd, Ni, and V) are plotted on the secondary axis and those with maximum concentrations less than 500 ppm (Cu, Cr, Pb, and Zn) are plotted on the primary axis. All of the metals show similar patterns of simultaneous increase and decrease in concentrations along the New Jersey shore, but the pattern for Ag and especially Cd is relatively subdued. The first sharp peak upstream from the Battery appears at sites T32A to T30A, near the Hoboken, West New York, and North Bergen Water Pollution Control Plants (WPCPs). A second broad peak occurs at T27A to T25A. There is a sharp peak in the Pb concentration (458 ppm) just south of the George Washington Bridge (GWB), at the north end of this broad peak, at site T25A. We interpret this single very high Pb value as possibly resulting from a small piece of metal captured in the sediment, such as a small piece of leaded paint. This interpretation is reasonable since the bridge has been painted over and over and, thus, the possibility of pieces of leaded paint being captured in sediments under or south of the bridge is high. The third broad peak contains several peaks at locations T22A, T2A, and T5A between the GWB and the Tappan Zee Bridge (TZB). The next peak appears just north of the TZB (T11A - T12A) and the last broad peak shows up at sites T16A, T17A, and T18A. Site T17A is located near the Jt. Reg. Sew-Haverstraw WPCP, and site T18A is downstream of the Stony Point WPCP.

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Figure 7. Metal Concentrations in Surficial Bottom Sediments, New Jersey Longitudinal Sections: A sites

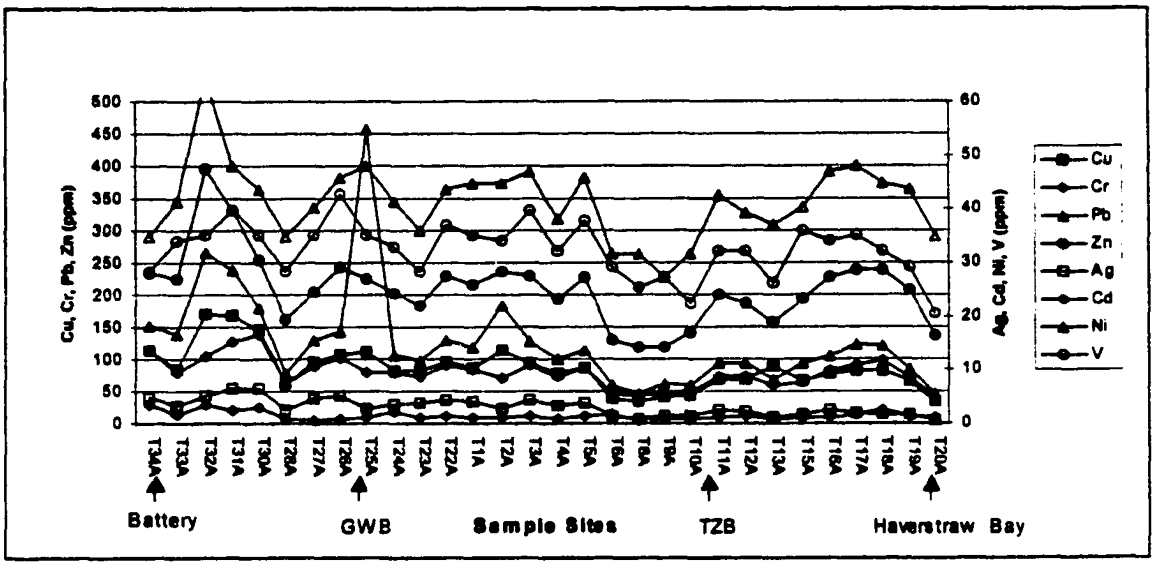
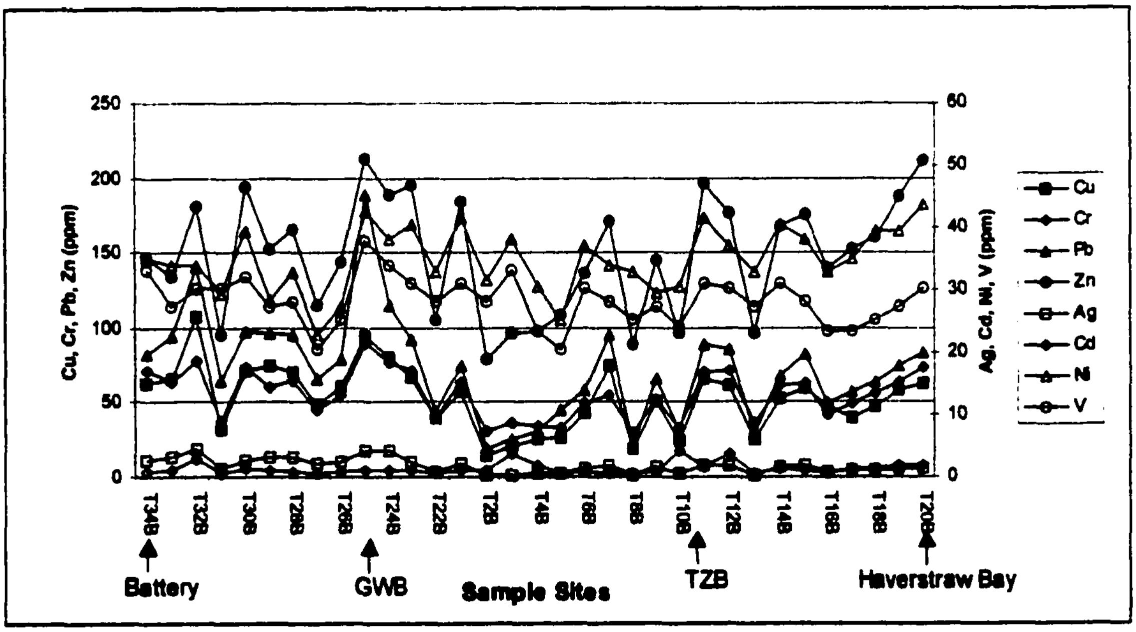


Figure 8. Metal Concentrations in Surficial Bottom Sediments, Mid-River Longitudinal Sections: B sites



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3.1.2. Longitudinal River Sections Along Mid-River – B sites

Figure 8 shows a longitudinal river section for the B-sites along the mid-river. Compared to longitudinal river section A-sites, peaks along longitudinal river sections B-sites are less pronounced, more numerous or not as well defined, yet maintain the same general pattern. There are, however, notable discrepancies at site T31 and T20 between the A and B sites. Peaks occur at sites T32B, T30B - 28B, T25B - T23B, T1B, T3B, T7B, T9B, T11B - T12B, T14B - T15B, and T19B - T20B. Site T32B is mid-river across from the Hoboken WPCP. T30B is mid-river across the North Bergen WPCP. Site T28B is south of the North River WPCP. Site T25B is south of the GWB. Site 1B is south of the Yonkers WPCP. Site 7B is south of Rockland Co. SD#1. Site T9B is across from the Orangetown WPCP. The peak at site T11B is slightly north of the TZB. The peak at T15B is south of the Ossining WPCP. A general increase in trace metals concentrations is observed at sites T18B, T19B, and T20B. These three sites are in the vicinity of the Jt.Reg. Saw-Haverstraw and Stony Point WPCPs.

3.1.3. Longitudinal River Sections Along New York Shoreline – C sites

Figure 9 shows the longitudinal river section along the New York shoreline. The general pattern along the New York shoreline differs from those of the New Jersey shoreline and mid-river. Here, the first significant peak is farther upstream at sites T29C, T28C, and T27C, with T27C being more pronounced. Site T27C is located in the vicinity of the North River WPCP. The second peak appears at site T22C, half way between The GWB and the Yonkers WPCP. Similar to the mid-river sites, the next peak is at site T5C, north of the Yonkers WPCP. The peak at site T11C is a location north of but slightly off of the TZB. Site T15C, south of Ossining WPCP, also shows slight increases in trace

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metals concentrations. Following a sharp decrease in trace metals concentrations at site T16C and T17C, a general upward trend in trace metals concentrations occurs, with site T20C being more pronounced.

Figure 9. Metal Concentrations in Surficial Bottom Sediments, New York Longitudinal Sections: C sites

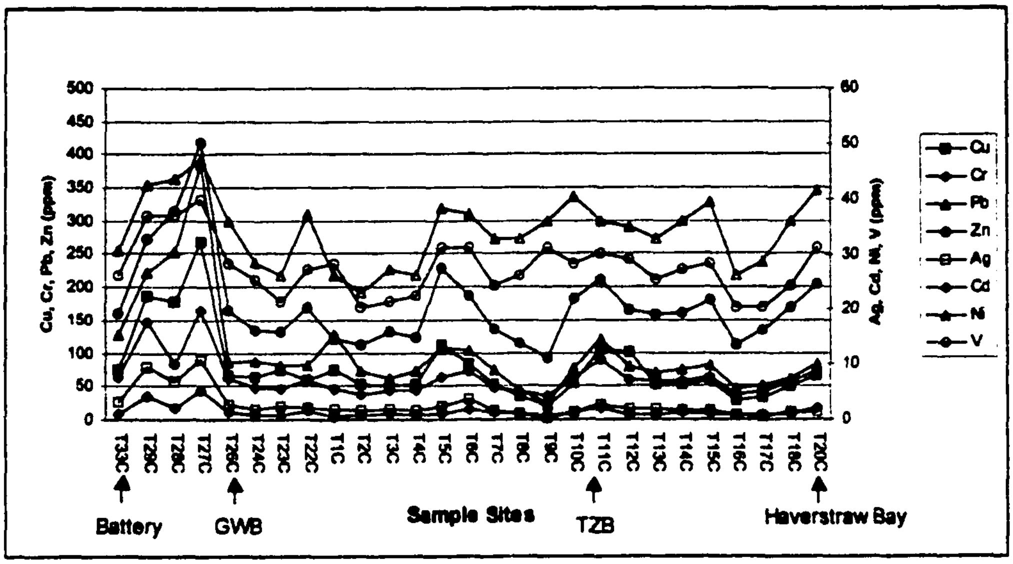
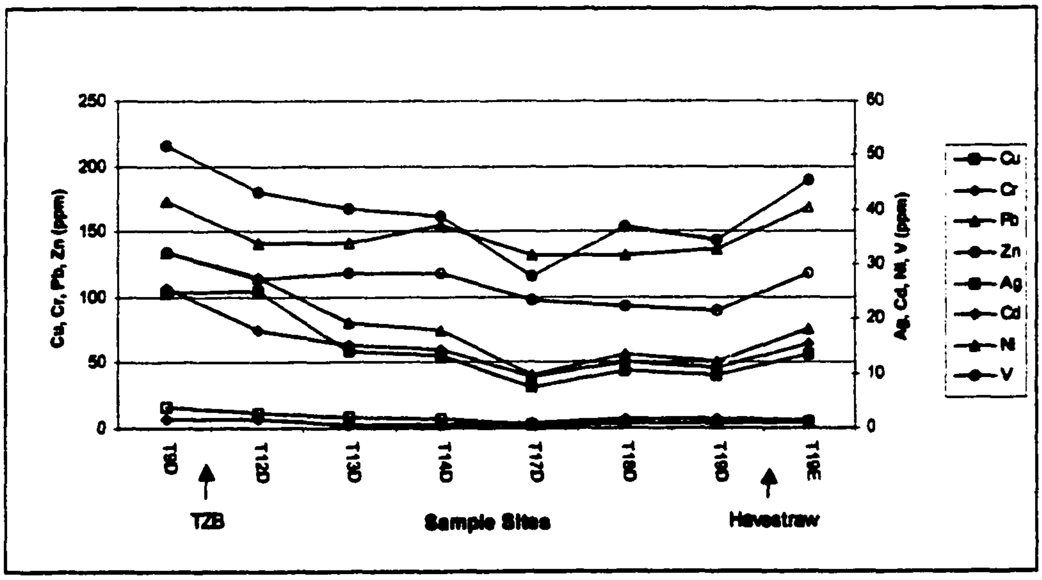


Figure 10. Metal Concentrations in Surficial Bottom Sediments, New York Longitudinal Sections: D- and E-Sites



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3.1.4. Longitudinal River Sections Along New York Shoreline – D & E Sites

From slightly south of the Tappan Zee Bridge north to Haverstraw Bay, where the Hudson River Estuary becomes wider, cross-river transects include additional sampling stations, which are designated by the letters D and E. All together there are seven D stations and only one E station. **Figure 10** shows a longitudinal river section for D and E sites. Each metal follows a similar longitudinal trend with lowest concentrations at T17D. Unlike the trace metals concentrations for A, B, and C sites, trace metals concentrations at D and E sites are low, with almost no peaks. The exception to this general pattern is that of Ni. Ni concentrations are comparable to those in longitudinal river sections A, B, and C.

3.1.5. Cross-River Transects

Cross-river transects were prepared to assess the magnitude of trace metals gradients from New York to New Jersey shorelines (**Appendix B**). Among 32 transects throughout the study area, from the Battery north to Haverstraw Bay, there are several transects that show significant cross-river trace metals gradients. For instance, trace metals concentrations along T32 show several-fold increases in Cr (3.40x), Cu (5.45x), Ni (1.53x), Pb (3.67x), and Zn (3.50x) on the NJ side as compared to the New York shore. In general, trace metals concentrations show increases along transects 29, 28, and 27 on the New York side, with transect 27, in the vicinity of the North River WPCP (located on New York side), showing a distinct pattern. Here a sharp decrease is observed in all trace metals concentrations at site T27B, the mid-river location. Transect 26, south

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of the GWB, shows increases in Cr, Cu, Ni, Pb, Zn, and V on the New Jersey side. Along transect 25, slightly south of the GWB, Pb concentration is unusually high on the New Jersey shoreline (458 ppm) as compared to the New York shoreline (188 ppm), while concentrations of other trace metals remain more or less the same. Transect 23, located north of the GWB, is interesting in that its mid-river site (T23B) shows higher concentrations of Ni, V and Zn as compared to those on the New Jersey and New York shores. Cross-river transects 1, 2, 3, and 4 show similar trace metal concentrations patterns. Transect 5 shows a drop in trace metals concentrations along the mid-river and an increase on both the New Jersey and New York sides. Transects 16, 17, and 18 show higher levels of trace metal concentrations along the New Jersey side. Transect 20, the northernmost transect in the study area, shows a significant drop in trace metals concentrations on the New Jersey side.

3.2. Percent Total Organic Carbon (%TOC)

Data on percentage total organic carbon content of surficial bottom sediments collected in August and September of 1997 are presented in **Table 8.** To assure the reproducibility of the analytical method, each sediment sample was analyzed two times and the reported result is the mean value. Plus and minus values are the standard deviation of the mean value. This study determined a range of percent TOC values from a maximum of 2.99% dry weight, at site T26A south of the George Washington Bridge along the New Jersey shoreline, to a minimum of 0.67% dry weight at site T2C south of the Yonkers WPCP along the New York shoreline.

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Table 8. Percent Total Organic Carbon in surficial bottom sediments in Lower Hudson Estuary, August and September 1997

	1st run				2nd run								Accuracy 98.8% applied			
Sites	**W (gr)**	**NaF (gr)**	**FAS (ml)**	**%TOC**	**W (gr)**	**NaF (gr)**	**FAS (ml)**	**%TOC**	**Mean**	**SD**	**High**	**Low**	**high**	**low**	**Mean (%TOC)**	**SD (±)**
T1 A	0.498	0.204	12.1	**2.486**	0.504	0.211	11.7	**2.555**	**2.521**	**0.035**	2.555	2.486	2.527	2.459	**2.490**	**0.034**
T1 B	0.501	0.205	13.5	**2.078**	0.502	0.206	13.2	**2.128**	**2.103**	**0.025**	2.128	2.078	2.105	2.055	**2.080**	**0.025**
T1 C	0.5	0.21	17.4	**0.947**	0.505	0.206	16.9	**1.043**	**0.995**	**0.048**	1.043	0.947	1.032	0.937	**0.980**	**0.048**
T2 A	0.501	0.211	12.5	**2.355**	0.506	0.205	12	**2.458**	**2.407**	**0.051**	2.458	2.355	2.431	2.329	**2.380**	**0.051**
T2 B	0.498	0.203	15.2	**1.579**	0.501	0.203	15.2	**1.548**	**1.564**	**0.015**	1.579	1.548	1.562	1.531	**1.550**	**0.015**
T2 C	0.503	0.206	18.4	**0.637**	0.503	0.204	18	**0.727**	**0.682**	**0.045**	0.727	0.637	0.719	0.630	**0.670**	**0.045**
T3 A	0.503	0.206	11.1	**2.765**	0.501	0.204	10.3	**2.979**	**2.872**	**0.107**	2.979	2.765	2.946	2.735	**2.840**	**0.106**
T3 B	0.503	0.203	14.8	**1.679**	0.5	0.209	14.5	**1.756**	**1.718**	**0.039**	1.756	1.679	1.737	1.661	**1.700**	**0.038**
T3 C	0.502	0.206	16.7	**1.131**	0.503	0.209	16.1	**1.28**	**1.206**	**0.074**	1.280	1.131	1.266	1.119	**1.190**	**0.074**
Blank	———	0.212	20.6		———	0.211	20.5									
T4 A	0.504	0.207	13.3	**2.124**	0.503	0.207	12.9	**2.211**	**2.168**	**0.044**	2.211	2.124	2.187	2.101	**2.140**	**0.043**
T4 B	0.503	0.206	15.2	**1.563**	0.502	0.202	13.2	**2.143**	**1.853**	**0.290**	2.143	1.563	2.119	1.546	**1.830**	**0.287**
T4 C	0.504	0.204	17.1	**1.011**	0.504	0.207	16.7	**1.118**	**1.065**	**0.053**	1.118	1.011	1.106	1.000	**1.050**	**0.053**
T5 A	0.504	0.208	11.2	**2.716**	0.506	0.204	11.7	**2.545**	**2.631**	**0.085**	2.716	2.545	2.686	2.517	**2.600**	**0.085**
T5 B	0.504	0.206	17.6	**0.867**	0.503	0.207	17.1	**0.989**	**0.928**	**0.061**	0.989	0.867	0.978	0.857	**0.920**	**0.060**
T5 C	0.501	0.202	14.2	**1.875**	0.506	0.206	14.1	**1.851**	**1.863**	**0.012**	1.875	1.851	1.854	1.831	**1.840**	**0.012**
T6 A	0.504	0.203	15.9	**1.358**	0.506	0.209	15.5	**1.446**	**1.402**	**0.044**	1.446	1.358	1.430	1.343	**1.390**	**0.044**
T6 B	0.506	0.207	14.9	**1.641**	0.506	0.206	14.3	**1.793**	**1.717**	**0.076**	1.793	1.641	1.773	1.623	**1.700**	**0.075**
T6 C	0.504	0.204	13.6	**2.023**	0.506	0.204	13.6	**1.996**	**2.010**	**0.014**	2.023	1.996	2.001	1.974	**1.990**	**0.013**
Blank	———	0.208	20.1		———	0.205	20.3									
T7 B	0.509	0.205	14.4	**1.788**	0.507	0.207	13.9	**1.919**	**1.854**	**0.066**	1.919	1.788	1.898	1.768	**1.830**	**0.065**
T7 C	0.504	0.207	16.5	**1.199**	0.507	0.204	16.2	**1.256**	**1.228**	**0.028**	1.256	1.199	1.242	1.186	**1.210**	**0.028**
T8 A	0.508	0.207	15.9	**1.347**	0.509	0.206	16	**1.308**	**1.328**	**0.019**	1.347	1.308	1.332	1.294	**1.310**	**0.019**
T8 B	0.508	0.21	14.4	**1.792**	0.511	0.202	14.3	**1.776**	**1.784**	**0.008**	1.792	1.776	1.772	1.756	**1.760**	**0.008**
T8 C	0.51	0.21	15.3	**1.528**	0.502	0.202	15.4	**1.501**	**1.515**	**0.014**	1.528	1.501	1.511	1.484	**1.500**	**0.013**
T9 A	0.507	0.201	16.6	**1.163**	0.507	0.203	17.2	**0.967**	**1.065**	**0.098**	1.163	0.967	1.150	0.956	**1.050**	**0.097**
T9 B	0.503	0.21	16.1	**1.317**	0.507	0.204	15.4	**1.472**	**1.395**	**0.078**	1.472	1.317	1.456	1.303	**1.380**	**0.077**

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Table 8. Percent Total Organic Carbon in surficial bottom sediments in Lower Hudson Estuary, continued

	1st run				2nd run								Accuracy 98.8% applied			
Sites	W (gr)	NaF (gr)	FAS (ml)	%TOC	W (gr)	NaF (gr)	FAS (ml)	%TOC	Mean	SD	High	Low	high	low	Mean (%TOC)	SD (±)
T9 C	0.507	0.207	13.7	1.996	0.507	0.203	13.7	1.977	1.987	0.009	1.996	1.977	1.974	1.955	1.960	0.010
T9 D	0.501	0.207	14.9	1.671	0.507	0.202	14.6	1.703	1.687	0.016	1.703	1.671	1.684	1.653	1.670	0.016
Blank	———	0.207	20.3		———	0.206	20.5									
T10 A	0.51	0.207	16.3	1.242	0.504	0.205	16.2	1.263	1.253	0.011	1.263	1.242	1.249	1.228	1.240	0.010
T10 B	0.51	0.204	15.1	1.571	0.508	0.205	15.1	1.556	1.564	0.007	1.571	1.556	1.554	1.539	1.550	0.008
T10 C	0.51	0.207	14	1.885	0.509	0.204	13.6	1.998	1.942	0.056	1.998	1.885	1.976	1.864	1.920	0.056
T11 A	0.505	0.205	12.7	2.278	0.507	0.208	12.9	2.208	2.243	0.035	2.278	2.208	2.253	2.184	2.220	0.035
T11 B	0.51	0.207	13.3	2.099	0.501	0.205	13.4	2.074	2.087	0.013	2.099	2.074	2.076	2.051	2.060	0.013
T11 C	0.503	0.207	15.4	1.506	0.506	0.204	15.1	1.562	1.534	0.028	1.562	1.506	1.545	1.489	1.520	0.028
T12 A	0.511	0.209	14.4	1.781	0.506	0.208	14.3	1.793	1.787	0.006	1.793	1.781	1.773	1.761	1.770	0.006
T12 B	0.505	0.208	14.3	1.831	0.505	0.207	14.4	1.768	1.800	0.031	1.831	1.768	1.811	1.749	1.780	0.031
T12 C	0.509	0.206	15.5	1.473	0.501	0.207	15.5	1.46	1.467	0.006	1.473	1.460	1.457	1.444	1.450	0.006
Blank	———	0.203	20.3		———	0.206	20.2									
T12 D	0.507	0.206	16.2	1.264	0.505	0.208	15.1	1.579	1.422	0.158	1.579	1.264	1.562	1.250	1.410	0.156
T13 A	0.507	0.204	16.4	1.206	0.506	0.206	15.6	1.417	1.312	0.105	1.417	1.206	1.401	1.193	1.300	0.104
T13 B	0.506	0.21	15.1	1.597	0.511	0.211	13.9	1.89	1.744	0.146	1.890	1.597	1.869	1.579	1.720	0.145
T13 C	0.504	0.208	13.8	1.965	0.509	0.202	15.2	1.524	1.745	0.221	1.965	1.524	1.943	1.507	1.730	0.218
T13 D	0.505	0.209	14.5	1.759	0.504	0.206	13.4	2.062	1.911	0.152	2.062	1.759	2.039	1.740	1.890	0.150
T14 A	0.205	0.207	16.5	2.913	No more sediment				2.913	0.000	2.913	2.913	2.881	2.881	2.880	0.001
T14 B	0.509	0.207	15.4	1.488	0.511	0.211	12.5	2.291	1.890	0.402	2.291	1.488	2.266	1.472	1.870	0.397
T14 C	0.507	0.21	13.2	2.126	0.504	0.21	14.6	1.728	1.927	0.199	2.126	1.728	2.103	1.709	1.910	0.197
T14 D	0.508	0.203	13.3	2.093	0.504	0.21	13	2.178	2.136	0.043	2.178	2.093	2.154	2.070	2.110	0.042
Blank	———	0.207	21.1		———	0.208	20.3									
T15 A	0.51	0.211	13.2	2.127	0.506	0.206	13.9	1.923	2.025	0.102	2.127	1.923	2.104	1.902	2.000	0.101
T15 B	0.508	0.209	13.5	2.035	0.508	0.213	13.8	1.93	1.983	0.053	2.035	1.930	2.013	1.909	1.960	0.052
T15 C	0.505	0.208	13.9	1.947	0.509	0.209	13.9	1.898	1.923	0.024	1.947	1.898	1.926	1.877	1.900	0.024
T16 A	0.512	0.209	10.7	2.83	0.513	0.211	11.8	2.482	2.656	0.174	2.830	2.482	2.799	2.455	2.630	0.172
T16 B	0.514	0.209	14.4	1.757	0.507	0.207	14.8	1.645	1.701	0.056	1.757	1.645	1.738	1.627	1.680	0.055

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Table 8. Percent Total Organic Carbon in surficial bottom sediments in Lower Hudson Estuary, continued

	1st run				2nd run								Accuracy 98.8% applied			
Sites	**W (gr)**	**NaF (gr)**	**FAS (ml)**	**%TOC**	**W (gr)**	**NaF (gr)**	**FAS (ml)**	**%TOC**	**Mean**	**SD**	**High**	**Low**	**high**	**low**	**Mean (%TOC)**	**SD (±)**
T16 C	0.513	0.215	16.7	1.107	0.515	0.206	16.7	1.094	1.101	0.007	1.107	1.094	1.095	1.082	1.090	0.006
T17 A	0.509	0.208	12.8	2.232	0.516	0.209	12.9	2.17	2.201	0.031	2.232	2.170	2.207	2.146	2.180	0.031
T17 B	0.511	0.206	16	1.311	0.509	0.207	16.1	1.265	1.288	0.023	1.311	1.265	1.297	1.251	1.270	0.023
T17 C	0.509	0.209	16.8	1.087	0.506	0.208	17	1.027	1.057	0.030	1.087	1.027	1.075	1.016	1.050	0.030
Blank	———	0.205	19.4		———	0.211	19.4									
T17 D	0.506	0.207	15.8	1.396	0.513	0.205	15.2	1.512	1.454	0.058	1.512	1.396	1.495	1.381	1.440	0.057
T18 A	0.493	0.212	14.7	1.743	0.512	0.216	14.3	1.772	1.758	0.015	1.772	1.743	1.753	1.724	1.740	0.014
T18 C	0.507	0.208	14.7	1.709	0.513	0.21	14.6	1.697	1.703	0.006	1.709	1.697	1.690	1.678	1.680	0.006
T18 D	0.507	0.207	15.9	1.364	0.505	0.212	15.7	1.391	1.378	0.013	1.391	1.364	1.376	1.349	1.360	0.013
T16 B	0.511	0.21	15.8	1.382	0.511	0.209	15.8	1.36	1.371	0.011	1.382	1.360	1.367	1.345	1.360	0.011
T19 A	0.509	0.207	13.8	1.96	0.509	0.21	13.4	2.041	2.001	0.041	2.041	1.960	2.019	1.938	1.980	0.040
T19 B	0.508	0.206	13.9	1.921	0.506	0.211	13.7	1.981	1.951	0.030	1.981	1.921	1.959	1.900	1.930	0.030
T19 D	0.511	0.207	15.7	1.411	0.506	0.21	15.9	1.345	1.378	0.033	1.411	1.345	1.395	1.330	1.360	0.033
T19 E	0.512	0.207	14	1.891	0.51	0.205	13.9	1.894	1.893	0.001	1.894	1.891	1.873	1.870	1.870	0.002
Blank	———	0.204	20.4		———	0.208	20.2									
T20 A	0.503	0.207	17.6	0.869	0.5	0.207	17.4	0.907	0.888	0.019	0.907	0.869	0.897	0.859	0.880	0.019
T20 B	0.508	207	13.6	2.021	0.507	0.21	14.1	1.847	1.934	0.087	2.021	1.847	1.999	1.827	1.910	0.086
T20 C	0.5	0.212	13.6	2.039	0.51	0.212	13.4	2.037	2.038	0.001	2.039	2.037	2.017	2.015	2.020	0.003
T22 A	0.496	0.201	11.9	2.554	0.514	0.208	10.9	2.733	2.644	0.089	2.733	2.554	2.703	2.526	2.610	0.089
T22 B	0.511	0.207	15.3	1.525	0.51	0.209	15.4	1.463	1.494	0.031	1.525	1.463	1.508	1.447	1.480	0.031
T22 C	0.508	0.208	14.8	1.677	0.513	0.207	14.8	1.626	1.652	0.026	1.677	1.626	1.659	1.608	1.630	0.025
T23 A	0.507	0.21	14.3	1.824	0.511	0.208	14.1	1.847	1.836	0.011	1.847	1.824	1.827	1.804	1.820	0.012
T23 B	0.507	0.209	12.5	2.341	0.505	0.204	12.8	2.231	2.286	0.055	2.341	2.231	2.315	2.206	2.260	0.054
T23 C	0.507	0.206	14.3	1.81	0.511	0.207	14.4	1.747	1.779	0.031	1.810	1.747	1.790	1.728	1.760	0.031
Blank	———	0.21	20.8		———	0.208	20.9									
T24 A	0.44	0.206	13.1	2.499	0.412	0.209	13.1	2.628	2.564	0.064	2.628	2.499	2.599	2.472	2.540	0.064
T24 B	0.513	0.204	14	1.874	0.502	0.202	12.9	2.23	2.052	0.178	2.230	1.874	2.205	1.853	2.030	0.176
T24 C	0.509	0.202	16.8	1.087	0.51	0.207	16.9	1.047	1.067	0.020	1.087	1.047	1.075	1.035	1.060	0.020

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Table 8. Percent Total Organic Carbon in surficial bottom sediments in Lower Hudson Estuary, continued

	1st run				2nd run								Accuracy 98.8% applied			
Sites	**W (gr)**	**NaF (gr)**	**FAS (ml)**	**%TOC**	**W (gr)**	**NaF (gr)**	**FAS (ml)**	**%TOC**	**Mean**	**SD**	**High**	**Low**	**high**	**low**	**Mean (%TOC)**	**SD (±)**
T25 A	0.491	0.215	13.9	**1.987**	0.496	0.202	13.5	**2.065**	**2.026**	**0.039**	2.065	1.987	2.042	1.965	**2.000**	**0.039**
T25 B	0.446	0.207	12.8	**2.547**	0.493	0.209	12.8	**2.286**	**2.417**	**0.130**	2.547	2.286	2.519	2.261	**2.390**	**0.129**
T26 A	0.497	0.207	10.4	**2.989**	0.495	0.213	10.2	**3.06**	**3.025**	**0.036**	3.060	2.989	3.026	2.956	**2.990**	**0.035**
T26 B	0.507	0.206	16.2	**1.278**	0.511	0.209	16.1	**1.26**	**1.269**	**0.009**	1.278	1.260	1.264	1.246	**1.260**	**0.009**
T26 C	0.507	0.2	14.8	**1.68**	0.508	0.21	14.5	**1.743**	**1.712**	**0.032**	1.743	1.680	1.724	1.662	**1.690**	**0.031**
T27 A	0.486	0.208	10.9	**2.922**	0.497	0.207	11.2	**2.738**	**2.830**	**0.092**	2.922	2.738	2.890	2.708	**2.800**	**0.091**
Blank	———	0.203	20.8		———	0.204	20.9									
T27 B	0.507	0.207	16.2	**1.264**	0.503	0.201	15.9	**1.338**	**1.301**	**0.037**	1.338	1.264	1.323	1.250	**1.290**	**0.037**
T27 C	0.48	0.203	10.8	**2.973**	0.487	0.208	10.7	**2.945**	**2.959**	**0.014**	2.973	2.945	2.940	2.913	**2.930**	**0.014**
T28 A	0.506	0.209	14.7	**1.698**	0.511	0.206	14.8	**1.632**	**1.665**	**0.033**	1.698	1.632	1.679	1.614	**1.650**	**0.033**
T28 B	0.505	0.205	15.3	**1.528**	0.508	0.209	14.9	**1.613**	**1.571**	**0.043**	1.613	1.528	1.595	1.511	**1.550**	**0.042**
T28 C	0.439	0.21	12.8	**2.604**	0.481	0.21	12.3	**2.51**	**2.557**	**0.047**	2.604	2.510	2.575	2.482	**2.530**	**0.046**
T29 A	0.456	0.202	14.1	**2.092**	0.496	0.208	13.4	**2.11**	**2.101**	**0.009**	2.110	2.092	2.087	2.069	**2.080**	**0.009**
T29 B	0.51	0.208	15.8	**1.371**	0.508	0.209	15.5	**1.455**	**1.413**	**0.042**	1.455	1.371	1.439	1.356	**1.400**	**0.042**
T29 C	0.465	0.207	14.4	**1.942**	0.498	0.209	14.1	**1.895**	**1.919**	**0.024**	1.942	1.895	1.921	1.874	**1.900**	**0.023**
T30 A	0.431	0.214	13.4	**2.433**	0.453	0.201	13.1	**2.391**	**2.412**	**0.021**	2.433	2.391	2.406	2.365	**2.390**	**0.021**
Blank	——	0.21	20.8		——	0.21	20.4									
T30 B	0.51	0.202	12.9	**2.213**	0.509	0.203	13.2	**2.113**	**2.163**	**0.050**	2.213	2.113	2.189	2.090	**2.140**	**0.049**
T31 A	0.462	0.218	11.5	**2.884**	0.497	0.207	11.2	**2.738**	**2.811**	**0.073**	2.884	2.738	2.852	2.708	**2.780**	**0.072**
T31 B	0.447	0.205	16.8	**1.238**	0.487	0.201	16.3	**1.262**	**1.250**	**0.012**	1.262	1.238	1.248	1.224	**1.240**	**0.012**
T32 A	0.48	0.202	13.3	**2.215**	0.494	0.212	13.1	**2.192**	**2.204**	**0.012**	2.215	2.192	2.191	2.168	**2.180**	**0.011**
T32 B	0.503	0.208	15.3	**1.549**	0.508	0.209	14.4	**1.772**	**1.661**	**0.111**	1.772	1.549	1.753	1.532	**1.640**	**0.110**
T33 A	0.429	0.201	13.5	**2.41**	0.49	0.208	12.8	**2.3**	**2.355**	**0.055**	2.410	2.300	2.383	2.275	**2.330**	**0.054**
T33 B	0.432	0.21	17.2	**1.143**	0.435	0.202	16.9	**1.211**	**1.177**	**0.034**	1.211	1.143	1.198	1.130	**1.160**	**0.034**
T33 C	0.506	0.206	15.7	**1.41**	0.502	0.207	15.9	**1.341**	**1.376**	**0.034**	1.410	1.341	1.394	1.326	**1.360**	**0.034**
T34 A	0.484	0.225	15.3	**1.61**	0.497	0.208	15.5	**1.472**	**1.541**	**0.069**	1.610	1.472	1.592	1.456	**1.520**	**0.068**
T34 B	0.458	0.206	15.2	**1.717**	0.466	0.213	13.8	**2.104**	**1.911**	**0.193**	2.104	1.717	2.081	1.698	**1.890**	**0.191**
Blank	——	0.212	20.8		——	0.212	20.5									

3.3. Grain- size Distribution

Forty-four out of 97 surficial bottom sediment samples were selected for grain-size analysis, based on (1) the observed variations in trace metal concentrations from site to site (thus selecting sediment samples that could represent a range of observed trace metals from the highest to lowest concentration values), and (2) the grain-size facies map of the Hudson River Estuary (Coch, 1986), which delineates the spatial variation in physical characteristics of bottom sediments.

Table 9 shows the results of grain-size analysis of selected sediment samples. Percent sand indicates grain-size fraction ranging from fine sand (250 to 125 micrometers) and very fine sand (125 to 62.5 micrometers), and % mud indicates grain-size fraction ranging from silt (62.5 – 3.9 micrometers) to clays (< 3.9 micrometers).

3.4. Percent Total Carbohydrate (%TCH)

In this study, sediment samples for TCH analysis were selected based on two criteria: (1) trace metals content exceeding the ERM sediment quality guidelines (Long & Morgan, 1991; Long *et al.*, 1995) and (2) high percent TOC. Except for the New York Bight area (see Hatcher and Keister, 1976; Harris, 1979; Harris and Waschitz, 1982), no previous data are available concerning the carbohydrate content of the Hudson estuarine sediments in the study area. Thirty samples of the same sediment fraction analyzed for %TOC were analyzed for TCH. The results of the analysis and the R values are reported in **Table 10.** The purpose of such analysis was to obtain a semi-qualitative source indicator for organic matter in the study areas, which are known to be sinks for trace metals.

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Table 9. Results of grain size analysis of selective surficial bottom sediment samples in the Lower Hudson Estuary, August-September 1997

Sites	Lat (deg)	Long (deg)	%Sand (250 – 62.5) µm	%Mud (< 62.5) µm	Sites	Lat (deg)	Long (deg)	%Sand (250 – 62.5) µm	%Mud (< 62.5) µm
20A	41.2306	73.9667	58.51	41.49	**4C**	40.9667	73.8931	41.43	58.57
20B	41.2306	73.9575	9.17	90.83	**3B**	40.9500	73.9042	7.26	92.74
19B	41.2167	73.9542	2.84	97.16	**3C**	40.9500	73.9008	21.64	78.36
18A	41.2000	73.9553	6.69	92.51	**2B**	40.9333	73.9142	15.05	84.22
18B	41.2000	73.9492	17.04	82.96	**22C**	40.9000	73.9175	18.21	81.79
18D	41.2000	73.9269	26.08	73.92	**23C**	40.8833	73.9236	50.55	49.25
16A	41.1667	73.9231	1.35	97.40	**24A**	40.8667	73.9492	6.44	93.56
16B	41.1667	73.9158	20.85	79.15	**24C**	40.8667	73.9347	54.05	45.95
16C	41.1667	73.9008	58.20	41.79	**25A**	40.8500	73.9583	21.71	83.45
15B	41.1500	73.8983	3.27	96.73	**25B**	40.8500	73.9539	44.57	55.43
15C	41.1500	73.8825	14.39	85.61	**26A**	40.8333	73.9669	8.10	91.90
13A	41.1167	73.9042	26.57	73.07	**26B**	40.8333	73.9594	31.82	68.18
12A	41.1000	73.9042	14.48	85.52	**26C**	40.8333	73.9525	19.77	80.23
12C	41.1000	73.8833	19.09	80.91	**27B**	40.8167	73.9700	49.59	50.41
12D	41.1000	73.8725	6.61	93.39	**27C**	40.8167	73.9656	39.01	60.99
10A	41.0667	73.8992	6.98	93.02	**28C**	40.8000	73.9772	13.94	84.64
10B	41.0667	73.8900	9.70	88.38	**29B**	40.7833	73.9953	5.88	94.12
9A	41.0500	73.9000	9.65	90.35	**29C**	40.7833	73.9883	20.60	77.24
7B	41.0167	73.8875	17.25	82.75	**30A**	40.7667	74.0122	27.10	72.90
6B	41.0000	73.8925	10.61	89.39	**31A**	40.7500	74.0200	39.16	60.84
5A	40.9833	73.9028	3.29	96.71	**31B**	40.7500	74.0128	44.81	55.19
5C	40.9833	73.8875	13.48	86.52	**34A**	40.7019	74.0325	43.14	59.73
4A	40.9667	73.9078	5.50	94.50					

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TCH was found to range from 2.6 (station T16C, north of Ossining WPCP) to 11.8 (station T26A, south of the George Washington Bridge and Edgewater WPCP) mg/g of sediment. Except for station T30A (TCH = 4.2 mg/g, %TOC = 2.39), TCH values for %TOC between 2- and 2.99% range from 6.4 to 11.82 mg/g sediment. Except for stations T23A (TCH = 6.4, %TOC = 1.82, north of the George Washington Bridge on the New Jersey side) and T32B (TCH = 6mg/g, %TOC = 1.64, near 72nd street), TCH values for %TOC less than 2% range from 2.6 to 4.7 mg/g sediment. R values range from 131 to 451, with the highest value located at station 24B, the mid-river site north of the George Washington Bridge. Sites along the New Jersey shoreline show higher TCH:TOC ratios than those few sites along the New York shoreline.

Carbohydrate concentration is reported as a percentage of TOC or as R-value. Such treatment causes this parameter, R, which is defined as

$$R = [(\text{mg TCH} / \text{g of sediment}) / \%\text{TOC}] \times 100$$

to become independent of sediment dry weight or of absolute concentration of organic matter (Hatcher and Keister, 1976; Harris and Wachitz, 1982). Details of the analysis are reported in (**Appendix C**).

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Table 10. Percent TOC and Total Carbohydrate in selected bottom sediments

Sites	Latitude (degrees)	Longitude (degrees)	TOC%	+/-	TCH mg/g	R = TCH/TOC
18A	41.2000	73.9553	1.74	0.01	4.61	265
17A	41.1833	73.9458	2.18	0.03	9.22	423
16A	41.1667	73.9231	2.63	0.17	9.81	373
16C	41.1667	73.9008	1.09	0.01	2.56	235
13A	41.1167	73.9042	1.30	0.10	2.47	190
11C	41.0750	73.8742	1.52	0.03	4.44	292
10B	41.0667	73.8900	1.55	0.01	3.18	205
9D	41.0500	73.8733	1.67	0.02	3.67	220
6C	41.0000	73.8867	1.99	0.01	4.48	225
5A	40.9833	73.9028	2.60	0.09	8.67	333
3A	40.9500	73.9153	2.84	0.11	7.47	263
2B	40.9333	73.9142	1.55	0.02	4.32	278
1A	40.9167	73.9253	2.49	0.03	6.73	270
22A	40.9000	73.9322	2.61	0.09	9.12	349
23A	40.8833	73.9397	1.82	0.01	6.42	352
23B	40.8833	73.9303	2.26	0.05	6.38	282
23C	40.8833	73.9236	1.76	0.03	4.10	233
24B	40.8667	73.9425	2.03	0.18	9.15	451
25A	40.8500	73.9583	2.00	0.04	8.65	432
25B	40.8500	73.9539	2.39	0.13	8.88	367
26A	40.8333	73.9669	2.99	0.04	11.82	395
27A	40.8167	73.9761	2.80	0.09	10.20	364
27C	40.8167	73.9656	2.93	0.01	7.32	250
28C	40.8000	73.9772	2.53	0.05	3.31	131
29C	40.7833	73.9883	1.90	0.02	4.73	249
30A	40.7667	74.0122	2.39	0.02	4.22	176
31A	40.7500	74.0200	2.78	0.07	12.21	437
31B	40.7500	74.0128	1.24	0.01	4.80	387
32B	40.7333	74.0153	1.64	0.11	6.00	366
34A	40.7019	74.0325	1.52	0.07	4.31	284

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3. 5. Statistical Analysis

3.5.1. Test for Normalcy

The test for normalcy is useful in that it helps to determine which procedure, parametric or non-parametric, must be applied in analyzing the data. If a data set yields a normal distribution, then the classic parametric procedures are satisfactory. The statistical software, JMP and JMP IN (Sall and Lehman, 1996), use the Shapiro-Wilk test to examine the distribution of data. In this test, the W statistic ranges from 0 to 1, with W=1 indicating the normal distribution. Histograms (**Figure 11**) accompanied by Normal Quantile Plots are prepared for each analyte (%TOC, Ag, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, and V). All the values for each analyte are shown as points in the plot with the y (vertical) coordinate being the actual values and the x (horizontal) coordinate being the normal quantile associated with the rank of the value after sorting the data. The location of the solid straight line in each plot is a function of the mean, and the slope of the line is the standard deviation of the data. Solid curved lines surrounding the straight line are the confidence interval (95%) limits for the distribution.

For a normal distribution, all the points fall along the solid straight line. In this study, however, some data points fall outside the 95% confidence limit curved lines. The quantile plot and outlier box plot and the S– shaped normal quantile plot all show a skewed distribution for most of the analytes, except for Fe % and TOC%, Ni, and V, which show a pattern close to a normal distribution. The test reports also show that of these four analytes, only the normal distribution suggested for V with a p value for W less than 0.05 is statistically significant.

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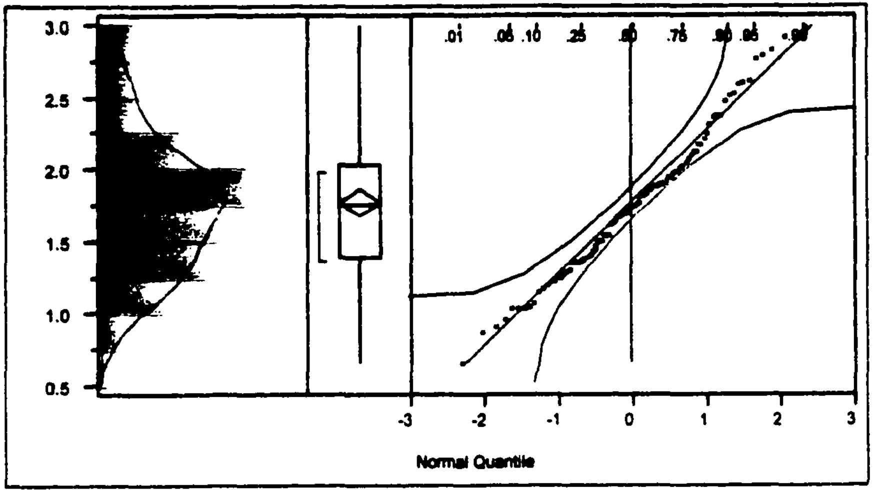
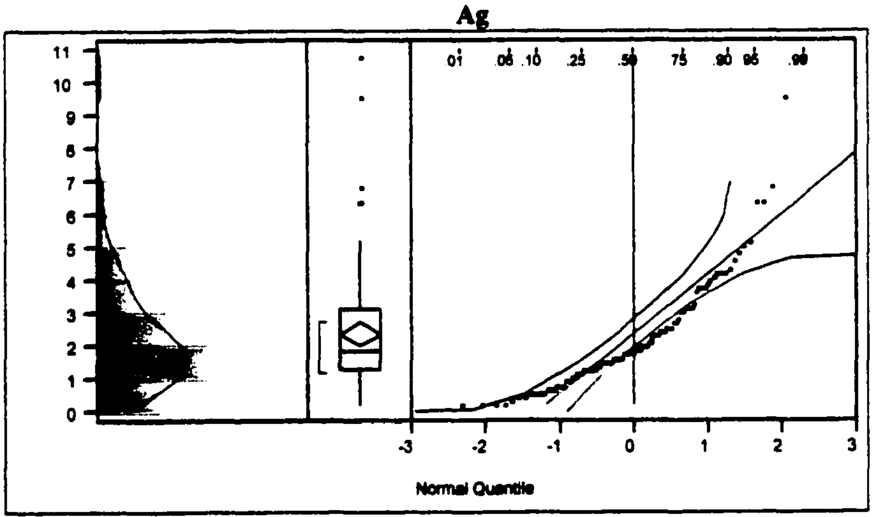
Figure 11. Test for Normalcy: Histograms, Quantile Box Plots, and S-shaped quantile plots for trace metals and %TOC

%TOC



Test for Normality: Shapiro-Wilk W Test W=0.972845 Prob<W=0.2224

Ag



Test for Normality: Shapiro-Wilk W Test W=0.834185 Prob<W=<.0001

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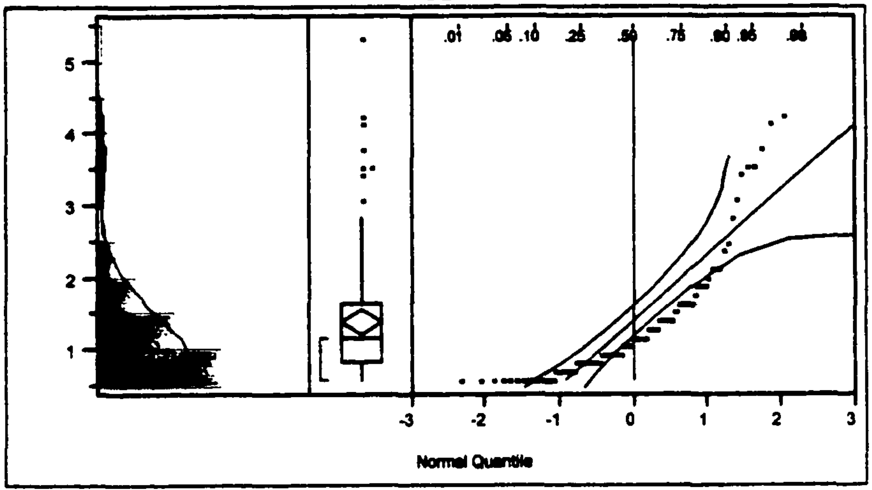
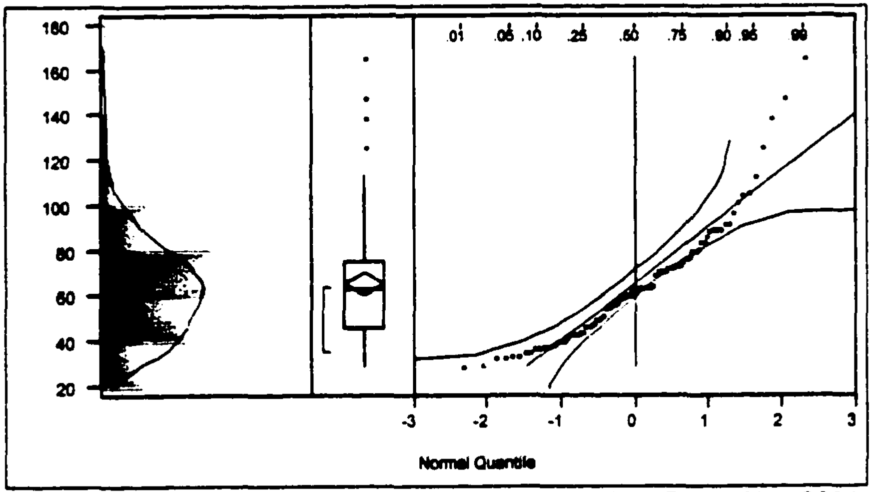
Cd



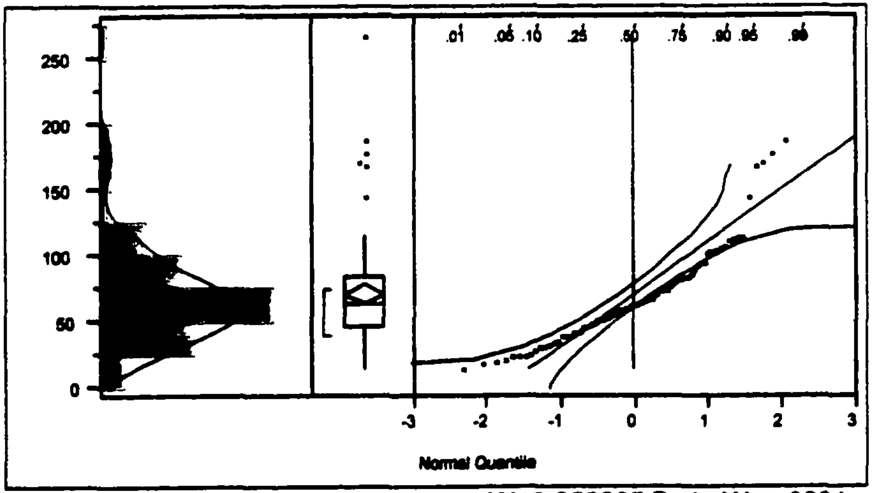
Test for Normality: Shapiro-Wilk W Test W=0.770982 Prob<W=0.0000

Cr



Test for Normality: Shapiro-Wilk W Test W=0.903928 Prob<W=<.0001

Cu



Test for Normality: Shapiro-Wilk W Test W=0.852295 Prob<W=<.0001

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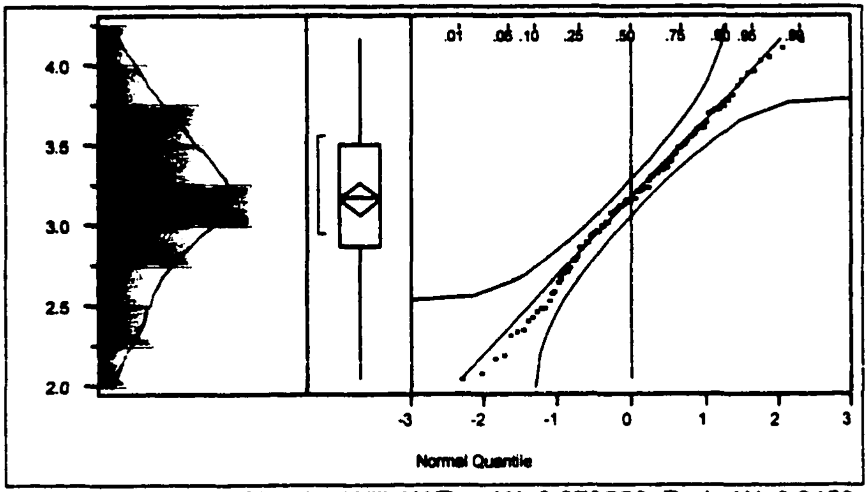
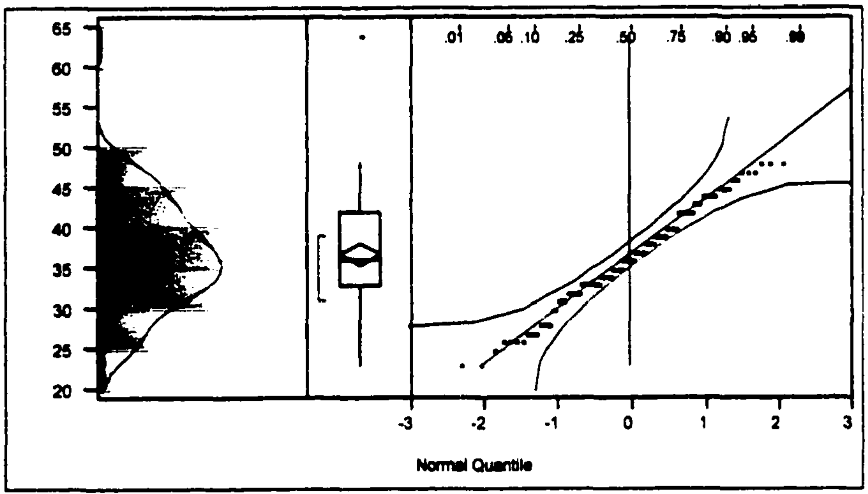
Fe%



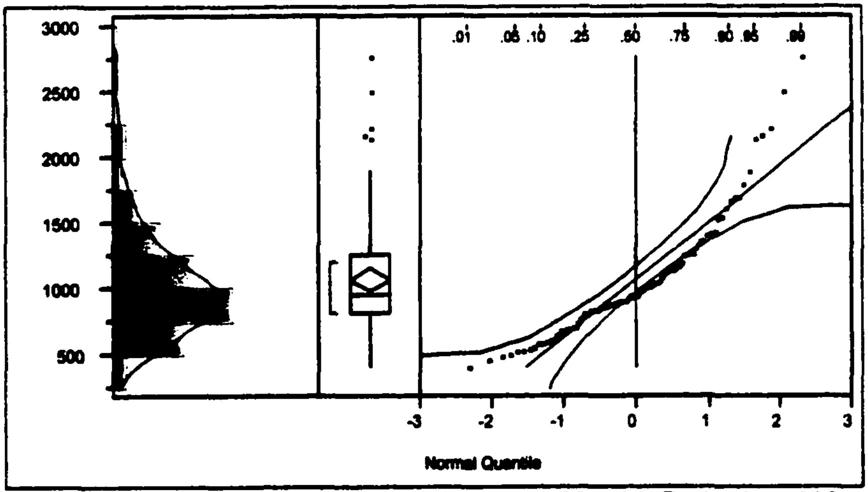
Test for Normality: Shapiro-Wilk W Test W=0.973552 Prob<W=0.2459

Ni



Test for Normality: Shapiro-Wilk W Test W=0.970830 Prob<W=0.1646

Mn



Test for Normality: Shapiro-Wilk W Test W=0.887235 Prob<W=<.0001

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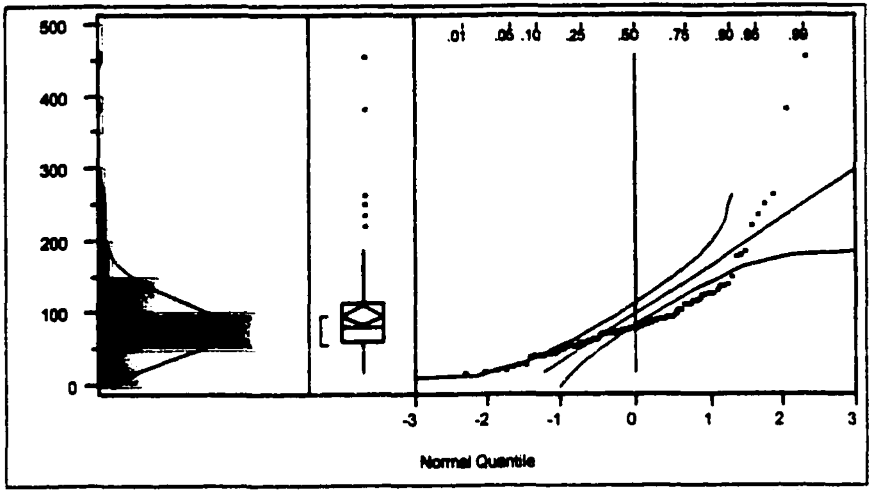
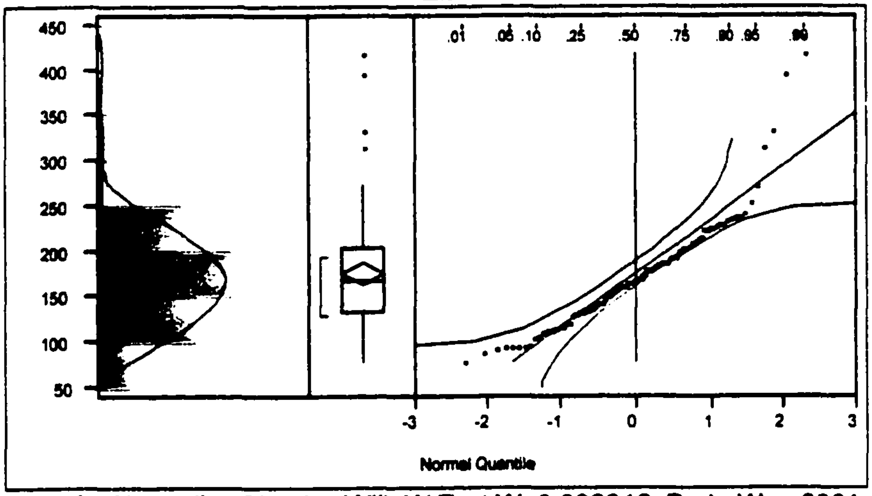
Pb



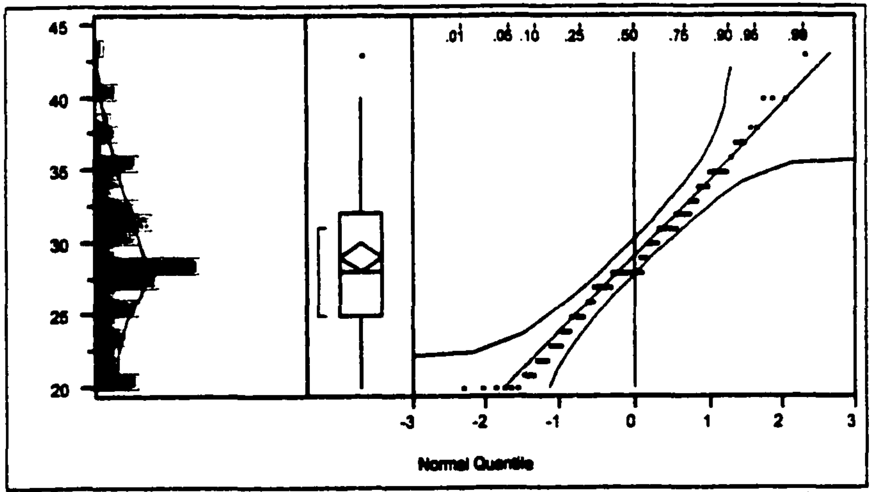
Test for Normality:Shapiro-Wilk W Test W=0.747504 Prob<W=0.0000

Zn



Test for Normality: Shapiro-Wilk W Test W=0.908618 Prob<W=<.0001

V



Test for Normality: Shapiro-Wilk W Test W=0.964291 Prob<W=0.0544

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3. 5. 2. One-Way Analysis of Variance (ANOVA)

ANOVA analysis is performed to test the variance around the group means and to examine the statistical significance of the differences observed between the group means. The sampling sites are grouped into three longitudinal river locations: NY (New York), NJ (New Jersey) and MC (or MR: Mid-River). For river transects containing less than or more than three sampling sites, sites were assigned to river locations according to the water depth. There are 32 sites in the NY group, 36 sites in the NJ group, and 30 sites in the MR group.

The mean response for each analyte along longitudinal river locations (NJ, NY, and MR) are compared (**Appendix D**). The actual analyte value is the continuous y variable, and locations are the nominal (grouping) x variable. Vertical scatter plots for each analyte along longitudinal river locations are shown side-by-side. The horizontal line across the middle indicates the overall mean (grand mean) of all the observations. The grand mean is calculated by pooling all the observations, regardless of their locations, into one big population. The group mean for each location is shown by the Mean Diamonds. The solid line at the center of the diamond is the group mean for its corresponding location. The solid line near the diamond apices are the 95% group overlap marks. For balanced data sets (our number of sampling stations for each group fits this criterion), the rule is that the group means are significantly different if the 95% group overlap marks of the mean diamonds do not overlap.

The difference circles (shown in red and black) show the results of the significance tests graphically. The center of each circle is aligned with its group mean. The radius of a circle is the 95% confidence interval for its group mean. Group means that are not significantly different from each other are shown in red and those that are

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significantly different remain black. The angle of intersection between the circles is also the key to seeing whether the group means are significantly different. The wider the angle of intersection between the circles (> 90 degrees), the less significant the differences between the group means. Two tests were used for this analysis. The Student's t-test measures the significance for each pair of group means. The Tukey-Kramer Honest Significance Difference tests more rigorously for the differences between all the pairs. In both cases, a positive result indicates a significant difference between the pair of group means.

In the ANOVA analysis, the F ratio measures the proportion of the variance that is explained by the model. A higher F ratio indicates a higher degree of differences among the group means. The P value, shown here as "Prob >F," measures the significance of the F ratio. A value less than 0.05 indicates a significant result.

ANOVA assumes normalcy. In this study, the distributions of the majority of metal concentrations were not normal. Therefore, I applied the non-parametric Wilcoxon Rank test, which is appropriate for non-normal distributions to test for differences in group means. The Wilcoxon Rank test uses the ranked data instead of the actual values. Chi-Squared is the measure of significance of the difference in ranking between the groups. If there are just two groups, Student t-test will be sufficient. If there are more than two groups, then Chi-Squared is reported as the ChiSQ Approximation. The results of ANOVA analysis for each analyte show that there are differences among group means between NY, NJ, and MC sites. **Table 11** shows a summary of the ANOVA analysis for each metal concentration grouped by longitudinal river locations. The results of ANOVA analysis indicate that %Fe and Ni have the largest F-ratios, indicating significant

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differences in their mean concentrations between NJ and NY. Also V, Mn, and %TOC follow the same pattern as the %Fe and Ni, whereas Ag, Cd, Cr, Cu, Pb and Zn follow a different pattern. The latter group of metals show significant differences in their group means between NJ and MR.

Table 11. A Summary of ANOVA Analysis Showing the Significance of Differences in Group Means Between Three Longitudinal River Sections: NJ, MR, and NY

Analyte	**F-ratio**	**Prob>F**	**Significant**
Ag	3.2798	0.0419	NJ – MR MR - NY
Cd	3.0974	0.0498	NJ – MR MR-NY
Cr	5.3269	0.0064	NJ – MR MR - NY
Cu	4.2476	0.0171	NJ – MR MR - NY
%Fe	13.4032	<0.0001	NY – NJ MR - NJ
Mn	6.8069	0.0017	NY - NJ
Ni	10.0996	0.0001	NY – NJ MR - NJ
Pb	3.8751	0.0241	MR - NJ
Zn	5.7727	0.0043	MR - NJ
V	7.3245	0.0011	NY – NJ MR - NJ
%TOC	5.8349		NY – NJ

3. 5. 3. Bivariate Analysis

Bivariate and Multivariate Analyses are commonly performed to see where the data points are located, where the distribution is dense, and how the variables are correlated. Assuming the distribution is normal, a bivariate scatterplot matrix of unstructured data is generated (**Figure 12**). The shape of ellipses and their orientation are

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influenced by the degree of correlation between each two variables. The ellipses are drawn at the 95% confidence limits. The narrower the ellipse, the more correlated the two variables. This graphical demonstration of correlation among each pair of variables helps to recognize the strongly correlated pairs.

In addition, the variables (Ag, Cd, Cr, Cu, Fe%, Mn, Ni, Pb, Zn, V, and %TOC) were also correlated, using the Spearman Rho non-parametric pairwise correlation test. Spearman's Rho is a correlation coefficient computed on the ranks of the data values (when data set is non-normally distributed) rather than on the values themselves (**Fig.13**). **Table 12** shows the best correlations (cut off being at 75%) were found between the following 21 pairs.

Table 12. Well- correlated pairs of analytes based on Spearman Rho pairwise correltion

Cu – Pb	0.9551
Cr – Zn	0.9469
Ag – Pb	0.9177
Cr – Pb	0.9065
Ag - Cu	0.8951
Cr – Cu	0.8901
Fe% - Ni	0.8659
Ni – Zn	0.8639
Pb – Zn	0.8586
Cr – Ag	0.8467
Cu – Zn	0.8547
V – Ni	0.8373
Ni - %TOC	0.8233
V - %TOC	0.8192
Fe% - %TOC	0.8177
Fe% - V	0.7968
V – Cr	0.7849
Cr – Ni	0.7971
V – Zn	0.7635 (borderline)
Ag – Zn	0.7484 (borderline)
Zn - %TOC	0.7349 (borderline)

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Figure 12. Bivariate Scatterplot Matrix for Eleven Analytes. The Shape of Ellipses and Their Orientations Are Influenced by the Degree of Correlation Between Each Two Variables

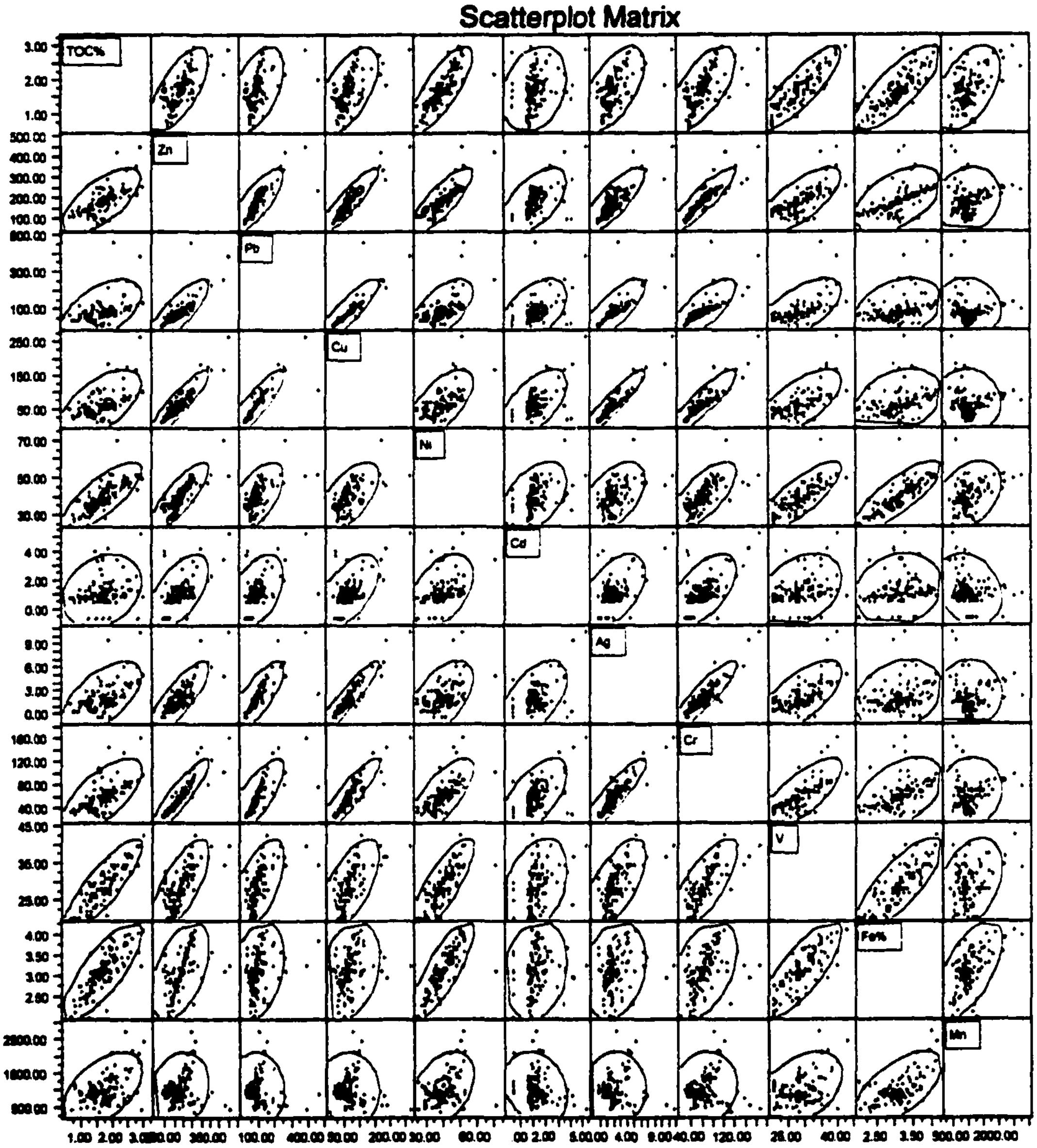

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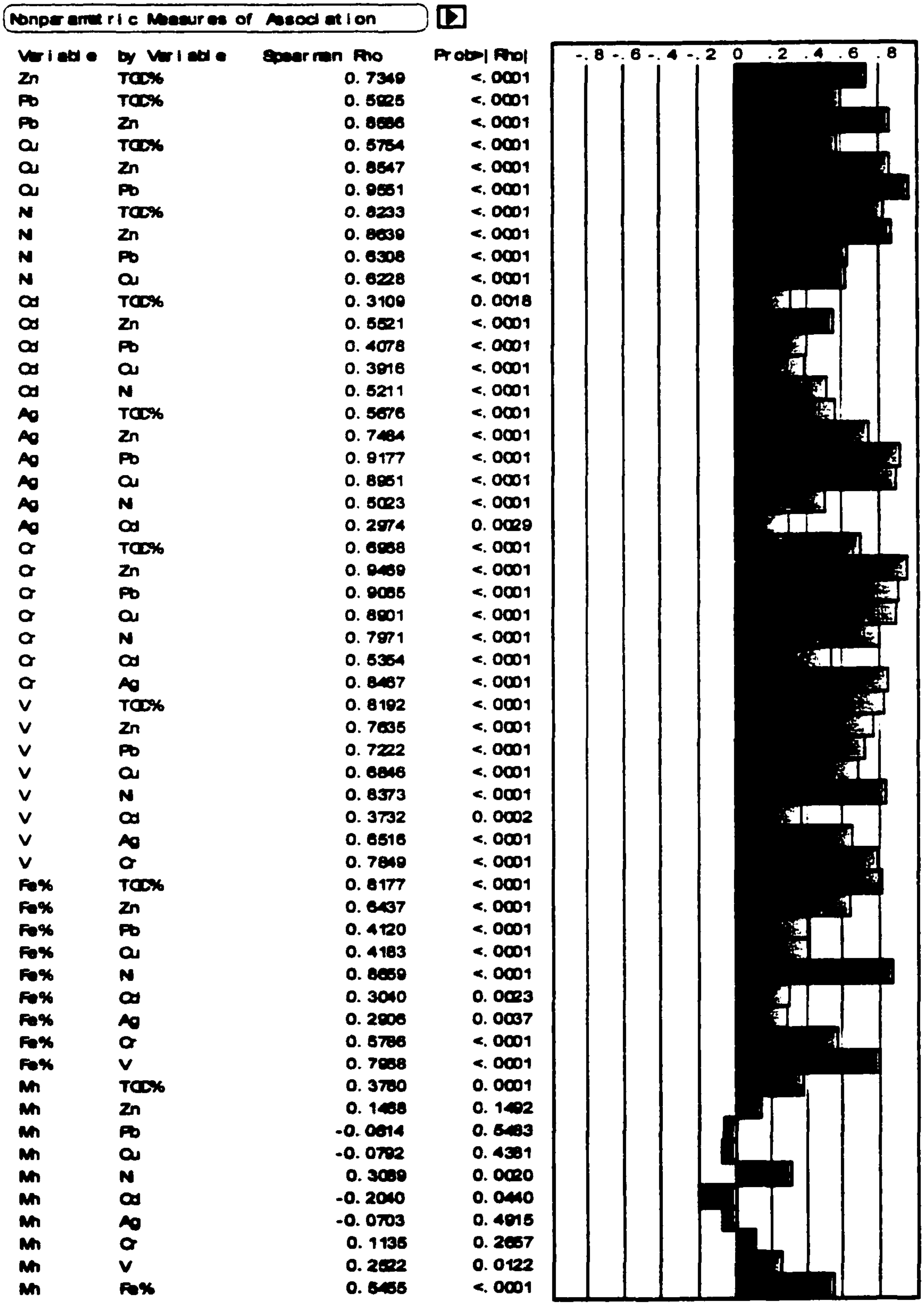
Figure 13. Non-parametric Spearman Rho Pairwise Correlation Between Eleven Anlytes. Correlation coefficient computed on the ranks of the data values. The cut off point for best correlated pairs is chosen at 0.75

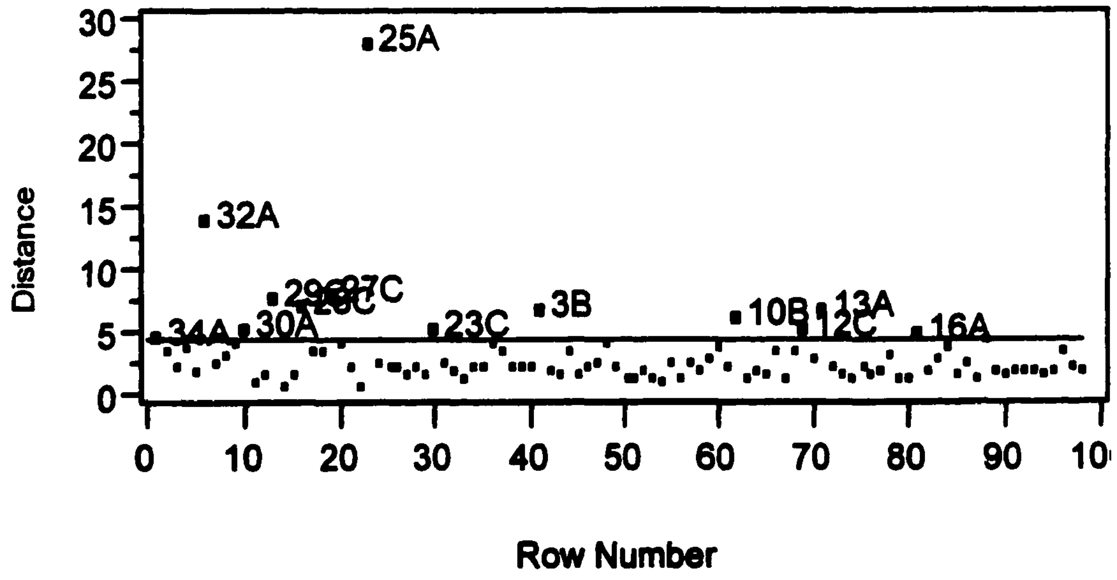


Nonparametric Measures of Association

Variable	by Variable	Spearman Rho	Prob>|Rho|
Zn	TOC%	0.7349	<.0001
Pb	TOC%	0.5925	<.0001
Pb	Zn	0.8686	<.0001
Cu	TOC%	0.5754	<.0001
Cu	Zn	0.8547	<.0001
Cu	Pb	0.9551	<.0001
Ni	TOC%	0.8233	<.0001
Ni	Zn	0.8639	<.0001
Ni	Pb	0.6308	<.0001
Ni	Cu	0.6228	<.0001
Cd	TOC%	0.3109	0.0018
Cd	Zn	0.5521	<.0001
Cd	Pb	0.4078	<.0001
Cd	Cu	0.3916	<.0001
Cd	Ni	0.5211	<.0001
Ag	TOC%	0.5676	<.0001
Ag	Zn	0.7484	<.0001
Ag	Pb	0.9177	<.0001
Ag	Cu	0.8951	<.0001
Ag	Ni	0.5023	<.0001
Ag	Cd	0.2974	0.0029
Cr	TOC%	0.6968	<.0001
Cr	Zn	0.9469	<.0001
Cr	Pb	0.9065	<.0001
Cr	Cu	0.8901	<.0001
Cr	Ni	0.7971	<.0001
Cr	Cd	0.5354	<.0001
Cr	Ag	0.8467	<.0001
V	TOC%	0.8192	<.0001
V	Zn	0.7635	<.0001
V	Pb	0.7222	<.0001
V	Cu	0.6846	<.0001
V	Ni	0.8373	<.0001
V	Cd	0.3732	0.0002
V	Ag	0.6516	<.0001
V	Cr	0.7849	<.0001
Fe%	TOC%	0.8177	<.0001
Fe%	Zn	0.6437	<.0001
Fe%	Pb	0.4120	<.0001
Fe%	Cu	0.4183	<.0001
Fe%	Ni	0.8659	<.0001
Fe%	Cd	0.3040	0.0023
Fe%	Ag	0.2906	0.0037
Fe%	Cr	0.5786	<.0001
Fe%	V	0.7958	<.0001
Mn	TOC%	0.3780	0.0001
Mn	Zn	0.1468	0.1492
Mn	Pb	-0.0614	0.5483
Mn	Cu	-0.0792	0.4381
Mn	Ni	0.3089	0.0020
Mn	Cd	-0.2040	0.0440
Mn	Ag	-0.0703	0.4915
Mn	Cr	0.1135	0.2657
Mn	V	0.2522	0.0122
Mn	Fe%	0.5455	<.0001

The data points that fall outside the 95% limit are called outliers. To verify these outliers, an outlier distance plot is generated. Such a plot is called the Mahalanobis Outlier Distance Plot. A more stringent alternate version of the Mahalanobis is the Jackknife Distance method, which does not include each observation in calculating the distance, thus, allowing a better estimate of the distance (**Figure 14**). The outlier distance plot shows the distance of each outlier with reference to the center of the correlation pattern. The solid line in the plot shows the estimated distance that contains 95% of the points. In this study, the following data points are identified as being the two – dimensional outliers: 34A, 32A, 30A, 29C, 28C, 27C, 25A, 23C, 3B, 10B, 12C, 13A, and 16A.

Figure 14. Jackknife Distance Plot Showing the Bivariate Outliers. The solid line is the estimated distance that contains 95% of the points



3.5.4. Principal Components Analysis

Principal Components Analysis is commonly used to show the spatial distributions of correlated variables in a multidimensional plot. The advantage of the Principal Components Analysis over bivariate analysis is that it allows examination of the distribution of all the variables simultaneously. For a normally distributed data set, the data points form an n-dimensional hyper-ellipsoid. The highest variation is concentrated along the longest axis, which is the principal component one (PC_1). The second highest variation is along the longest vector orthogonal to PC_1, which is labeled as PC_2, and so on. The number of PC axes is equal to the number of variables. The length of each principal component axis is known as its Eigenvalue. JMP calculates the percentage of variance carried by each principal component. In highly correlated variables, the highest percentage of the total variance is carried by the first few principal components.

In this study, eleven variables (%TOC, Ag, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, and V) are subjected to Principal Components Analysis. The results of Principal Components Analysis (**Table 13**) indicates that the first PC carries 62.6411% of the variance, the second PC carries 19.2882, and the third PC carries 6.344 percentage. In fact, about 88% of the variance is carried by the first three principal components – an indication of good correlation. A close look at the columns of Eigenvalues vector for each PC in **Table 13** reveals that each principal variable point component can be derived from a linear combination of the standardized original variables. For instance, in this study the PC_1 can be described as follows:

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PC_1= a (TOC%) + b (Zn) + c (Pb) + d (Cu) + e (Ni) + f (Cd) + g (Ag) + h (Cr) + i (V) + j (Fe%) + k (Mn)

Where a = 0.32, b =0.36, c = 0.31, d = 0.34, e = 0.33, f = 0.21, g = 0.32, h = 0.35, i = 0.34, j = 0.25, and k = 0.09.

This equation seems to define in which direction PC_1 lies in terms of the variables. The above equation is based on this author's understanding of the Eigenvalues.

Principal Components Analysis technique has a certain flexibility. For instance, when PC_1, PC_2, and PC_3 are rotated onto the x, y, and z axes, the variations are maximized so that the correlations between the variables (shown as rays) and points become more visible. This approximation of a high-dimensional space is known as a Gabriel Biplot. In general, the smaller the angle between the rays, the better correlated are the variables (**Figure 15**). In this study, the correlated variables found are: Ag-Pb-Cu, Cr-Zn, TOC-V, and Fe-Ni. However, if the last three PCs (PC9, PC10, and PC11), which carry the minimum amount of variations, were rotated onto the x, y, and z axes, the multivariate outliers in the data set become more visible (**Figure 16**). Such an approach helps to distinguish the high-dimensional outliers in the less populated areas, because all the well-correlated points are brought together, the less correlated points or outliers stand out. To verify these high-dimensional outliers, the outlier distance plot is generated. Such a plot is called the Mahalanobis Outlier Distance plot. A more stringent alternate version of the Mahlannobis is the Jackknife Distance method, which does not include each observation in calculating the distance, thus, allowing a better estimate of the distance (**Figure 17**). The outlier distance plot shows the distance of each outlier with reference to

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the center of the correlation pattern. The solid line in the plot shows the estimated distance that contains 95% of the points. In this study, the following data points are identified as being the high-dimensional outliers: 34A, 32A, 31B, 30A, 29C, 28C, 23C, 18A, 16A, 13A, 12C, 10B, and 3B

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Table 13. Eigennvalues for Each Principal Component. 88% of variance is carried by the first three principal components — an indication of good correlation among some variables

	Principal Components										
Eigen value	6.8905	2.1217	0.6983	0.423	0.3044	0.2040	0.1509	0.0763	0.0699	0.0405	0.0196
%	62.6411	19.2882	6.3485	3.854	2.7674	1.8541	1.3714	0.6935	0.6357	0.3678	0.1782
Cumn%	62.6411	81.9293	88.2778	92.131	94.8991	96.7532	98.1247	98.8182	99.4539	99.821	100.000
Eigen vectors											
TOC%	0.31610	0.28024	-0.06056	-0.0094	-0.40916	-0.12614	0.74777	-0.15531	-0.06545	-0.17496	0.1276
Zn	0.35850	-0.1018	0.00773	-0.0166	0.37467	-0.37791	0.09764	0.19840	0.22320	-0.38342	-0.5760
Pb	0.30933	-0.2227	-0.23160	-0.3911	0.34293	0.65603	0.17142	-0.22081	-0.13714	-0.02740	-0.0491
Cu	0.33494	-0.2714	-0.20795	0.0036	0.05137	-0.07359	-0.00451	0.64294	0.06419	-0.01024	0.5875
Ni	0.32623	-0.1968	0.31009	-0.2936	0.33919	-0.34074	-0.06373	-0.33922	0.22223	0.42883	0.2981
Cd	0.21240	-0.3100	0.74173	0.4255	-0.03709	0.31829	0.13134	0.01353	0.08445	-0.00634	0.0155
Ag	0.32154	-0.2407	-0.35077	0.2917	-0.26811	-0.03723	-0.01462	-0.05085	0.08387	0.65504	-0.3439
Cr	0.35323	-0.1371	-0.06581	0.2486	-0.01865	-0.23353	-0.36639	-0.36094	-0.61293	-0.27640	0.1371
V	0.33622	0.1991	-0.02908	-0.1392	-0.44914	0.23298	-0.47480	-0.10111	0.49850	-0.29471	0.0067
Fe%	0.24960	0.4626	0.26599	-0.2265	-0.10293	0.13684	-0.14384	0.46477	-0.47119	0.21254	-0.2613
Mn	0.09297	0.5678	-0.23261	0.6014	0.41351	0.24318	-0.00365	0.00591	0.11496	-0.00900	0.0983

Figure 15. Gabriel Biplot Showing Correlation Between Variables. Correlated variables are Ag-Pb-Cu, %TOC-V, and Fe-Ni. The angle between these rays of correlated variables are small

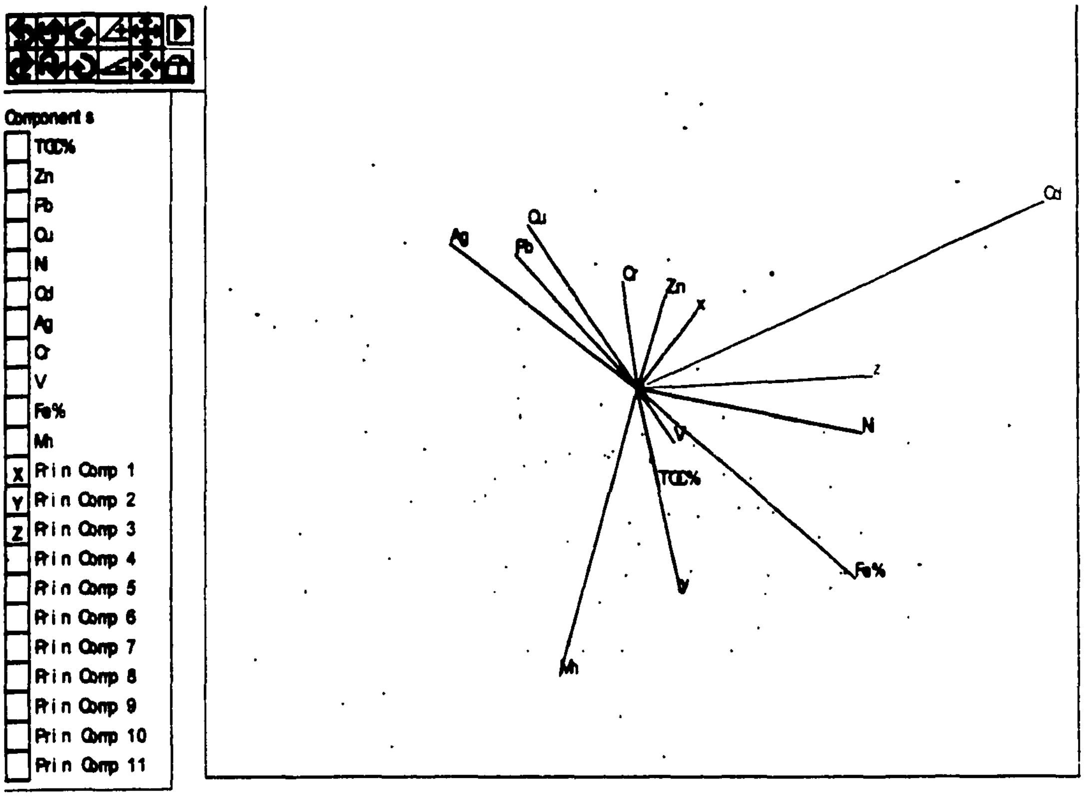

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Figure 16. Principal Components (X, Y, and Z) Showing the Minimum Amount of Variations. The high-dimensional outliers are distinguished in the less populated areas

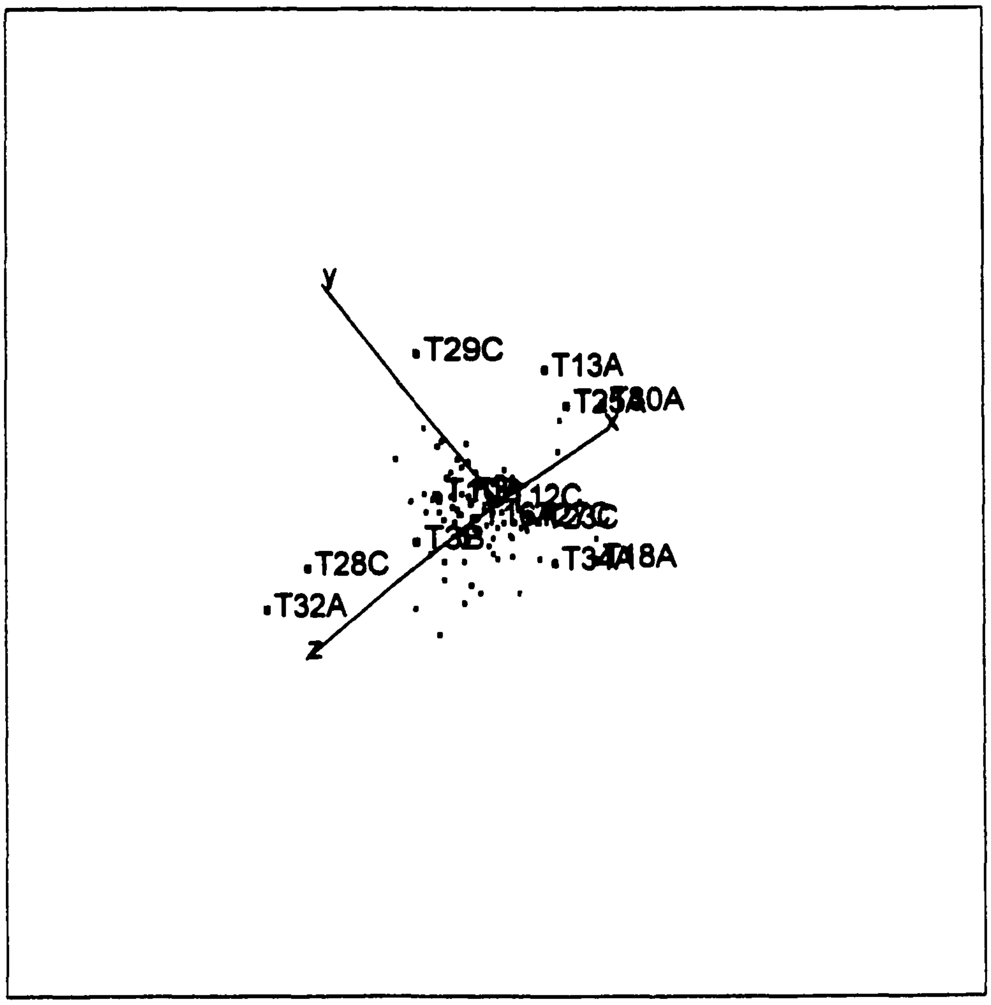
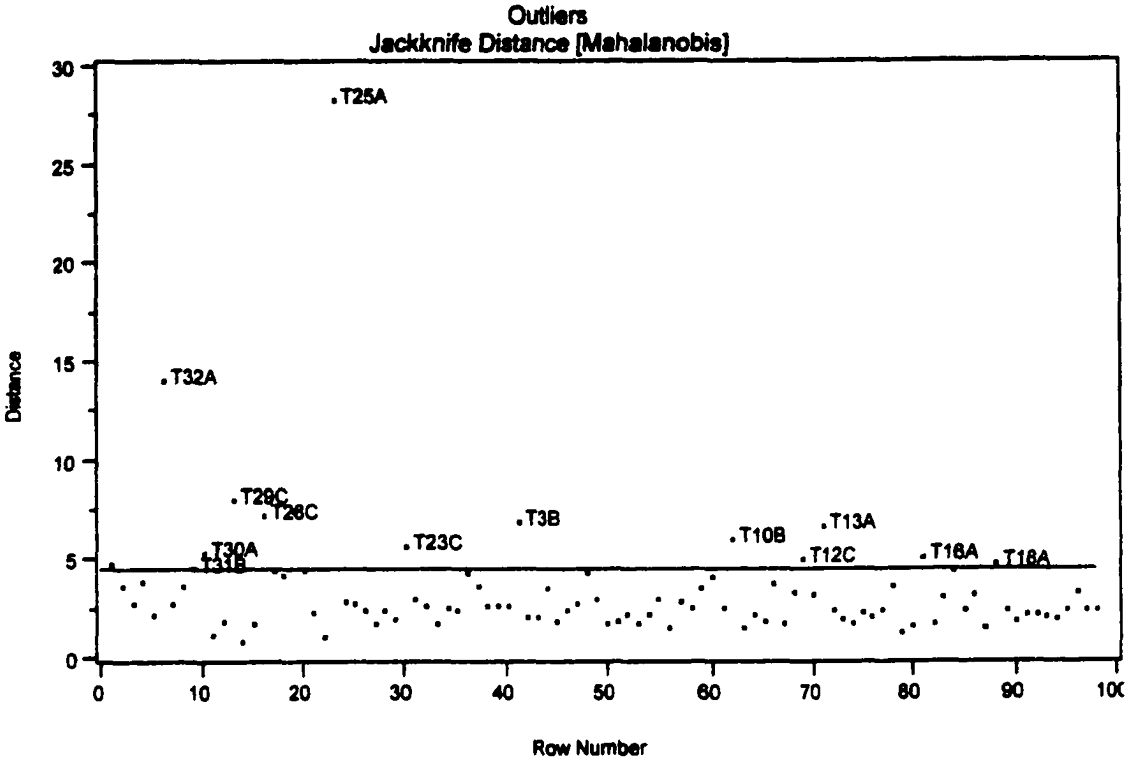


Figure 17. High-Dimensional Outliers Based on Principal Component Analysis. The solid line in the plot shows the estimated distance that contains 95% of the points



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Chapter 4 – Discussion

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4. 1. Historical Sources of Trace Metals Contamination in the Study Area

Industrially important trace metals, including Ag, Cd, Cr, Cu, Ni, Pb, Zn, and V, have been identified as being toxic to aquatic life even at moderate concentrations (Pfizer, 1972). These metals are added to the depositional environments from (a) natural processes such as geological weathering and biological decomposition and (b) human activities associated with agricultural practices, fossil fuel burning, automobile exhaust, industrial activity, sewage etc. (Raiswell *et al.*, 1980) One of the largest impacts of human activities has been an increase in the amount and rate of transfer of toxic substances, including trace metals, from diffuse and point sources, causing contamination on a local and global scale.

Pb, for instance, is one the most widely used nonferrous metals. It is found either as sulfide (Galena), oxide, or carbonate (anglesite, cerusite) in nature, and it has been used for centuries in the manufacture of various products (Goyer and Chisolm, 1972). Across the modern industrial world, the beginning of the Industrial Revolution is registered by an increase in Pb concentrations in sediments deposited around 1850-1890, followed by a sharp increase in the early 1900s, and a maximum plateau around 1978 (Summerhayes *et al.*, 1985). This strong increase in Pb concentration coincides with the introduction of tetraethyl leaded gasoline. Leaded gasoline is primarily used to increase the antiknock qualities of gasoline in internal combustion engines; the amount of Pb additives varied from 0.39 g/l for regular- to 0.55 g/l for premium-grade gasolines (Engel *et al.*, 1971). The U.S. EPA mandated the phasing out of Pb in gasoline starting in 1975. The other major industrial activities associated with Pb pollution include mining, smelting, refining,

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secondary recovery, Pb batteries, and welding and cutting metal coated with Pb-based paints.

In the New York/New Jersey area, the major potential sources of Pb emission from the late 1800's to the 1920's were some of the largest producers of refinery lead in Middlesex County in New Jersey (Rod *et al.*, 1989). The activities of these refineries had largely ceased by the 1950's, while some secondary smelting still existed as of the 1980's (Rod *et al.*, 1989). Variation with depth of Pb and Cs-137 profiles in cores collected in this area has revealed that Pb concentrations in sediments reached their maximum values in the mid –1970's, with major decreases in the late 1980's (Bopp and Simpson, 1989).

Cd, a relatively rare element in the earth's crust (0.2 ppm), is produced in significant amounts by industrial countries. Fassett (1972) reported that a variety of solders, e.g., silver solder, contain Cd. Cd is also used in electroplating (in which it forms a bright, corrosion-resistant finish), in plastic stabilizers, in pigments, in nickel-cadmium batteries, and in semi-conductors and photocells (Klein *et al.*, 1974). Phosphate fertilizers also contain 5 – 100 mg Cd/kg, and this increases soil and plant Cd levels when these fertilizers are used. **Zn** is used to prevent corrosion by galvanizing, and also in alloys, in paints, in dyes, and in tires. Unlike Cd, which has no known useful biological function, Zn is an essential element. Principal sources of **Cd**, **Ni**, and **Cr** in New York/New Jersey were industrial discharges from electroplating and metal finishing. Cd enrichment in waters mainly results from the galvanizing industry. An investigation by the New York City authorities in 1970 (Klein *et al.*, 1974) indicated that the then existing 250 electroplating plants discharged the following amounts of metal wastes (unit = kg/d) to

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sewers daily: Cd (30), Cr VI (154), Ni (477), Cu (227) and Zn (304). Approximately 85% of these totals entered the WPCPs, and the remainder was discharged to the harbor as wastewater. These high concentrations of trace metals in electroplating liquid wastes were, however, reduced 70% to 90% by 1993 (Brosnan *et al.*, 1994), primarily due to the regulations set by the New York City EPA for maximum allowable metals in industrial waste discharges beginning in 1963.

Additional sources of Cd and Ni in the Hudson River estuary are considered to be contaminated sediments transported from (a) Foundry Cove, and (b) the Upper Hudson River (Chillrud, 1996). Sediments from Foundry Cove (*ca.* mp 45, opposite West Point) were highly contaminated (i.e., Cd up to 5000 ppm) by discharges from a battery plant from the 1950's to the 1960's. A large amount of contaminated sediment from the cove was, however, dredged in the summer and fall of 1972 and again in the spring and early summer of 1973. Surface grabs taken later at many locations in the cove indicated several orders of magnitude decrease in Cd and Ni concentrations from the eastern (0.9 – 3 ppm) to western edge of the cove (Bower et al., 1978, reported in Chillrud, 1996). Chillrud (1996) reported "Given the measured low levels of Cd to Ni ratios (*ca.* 0.1 – 0.2) for the Harbor sediments, it is fairly impossible to consider sediment transportation from the cove as the source of current Cd and Ni contamination in the study area. Instead, transport of contaminated sediment from the Upper Hudson River seems to be a potential source of Cd and Ni to NY harbor sediments based on similarities between the Cd and PCB's depth profiles from the cores taken near Kingston (mp 86.6 and mp 91.8) and the harbor."

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A good source of **Zn, Pb, Cu** and to a lesser extent Cd is also found to be related to corrosion within the urban water supply network (Brosnan et al., 1994); high Cu and Zn concentrations were reported from all 14 New York City WPCPs. An additional source of Cu is $CuSO_4$ that is added to upstate New York water reservoirs to kill off the algae. High Cu concentrations (181 ppm) are also reported from some of the sediment samples collected in the lower Hudson (Brosnan, 1994a).

Ag values higher than those in the earth's crust (0.07 ppm) and an average shale (0.07 ppm) measured in the sediments collected from the Hudson River Estuary mainly result from photochemical industries. Ag content of surficial bottom sediment samples collected by DEP throughout the estuary indicated high Ag concentration in the lower Hudson River estuary (*ca.* 20 ppm) (Brosnan, 1994).

Vanadium compounds are present in fossil fuels such as coal and fuel oil at concentrations substantially greater than that of many other trace metals (Smith, 1972). According to Smith " the vanadium content of coal from various sections of the United States is shown to vary from 16 to 176 ppm, while the resulting ash is enriched to such as extent that levels as high as 1000 ppm are found. In view of the enormous quantities of coal and oil which are burned daily, it is not surprising that the particulate matter in urban air always contains a measurable amount of vanadium." Accordingly, the high concentration of vanadium in aquatic environments is primarily due to the burning of heavy fuel oil containing high concentrations of vanadium porphyrin complexes. Vanadium is also used in the manufacture of steel, and to a lesser extent as a catalyst in the manufacture of sulfuric acid. Vanadium toxicity seems to be dependent upon the

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valence of the V compounds; pentavalent compounds such as $V_2 O_5$ are generally more toxic than trivalent compounds.

4.2. Comparison to Old Hudson Sediment (Background Levels) – Enrichment Factors

To assess the magnitude of trace metal contamination in surficial bottom sediment samples, the measured trace metals concentrations are compared to Old Hudson Sediment (background levels) in terms of enrichment factors (EF). The EF is defined as the measured sediment concentration divided by the Old Hudson Sediment concentration of a given trace metal. The underlying assumptions in such an approach are that the sedimentary conditions have been uniform over time and the sediment characteristics are the same. Surficial bottom sediment samples from this study are not dated by the commonly used radionuclide Be-7 with the half-life of 53 days.

Table 14 shows estimates of background (natural) levels of metals in the Old Hudson Sediments that are based on analysis of fine-grained uncontaminated sediments from cores collected in the Hudson River (Old Hudson Sediment, Williams *et al.*, 1978) and New York harbor (Chillrud, 1996). The Old Hudson Sediment represent natural or pre-industrial levels of metal concentrations in uncontaminated sediments prior to atmospheric nuclear weapon tests conducted in the early 1950's. The term pre-industrial is this context is a bit misleading, in the sense that it does not really refer to the beginning of the historical Industrial Revolution. Where data on the natural (background) level of metals are not indicated in the Old Hudson Sediment, the enrichment factor was calculated using the metal concentrations at site 2B from this study.

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Table 14. Enrichment Factors (EF) for Trace Metals in the Study Area. Trace Metal Concentrations are in ppm.

	Ag	Cd	Cr	Cu	Ni	Pb	Zn	V
Site 2B (ppm) *	0.24							28
Old Hudson Sediment (ppm)**		0.5	60	25	35	20	80	
Maximum EF compared to Old Hudson Sediment		10.7	2.8	10.8	1.8	23	5.2	
Minimum EF compared to Old Hudson Sediment		1.2	0.5	0.6	0.7	0.9	1.0	
Maximum EF compared to Site 2B	45							1.5
Minimum EF compared to Site 2B	1.0							0.7

* From this study (1997)

** Average background concentrations based on analyses of fine-grained sediment obtained from deep sections in cores collected in the Hudson River and New York harbor (Williams *et al.*, 1978; Chillrud, 1996)

A close look at **Table 14** reveals that Pb and Cu display the largest maximum enrichment factors (23 and 10.8) compared to their corresponding background levels (Old Hudson Sediment). Given the similar background values for Cu (25 ppm) and Pb (20 ppm), the greater Pb enrichment indicates either much larger influxes of Pb since 1954 or the greater ability of the fine-grained sediments to retain Pb. Cd (EF = 10.7) has been enriched nearly 6x compared to Ni (EF = 1.8). The observed large differences in Ni and Cd enrichment levels result from the much lower background level of Cd. The maximum enrichment factor for Zn is 5.2, which is relatively large given the higher Zn background level (80 ppm). The maximum enrichment factor for Cr (EF = 2.8) is also large for its high background level (60 ppm). As the results of enrichment factors indicate, all the comparable trace metals measured in this study have concentrations greater than the Old Hudson Sediment background levels (**Table 14**). In the absence of background levels for Ag and V in the Old Hudson Sediment (Williams *et al.*, 1978), the maximum enrichment

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factors for these two metals are calculated using their corresponding concentrations at site T2B from this study (**Table 14**).

4. 3. Trace Metal Levels in Sediments Compared to Sediment Quality Guidelines

To assess potential adverse biological effects for future benthos studies, trace metals concentrations from this study were compared to the U.S.E.P.A. adopted effect-based sediment quality guidelines identified by Long and Morgan (1991) and Long *et al.* (1995). Sediment quality guidelines establish certain "screening or levels of concern" for sediment toxicity based on three types of measurements: (1) concentrations of toxic chemicals, (2) toxicity of environmental samples, and (3) evidence of modified residence biota, preferably the infauna (Long and Chapman, 1985).

Effect-based values consist of two threshold levels for trace metals: ERL and ERM. ER –L stands for Effects – Range Low, indicating metal concentrations at which adverse biological effects begin to be seen. E – RM stands for Effects – Range Median, concentrations above which adverse biological effects are probable. The range between these two values indicates a "possible-effect range." Although the trace metals concentrations measured alone do not provide an indication of biological damage, such information is the first necessary step to determine the degree and nature of contamination. **Table 15** shows the ERL and ERM concentrations commonly used for sediment trace metals data.

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Table 15. USEPA Adopted ERL and ERM Concentrations for Sediment Trace Metals (Long and Morgan, 1991; Long et al., 1995)

Chemical Analyte	**ERL concentration**	**ERM concentration**
Silver	1.0	3.7
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Nickel	20.9	51.6
Lead	46.7	218
Zinc	150	410

When the trace metal concentrations in surficial bottom sediments from the study area were mapped with reference to ERL and ERM values, the resultant spatial patterns made it possible to see (a) the spatial trend in contamination and (b) the proximity to possible point sources of contamination (WPCPs). **Figure 18** shows trace metals concentrations with reference to ERL and ERM values. Examination of individual trace metals shows that Ag and Pb are the most pervasive contaminants at levels above their corresponding ERM values. Cd, Cr and Cu concentrations never exceeded their ERM values. Zn exceeds its ERM value at only one station, T27C. Only a very few stations show Cr concentrations that fall between their ERL and ERM values. **Table 16** shows a summary of percent stations in the study area with respect to their ERL and ERM values. No ERL and ERM values have as yet been identified for vanadium.

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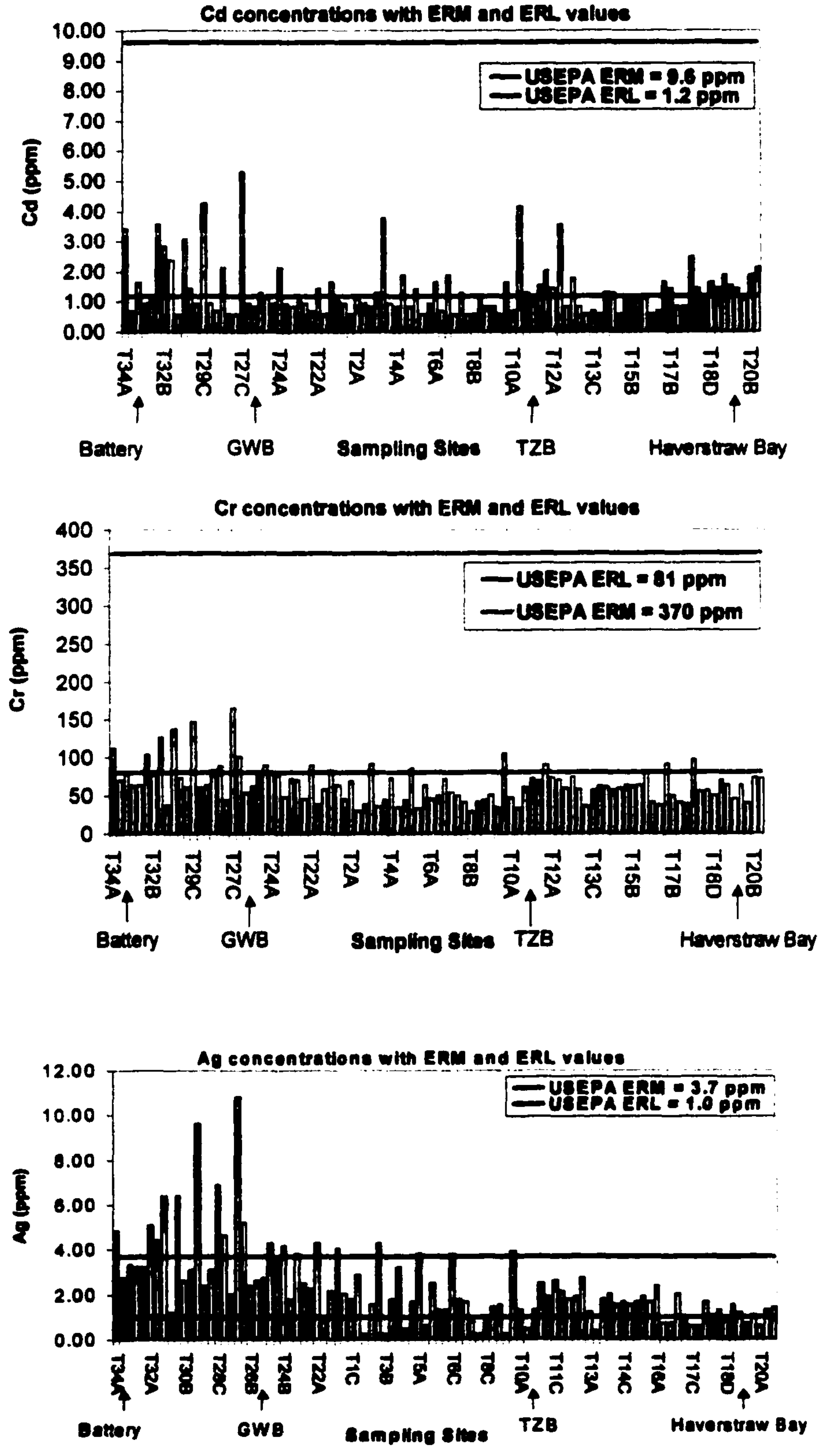
Figure 18. Metal Concentrations in Surficial Bottom Sediments Collected in Lower Hudson Estuary as Compared to Sediment Quality Guidelines



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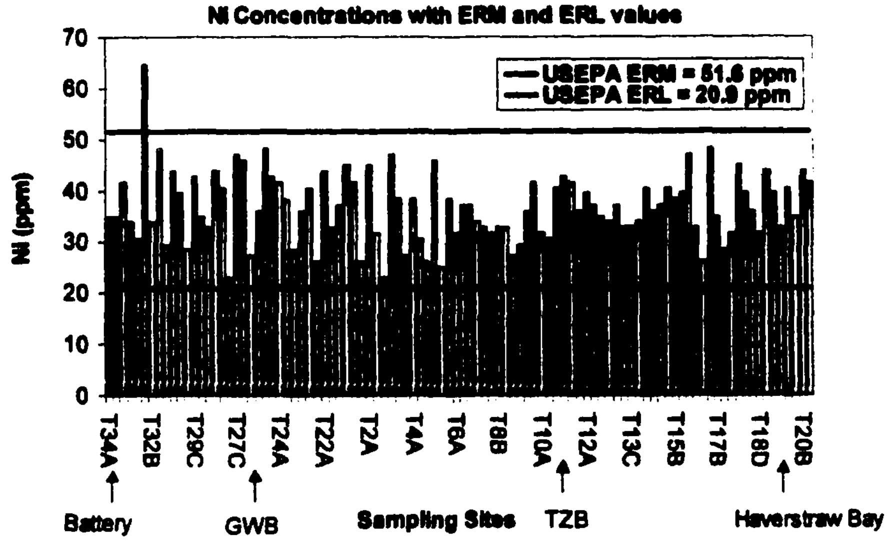

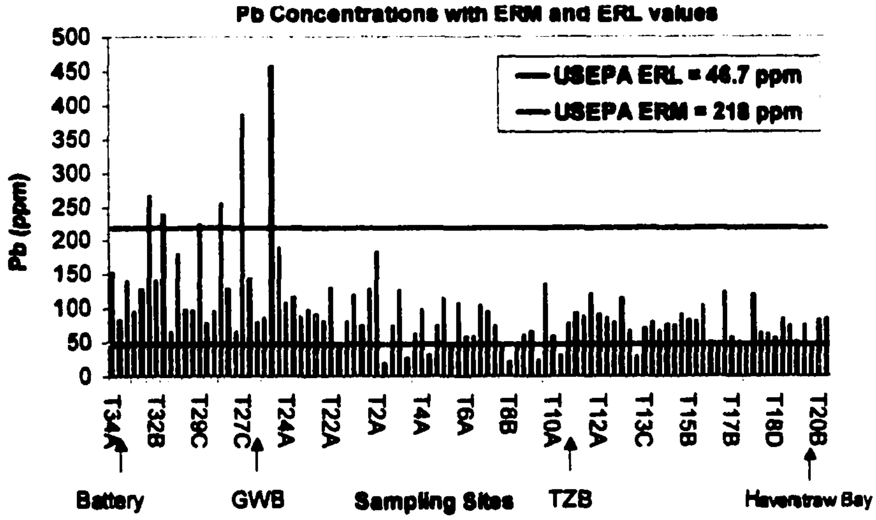

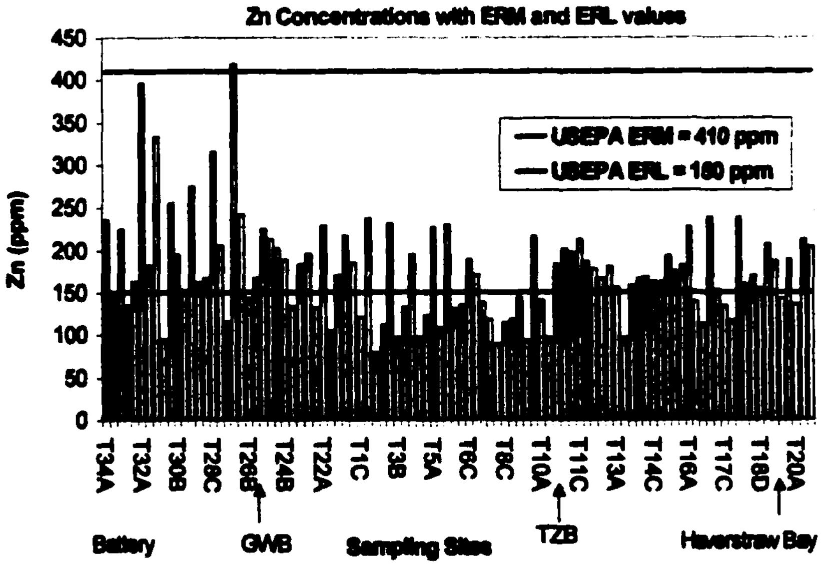

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Table 16. Percentage of Stations Above and Below ERL and ERM Values – 97 Stations

Chemical Analyte	Maximum (ppm)	Minimum (ppm)	< ERL (ppm)	ERL-ERM (ppm)	>ERM (ppm)
Ag	10	0.24	20%	55%	26%
Cd	5.33	0.59	58%	42%	0%
Cr	166	29	82%	0%	18%
Cu	268	15	13%	87%	0%
Ni	64	23	99%	0%	1%
Pb	458	19	14%	62%	24%
Zn	418	79	33%	66%	1%

Cu (87% of the stations) and Pb (86%) followed closely by Ag (81%) and by Zn (67%) are the most pervasive metal contaminants in the area studied when compared to ERL values. Of the metals studied, Ag (26%), closely followed by Pb (24%) and Cr (18%), are the only ones that exceed ERM values (**Table 16**).

A close look at the spatial distribution of each trace metal in the study area (**Figures 19–25**) reveals that metal concentrations are generally higher downriver. In addition, the stations with trace metals values greater than the ERM values appear to be in the vicinity of Water Control Pollution Plants located either along the New Jersey or New York shores. An estimate of the degree of biological damage caused by the trace metals concentrations measured in the bottom sediments sampled, with reference to the U.S.E.P.A. adapted sediment quality screening values, however, cannot be made at this time, as it would require specific tests for bioassay toxicity.

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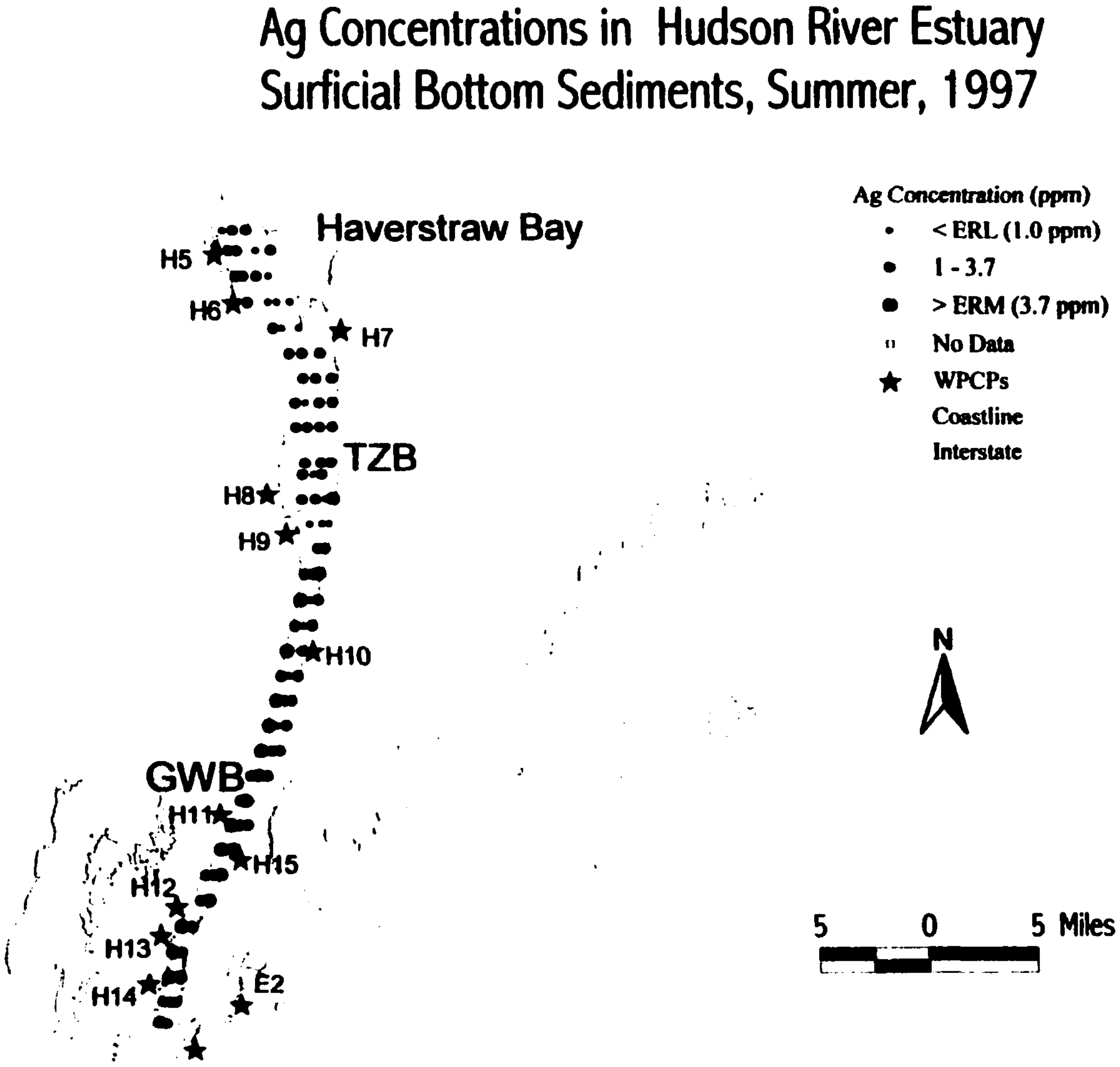

Figure 19. Spatial distribution of Ag concentration in the study area

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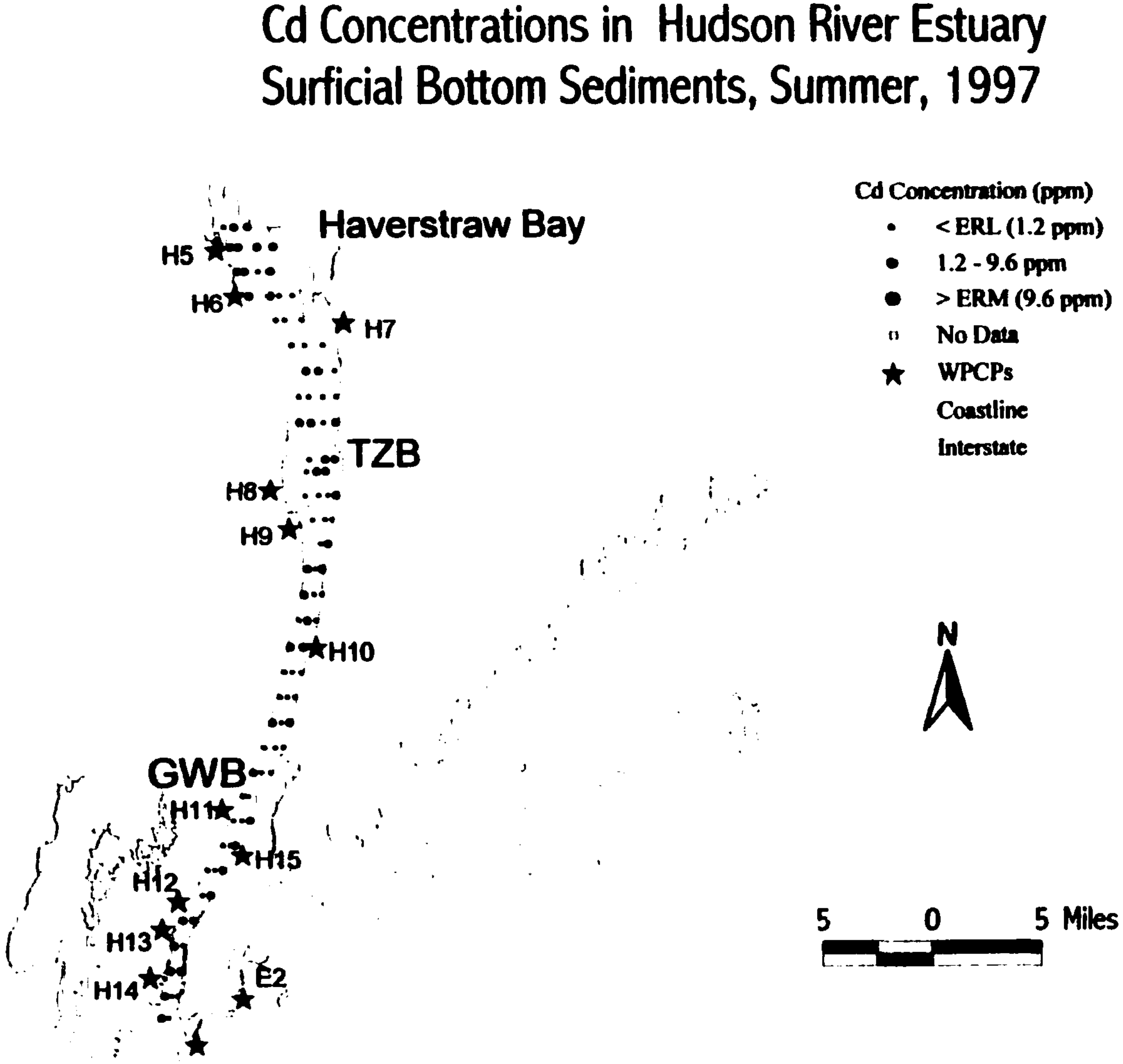

Figure 20. Spatial distribution of Cd concentration in the study area

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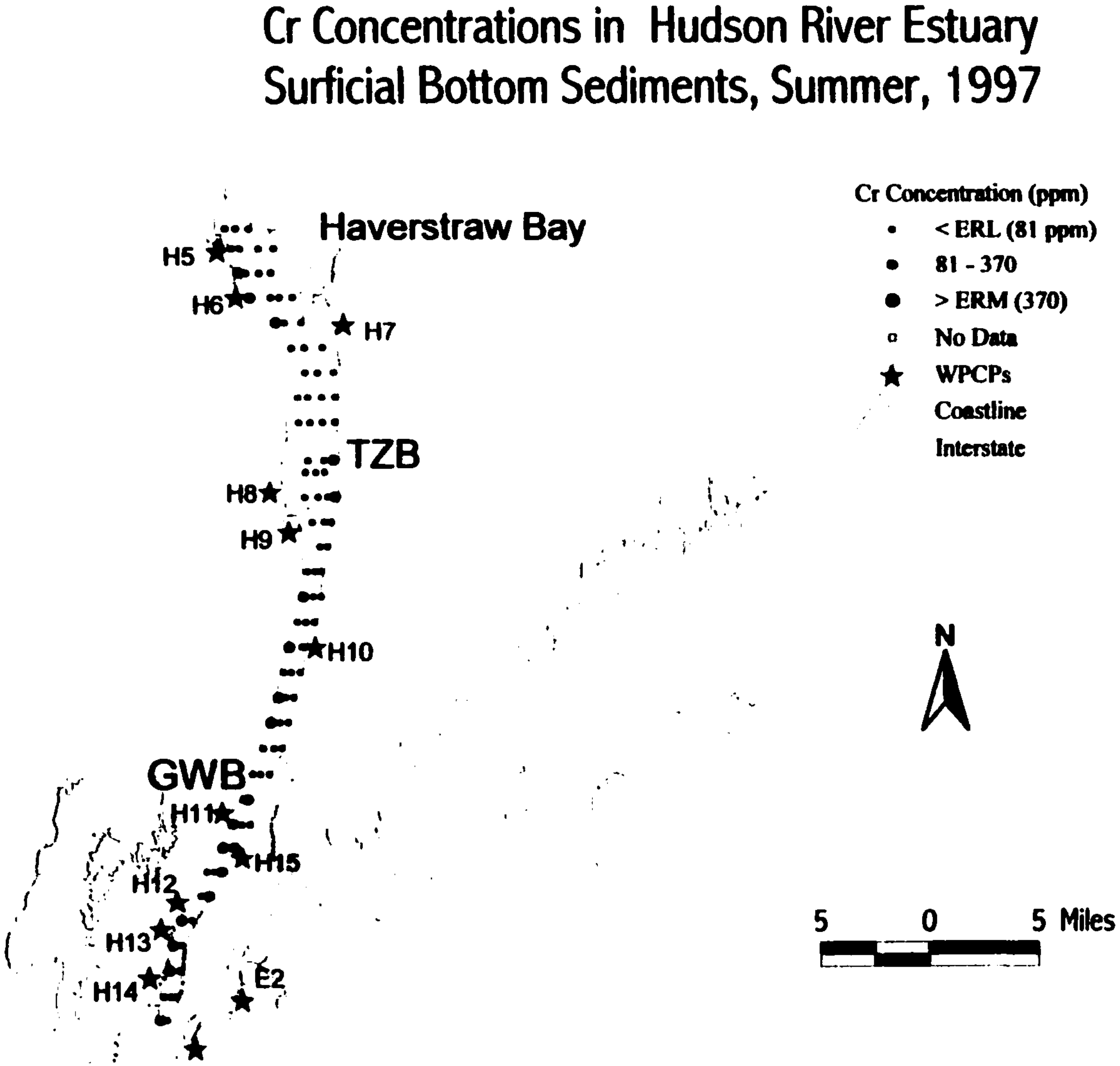

Figure 21. Spatial distribution of Cr concentration in the study area

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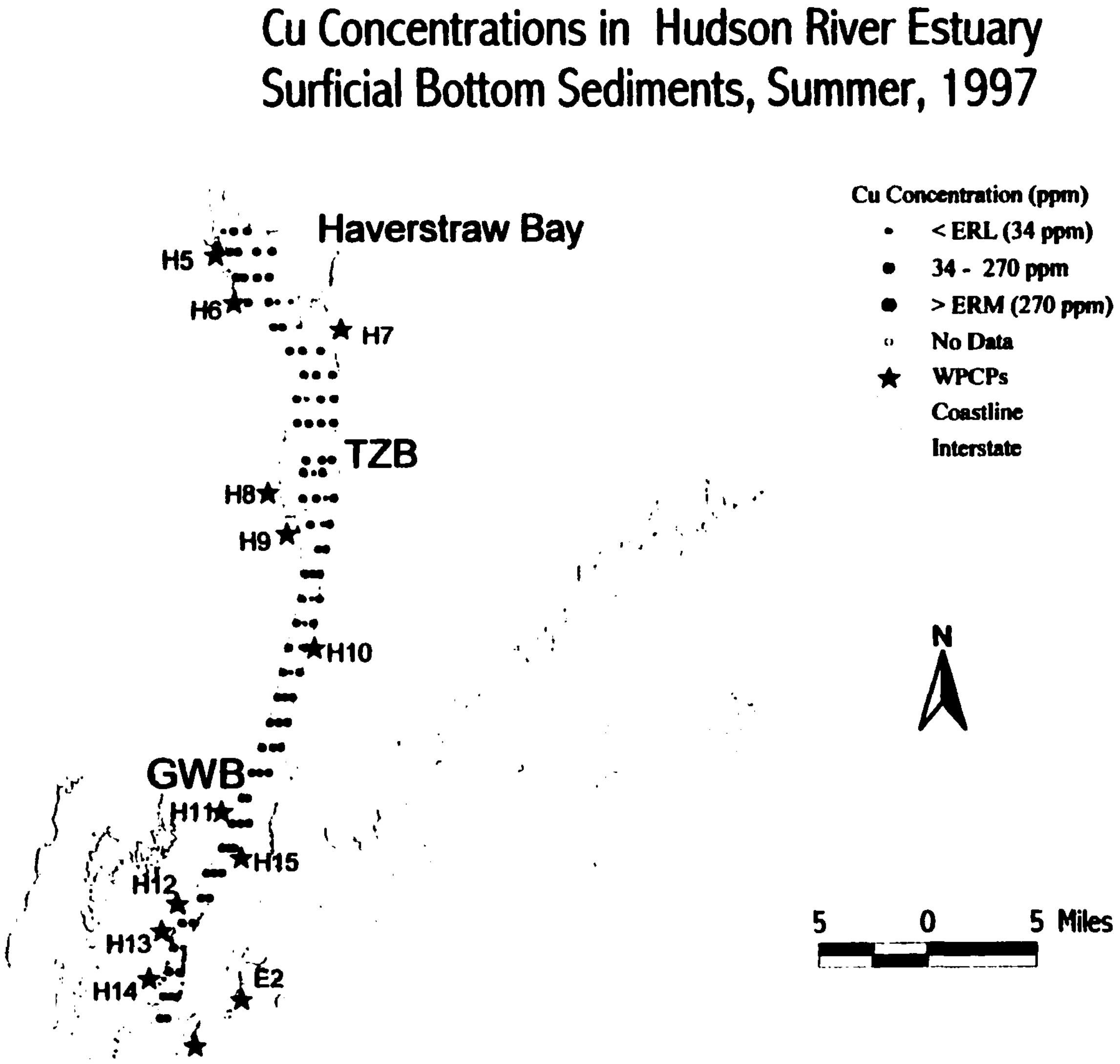

Figure 22. Spatial distribution of Cu concentration in the study area

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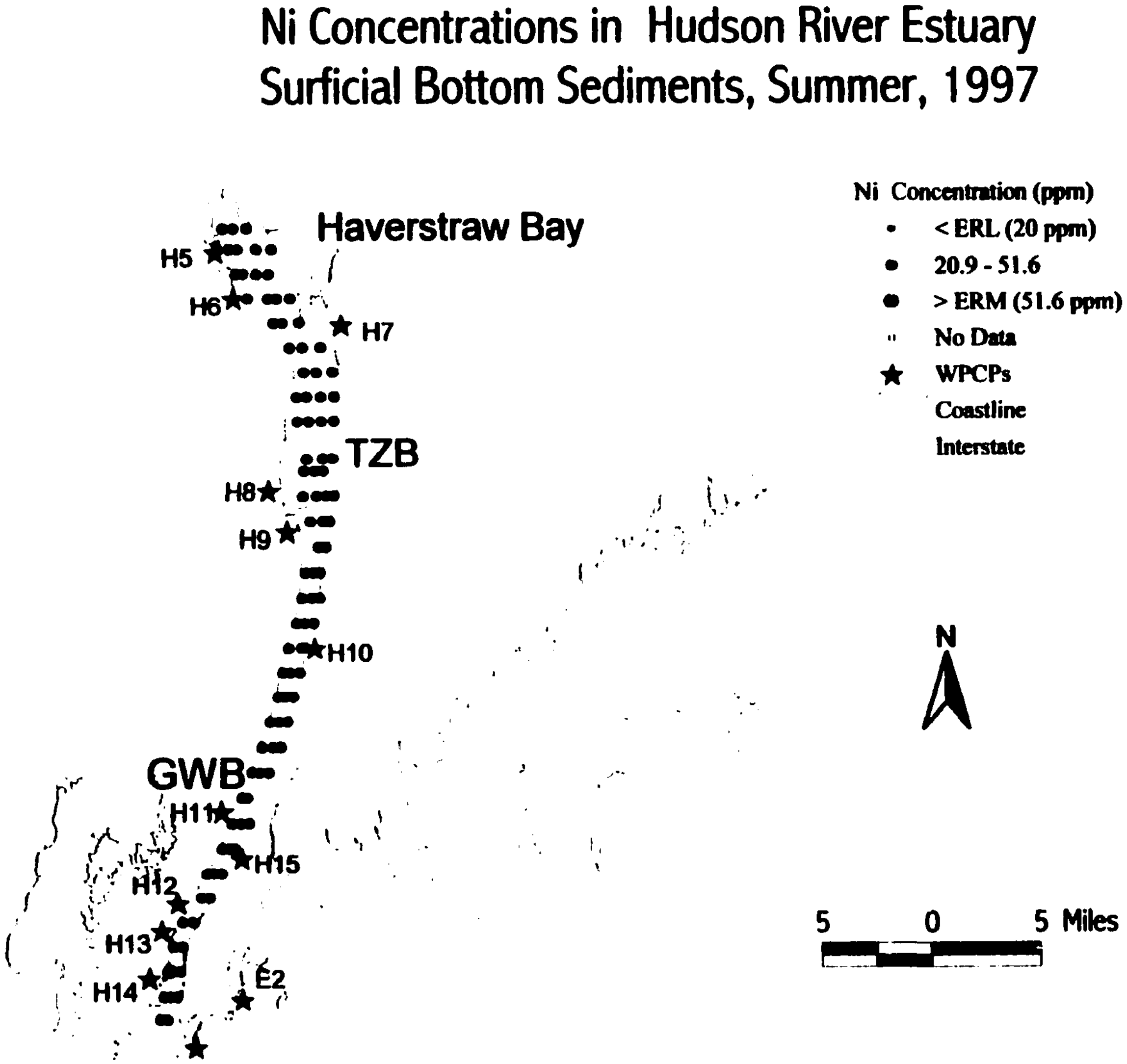

Figure 23. Spatial distribution of Ni concentration in the study area

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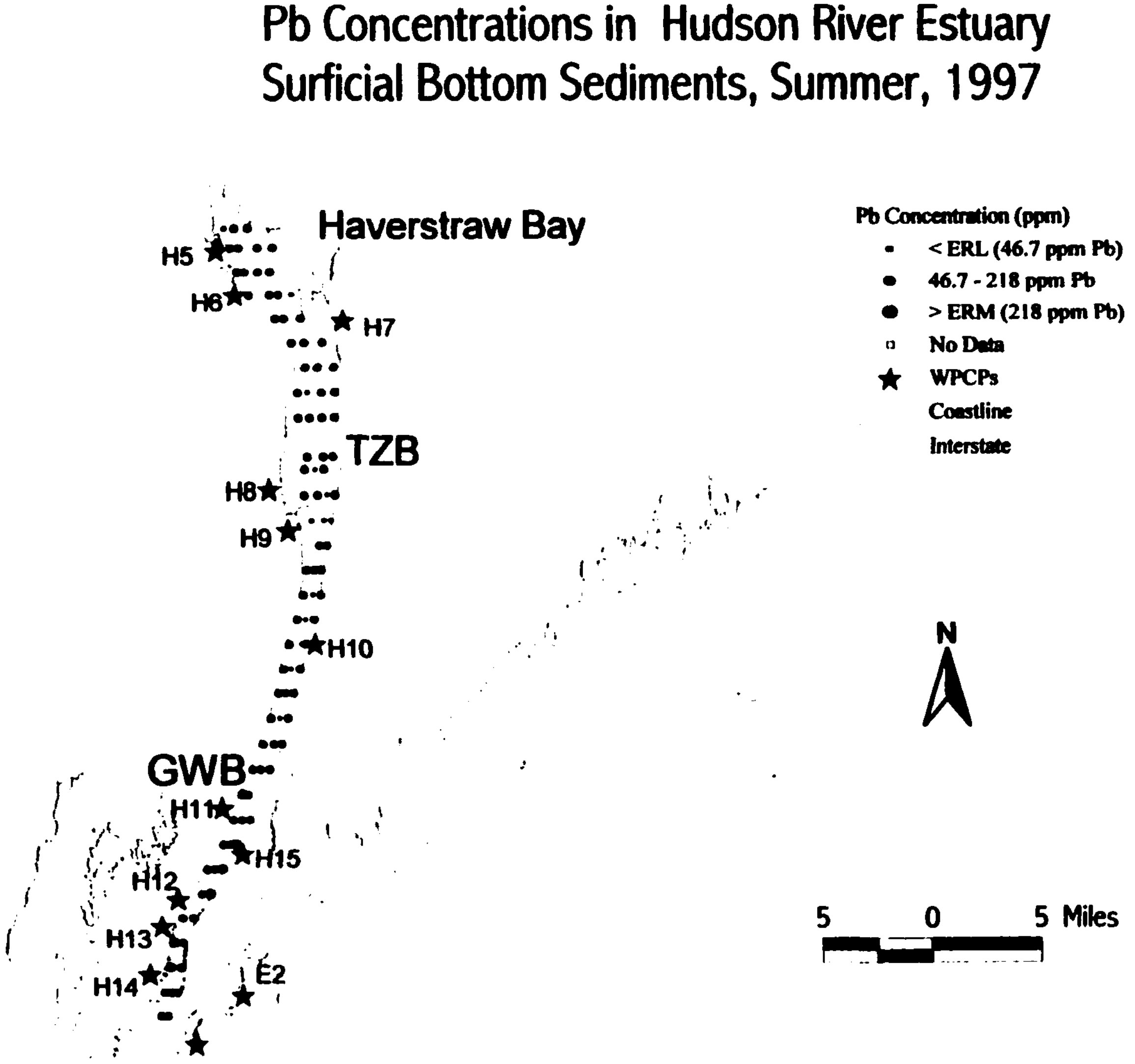

Pb Concentrations in Hudson River Estuary Surficial Bottom Sediments, Summer, 1997

Figure 24. Spatial distribution of Pb concentration in the study area

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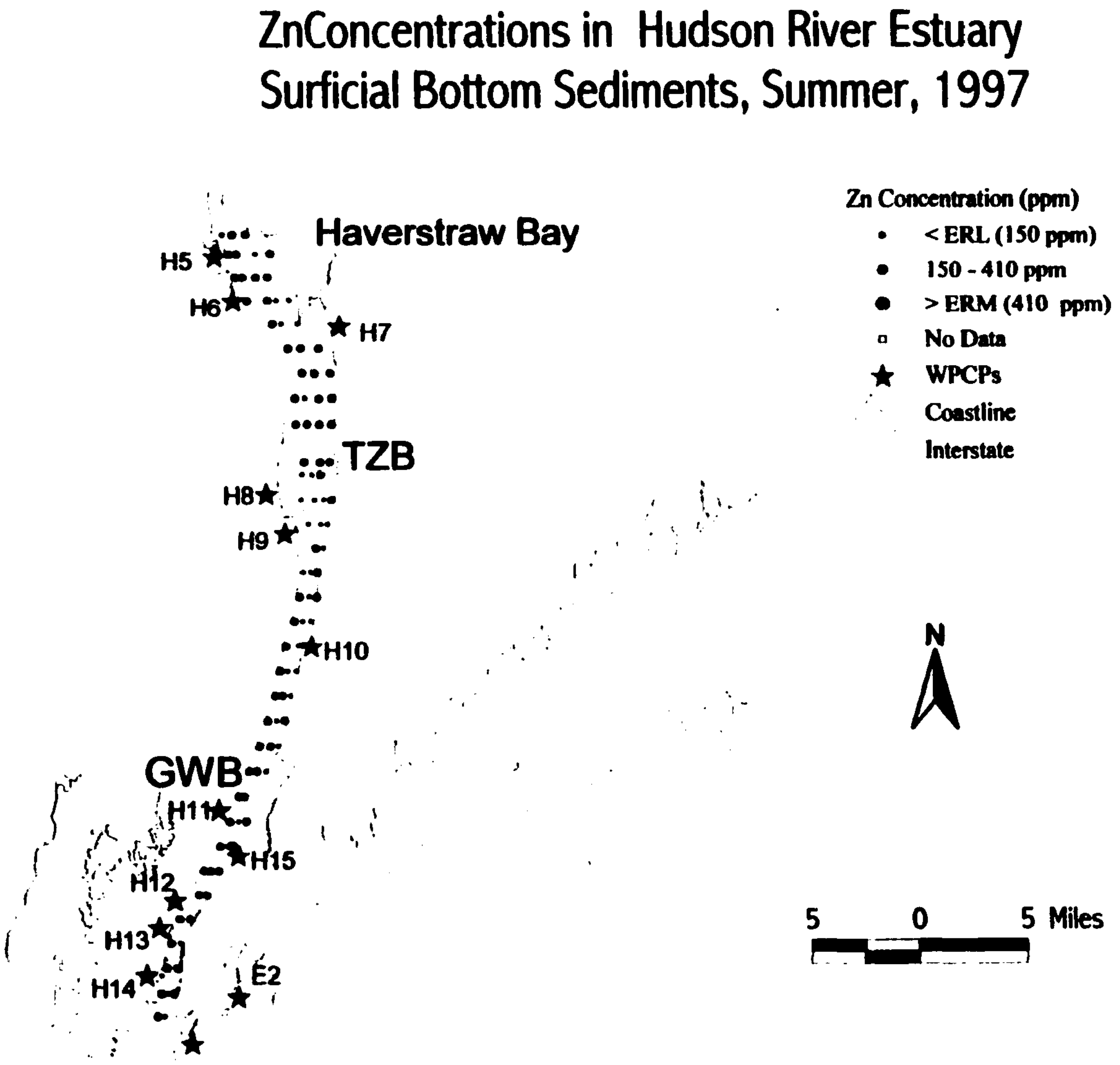

Figure 25. Spatial distribution of Pb concentration in the study area

4.4. Seasonal Variation in Trace Metals Concentrations: Comparison Between 1997 and 1998 Trace Metals Concentrations Downriver

Eleven of the downriver stations with trace metal concentrations greater than the U.S.E.P.A. adapted ERM sediment quality screening values for at least one measured trace metal were selected for additional sampling (see **Table 7**, Sec. 3.1 <u>in</u> **Chapter 2**). Trace metals concentrations in surficial bottom sediment are in general lower in 1998 than those in the comparable 1997 samples (**Figure 26**). To determine the amount of "seasonal change" in trace metals concentrations between summer, 1997 and fall, 1998, percent decrease and/or increase for each trace metal has been calculated considering the background level of each metal (**Tables 17**).

Table 17. Decreases/Increases in Trace Metal Concentrations in Fall, 1998 Surficial Bottom Sediment Samples as Compared to Comparable Sites in Summer, 1997. Changes in contamination are reported as orders of magnitude

	Ag	Cd	Cr	Cu	Ni	Pb	Zn	V
25A	1.62	1.52	2.58	2.02	12.16	1.96	1.37	9.50
26A	1.19+	1.79+	1.79+	1.23+	1.11	1.07	1.00	1.85
27C	3.71	14.67	8.98	4.06	2.73	3.82	3.59	16.06
28A	1.11+	1.36	0.12	2.55+	1.00	2.80+	1.86+	0.09
28C	1.27	3.65	1.97+	1.92	2.68	2.60	1.77	2.18
29C	1.16	1.23	1.19	1.00	3.53	1.33	1.14	2.18
30A	1.37	28.66	2.06	1.60	8.16	1.70	1.42	1.38
31A	3.72	20.26	4.92	1.49	2.98	1.28	1.45	1.04
32A	41.90	33.93	2.00	2.72	2.08	2.67	1.11	1.92
33A	1.15+	5.50	1.05	1.07+	1.49	1.28	1.18	1.66
34A	1.03+	2.82	1.33	1.02	0.02	1.28	1.24	5.21+

Note: Cd, Cr, Cu, Ni, Pb, and Zn background concentrations used here are those in the Old Hudson sediments (Williams, *et al.*, 1978). Ag (0.24 ppm) and V (28 ppm) background concentrations used are those reported for Site 2B from this study (1997). Positive values indicate increases in trace metal concentration in Fall, 1998 surficial bottom sediments as compared to those in Summer, 1997.

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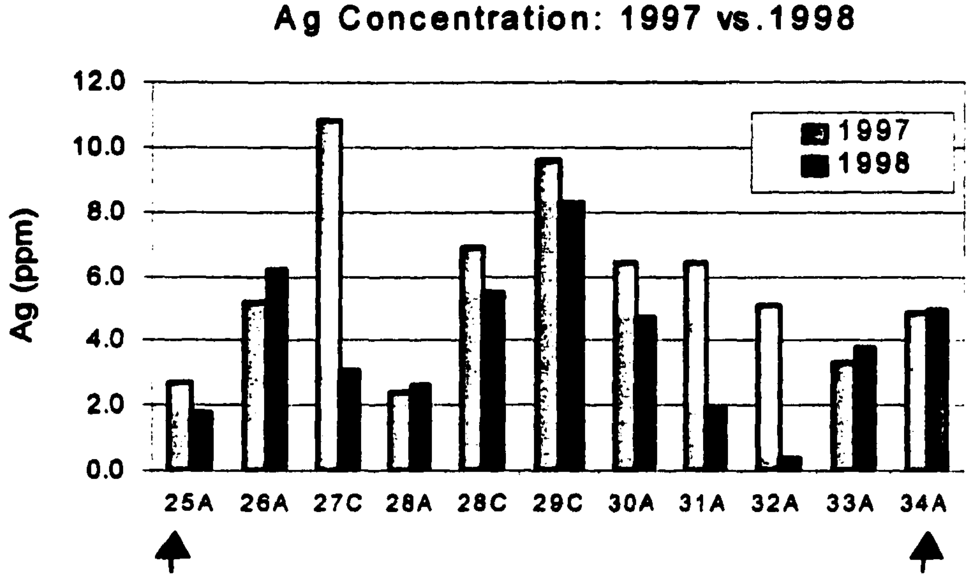
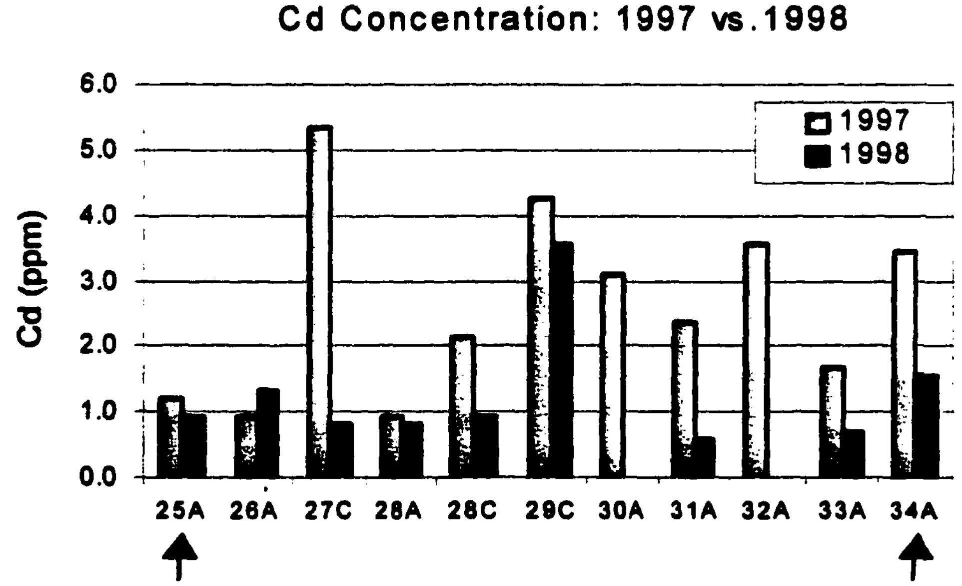
Figure 26. Comparison of Trace Metals Concentrations Between Summer, 1997 and Fall, 1998 at Selected Sample Sites. 34A represents a location near Battery, and 25A a location south of the George Washington Bridge





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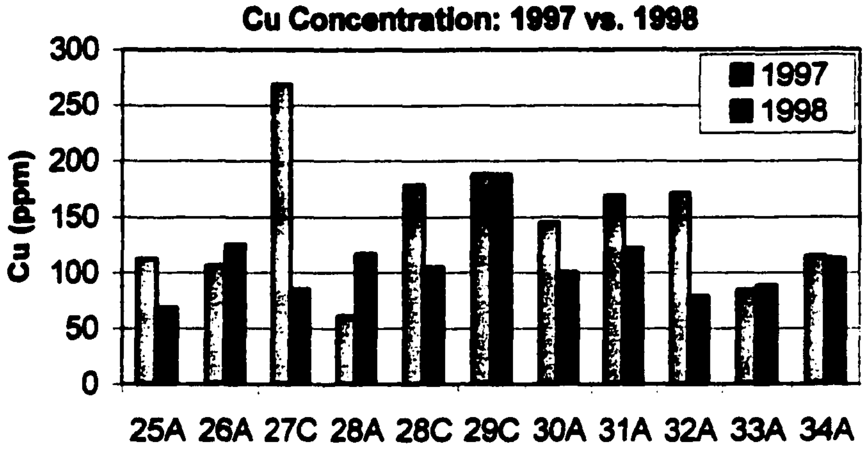

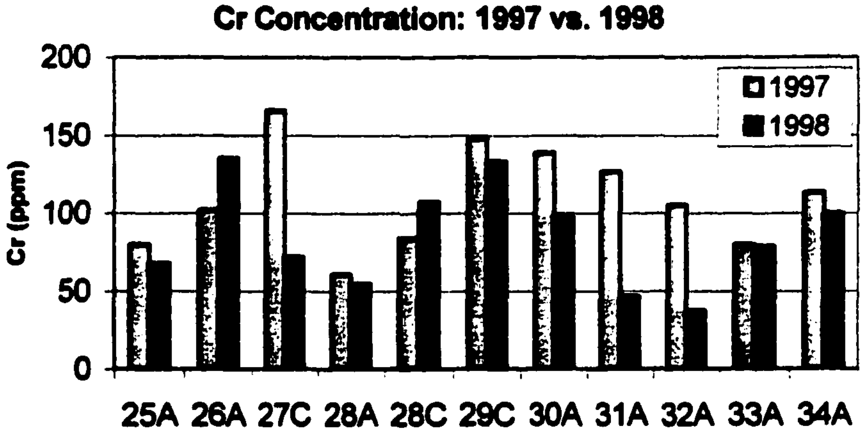

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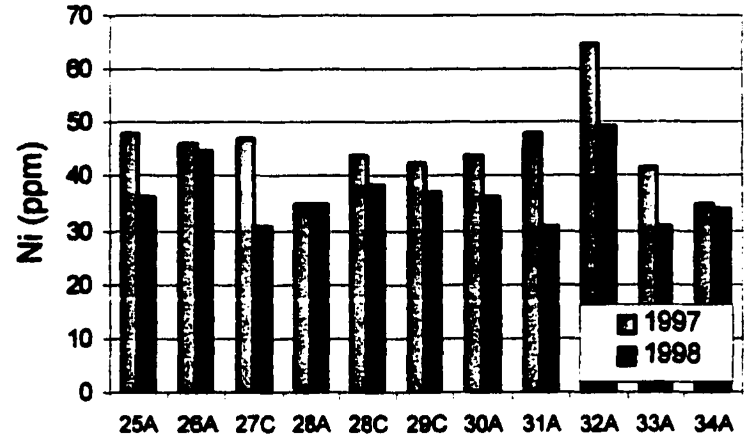
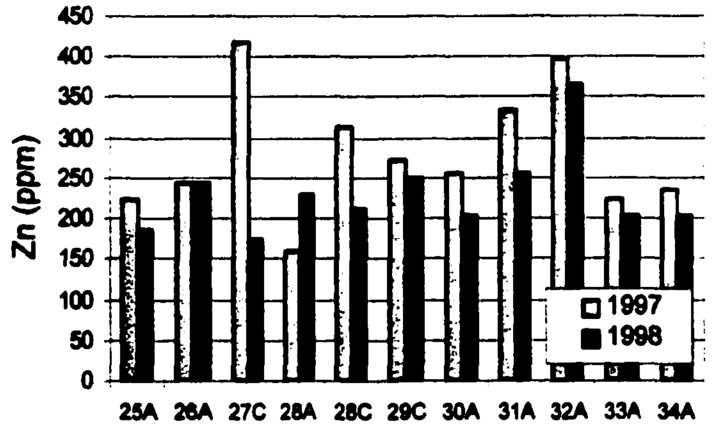
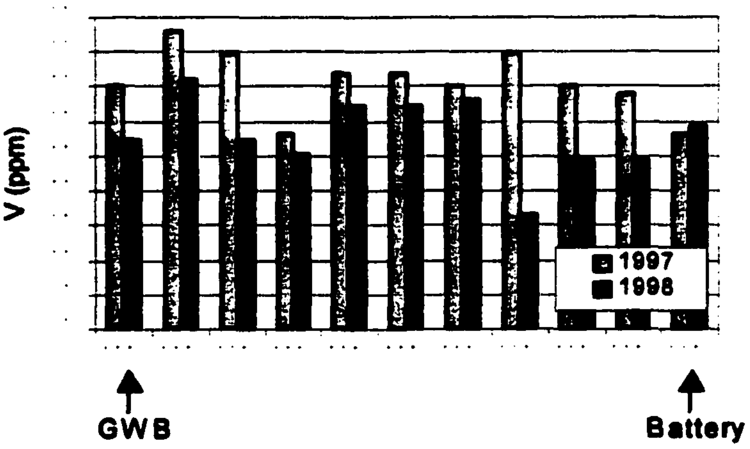


Ni Concentration: 1997 vs.1998



Zn Concentration: 1997 vs.1998



V Concentration: 1997 vs.1998

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The results of such comparison suggest that trace metals concentrations at sites 25A, 27C, 29C, 30A, 31A and 32A decreased substantially in 1998. Stations 26A, 28A, 33A, and 34A, all along the New Jersey shoreline, show general increases in several metals, including Ag, Cd, Cr, Cu, Ni, Pb, and Zn. Station 28A shows the largest increase in Pb.

The observed "seasonal changes" in trace metal concentrations could be explained based on several factors: (a) the textural property of sediment samples arising from small-scale spatial variation in sediment characteristics, and thus variation in their metals concentrations, (b) seasonal variation in total organic carbon content of sediment samples that are sinks for metal accumulation, (c) changes in metal input from point sources of contamination, namely, water pollution control plants, discharging into the water in the study area, or (d) fall oxidation of the surficial sediment layer relative to summer reduction.

The result of sediment grain-size analysis shows certain degrees of textural difference between the 1997 and 1998 sediment samples (**Table 18**). Except for sites 31A and 34A there was a small decrease in the % mud in 1998 relative to 1997. Only sites 32A, 33A and 34A differ between the two sampling periods in % mud by more than 5%.

The degree of reproducibility of the 1997 sediment samples is questionable because changes in the river's hydrodynamics at any moment of time, especially from one season to another or over the tidal cycle, could affect the wire angle of the sampling device in the water at the time of sampling. This means that the grab sampler is probably *not* sampling exactly the same site, but rather an area in the vicinity of the desired site, that could have different sediment characteristics and thus different trace metals and total organic carbon content.

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Table 18. Comparison of Grain-Size Distribution in Selected Surficial Bottom Sediment Samples: August 1997 and October 1998

Sites	Lat (deg)	Long (deg)	%Sand	%Mud	Sites	Lat (deg)	Long (deg)	%Sand	%Mud
1997					1998				
25A	40.8500	73.9583	21.71	78.29	25A	40.8500	73.9580	26.43	73.57
26A	40.8333	73.9669	8.10	91.90	26A	40.8330	73.9670	13.54	86.46
27C	40.8167	73.9656	39.01	60.99	27C	40.8170	73.9660	44.26	55.74
28A	40.8000	73.9900	48.34	51.66	28A	40.8000	73.9900	51.16	48.84
28C	40.8000	73.9772	13.94	86.06	28C	40.8000	73.9770	15.62	84.38
29C	40.7833	73.9883	20.60	79.40	29C	40.7830	73.9880	23.40	76.60
30A	40.7667	74.0122	27.10	72.90	30A	40.7670	74.0120	30.12	69.88
31A	40.7500	74.0200	39.16	60.84	31A	40.7500	74.0200	34.53	65.47
32A	40.7333	74.0239	14.37	85.63	32A	40.7330	74.0240	22.56	77.44
33A	40.7167	74.0294	34.25	65.75	33A	40.7170	74.0290	49.36	50.64
34A	40.7019	74.0325	43.14	56.86	34A	40.7020	74.0320	31.54	68.46

Note: Percent sand includes grain-size fractions from 250 to 62.5 μm (fine to very fine sand) and percent mud includes grain-size fractions less than 62.5 μm (silt to clay).

Assuming the 1998 sediment samples were taken within the accuracy limit of the global positioning system utilized (± 50 feet or ±15 meters), and assuming similarity in % mud (silt + clay) distribution between the 1997 and 1998 sediment samples, then the smaller concentrations of trace metals observed in the 1998 sediment samples (see **Table 18**) can be attributed to degradation or oxidation of organic matter in the October, 1998 surficial bottom sediment samples (see **Table 7**, Sec. 3.1, in **Chapter 3**) suggesting (1) a strong selectivity of organic matter for the measured trace metals and (2) their subsequent mobility when the surficial sediment layer is oxidized (green color in sediment description, see **Table 3** in **Chapter 2**).

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Sediment samples in 1998 were collected on October 24, at the beginning of the Fall breakdown of density stratification in the water column. Two indications of density stratification breakdown are the observed changes in water temperatures and dissolved oxygen (see **Table 3** in **Chapter 2**). The surface and bottom water temperatures measured on October 24, 1998, are on average as much as 7.62 °C and 8.24 °C, respectively, lower than those at the same stations in 1997. In other words, the water column became cooler. At the same time, average surface and bottom percent oxygen saturations increased by 10.57% and 16.46%, respectively. **Figure 27** shows the variation in percent oxygen saturation and water temperature between the August, 1997 and October, 1998 samplings. Unfortunately, redox potential values for the October, 1998 sampling were not measured due to an equipment malfunction. Overall, the observed decreases in temperature and increases in percent oxygen saturation suggest the presence of more oxygenated bottom water for the time of our October, 1998 sediment sampling period.

The presence of more oxygenated bottom water in October, 1998 in the study area is also evident by the fact that total organic carbon (%TOC) was below the detection limits for the analytical method in the sediment samples from this. Harris (1976) pointed out that TOC concentration in surficial bottom sediments varies seasonally, with maximum concentrations in late spring and summer. Undetectable levels of TOC in the fall surficial bottom sediment samples are in agreement with Harris's findings. Sediment particles are known to be covered by organic coatings originating from dissolved organic material in

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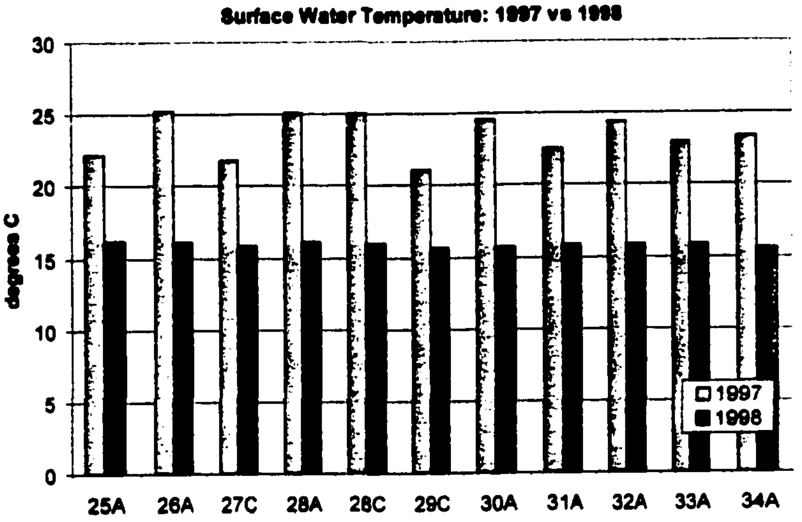
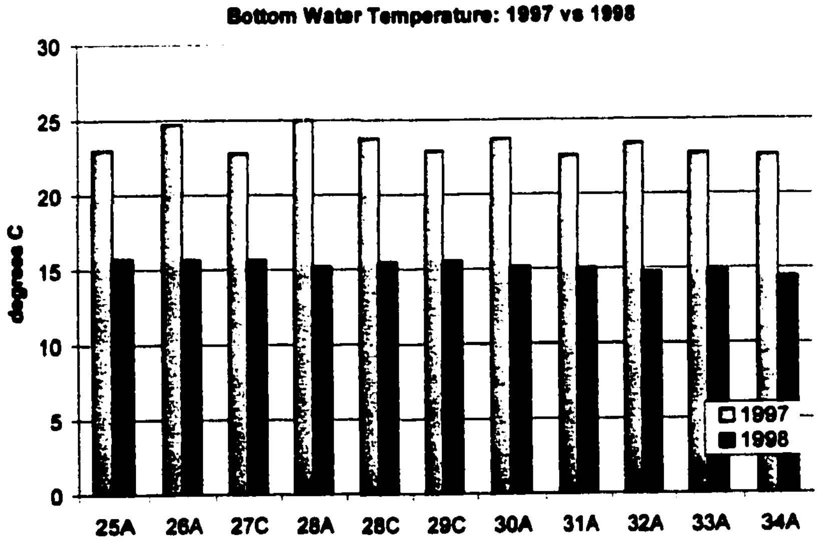
Figure 27. Comparison of Water Temperature and Percent Oxygen Saturation Between August, 1997 and October, 1998 Sampling at Selected Sites





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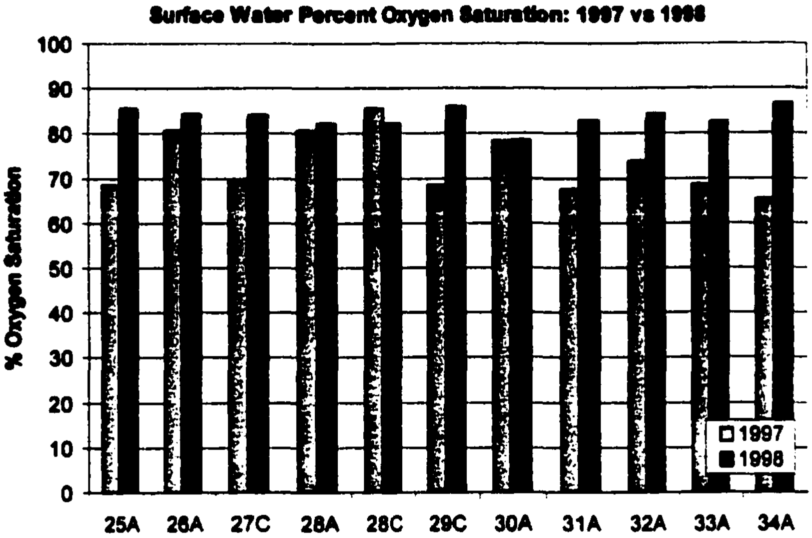
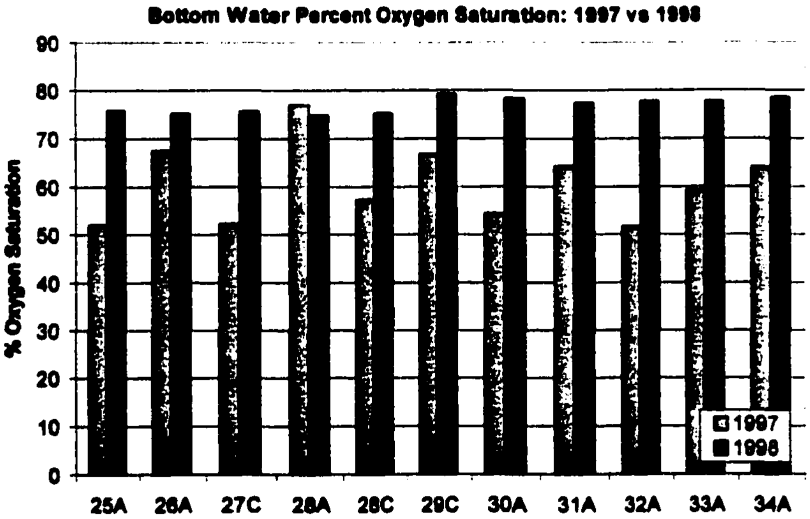


Surface Water Percent Oxygen Saturation: 1997 vs 1998



Bottom Water Percent Oxygen Saturation: 1997 vs 1998

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the water column, and it is therefore likely that some metal-organic complexes would be associated with these particles (Hunter and Liss, 1982).

The observed variation in degree by which trace metals released from our 1998 sediment samples, however, can also be attributed to the stability and reaction rates of organic complexes, as pointed out by Van Den Berg (1993) with reference to differing estuarine behavior of some metals, such as Cu and Ni. Given the lack of information on absolute values of organic phase metals in the samples (as opposed to percent total organic carbon), the observed increases in several trace metal concentrations is attributed to the presence of other-than-TOC-related phases of organic fractions, or of Fe/Mn oxyhydroxides, or of cation exchange sites on clay minerals serving as a potential depository for trace metals.

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4.5. Water Pollution Control Plants As Sources of Metal Contamination in the Study Area

An inventory of metal effluent loadings (**Table 19**, see also **Table 1** in **Chapter 1** and **Appendix E**) from nearby Water Pollution Control Plants (Hoboken, West New York, North River, Yonkers, Orangetown, Haverstraw, and Ossining) during 1996, 1997, and 1998 indicates that these plants serve as point sources of contamination in the study area. The magnitude of the effluent metal loadings discharged from these plants into the study area has less bearing on their flow capacity. For instance, metal loading from the West New York WPCP, with an annual average flow of 11.8 MGD (see **Table 1** in **Chapter 1**) is comparable to that of North River WPCP, with an annual average flow of 140.7 MGD. Yonkers WPCP, with an average flow of 92 MGD, is discharging approximately as much Cu into the estuary as the North River plant, with an average daily flow of 140.7 MGD. However, the Cu signal appears near the North River plant, but not in the vicinity of the Yonkers plant. Annual effluent metal loadings also vary. North River WPCP, for instance, discharged greater amount of Cd (34%), Cr (37%), Pb (~22%), and Zn (5%) in 1998 than in 1997. Over the same period, West New York WPCP discharged higher amount of Pb (23%), Zn (5%), Cu (1%), and Cr (~29%); the amount of Cd decreased by almost 5x over the same period. Yonkers WPCP discharged higher amounts of Ni (26%), Pb (11.7%), and Zn (24%) in 1998 than in 1997. The amount of Cr discharged by Yonkers WPCP was doubled in 1998 as compared to 1997. In general, Yonkers WPCP discharges three times as much Cr annually as the North River plant. Among the three water pollution control facilities along the New Jersey shoreline, West New York WPCP seems to be a major source of Ag, Cu, Ni, Pb, and Zn discharged into the estuary.

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Table 19. Summary of Some of NY/NJ WPCPs' Annual Effluent Metals Loading Discharged into the Hudson Estuary (Study Area) in 1996, 1997, 1998

Date	WPCP	Ag	Cd	Cr	Cu	Ni	Pb	Zn
1996	Hoboken	48.1	49.4	87.1	200	146.6	125.1	357.1
1996	West NY	942.8	141.4	688.3	3961.2	1298.3	866.9	9721
1996	Haverstraw J. R	116.9	NA	NA	275.2	361.6	43.8	327.8
1997	West NY	1212.7	30	409.8	4382.3	1074.8	505	9706.8
1997	North River	1184.58	30.33	429.48	4480.73	1173.24	496.6	9501.59
1997	Yonkers	NA	258.5	1237.73	9131.11	2866.67	6372.47	6955.42
1997	Orangetown	NA	NA	NA	266.3	300.3	NA	322.7
1997	Ossining	NA	5.39	NA	77.32	55.74	NA	153.26
1997	Haverstraw J. R	76.15	NA	NA	221.1	300.3	43.51	329.07
1998	West NY	1197.7	47.6	574.8	4435.9	1100.3	658.9	10189.5
1998	North River	1151.25	46.28	684.3	4436.73	1092.52	634.69	10061.68
1998	Yonkers	NA	262.9	2617.8	8020.14	3876.15	7217.32	9151.38
1998	Orangetown	NA	NA	NA	204	324.9	NA	234.8
1998	Ossining	NA	14.04	NA	118.01	117.6	NA	526.59
1998	Haverstraw J. R	75.87	NA	NA	200.49	324.89	46.47	293.65

Note: Underlined figures indicate modified data based on some estimated load. NA indicates no data available.

To what extent the estimated increases/decreases in NJ/NY WPCPs effluent metal loadings are related to small-scale spatial differences observed between Summer, 1997 and Fall, 1998 sampling runs is not clear as the sediment samples were not dated by the conventional radionuclide Be^7 with a half-life of 53 days.

The cumulative effect of effluent metal loadings on the present level of metal contaminants in surficial bottom sediments, however, is more pronounced downriver, where surficial bottom sediments are found to have a higher level of contamination. Despite the homogenizing effect of tidal currents in dispersing contamination in the

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estuary, bottom sediments in the vicinity of the WPCPs are more contaminated than other areas in the estuary. This is specifically true for sites along the New Jersey shoreline where contamination level is higher and more uniform.

In addition to proximity to WPCPs, accumulation of contaminants seems to be related to the type of bottom sediment too. Krank (1972) pointed out the close relationship between the type of bottom sediment and the strength of the current. The results of grain-size analysis (**Table 18**) of my surficial bottom sediments indicated a sandier bottom along the New York shoreline (4x) as opposed to a more muddy (silt + clay) bottom along the New Jersey side, suggesting the possible effects of stronger currents along the New York side of the Hudson estuary, preventing contaminants being accumulated along the New York shore as compared to the New Jersey shore.

4. 6. Percent Total Organic Carbon (%TOC) in 1997 sediment samples

Present-day Hudson estuarine sediments are a mixture of organic and inorganic materials. Inorganic materials are the products of the natural weathering of rocks underlying the Hudson watershed or those transported landward from the ocean (Mead, 1969). Sediment organic matter is the biologically produced compounds as well as synthetic organic substances. Synthetic organic substances originate from industrial and agricultural applications (Förstner and Wittmann, 1981). The organic matter of the aquatic system is in dissolved (DOC) and particulate (POC) forms. The division between DOC and POC is arbitrary in that all organics that on filtration of a water sample are retained on a 0.4 to 1.0 μm filter are termed POC, whereas those passing through into the filtrate are termed DOC (Förstner and Wittmann, 1981).

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Many suspended particles in natural waters are covered by organic coatings, originating from dissolved organic material (Hunter and Liss, 1982), especially humic substances from effluents of WPCPs (Reuter and Perdue, 1977). For the pH values that occur in estuarine waters, dissolved trace metals in estuaries interact with suspended particles and organic materials due to the predominantly negative charges of natural organic compounds (Neihof and Loeb, 1972) and suspended particles (Hunter and Liss, 1982). Estuarine and coastal mud are found to have total organic carbon up to 0.5% in unpolluted areas, and 20% in areas where pollution is a major factor (Folger, 1972).

In their work on trace metals contamination in surficial bottom sediments in the New York Bight, Harris and Waschitz (1982) pointed out that TOC, in general, is inversely related to the mean grain-size distribution of sediment particles – that is, it is associated mostly with fines. In this study, however, the above inverse relationship is not as straight forward as expected. For instance, site T27C, near the North River WPCP along the New York side, contains 2.93% TOC with only 60.99% mud and 39.01% sand (see **Table 7** and **Table 18**), whereas site T26A, located south of the George Washington Bridge on the New Jersey side, with a similar amount of TOC (2.99%), contains 91.90% mud and only 8.10% sand. Similarity in total organic content of the above sites, despite significant differences in their % sand (fine + very fine) vs. % mud (silt + clay) grain size distribution, can be explained to a large extent by proximity to source (s) of organic matter input. Site T27C, as mentioned before, is located close to the North River WPCP and receives possibly higher amounts of organic matter from the plant's effluent. Most probably even sand grains at this site are coated with organic matter (I did not measure %TOC in the sand-size sediment fraction at site T27C).

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A reverse situation is observed at site T9A, along the New Jersey shore south of the Tappan Zee Bridge, with 90.35 % mud and 9.65% sand, and TOC content as low as 1.05%. Site T27C also has high concentrations of trace metals. It must be cautioned that in addition to chelating with organic matter, metal ions are also known to be associated with a number of sediment – forming materials with large surface area, such as freshly precipitated Fe/Mn oxyhydroxides, clays and amorphous silica (Förstner and Wittmann, 1981). Eh and pH values measured near the sediment/water interface at each sampling site (see **Table 2**) are also in agreement with the stability field of Fe/Mn oxyhydroxides identified from the pH- Eh stability field for the system Fe-CO_2 – S- H_2O (Garrels and Christ, 1965).

In this study, %TOC values range from a minimum of 0.67% (T2C) north of the Tappan Zee Bridge to 2.99% (T27C) in the vicinity of North River WPCP (see **Table 8**). A closer look at the spatial distribution of %TOC in the study area (**Figure 28**) reveals that %TOC content at the majority of sampling sites along the New Jersey shoreline below transect 5 (north of the Yonkers WPCP) varies between 2 and 2.99%, while only a few of the sampling sites along the New York shoreline have TOC more than 2%, and these sites are primarily located south of the North River WPCP. The general low %TOC content found in surficial sediment samples along the New York shoreline could be attributed to the prevalent stronger current along the New York shoreline. Sediment samples found along the New York shore, as mentioned before, contain on average 4x more sand than those along the New Jersey shoreline. The average sand content of sediment samples along the New York shore is about 28.58%, whereas the average sand along the New Jersey shoreline is about 6.45%.

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Based on my findings, two factors seem to be accountable for the observed spatial variation in %TOC found in surficial bottom sediments. One is the type of sediment covering the estuary floor (sandy vs. muddy) and the other is the proximity to sources of organic matter (WPCPs). My results, however, do not show a clear relationship between the bathymetry of the study area and %TOC distribution. However, except for V (r = 0.82) and Fe (r = 0.83), which show a strong association with %TOC in the sediment samples (see **section 2.6 on statistics: pair wise correlation – nonparametric measures of association**), no other measured trace metals demonstrated such a strong association.

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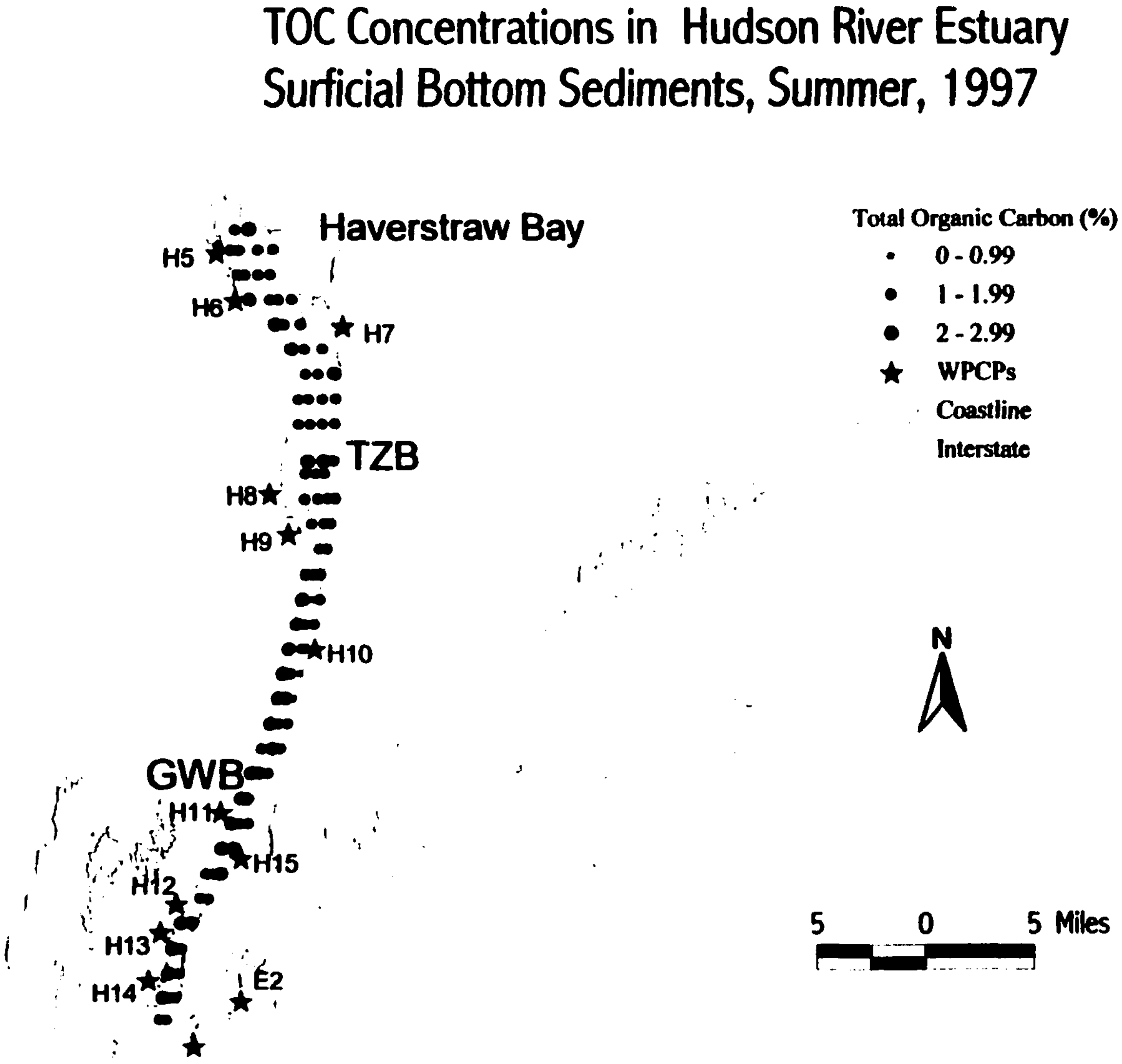

Figure 28. Spatial distribution of percent total organic carbon concentration in the study area

4. 7. Percent Carbohydrate (%TCH): A Qualitative Indicator of Sewage Contamination

To obtain a qualitative or semi-quantitative indicator of sewage-derived organic matter, carbohydrate content of sediment samples must be normalized to their total organic carbon content (Hatcher and Keister, 1976). Previous studies also indicated that the enrichment in total organic carbon alone cannot be taken as indicative of sewage (Hatcher and Keister, 1976). The resultant ratio, R, which is the weighted average of the TCH:TOC from several sources of organic carbon, is found to vary depending on the origin of the carbohydrate in the sediment. Hatcher and Keister (in Harris and Waschitz, 1982) established the following ranges for R values:

$R = 50 - 60$ (sands); $TOC < 1\%$

$R = 40 - 50$ (silty muds); $TOC > 1\%$

Indicates that the organic matter contains relatively large amounts of sewage-derived materials

$R = 30 - 40$

Indicates a mixture of sewage-derived and phytoplankton-derived materials

$R \leq 20$

Indicates that the sediment organic matter is composed of phytoplankton organic matter alone or in combination with a smaller amount of sewage.

$R \leq 10$

Indicates that the major source of organic matter to the sediments is phytoplankton; or humic materials and organic mater of terrestrial origin or bay-marsh muds, or newly treated sewage effluent or new raw sewage (Harris, 1979; Waschitz, 1980)

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Based on the above literature reports concerning the TCH:TOC ratio of various types of organic matter present in the environment, as mentioned earlier, my findings (R varies from 131 to 451) indicate that the major source of the high carbohydrate organic matter in my surficial bottom sediments is sewage, which contains refractory organic matter. Sewage-derived refractory organic matters are the oxidation – resistant carbohydrates (as cellulose and hemi-cellulose) from industrial wastes that are buried in the sediment as particulate organic matter (Hunter and Heukelekian, 1965). Cellulose is a polymer of β-glucose (a simple sugar that cannot be hydrolyzed to any simpler carbohydrate) that is used by plants as structural material. Unlike plant starch (a polymer of α-glucose) and animal starch (glycogen), which are easily hydrolyzed by enzymes in the sediments (bacterial decomposition), cellulose and hemi-cellulose and chitins (structural support of arthropods and crustaceans such as crabs, lobsters, and shrimps) are not easily hydrolyzed because most organisms (bacteria) do not have the enzymes necessary to break them down as rapidly.

The question arises: Is there any contribution by terrestrial and phytoplankton constituents of organic matter to these TCH:TOC values? And if so, how much? A previous study (Howarth *et al.*, 1996) on metabolism and organic carbon fluxes in the tidal freshwater Hudson River (the freshwater stretch of the upriver from Newburgh, RKM 100, to Troy Dam, RKM 248) indicated that allochthonous inputs from non-point sources on land (61%) and gross primary productivity by phytoplankton (28%) are the major sources of organic carbon in the system. According to Howarth *et al.* (1996), the major losses of organic carbon from the ecosystem are through respiration (54%) and downstream advection into the saline estuary (41%).

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Ellsworth (1986) calculated the total net input of fine-grained silt and clay-sized particles from tributaries, the sea, and *in situ* primary productivity to the lower Hudson River to be between 1.194 and 1.789 × 10^6 metric tons per year (T/yr), of which from 0.819 to 1.313 × 10^6 MT/yr (26% – 30%) are inorganic. According to Ellsworth (1986), anthropogenic wastes are relatively minor sources of fine- grained material to the river, and the atmospheric input is negligible. However, terrestrially-derived organic matter is typically low in carbohydrates (Kononova, 1966), with the TCH:TOC ratio being on the order of 10-20. Typical sawgrass peats, for instance, had a TCH:TOC ratio of about 5, meaning that most labile carbohydrates in plants undergo rapid bacterial decomposition (Waksman and Stevens, 1929, in Hatcher and Keister, 1976).

Furthermore, only small amounts of cellulose are found in material older than the Pleistocene (Vallentyne, 1963, in Hatcher and Keister, 1976). This means that, despite the large amount of organic input (41%) from upstream terrestrial sources to the lower Hudson estuary, the contribution of terrestrial material to the TCH:TOC in the study area is expected to be negligible. Additionally, cellulose and hemi-cellulose form a minute fraction of carbohydrates in both phytoplankton and zooplankton (Parsons *et al.*, 1961, in Hatcher and Keister, 1976). This leaves only sewage-derived refractory carbohydrates, despite sewage effluents being a minor source of fine-grained material to the study area, as the major contributor to the high TCH:TOC ratio found in the examined surficial sediment samples.

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4.8. Comparison with Previous Studies

To assess the magnitude of trace metal reduction/ and or increase in surficial bottom sediments over the past few decades, data from several pervious studies are used. Where either the coordinates (latitude & longitude) or the bearings (west, east) of reference sites in previous studies are not provided, the closest river transects to these sites were used. For reference sites with known coordinates, the closest comparable sites from this study were selected. Care was taken in both situations to compare sites of similar sediment facies (Coch, 1986).

One of the earliest studies on sediment contamination in the Lower Hudson Estuary including the New York Harbor area is that of Williams *et al.* (1978). Core samples in their study were taken from the New York Bight (MP 38) to north of the Hudson Highlands (MP 56). For the purpose of this comparison, only five top cores from Williams *et al* (1978) total of 12 cores were selected. These cores fall within the present study area from the Battery (MP 0) north to the vicinity of the Tappan Zee Bridge (MP 25). **Table 20** shows the results of the comparison made between my study (1997) and those of Williams *et al.*, (1978). The average reductions in sediment contamination for the area near the Battery to approximately W. 42nd Street from 1978 to 1997 are significant: Cu is reduced by 50%, Pb by 70% and Zn by 28%, respectively. For samples collected in the area from north of the Yonkers WPCP to the vicinity of the Tappan Zee Bridge (TZB), reductions in sediment contamination are even greater: Cu about 79%, Pb by 60%, and Zn by 29%. The actual reductions in sediment contamination could be much larger than what are calculated here if the coordinates of the reference sites reported in

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Table 20. Comparison Between Trace Metals Sediment Data from Williams *et al.* (1978) and the Present Study in Summer of 1997

In the vicinity of the Battery						
Sites	**Date**	**Lat. (deg)**	**Long. (deg)**	**Cu**	**Pb**	**Zn**
MP 0	1978	NA	NA	180	140	260
MP 2	1978	NA	NA	225	830	345
		Average		203	485	303
		SD		31.8	487.9	60.1
Sites from present study						
T34A	August 12, 1997	40.7019	74.0325	114	152	235
T34B	August 12, 1997	40.7019	74.0267	63	83	147
T32A	August 12, 1997	40.7333	74.0239	171	266	397
T32B	August 12, 1997	40.7333	74.0153	108	141	181
		Average		114	161	240
		SD		44.3	76.6	110.8
		% (Reduction) / Increase		(50)	(70)	(28)
From north of Yonkers WPCP north to near the Tappan Zee Bridge						
MP 19	1978	NA	NA	35	55	48
MP 24	1978	NA	NA	115	175	230
MP 25	1978	NA	NA	99	92	190
		Average		83.0	107.3	156.0
		SD		42.3	61.5	95.6
From the present study						
T5B	August 14, 1997	40.9833	73.8942	26	45	108
T9A	August 14, 1997	41.0500	73.9000	42	61	118
T10A	August 13, 1997	41.0667	73.8992	43	58	141
		Average		37.0	54.7	122.3
		SD		20.5	25.7	48.1
		% (Reduction)/ Increase		(79)	(60)	(44)

*Trace metal concentration in ppm.

Source: Williams *et al.*, 1978. Sources of heavy metals in sediments of the Hudson River Estuary. Marine Chemistry. 6:195-213.

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Williams *et al.* (1978) were known, and more importantly if my surficial sediments were dated.

Another study on surficial sediment trace metals contamination that is used here as a basis for comparison is the 1987 survey conducted by the New York City Department of Environmental Protection (1988). The NYC DEP assesses the effectiveness of its water pollution control activities each year by measuring contamination levels in both water and surficial bottom sediment in New York Harbor and its environs – this pollution assessment program is known as the NY Harbor Water Quality Survey. Data on the average trace metals concentrations in grab samples for the period from 1983 to 1986 were reported in the NY Harbor Water Quality Survey (1986). Out of the total 21 stations along the Hudson, 7 stations were chosen. These stations fall in the areas between Battery (km 0) and almost half way between the GWB and TZB, approximately a 30 km stretch of the lower estuary. **Table 21** shows the results of such a comparison.

The NYC EPA data suggest a general decrease in metals concentrations except for Cd and Pb in surficial bottom sediment down river towards the Battery during the time period 1983-1986 compared to 1997. In the area between W. 72nd Street (sites N3A and T29C) and W. 125th Street (sites N3B and T27C), however, the present study indicates somewhat higher levels of contamination in surficial bottom sediments relative to 1983-1985, except for Cd (N3A near West 72nd Street), which had the (1983-1985) abnormal concentration of 180.45 ppm. On a site by site basis, the NYC EPA's site N3B, near W. 125th Street also shows much lower concentrations of Cd, Cr, Cu, Ni, Pb, and Zn during 1983-1985 as compared to those metals in 1997 at my site T27C. The NYCEPA's site N3A near W. 72nd Street relative to my T29C site shows a similar relationship except for

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Table 21. Comparison Between Surficial Bottom Sediment Trace Metals Concentrations Reported in NYCEPA (June-September 1983-1986) and the Present Study (August-September of 1997)

Sites	Lat. (deg.)	Long. (deg.)	Cd*	Cr*	Cu*	Ni*	Pb*	Zn*
From the Battery north to the George Washington Bridge								
N5	40.7044	74.0261	2.85	106.5	117	23.3	246	227.5
N4	40.7639	74.0067	2.62	103.75	113	31	144.3	184.5
N3A	40.7831	73.9922	180.45	111.75	100.8	25.5	304	151
N3B	40.8211	73.9653	2.7	79	88	25.7	140	137.7
N3	40.8364	73.9542	3.22	112	135.5	25.5	135.3	190
	Average		47.2	100.3	104.7	26.4	208.6	175.2
	SD		88.9	14.6	13.1	3.3	80.3	40.1
Sites from the present study								
T34B	40.7019	74.0267	0.71	71	63	35	83	147
T30B	40.7667	74.0036	1.42	74	71	39	98	194
T29C	40.7833	73.9883	4.26	148	188	43	223	274
T27C	40.8167	73.9656	5.33	166	268	47	385	418
T26C	40.8333	73.9525	1.3	63	65	36	87	166
	Average		2.60	104.4	131	40	175.2	239.8
	SD		2.1	48.6	93.0	5.0	130.9	110.8
	% (Reduction)/Increase		(96)	9	25	272.5	(18)	40
North of the George Washington Bridge								
N2	40.8783	73.9314	1.56	41	67	21	67	109
N1	40.9136	73.9167	2.12	39	75	18	76	122
	Average		1.84	40	71	19.5	71.5	115.5
	SD		0.4	1.4	5.7	2.1	6.4	9.2
Sites from the present study								
T23C	40.8833	73.9236	0.71	47	75	26	81	131
T1B	40.9167	73.9192	0.95	64	57	42	75	184
	Average		0.83	55.5	66	34	78	157.5
	SD		0.2	12.0	12.7	11.3	4.2	37.5
	% (Reduction)/Increase		(75)	29	(11)	6.9	11	54

*Trace metal concentration in ppm.

Source: New York City Department of Environmental Protection. 1988. New York Harbor Water Quality Survey 1987, Wards Island, New York.

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Pb. As the concentrations of all trace metals measured at sites T27C and T29C (except for Cd and Pb) are significantly higher than those measured at comparable 1983-1985 sites, there should either be a new post-1985 local point source of contamination in a nearby area or the annual input of these metals at existing WPCPs should have increased.

The most probable point source of contamination could be the metal loadings of the North River WPCP, located at W. 125th Street in Manhattan. North River WPCP was constructed and upgraded over the period 1986-1991 in an effort to reduce the amount of both dissolved and solid organics and trace metals in untreated wastewaters discharged into the Hudson estuary. In general, for the area extending from the Battery (km 0) to near the George Washington Bridge (*ca.* km 18), increases occur in Cr (9%), Cu (25%) and Zn (40%). Cd and Pb show decreases of 96% to 18 %, respectively. Ni shows an unusually high increase by 1997, primarily due to its high background level (35 ppm)

For the area north from the George Washington Bridge (GWB) to Mt. St. Vincent, trace metals concentrations in surficial bottom sediments do not show a uniform change. For instance, Zn and Pb concentrations between 1983-1985 and 1997 increased by 54% and 11%, respectively, whereas in the area below the George Washington Bridge the Pb concentration had decreased by 18% over the same time period. Cu and Cd concentrations were reduced by 11% and 75%, respectively north of the GWB by 1997. Cr and Ni, on the other hand, were increased by 29% and 7%, respectively north of the GWB over the same time period.

Data from another interesting study (**Table 22**), that was used in comparison with mine, are obtained from the work of Chillrud (1996), who studied the historical record of contamination over the time period from 1982 to 1994. Chillrud's data, based on dated

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core samples, are interesting in that they provides valid information on temporal reductions in trace metals concentrations over three important periods (1982-1984, 1989, and 1994). These periods are important in that they reflect the effectiveness of the NYC EPA programs (initial Industrial Pretreatment Program (IPP), accelerated IPP, Corrosion Control Program) in reducing the trace metals levels in the City's drinking water, sewage, and sludge. Compared to Chillrud's 1982-1984 top cores, collected in the area between the Holland Tunnel and Lincoln Tunnel, 1997 samples (this study) only show increases in Zn by 11% and Ni by 47%. Given the lack of information on the coordinates of Chillrud's (1996) cores (only bearings are given), the observed differences could be related to small-scale spatial variations between the compared surficial sediments. Spatial variability in radionuclide and trace metals concentrations ranging from 28% to 93% are reported in multiple sediment cores collected in June 1994 near Km 8 (around W. 79th Street) of the Hudson River estuary off Manhattan (Fang *et al.*, 1998). Fang's findings are important in that they validate deposition of "recent" sedimentation (< 1 year) in the area of relatively low bottom shear stress under which fine-grained sediments are preserved.

Chillrud's data from 1989 (Site 2.34W) show the effects of an accelerated Industrial Pretreatment Program implemented by the NYC EPA in an effort to reduce the metal loadings into and from the NYC WPCPs. Except for his unusually high 1989 Pb concentration (2660 ppm) and increase in Zn concentration in his 2.34W top core, all other trace metals levels in his top cores decreased compared to those in 1982-1984. Trace metals concentrations at my comparable 1997 sites show decreases in Zn (25%),

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Table 22. Comparison of Trace Metal Concentrations in Chillrud's (1996) Top Cores and the Present Study in 1997

Sites	Date	Lat.	Long.	Cd	Cr	Cu	Ni	Pb	Zn
Vicinity of Holland Tunnel									
2.3 W	1982-1984	NA	NA	3.03	170	180	40	199	331
2.35 W	1982-1984	NA	NA	3.4	167	178	42	192	351
2.75E	1982-1984	NA	NA	2.5	130	145	42	171	3.01
	Average			3.0	155.7	167.7	41.3	187.3	228.3
	SD			0.5	22.3	19.7	1.2	14.6	195.4
Sites from this study									
T31B	September 4, 1997	40.7500	74.0128	0.59	37	31	30	65	95
T32A	August 12, 1997	40.7333	74.0239	3.55	105	171	64	266	397
	Average			2.07	71	101	47	166	246
	SD			2	48	99	24	142	214
	% (Reduction)/ Increase			(37)	(89)	(47)	47	(13)	11
Vicinity of Holland Tunnel to south of the George Washington Bridge									
2.34 W	1989	NA	NA	1.64	109	124	38	2660	374
2.73 E	1989	NA	NA	2.8	162	191	44	212	341
6.3 W	1989	NA	NA	1.44	124	128	34	138	246
9.7 W	1989	NA	NA	1.31	102	111	32	118	233
	Average			2	124	139	37	156	299
	SD			1	27	36	5	50	70
Sites from this study									
T32A	August 12, 1997	40.7333	74.0239	3.55	105	171	64	266	397
T32B	August 12, 1997	40.7333	74.0153	0.59	78	108	34	141	181
T29B	September 4, 1997	40.7833	73.9953	0.95	61	74	28	97	153
T26A	August 12, 1997	40.8333	73.9669	0.95	102	106	46	144	243
	Average			1.51	86.5	114.8	43	162	243.5
	SD			1.4	20.9	40.6	15.9	72.6	109.0
	% (Reduction)/ Increase			(22)	(59)	(21)	75	4	(25)
Vicinity of Holland Tunnel to south of the George Washington Bridge									
2.33 W	1994	NA	NA	1.65	149	137	38	150	241
2.76 E	1994	NA	NA	1.4	106	134	38	150	235
6.31W	1994	NA	NA	1.22	91	117	28	170	201
9.71 W	1994	NA	NA	1.02	75	88	30	94	167
	Average			1.3	105	119	34	141	211
	SD			0.3	31.8	22.5	5.3	32.7	34.2
Sites from this study									
T32A	August 12, 1997	40.7333	74.0239	3.55	105	171	64	266	397
T31B	September 4, 1997	40.7500	74.0128	0.59	37	31	30	65	95
T29B	September 4, 1997	40.7833	73.9953	0.95	61	74	28	97	153
T26A	August 12, 1997	40.8333	73.9669	0.95	102	106	46	144	243
	Average			1.5	76.3	95.5	42	143	222
	SD			1.4	33.0	59.0	16.7	88.2	131.6
	% (Reduction)/ Increase			19	(64)	(25)	121	2	8

Note: Trace metal concentrations in ppm.

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Cu (21%), Cr (59%) and Cd (22%) and increases in Pb and Ni by 4% and 75%, respectively, relative to 1989. On examination of the differences between these sites on a one – to – one basis, matching sites 6.3W and T29B stand out. Site T29B marks a location down river from the North River WPCP and it shows much lower concentrations of trace metals than at site 6.3W from Chillrud's 1989 top cores. Despite the disparity in location of theses two sites, trace metals reductions in Cd, Cr, and Zn are significant.

Chillrud's 1994 data, compared to his previous years' down core dated intervals, suggest both spatial and temporal reductions in trace metal distributions in core tops from the area between the Holland Tunnel and the George Washington Bridge by the year 1994. Exceptions are Cr, Cu and Ni at 2.33W and Pb at 6.31W. My comparable sites, however, suggest increases in Zn (8%), Pb (2%), and Cd (19%), and reductions in Cu (25%) and Cr (64%), with Ni showing more than a 100 % increase in concentration. Such non-uniform changes in trace metals distributions in surficial sediments are not as easy to interpret as one might think. First, the distances between the compared sites are not very clear. Second, unlike those of Chillrud my surficial bottom sediment samples are not dated by the commonly used Be-7 isotope dating method. However, there is a long-standing belief that the sedimentation rates in shoals on the west side of the Hudson (New Jersey shore) off Manhattan Island are relatively high, on the order of 100-300 mm per year (Olsen *et al.*, 1978; Olsen *et al.*, 1981; Bokuniewicz and Hirschberg, 1982). The comparable 1997 surficial samples (T32A, T31B, T29B, and T26A) were all collected from the western margin of the estuary, an area of high sedimentation rates, suggesting that the 1997 surficial sediment samples have a high chance of being "recent" deposition. If that is so, then the higher levels of Zn, Pb, Ni and Cd in these samples may suggest

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some number of external sources of trace metal influx into the estuary, most probably from the nearby WPCPs on the New Jersey side of the estuary such as Hoboken, West New York, North Bergen and Egdewater.

In still another study conducted by the NY-NJ EPA (Adams *et al.*, 1998), surficial bottom sediments were collected in the summers of 1993 and 1994. The EPA's sediment sampling was part of the New York–New Jersey Harbor Estuary Program (NY-NJ HEP) effort to develop the Comprehensive Conservation and Management Plan (CCMP) for the Harbor and Bight apex. **Table 23** shows some of the EPA's trace metals data and those of my nearby sites.

Compared to the U.S.EPA.'s 1993 data, a general decrease is observed in Ag (16%), Cd (45%), Cr (19%), Cu (47%) and Zn (9%) levels, while Pb increased by 6%. Ni increased from an average of 24.8 ppm in 1993 to its background level (35.3 ppm) in 1997. If only the area near the Harlem River is considered (sampling sites UH003 and UH004, and T24B), however, then the reduction in Cd (30%) and Cu (3%) by 1997 is less while Ag, Cr, Pb, and Zn increased by 17%, 122%, 42%, and 32%, respectively. Ni concentration by 1997 had risen to a little higher than its background level (35 ppm). For the area near the Battery (UH014, UH018, T31B, and T34B), there are significant reductions in Ag (17%), Cd (56%), Cr (64%), Cu (58%), Pb (30%) and Zn (20%) concentrations by 1997 relative to 1994; Ni concentration was still below its background level. These findings are interesting in that data from both studies represent (1) similarity in sampling time – summer sampling, and (2) the degree of spatial closeness between the corresponding sites.

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Table 23. Comparison Between Trace Metal Sediment Data for the Hudson River Estuary from Adams *et al.* (USEPA, R-EMAP Project, 1998) and Present Study in 1997

From near the Harlem River to the Battery

Sites	**Date**	**Lat. (deg)**	**Long. (deg)**	**Ag***	**Cd***	**Cr***	**Cu***	**Ni***	**Pb***	**Zn***
UH003	8/24/1993	40.8677	73.9435	5	2.4	93	130	27	107	184
UH004	8/24/1993	40.8651	73.9407	0	0.3	22	35	18	44	122
UH014	8/25/1993	40.7562	74.0199	4.7	0.3	87	98	32	114	196
UH018	8/25/1993	40.7066	74.0222	4.8	1.2	65	128	22	96	147
		Average		3.6	1.1	66.8	97.8	24.8	90.3	162.3
		SD		2.4	1.0	32.2	44.3	6.1	31.7	34.0
Sites from this study										
T24B	8/12/1997	40.8667	73.9425	4.15	0.95	77	80	38	116	188
T24B	8/12/1997	40.8667	73.9425	4.15	0.95	77	80	38	116	188
T31B	9/ 4/1997	40.7500	74.0128	1.19	0.59	37	31	30	65	95
T34B	8/12/1997	40.7019	74.0267	2.73	0.71	71	63	35	83	147
		Average		3.1	0.8	65.5	63.5	35.3	95.0	154.5
		SD		1.4	0.2	19.2	23.1	3.8	25.3	44.1
%(Reduction)/Increase				(16)	(45)	(19)	(47)	2.8	6	(9)

From south of the Harlem River to the Battery

Sites	Date	40.914167	73.92267	2	1.02	60	52	25	48	117
UH003	8/14/1994	40.8905	73.93367	3	1.35	81	77	27	70	157
UH004	8/14/1994	40.803167	73.97983	0	0.8	50	55	20	46	99
UH014	8/14/1994	40.713833	74.029	4	1.6	96	96	27	99	169
UH018	8/14/1994	Average		2.3	1.2	71.8	70.0	24.8	65.8	135.5
		SD		1.7	0.4	20.7	20.6	3.3	24.7	33.0
Sites from this study										
T1A	9/ 4/1997	40.9167	73.9253	4.04	1.07	84	87	45	119	216
T23B	9/ 4/1997	40.8833	73.9303	2.49	0.95	71	67	40	92	195
T28C	8/12/1997	40.8000	73.9772	6.88	2.13	84	178	44	254	315
T33A	9/ 4/1997	40.7167	74.0292	3.32	1.66	80	84	42	140	225
		Average		4.2	1.5	79.8	104.0	42.8	151.3	237.8
		SD		1.91	0.55	6.13	50.11	2.22	71.26	53.01
%(Reduction)/Increase				47	27	41	43	232	65	65

*Trace metal concentration in ppm.

Source: Adams, D. A, *et al.*, 1998. Sediment quality of the NY/NJ Harbor system, (EPA/902-R-98-001) U.S. Environmental Protection Agency. Region 2, New York, NY and Edison, NJ.

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Compared to the NYC EPA's 1994 trace metals data, my comparable sites show considerable increases in all the measured trace metals: Ag (47%), Cd (27%), Cr (41%), Cu (43%), Pb (65%) and Zn (65%). Similarity in the magnitude of the Pb and Zn increases may lead to a somewhat misleading conclusion. The increase in Zn is much higher than the increase in Pb because of the higher Zn background level (80 ppm versus 20 ppm for Pb).

On a site by site basis, the observed differences are interesting. For instance, site UH004 has a zero Ag value, while the closest site from my study, T28C, had 6.88 ppm Ag, which is the 2nd highest in magnitude for Ag after site T27C (Ag = 10.80 ppm) among all my samples. Other trace metals concentrations at site T28C are also several orders of magnitude higher than those measured at site UH004 (see **Figure 9** on longitudinal river sections-C sites). Sediment samples from the NYC EPA study and mine, except for sites UH004 and T28C, were collected along the western shore of the river, on the New Jersey side. This side of the estuary was previously characterized as being a repository for sediment accumulation ranging from 100 to 300 mm/year (Olsen *et al.*, 1981; Olsen *et al.*, 1985; Olsen *et al.*, 1993). As samples from both these studies were taken from the top 1 cm of surficial bottom sediment, the observed increases in my 1997 surficial sediment trace metals concentrations could be the result of either small-scale spatial variation in trace metals or simply trace metal fluxes from a nearby local source of contamination.

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4. 9. Statistical Analysis

The results of ANOVA statistical analysis, One-Way Analysis of Variance (**see Appendix D**), indicate that there are significant spatial differences in trace metals concentrations with respect to geographic location indicated by grouping of the sampling sites into New York (NY), New Jersey (NJ), and Mid-River (MC) areas. The results of bivariate analysis also show 17 to 18 well-correlated pairs of variables using non-parametric Spearman Rho pairwise correlation (**see Figure 13**) as follows:

Table 24. A Summery of Well-Correlated Pairs Based on the Spearman Rho Pairwise Correlation

Correlated Pairs	Coefficient of Correlation
%TOC – V	0.85
%TOC - %Fe	0.80
%TOC – Ni	0.78
Zn – Cu	0.90
Zn – Pb	0.80
Zn – Ag	0.81
Zn – Cr	0.90
Ag – Cr	0.89
%Fe – V	0.79
Zn – Ni	0.82
Pb – Cu	0.86
Pb – Ag	0.77
Pb – Cr	0.76
Cu – Ag	0.92
Cu – Cr	0.89
Ni - %Fe	0.80
Ni – V	0.80

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This is not surprising given the similarity in geochemical behavior of the examined elements. Given the sewage– related source of measured trace metals in sediments, substantiated by a very high carbohydrate to %TOC ratio (see **Table 10**), one would expect to see a good correlation between %TOC and all the measured metals concentrations in surficial bottom sediments. The poor correlations observed between %TOC and the metals other than V, %Fe, and Ni may indicate the partitioning effect of other phases present in competing for particle-reactive trace metals in bottom sediment. However, when the same data set was subjected to n-dimensional analysis (Principal Components Analysis) only a few well-correlated pairs – Ag-Pb-Cu, %TOC-V, Cr-Zn and %Fe-Ni were identified.

A more meaningful degree of correlation by stations would have been possible if the data on metal concentrations had been normalized. Previous studies (Grant, 1990) show that the lack of normalization due to the inherently inhomogeneous nature of sediment grain size, which influences the normal distribution of contaminants, distorts the linear relationship between the fine-grained sediments and metal contaminant levels. A number of normalization methods using Al, Si, Rb and/or some other conservative element (Coakley and Poulton, 1993; Grant and Middleton, 1998) have been proposed to overcome this persistent problem. Uneven dilution by sediment grain size is also reflected in my data set too – except for %TOC, V, Ni, and %Fe, the remaining elements investigated were not normally distributed. Previous studies (Alkermann *et al.*, 1984) also show that even separation of the fraction less than 250 micrometers prior to the chemical analysis does not seem to resolve the influence of grain size on results.

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In this study, the sediment fraction less than 250 micrometers was analyzed for environmentally available, not total, trace metals concentrations. Such an approach would affect the prior normalization of the concentration values with reference to aluminum. Attempts made to normalize the data with reference to Ni, V, and %TOC failed to yield a better normalcy in the metal concentration values. In the absence of normalization in distribution, clustering of my concentration values amounts to nothing more than a grouping of the sediment samples according to their textural properties. Such clustering based on textural properties would, in turn, generate separate statistical groupings or clusters that are not truly representative of the effect of local sources of contamination. Given the above complications, the concentration values from this study are not clustered into statistical groupings by stations.

Lack of clustering, however, does not mean we cannot locate stations that do not fall within the correlation patterns, generated by other statistical methods, *viz.* the Principal Component Analysis and the Bivariate Analysis. In this study, fourteen stations were identified as being outliers because they fell outside the correlation patterns (see **Figures 13, 16,17**). **Table 25** shows the geochemical characteristics of the stations identified as outliers.

A close look at the geographical location of these stations (**Figure 29**) further shows why they are being singled out as outliers. The majority of these stations are located near the present location of WPCPs in the study area. Thus, they are subjected to higher amounts of certain metal contaminants discharged from these facilities into the estuary than are other sites. The statistical outliers, however, include another type of stations as well:(1) those under the bridges (stations 25A and 10B), and (2) one near the confluence

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of the Harlem River and Hudson River, station 23C. Of these, the latter (station 23C) shows the lowest concentration of Ni, Pb, Zn, V, and Ag, among all of the other stations identified as being outliers. Station 25A, under the George Washington Bridge was identified for its high level of Pb, 458 ppm, and station 10B, under the Tappan Zee Bridge, for its high level of Cd, 4.15 ppm.

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Table 25. Geochemical Characteristics of the Sites Identified as Statistical Outliers

Sites	Lat (deg)	Long (deg)	WD (m)	% Sand	% Mud	TOC%	Ag	Cd	Cr	Cu	Fe%	Mn	Ni	Pb	Zn	V
18A	41.2000	73.9553	3.05	6.69	92.51	1.74	1.66	2.49	97	81	3.40	693	45	120	238	32
16A	41.1667	73.9231	9.14	1.35	97.40	2.63	2.37	1.18	81	78	4.04	2769	47	105	227	34
13A	41.1167	73.9042	3.66	26.57	73.07	1.30	1.19	0.83	59	89	3.59	1173	37	67	156	26
12C	41.1000	73.8833	8.53	19.09	80.91	1.45	1.90	0.83	60	102	3.08	807	35	80	166	29
10B	41.0667	73.8900	3.66	9.70	88.38	1.55	0.47	4.15	33	24	3.03	876	31	31	96	24
3B	40.9500	73.9042	13.71	7.26	92.74	1.70	0.24	3.79	36	21	3.73	1052	38	25	96	33
23C	40.8833	73.9236	11.27	50.55	49.25	1.76	2.26	0.71	47	75	2.20	651	26	81	131	21
25A	40.8500	73.9583	5.48	21.71	83.45	2.00	2.73	1.18	80	112	3.91	913	48	458	225	35
27C	40.8167	73.9656	7.92	39.01	60.99	2.93	10.80	5.33	166	268	3.31	461	47	385	418	40
28C	40.8000	73.9772	1.83	13.94	84.64	2.53	6.88	2.13	84	178	3.50	895	44	254	315	37
29C	40.7833	73.9883	8.84	20.60	77.24	1.90	9.61	4.26	148	188	3.01	594	43	223	274	37
30A	40.7667	74.0122	16.45	27.10	72.90	2.39	6.41	3.08	139	145	3.32	807	44	180	255	35
31B	40.7500	74.0128	13.1	44.81	55.19	1.24	1.19	0.59	37	31	2.59	946	30	65	95	30
32A	40.7333	74.0239	16.76			2.18	5.10	3.55	105	171	3.17	593	64	266	397	35
34A	40.7019	74.0325	14.7	43.14	59.73	1.52	4.87	3.44	113	114	2.36	404	35	152	235	28

Note: Percent sand includes grain-size fractions from 250 to 62.5 micrometers. Percent mud includes grain-size fractions less than 62.5 micrometers. Metal concentrations are in ppm.

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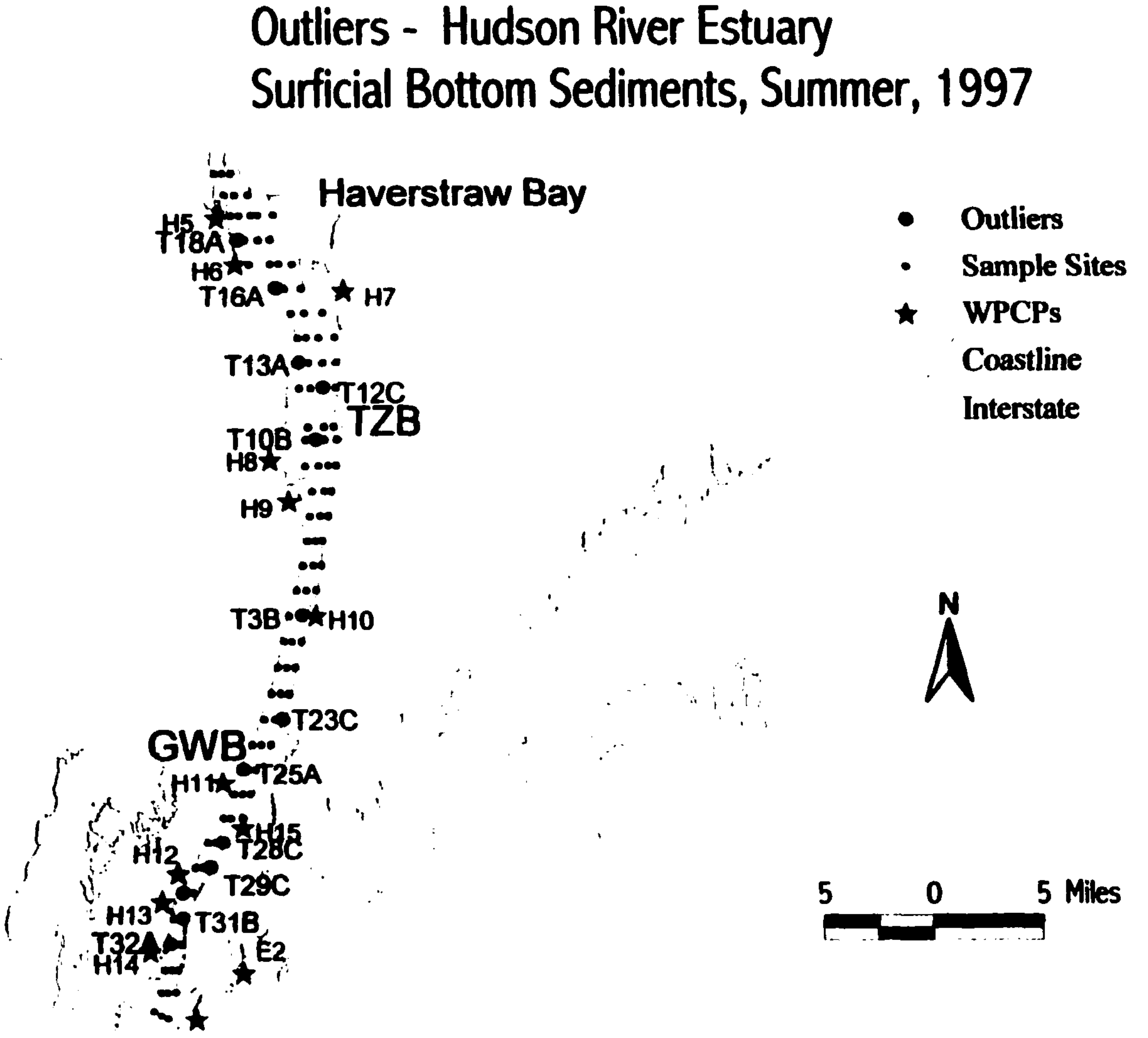

Figure 29. Spatial distribution of sampling sites characterized as being outliers in the study area

Chapter 5 - Conclusions

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Analysis of 97 fine-grained (< 60 µm) surficial bottom sediment samples collected in August – September 1997 in the lower Hudson Estuary displayed trace metals concentrations between 1.8 and 23 times higher than the historical levels of metals measured in fine-grained sediments from the Old Hudson Sediment (representing the pre-industrial levels of metal concentrations in uncontaminated sediments prior to atmospheric nuclear weapon tests conducted in the early 1950s). Compared to Ag (0.24 ppm) and V (28 ppm) at site 2B from this study, they show maximum enrichment between 0.3 (V) and 154 (Ag) in the study area.

Compared to the late 1970's and early 1980's metals concentrations measured in dated fine-grained top cores, this study shows a significant reduction in metal contamination levels in surficial bottom sediment of the same size-fraction measured in Summer of 1997. Compared to early 1990's metal concentrations measured in dated fine-grained top cores, occasional increases observed in some trace metals contaminants on a site-by-site basis.

Despite cleaner sediments found at a number of stations, this study shows that sediment contamination down river can still be an issue of concern. Surficial sediment samples collected near the NJ/NY water pollution control plants (WPCPs), especially down river, show metal contamination levels exceeding those of the sediment quality guidelines, established by NOAA (adopted by USEPA) since the early 1990's. The concentration of Ag measured in surficial bottom sediments exceeded the sediment quality guidelines threshold value at about 26% of the stations, especially at sites along the New Jersey shore. Pb and Cr were also elevated. An estimate of the degree of

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biological damage caused by trace metal concentrations measured in the bottom sediments sampled, with reference to the USEPA adopted sediment quality guidelines, however, cannot be made at this time, as it would require specific tests for bioassay toxicity.

In addition to current NJ/NY WPCPs as being the largest sources of trace metal contamination affecting both water and sediment quality in the study area, other potential sources of sediment contamination have been identified. A typical example is the contaminated wastes discharged by the once active General Motors factory located near the TZB, along the New York shore. Trace metal concentrations measured in surficial bottom sediment samples near this abandoned factory all show higher levels of Cd, Cr, Cu, Ni, Pb, Zn, and V as compared to those found in nearby sites.

The observed seasonal changes (from August 1997 to October 1998) in trace metal concentrations can be explained based on several factors such as: (1) the textural property of sediment samples arising from small-scale spatial variation in sediment characteristics, and thus variation in their metals concentrations, (2) seasonal changes in sediment organic carbon content that are sinks for metal accumulation, (3) changes in New York / New Jersey water pollution control plants effluent metal loadings discharged into the river, and (4) fall oxidation of the surficial sediment layer relative to summer reduction.

The distribution of metals in the surficial bottom sediment samples is found to be grain-size dependent as well. Analysis of one sediment sample (34A) for both the sediment size fraction greater and less than 250 micrometers indicated that trace metals

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are associated with the "fines," less than 250 micrometers. Furthermore, the results of grain-size analysis showed that bottom sediments along the New York shore contain, on average, 4x more sand than those along the New Jersey shore. The average sand content of sediment samples along the New York shore is about 28.58%, whereas the average sand along the New Jersey shoreline is about 6.45%. The observed grain-size distribution in the study area is a reflection of the physical processes (stronger or weaker flow of the current) in the transportation and deposition of suspended particles, which in turn, influenced the observed trace metal concentration in surficial bottom sediments from the study area. The similarity in metal contaminations along the New Jersey shore, on the hand, could be related to the dispersing action of the tidal currents, displacing particle associated contaminants along the shore.

The concentration of organic matter (%TOC), as sinks for metal accumulations in the study area, varies from 0.67% to 2.99%, and was found to be greater along the New Jersey shore as compared to those along the New York shore. Sediment grain-size and proximity to WPCPs were found to be accountable for the observed spatial variation in %TOC. The contribution of sewage-derived organic matter (as Cellulose and hemi-cellulose) was found to be also very high (R = 131 – 451) as compared to phytoplankton organic matter (R = 10), and it is even higher near the NJ/NY WPCPs.

Statistical analysis of metal contaminants data sets has further helped reveal the similarities in geochemical behavior of the studied trace metal contaminants. The results of bivariate analysis (Spearman-Rho non-parametric pairwise correlation) indicated good correlations, at 95% confidence limit, between Zn - Cr (0.90), Zn- Cu (0.90), Zn - Ag

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(0.81), Zn - Ni (0.82), Zn - Pb (0.80); Pb - Cu (0.86), Pb - Ag (0.77), Pb - Cr (0.76); Cu - Ag (0.92), Cu - Cr (0.89); Ni - %Fe (0.80), Ni - V (0.80); %Fe - V (0.79); %TOC - V (0.85), %TOC - %Fe (0.80), and %TOC - Ni (0.78).

A good number of stations, with metal values greater than those of the sediment quality guidelines, were also identified as being statistical outliers. The majority of these stations are located near the present location of WPCPs in the study area. Thus, they are subjected to higher amount of certain metal contaminations discharged from these facilities into the estuary. The statistical outliers, however, include stations with unusually high or low metal contents.

In the course of statistical analysis of my data sets, however, pretreatment of trace metals contaminants data to remove grain-size-related bias, was not successful, as the sediment samples were initially analyzed for environmentally available rather than total metals concentrations. Although such an approach gives a better estimate of the amount of surface adsorbed or complexed trace metals contaminants, it seems to be less effective in permitting differentiation between the point sources of contamination and transport-related behavior. As a result of that, Cluster Analysis, which is normally effective in subdividing the sediments into major groups, became a measure of sediment grouping based on sediment textural characteristics, rather than enhancing source-related spatial patterns and trends.

In summary, the NJ/NY WPCPs effluent metal loadings, the bottom sediment characteristics, and estuarine hydrodynamic processes are found to be accountable for the observed level of metal concentrations in surficial bottom sediments in the study area.

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Appendices

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Appendix A

Tidal Current Velocity and Direction Predictions Computed based on NOS publication "Tidal Current Tables – Atlantic Coast, 1997."

Site	Latitude (deg)	Longitude (deg)	Date/Time of Sampling (EST)	Cycle	Slack	Interval bet slack & sample time	Flow at sampling site & time (Chart method)	Current direction at sampling site
T20 C	41.2306	73.9700	8/13/97 13:25	Ebb	SBF	1:16	-0.72	158
T20 B	41.2306	73.9575	8/13/97 13:33	Ebb	SBF	1:08	-0.6	158
T20 A	41.2306	73.9458	8/13/97 13:41	Ebb	SBF	1:00	-0.6	158
T19 E	41.2167	73.9242	8/14/97 9:39	Ebb	SBE	0:36	-0.39	152
T19 D	41.2167	73.9375	8/14/97 9:28	Ebb	SBE	0:25	-0.13	152
T19 B	41.2167	73.9542	8/14/97 9:20	Ebb	SBE	0:17	-0.13	152
T19 A	41.2167	73.9611	8/14/97 9:10	Ebb	SBE	0:07	-0.13	152
T18 D	41.2000	73.9269	8/13/97 13:07	Ebb	SBF	1:29	-0.72	145
T18 C	41.2000	73.9375	8/13/97 12:56	Ebb	SBF	1:40	-0.96	145
T18 B	41.2000	73.9492	8/13/97 12:48	Ebb	SBF	1:48	-0.96	145
T18 A	41.2000	73.9553	8/13/97 12:39	Ebb	SBF	1:57	-1.08	145
T17 D	41.1833	73.9083	8/14/97 9:51	Ebb	SBE	0:57	-0.52	142
T17 C	41.1833	73.9200	8/14/97 10:02	Ebb	SBE	1:08	-0.52	142
T17 B	41.1833	73.9275	8/14/97 10:10	Ebb	SBE	1:16	-0.65	142
T17 A	41.1833	73.9458	8/14/97 10:19	Ebb	SBE	1:25	-0.65	142
T16 C	41.1667	73.9008	8/13/97 11:58	Ebb	SBF	2:33	-1.2	140
T16 B	41.1667	73.9158	8/13/97 12:09	Ebb	SBF	2:22	-1.08	140
T16 A	41.1667	73.9231	8/13/97 12:22	Ebb	SBF	2:09	-1.08	140
T15 C	41.1500	73.8825	8/14/97 10:47	Ebb	SBE	2:02	-1.12	148
T15 B	41.1500	73.8983	8/14/97 10:40	Ebb	SBE	1:55	-1.12	148
T15 A	41.1500	73.9094	8/14/97 10:32	Ebb	SBE	1:47	-0.98	148
T14 D	41.1333	73.8725	8/13/97 11:38	Ebb	SBF	2:47	-1.4	156
T14 C	41.1333	73.8867	8/13/97 11:31	Ebb	SBF	2:54	-1.4	156
T14 B	41.1333	73.8975	8/13/97 11:22	Ebb	SBE	3:40	-1.4	156
T14 A	41.1333	73.8975	8/13/97 11:13	Ebb	SBE	3:31	-1.4	156
T13 D	41.1167	73.8717	8/14/97 11:01	Ebb	SBE	2:25	-1.12	164
T13 C	41.1167	73.8833	8/14/97 11:08	Ebb	SBE	2:32	-1.26	164
T13 B	41.1167	73.8958	8/14/97 11:19	Ebb	SBE	2:43	-1.26	164
T13 A	41.1167	73.9042	8/14/97 11:29	Ebb	SBE	2:53	-1.4	164
T12 D	41.1000	73.8725	8/13/97 10:28	Ebb	SBE	2:56	-1.4	172
T12 C	41.1000	73.8833	8/13/97 10:41	Ebb	SBE	3:09	-1.4	172
T12 B	41.1000	73.9042	8/13/97 10:47	Ebb	SBE	3:15	-1.4	172
T12 A	41.1000	73.8942	8/13/97 10:54	Ebb	SBE	3:22	-1.4	172
T11 C	41.0750	73.8742	8/14/97 11:58	Ebb	SBE	3:49	-1.6	181
T11 B	41.0750	73.8825	8/14/97 11:47	Ebb	SBE	3:38	-1.6	181

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Site	Latitude (deg)	Longitude (deg)	Date/Time of Sampling (EST)	Cycle	Slack	Interval bet slack & sample time	Flow at sampling site & time (Chart method)	Current direction at sampling site
T11 A	41.0750	73.8967	8/14/97 11:39	Ebb	SBE	3:30	-1.6	181
T10 C	41.0667	73.8825	8/13/97 9:44	Ebb	SBE	2:20	-1.2	182
T10 B	41.0667	73.8900	8/13/97 9:27	Ebb	SBE	2:03	-1.2	182
T10 A	41.0667	73.8992	8/13/97 9:10	Ebb	SBE	1:46	-1.05	182
T9 D	41.0500	73.8733	8/14/97 12:14	Ebb	SBF	2:39	-1.6	185
T9 C	41.0500	73.8800	8/14/97 12:27	Ebb	SBF	2:26	-1.44	185
T9 B	41.0500	73.8883	8/14/97 12:34	Ebb	SBF	2:19	-1.44	185
T9 A	41.0500	73.9000	8/14/97 12:41	Ebb	SBF	2:12	-1.44	185
T8 C	41.0333	73.8775	8/12/97 15:26	Flood	SBF	2:25	1.3	12
T8 B	41.0333	73.8833	8/12/97 15:18	Flood	SBF	2:17	1.3	12
T8 A	41.0333	73.8942	8/12/97 15:11	Flood	SBF	2:10	1.3	12
T7 C	41.0167	73.8811	8/14/97 13:11	Ebb	SBF	1:25	-1.12	190
T7 B	41.0167	73.8875	8/14/97 13:02	Ebb	SBF	1:34	-1.28	190
T7 A	41.0167	73.8875	8/14/97 12:54	Ebb	SBF	1:42	-1.28	190
T6 C	41.0000	73.8867	8/12/97 14:48	Flood	SBF	2:01	1.26	10
T6 B	41.0000	73.8925	8/12/97 14:55	Flood	SBF	2:08	1.26	10
T6 A	41.0000	73.8992	8/12/97 15:02	Flood	SBF	2:15	1.26	10
T5 C	40.9833	73.8875	8/14/97 13:29	Ebb	SBF	0:55	-0.78	190
T5 B	40.9833	73.8942	8/14/97 13:39	Ebb	SBF	0:45	-0.52	190
T5 A	40.9833	73.9028	8/14/97 13:47	Ebb	SBF	0:37	-0.52	190
T4 C	40.9667	73.9008	8/12/97 14:33	Flood	SBF	1:58	1.26	9
T4 B	40.9667	73.8931	8/12/97 14:28	Flood	SBF	1:53	1.26	9
T4 A	40.9667	73.9078	8/12/97 14:17	Flood	SBF	1:42	1.12	9
T3 C	40.9500	73.9008	8/14/97 14:14	Flood	SBF	0:01	0.32	8
T3 B	40.9500	73.9042	8/14/97 14:05	Ebb	SBF	0:07	-0.26	190
T3 A	40.9500	73.9153	8/14/97 13:56	Ebb	SBF	0:16	-0.26	190
T2 C	40.9333	73.9064	8/12/97 13:50	Flood	SBF	1:27	0.84	8
T2 B	40.9333	73.9142	8/12/97 13:57	Flood	SBF	1:34	1.12	8
T2 A	40.9333	73.9208	8/12/97 14:03	Flood	SBF	1:40	1.12	8
T1 C	40.9167	73.9125	9/4/97 14:03	Ebb	SBE	0:36	-0.42	190
T1 B	40.9167	73.9192	9/4/97 13:53	Ebb	SBE	0:26	-0.28	190
T1 A	40.9167	73.9253	9/4/97 13:21	Flood	Next SBE	0:15	0.15	7
T22 C	40.9000	73.9175	8/12/97 13:37	Flood	SBF	0:37	0.52	15
T22 B	40.9000	73.9247	8/12/97 13:29	Flood	SBF	0:29	0.52	15
T22 A	40.9000	73.9322	8/12/97 13:20	Flood	SBF	0:20	0.26	15
T23 C	40.8833	73.9236	9/4/97 14:36	Ebb	SBE	1:27	-1.54	190
T23 B	40.8833	73.9303	9/4/97 14:25	Ebb	SBE	1:16	-1.1	190
T23 A	40.8833	73.9397	9/4/97 12:13	Flood	Next SBE	1:01	0.75	20
T24 C	40.8667	73.9347	8/12/97 12:53	Flood	SBF	0:07	0.28	20
T24 B	40.8667	73.9425	8/12/97 13:00	Flood	SBF	0:14	0.56	20
T24 A	40.8667	73.9492	8/12/97 13:10	Flood	SBF	0:24	0.56	20

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Site	Latitude (deg)	Longitude (deg)	Date/Time of Sampling (EST)	Cycle	Slack	Interval bet slack & sample time	Flow at sampling site & time (Chart method)	Current direction at sampling site
T25 C	40.8500	73.9342	9/4/97 11:46	Flood	Next SBE	1:23	0.9	20
T25 B	40.8500	73.9539	9/4/97 11:37	Flood	Next SBE	1:32	1.05	20
T25 A	40.8500	73.9583	9/4/97 11:17	Flood	Next SBE	1:52	1.2	20
T26 C	40.8333	73.9525	8/12/97 12:10	Ebb	SBF	0:05	-0.28	205
T26 B	40.8333	73.9539	8/12/97 12:30	Flood	SBF	0:14	0.32	22
T26 A	40.8333	73.9669	8/12/97 12:38	Flood	SBF	0:22	0.32	22
T27 C	40.8167	73.9656	9/4/97 10:24	Flood	Next SBE	2:38	1.36	24
T27 B	40.8167	73.9700	9/4/97 10:33	Flood	Next SBE	2:29	1.19	24
T27 A	40.8167	73.9761	9/4/97 10:44	Flood	Next SBE	2:18	1.19	24
T28 C	40.8000	73.9772	8/12/97 11:56	Ebb	SBF	0:00	0	209
T28 B	40.8000	73.9839	8/12/97 11:49	Ebb	SBF	0:07	0	209
T28 A	40.8000	73.9900	8/12/97 11:41	Ebb	SBF	0:15	-0.33	209
T29 C	40.7833	73.9883	9/4/97 9:41	Flood	Next SBE	3:13	1.4	20
T29 B	40.7833	73.9953	9/4/97 9:51	Flood	Next SBE	3:03	1.4	20
T29 A	40.7833	73.9989	9/4/97 9:59	Flood	Next SBE	2:55	1.4	20
T30 B	40.7667	74.0036	8/12/97 11:25	Ebb	SBF	0:24	-0.33	205
T30 A	40.7667	74.0125	8/12/97 11:10	Ebb	SBF	0:39	-0.55	205
T31 B	40.7500	74.0128	9/4/97 9:16	Flood	SBF	2:39	1.4	15
T31 A	40.7500	74.0200	9/4/97 9:06	Flood	SBF	2:29	1.4	15
T32 B	40.7333	74.0153	8/12/97 10:30	Ebb	SBF	1:13	-1.1	202
T32 A	40.7333	74.0239	8/12/97 10:44	Ebb	SBF	0:59	-0.77	202
T33 C	40.7167	74.0183	9/4/97 16:08	Ebb	SBE	3:32	-1.4	200
T33 B	40.7167	74.0233	9/4/97 15:54	Ebb	SBE	3:18	-1.4	200
T33 A	40.7167	74.0292	9/4/97 15:36	Ebb	SBE	3:00	-1.26	200
T34 C	40.7019	74.0011	8/12/97 10:14	Ebb	SBF	1:37	-1.28	201
T34 B	40.7019	74.0267	8/12/97 10:00	Ebb	SBF	1:51	-1.44	201
T34 A	40.7019	74.0325	8/12/97 9:20	Ebb	SBF	2:31	-1.6	201

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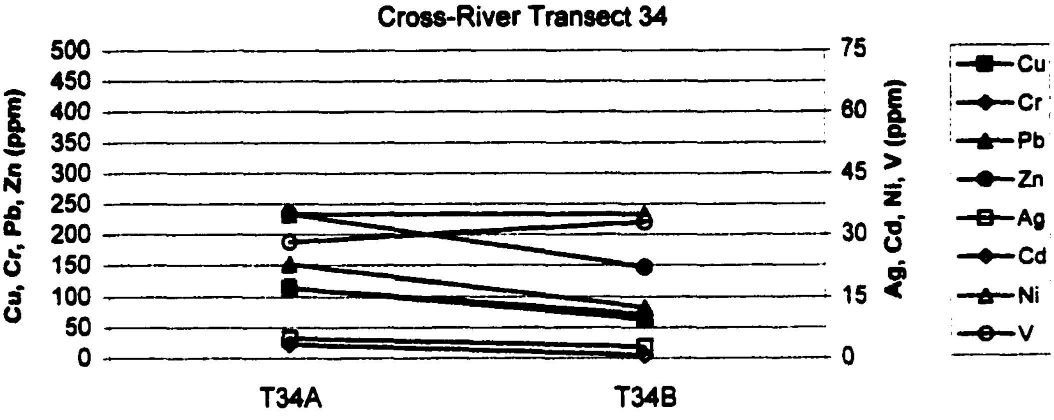
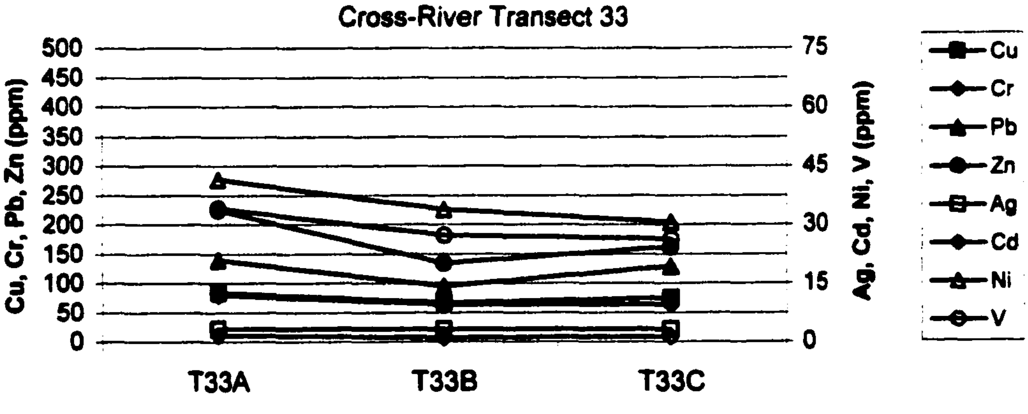
Appendix B

Cross-River Transects Showing Trace Metal Concentrations. A (NJ), B (Mid –River), C, D, E (NY)





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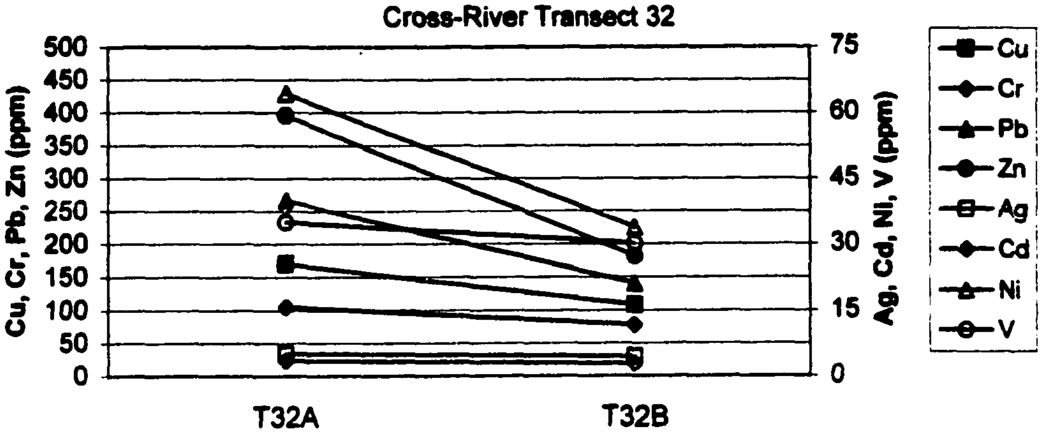

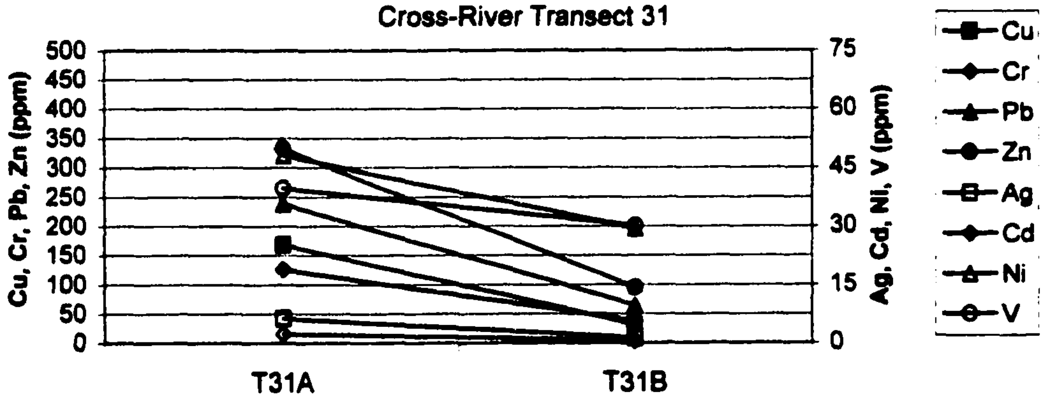

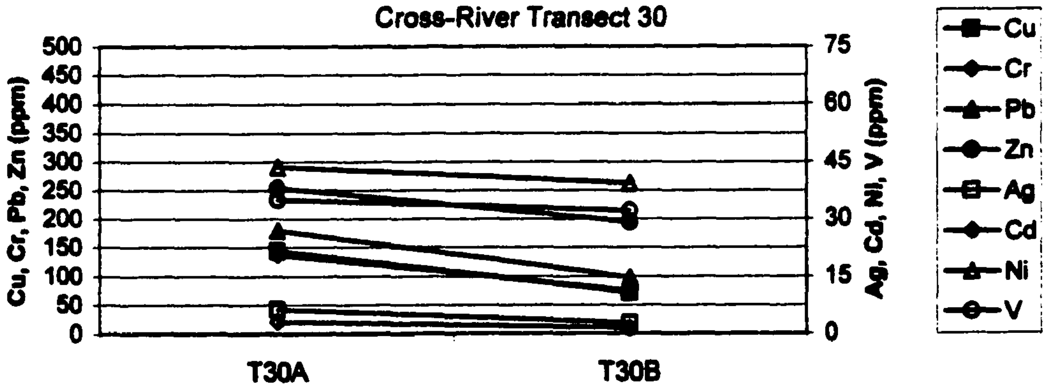

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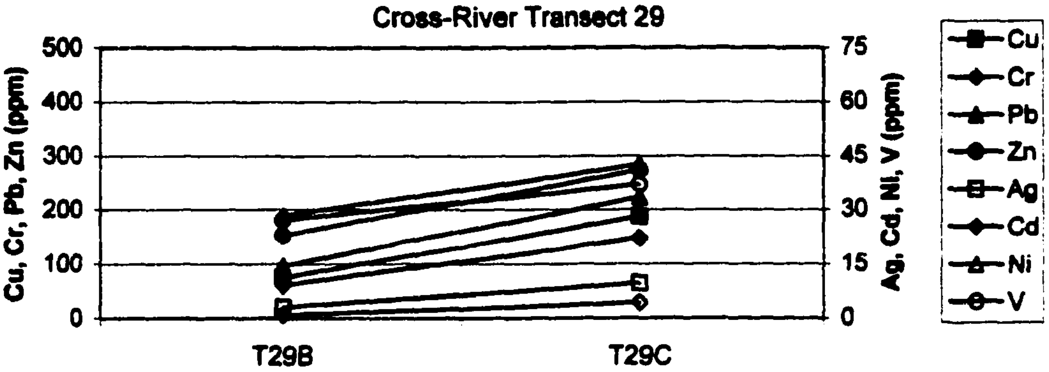

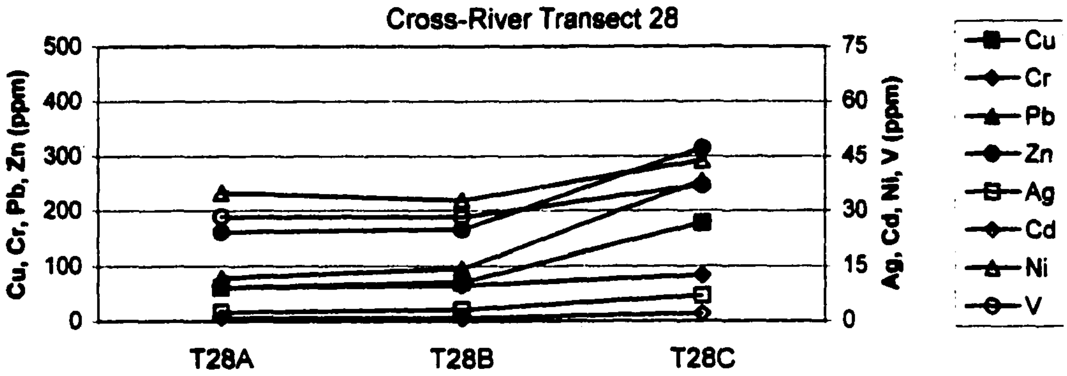

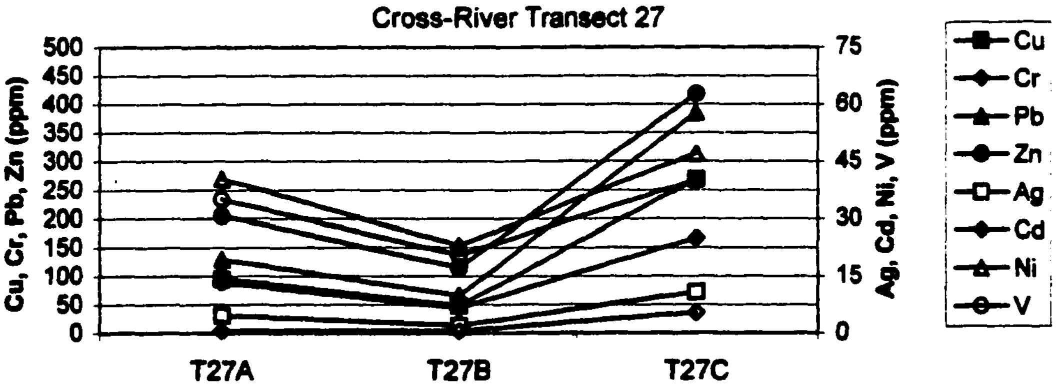

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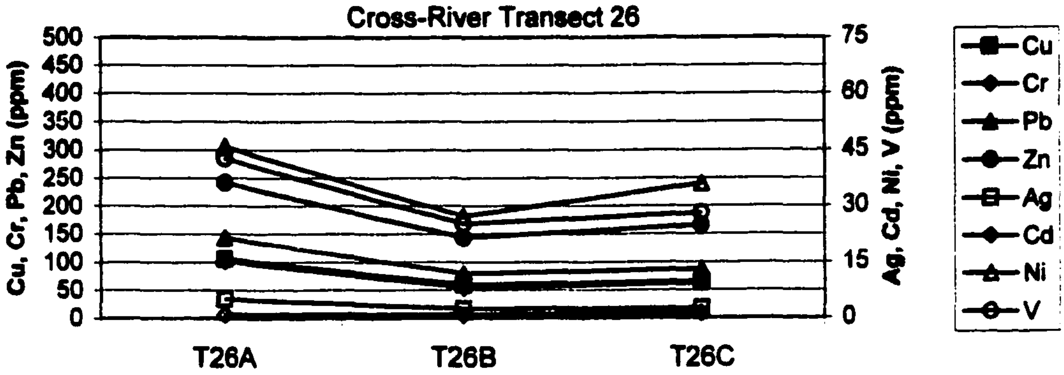

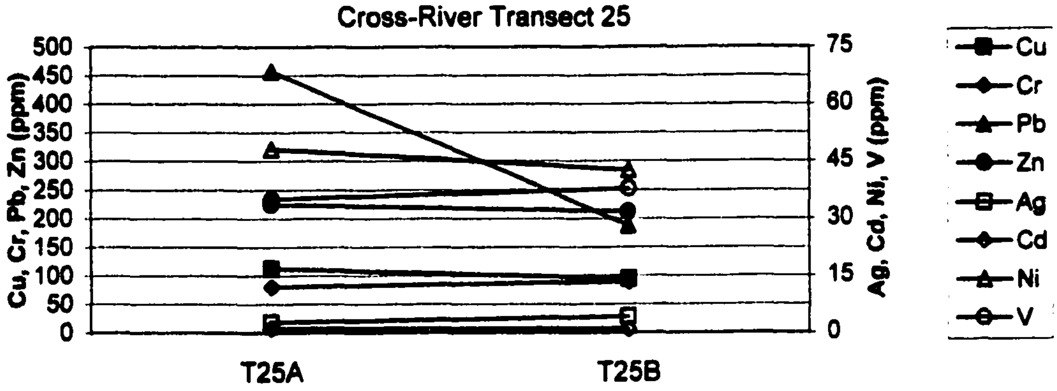

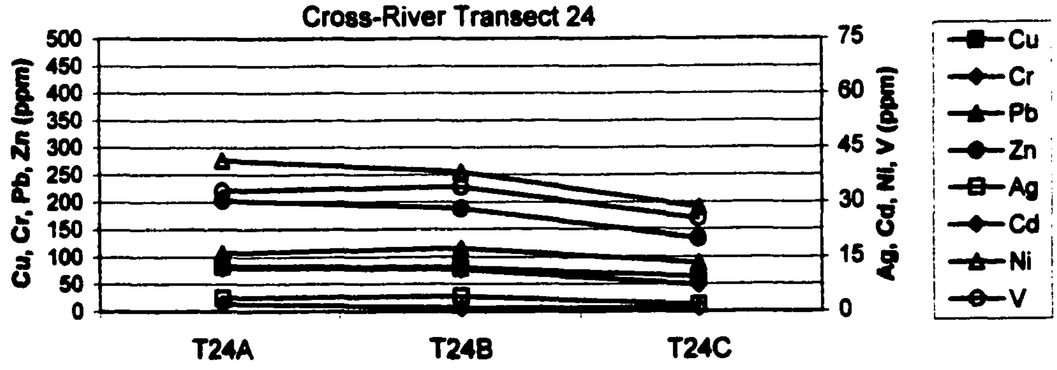

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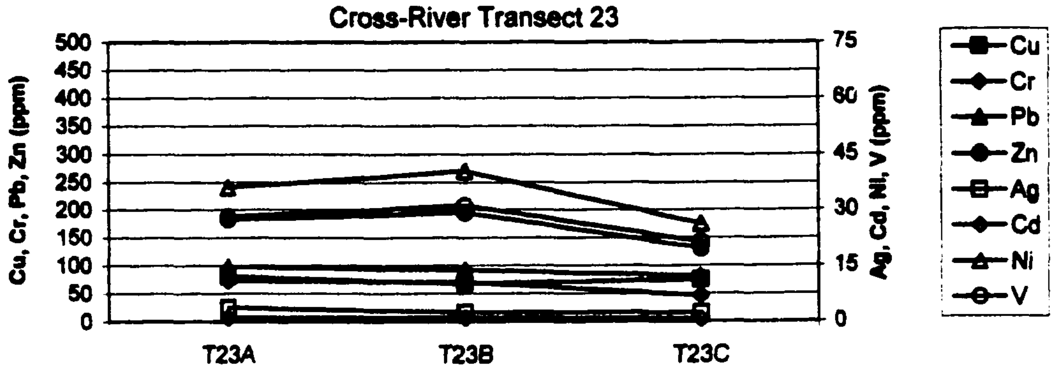

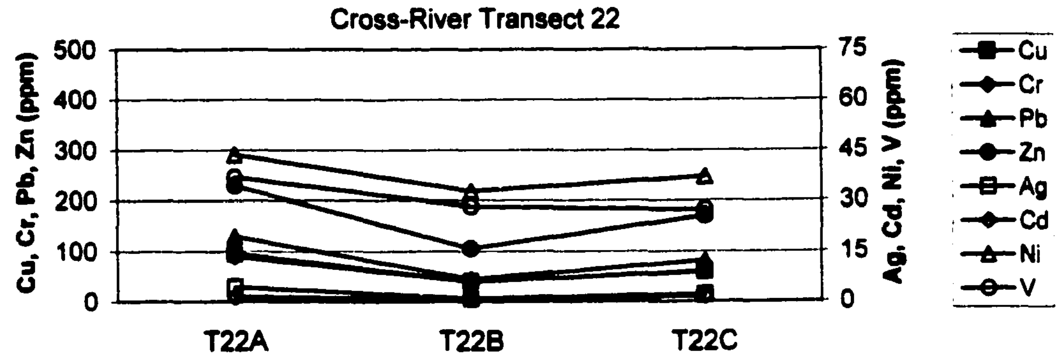

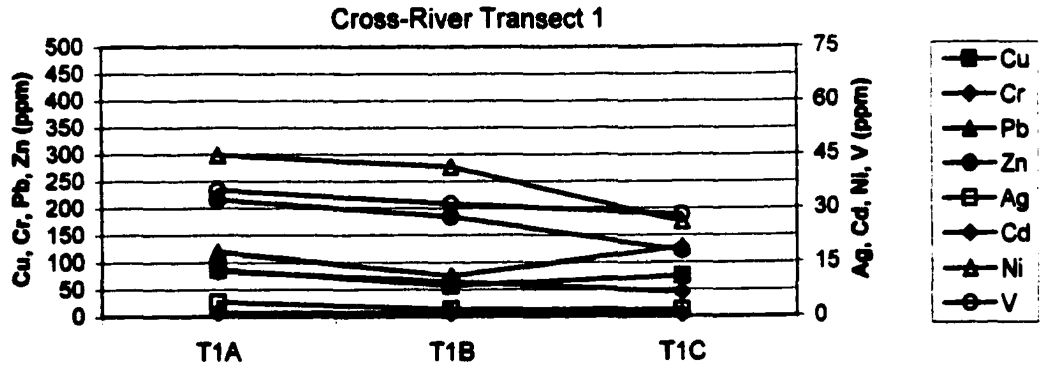

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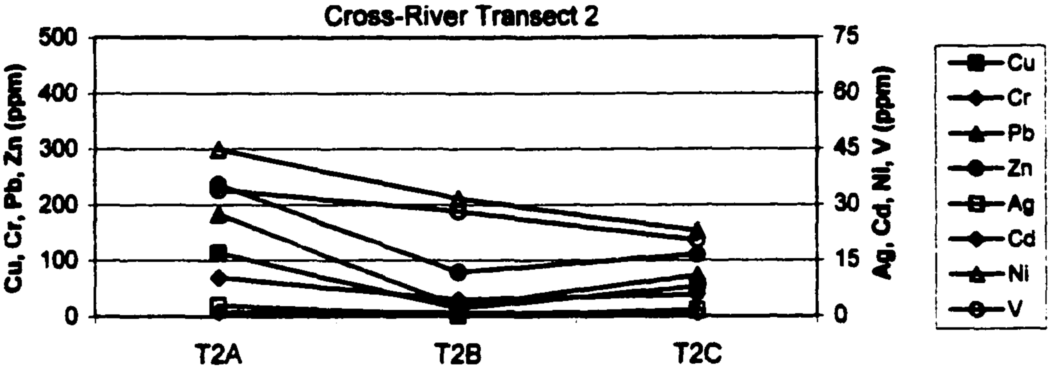
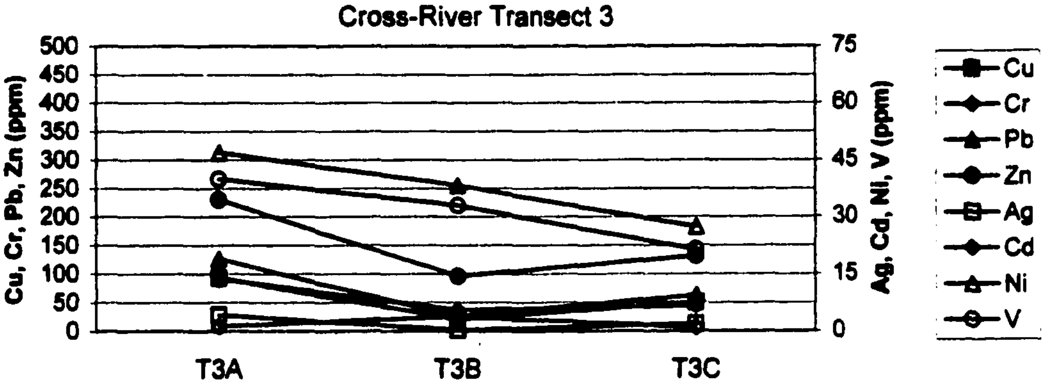
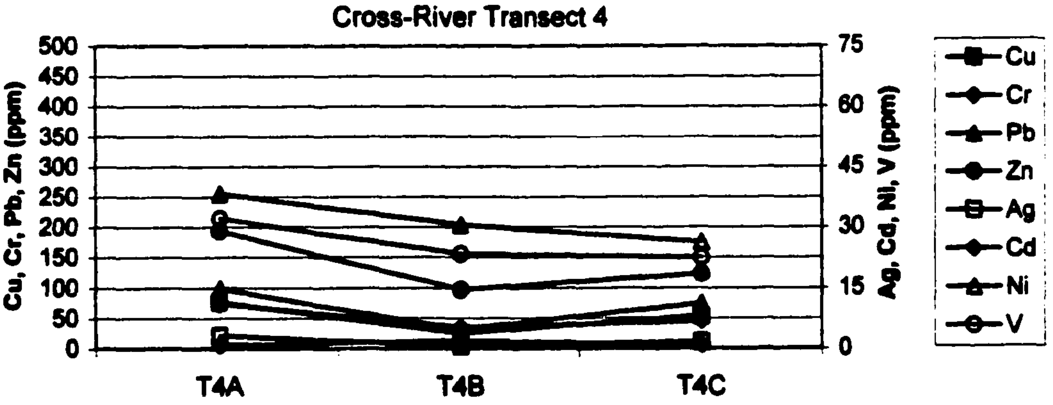


Cross-River Transect 2



Cross-River Transect 3



Cross-River Transect 4

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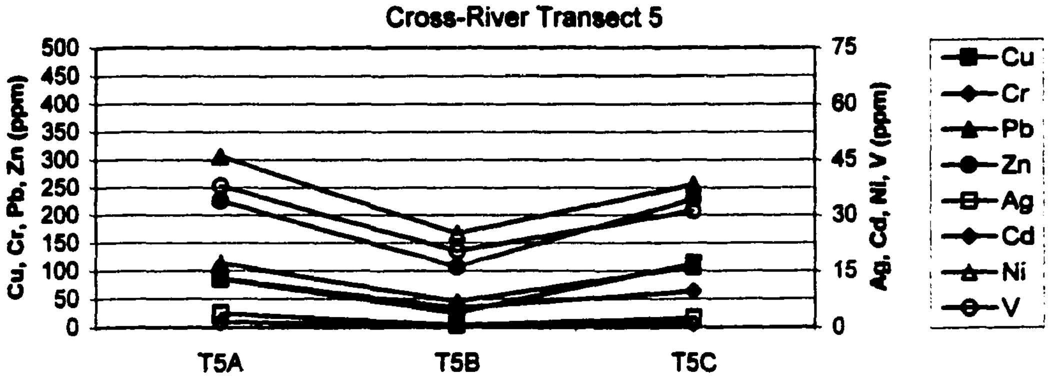

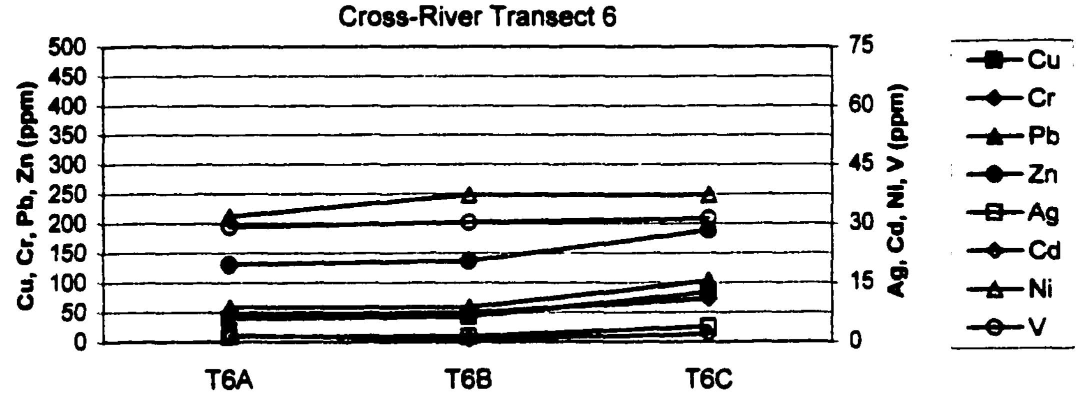

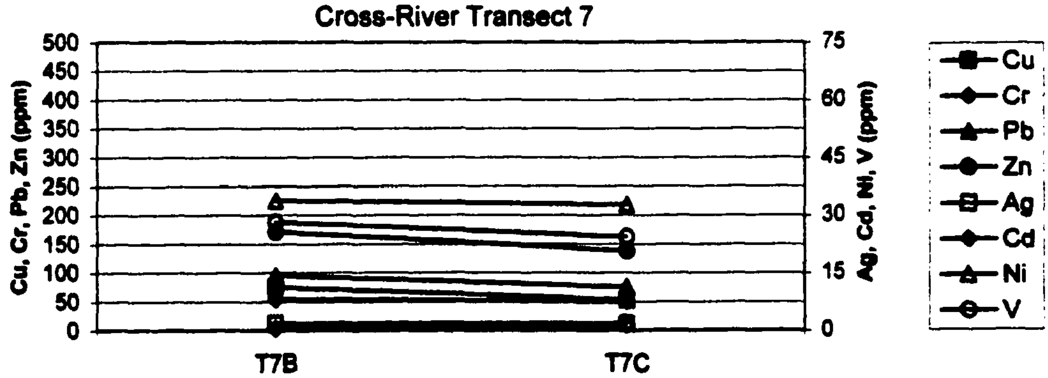

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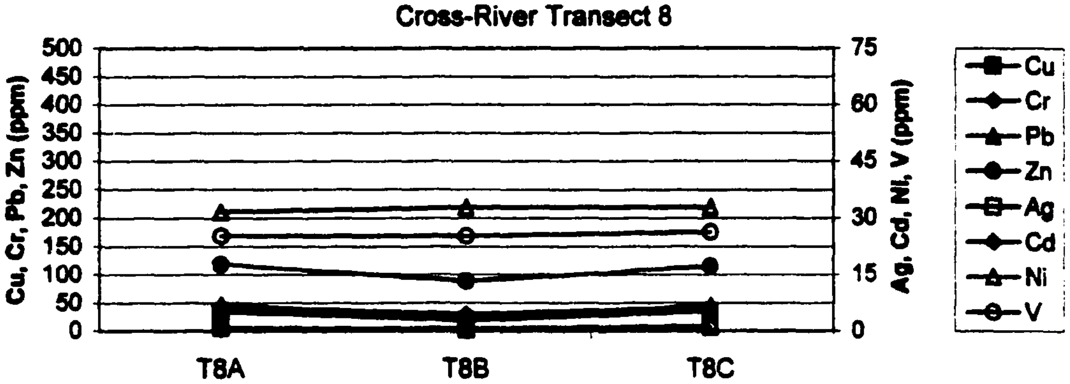

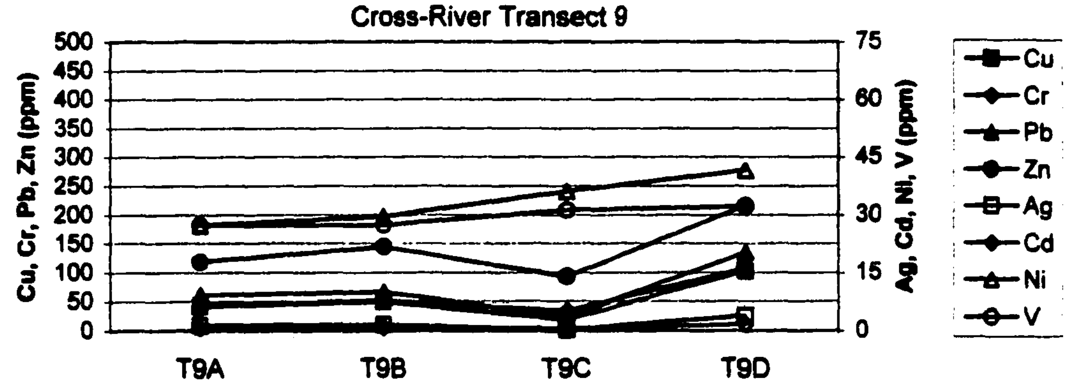

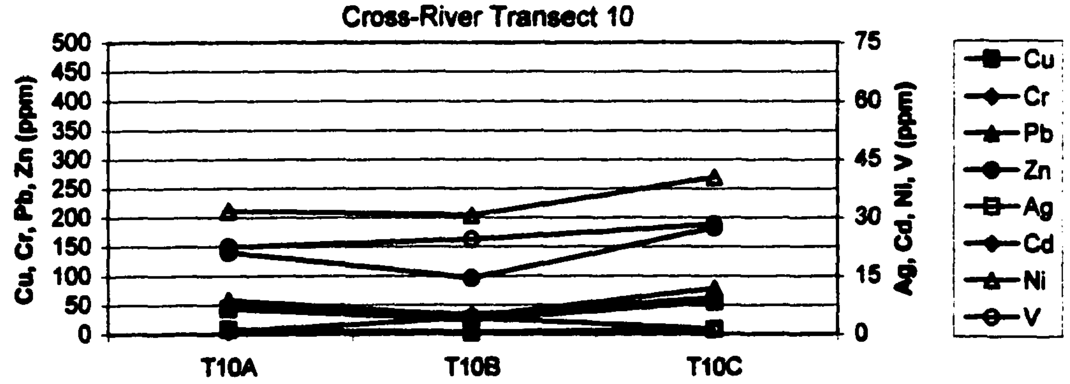

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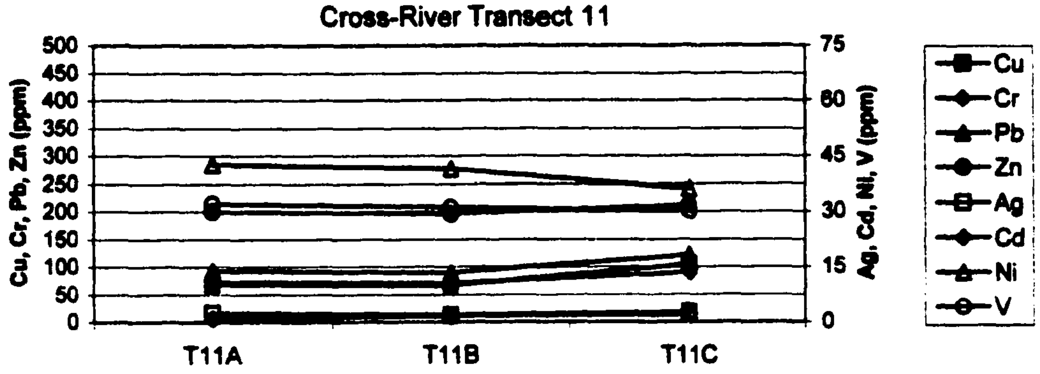

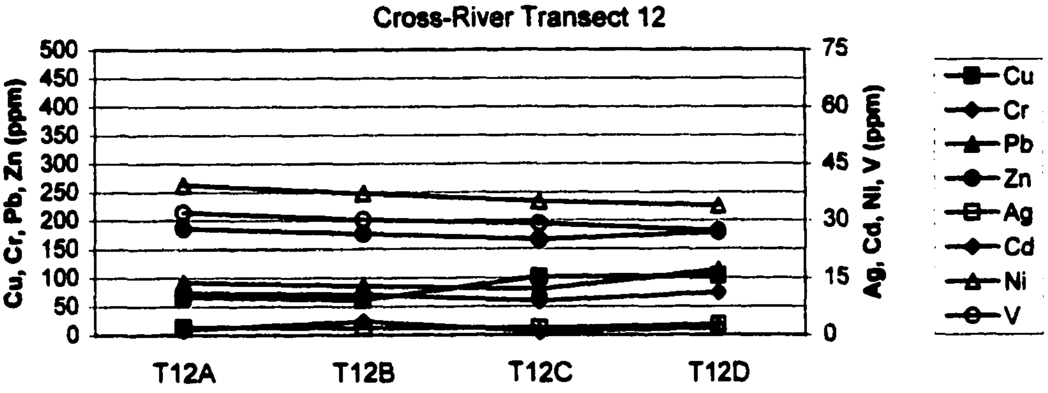

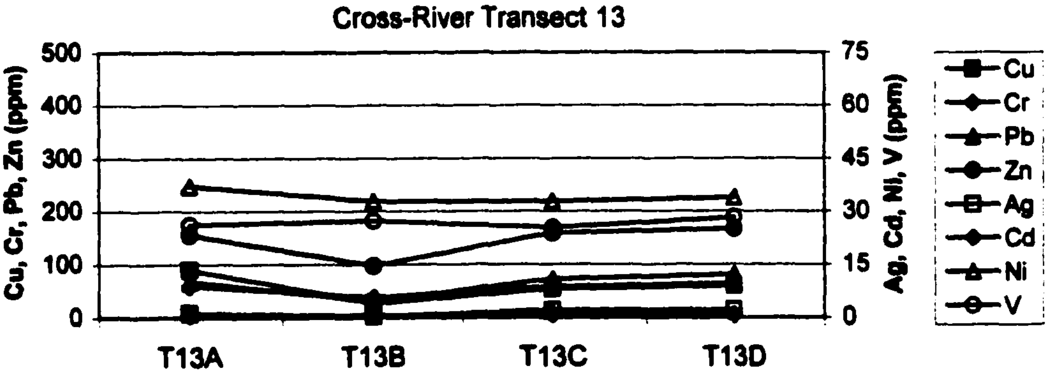

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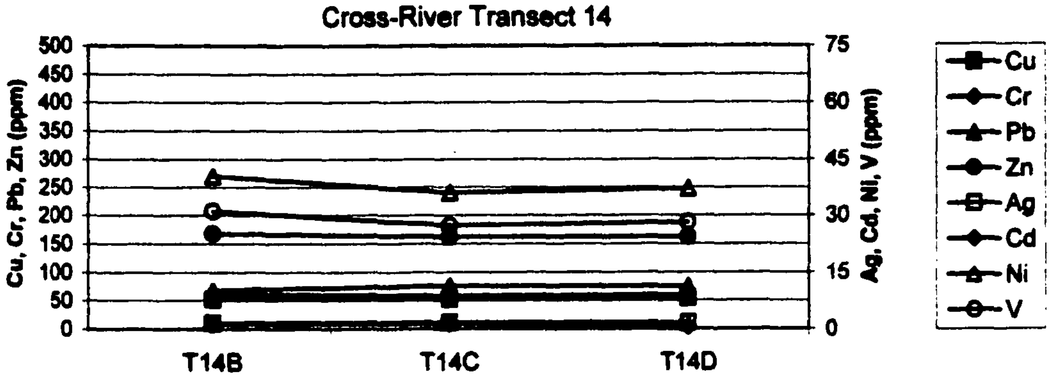

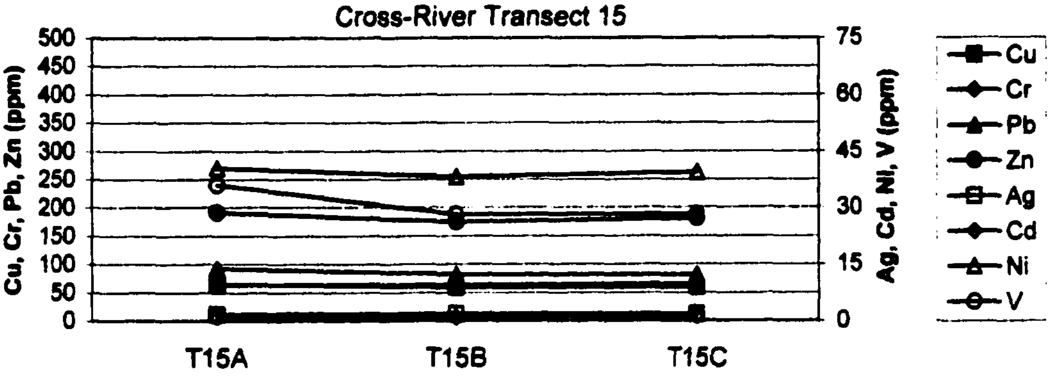

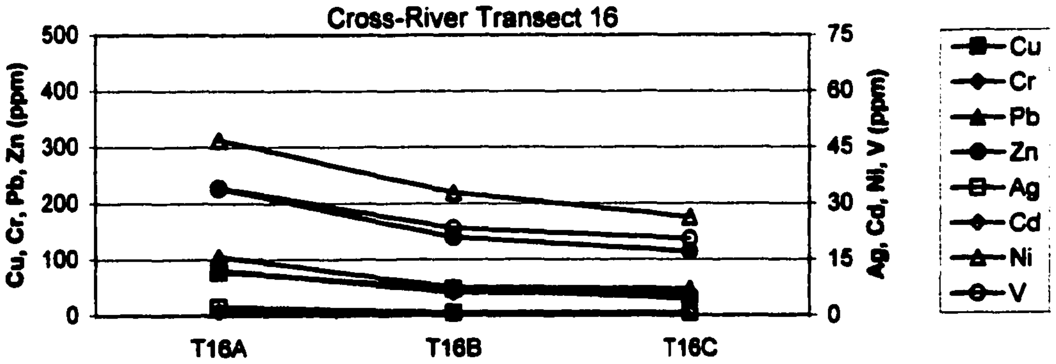

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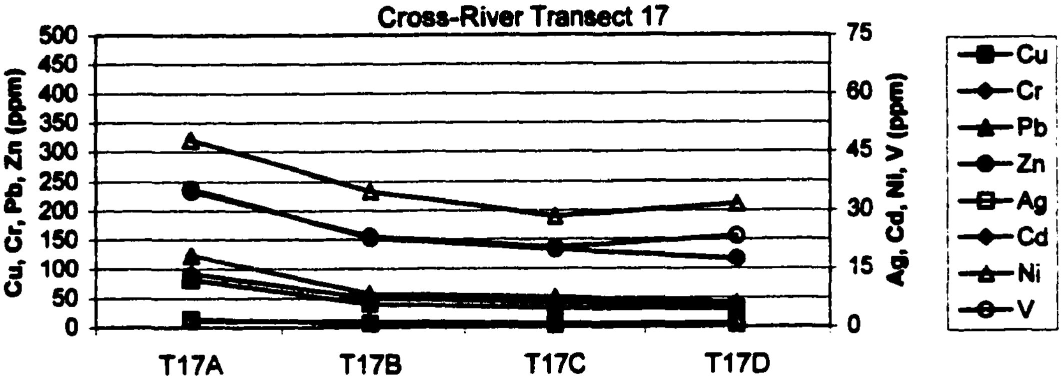

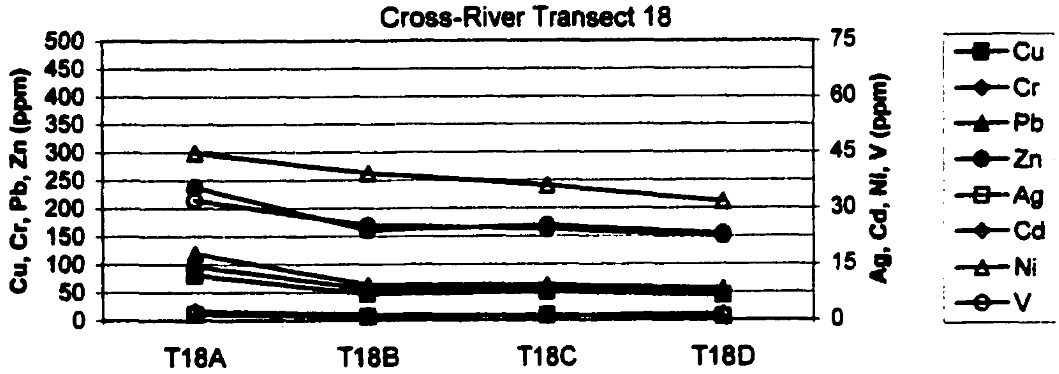

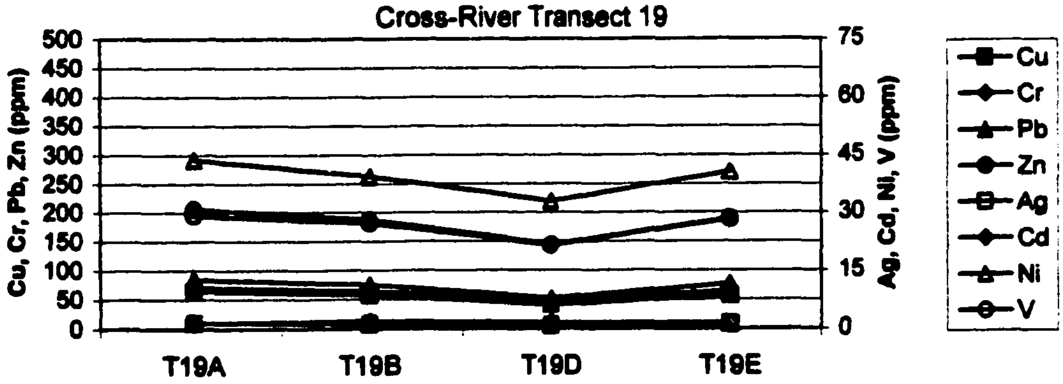

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Appendix C

Percentage TCH values in Selected Surficial Bottom Sediment. August - September 1997

Sites	Ref	Abs(C - PhC)	AbsA - AbsB	Abs Sample (Y)	TCH ug/2 ml (x)	Sed. (gr)	TCH ug/ gr sediment	TCH mg/g sediment	% TCH	%TOC	R
18A	Ph-C	0.038	1.116	1.078	266	0.5770	4614	4.6	0.461	1.74	265
17A	Ph-C	0.037	1.715	1.678	424	0.4601	9218	9.2	0.922	2.18	423
16A	Ph-C	0.023	1.518	1.496	376	0.3835	9809	9.8	0.981	2.63	373
16C	Ph-C	0.029	0.983	0.954	234	0.9140	2556	2.6	0.256	1.09	235
13A	Ph-C	0.053	0.838	0.785	189	0.7674	2466	2.5	0.247	1.30	190
11C	Ph-C	0.054	1.228	1.174	292	0.6561	4443	4.4	0.444	1.52	292
10B	Ph-C	0.045	0.890	0.845	205	0.6447	3177	3.2	0.318	1.55	205
9D	Ph-C	0.040	0.937	0.898	219	0.5965	3668	3.7	0.367	1.67	220
6C	Ph-C	0.025	0.953	0.928	227	0.5066	4478	4.5	0.448	1.99	225
5A	Ph-C	0.023	1.343	1.320	330	0.3807	8669	8.7	0.867	2.60	333
3A	Ph-C	0.019	1.082	1.062	262	0.3512	7465	7.5	0.747	2.84	263
2B	Ph-C	0.036	1.163	1.127	279	0.6470	4316	4.3	0.432	1.55	278
1A	Ph-C	0.030	1.121	1.091	270	0.4009	6727	6.7	0.673	2.49	270
22A	Ph-C	0.011	1.405	1.395	350	0.3834	9119	9.1	0.912	2.61	349
23A	Ph-C	0.026	1.421	1.395	350	0.5449	6415	6.4	0.642	1.82	352
23B	Ph-C	0.026	1.163	1.137	282	0.4420	6378	6.4	0.638	2.26	282
23C	Ph-C	0.027	0.972	0.946	231	0.5641	4102	4.1	0.410	1.76	233
24B	Ph-C	0.018	1.797	1.779	451	0.4928	9146	9.1	0.915	2.03	451
25A	Ph-C	0.022	1.748	1.726	437	0.5049	8650	8.6	0.865	2.00	432
25B	Ph-C	0.025	1.481	1.456	366	0.4174	8764	8.8	0.876	2.39	367
26A	Ph-C	0.030	1.602	1.572	396	0.3352	11819	11.8	1.182	2.99	395
27A	Ph-C	0.029	1.483	1.454	365	0.3580	10199	10.2	1.020	2.80	364
27C	Ph-C	0.001	1.024	1.023	252	0.3440	7323	7.3	0.732	2.93	250
28C	Ph-C	0.040	0.604	0.564	131	0.3954	3312	3.3	0.331	2.53	131
29C	Ph-C	0.012	1.041	1.029	253	0.5362	4726	4.7	0.473	1.90	249
30A	Ph-C	0.013	0.749	0.736	176	0.4182	4215	4.2	0.422	2.39	176
31A	Ph-C	0.016	1.752	1.736	439	0.3615	12156	12.2	1.216	2.78	437
31B	Ph-C	0.014	1.550	1.536	387	0.8056	4800	4.8	0.480	1.24	387
32B	Ph-C	0.024	1.472	1.449	364	0.6064	6000	6.0	0.600	1.64	366
34A	Ph-C	0.010	1.152	1.141	283	0.6560	4313	4.3	0.431	1.52	284

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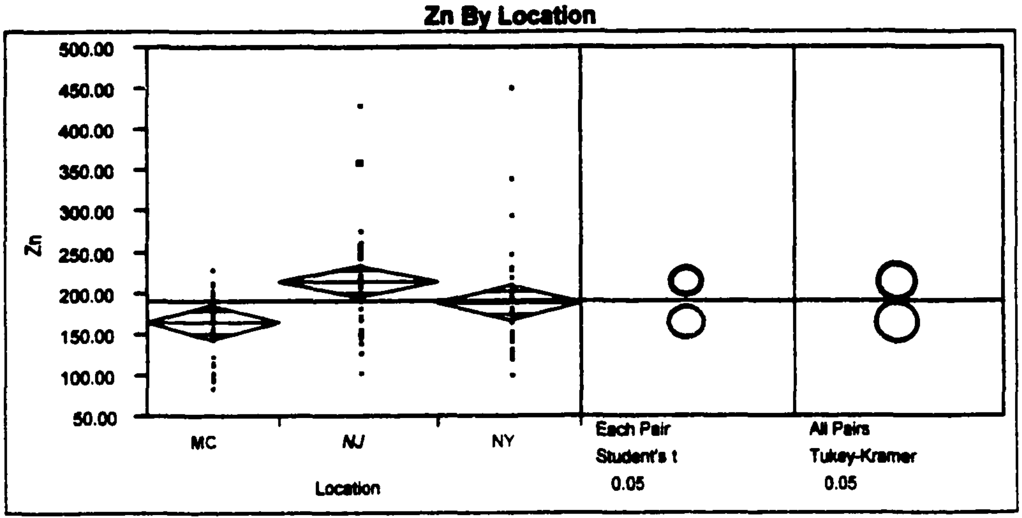
Appendix D

The Results of One-Way ANOVA Analysis of Metal Data on NJ (New Jersey), MC (Mid-river), and NY (New York) Longitudinal River Sections



```
                    Analysis of Variance
Source          DF        Sum of Squares      Mean Square        F Ratio
Model            2              43846.64          21923.3         5.7727
Error           95             360784.70           3797.7         Prob>F
C Total         97             404631.34           4171.5         0.0043
                    Means for Oneway Anova
          Level          Number        Mean       Std Error
          MC                 30     163.719          11.251
          NJ                 36     215.399          10.271
          NY                 32     189.337          10.894
          Comparisons for each pair using Student's t
                         T = 1.98526
      Abs(Dif)-LSD                   NJ            NY            MC
      NJ                       -28.8366       -3.6630       21.4359
      NY                        -3.6630      -30.5858       -5.4726
      MC                        21.4359       -5.4726      -31.5889

      Positive values show pairs of means that are significantly different.
         Comparisons for all pairs using Tukey-Kramer HSD
                         q*= 2.38102
      Abs(Dif)-LSD                   NJ            NY            MC
      NJ                       -34.5851       -9.5884       15.4068
      NY                        -9.5884      -36.6830      -11.6706
      MC                        15.4068      -11.6706      -37.8861

      Positive values show pairs of means that are significantly different.
            Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level            Count      Score Sum      Score Mean        (Mean-Mean0)/Std0
MC                  30           1135         37.8333                   -2.694
NJ                  36           2240         62.2222                    3.372
NY                  32           1476         46.1250                   -0.814

1-way Test, Chi-Square Approximation
                     ChiSquare          DF        Prob>ChiSq
                       12.7105           2            0.0017
```

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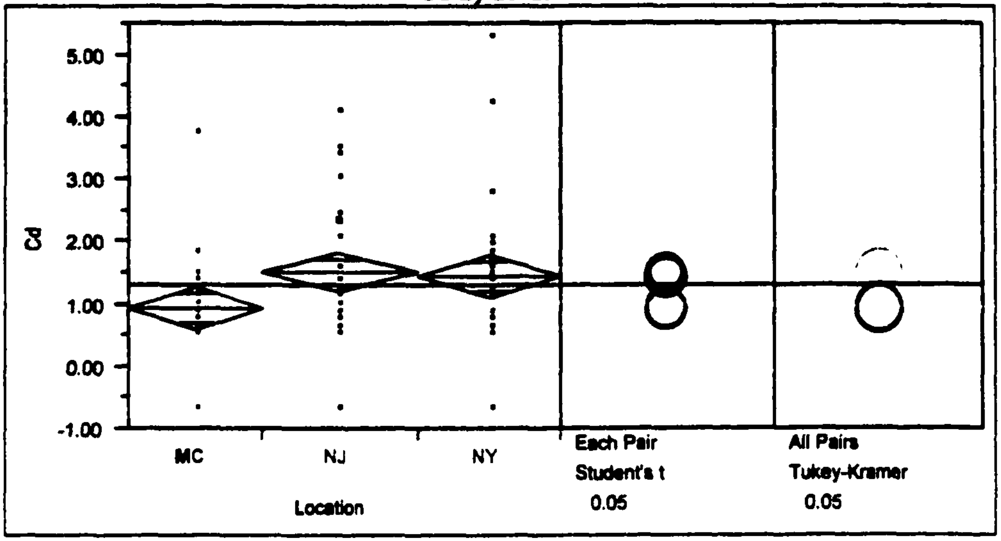

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	6.32315	3.16158	3.0974
Error	95	96.96876	1.02072	Prob>F
C Total	97	103.29191	1.06487	0.0498

Means Comparisons

Dif=Mean[i]-Mean[j]	NJ	NY	MC
NJ	0.000000	0.040660	0.569056
NY	-0.04066	0.000000	0.528396
MC	-0.56906	-0.5284	0.000000

Alpha = 0.05

Comparisons for each pair using Student's t

T = 1.98526

Abs(Dif)-LSD	NJ	NY	MC
NJ	-0.47275	-0.44664	0.073226
NY	-0.44664	-0.50143	0.018675
MC	0.073226	0.018675	-0.51788

Positive values show pairs of means that are significantly different.

Comparisons for all pairs using Tukey-Kramer HSD

q*= 2.38102

Abs(Dif)-LSD	NJ	NY	MC
NJ	-0.567	-0.54379	-0.02562
NY	-0.54379	-0.60139	-0.08294
MC	-0.02562	-0.08294	-0.62111

Positive values show pairs of means that are significantly different.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
MC	30	1136	37.8667	-2.694
NJ	36	2022	56.1667	1.770
NY	32	1693	52.9063	0.824

1-way Test, Chi-Square Approximation

ChiSquare	DF	Prob>ChiSq
7.5021	2	0.0235

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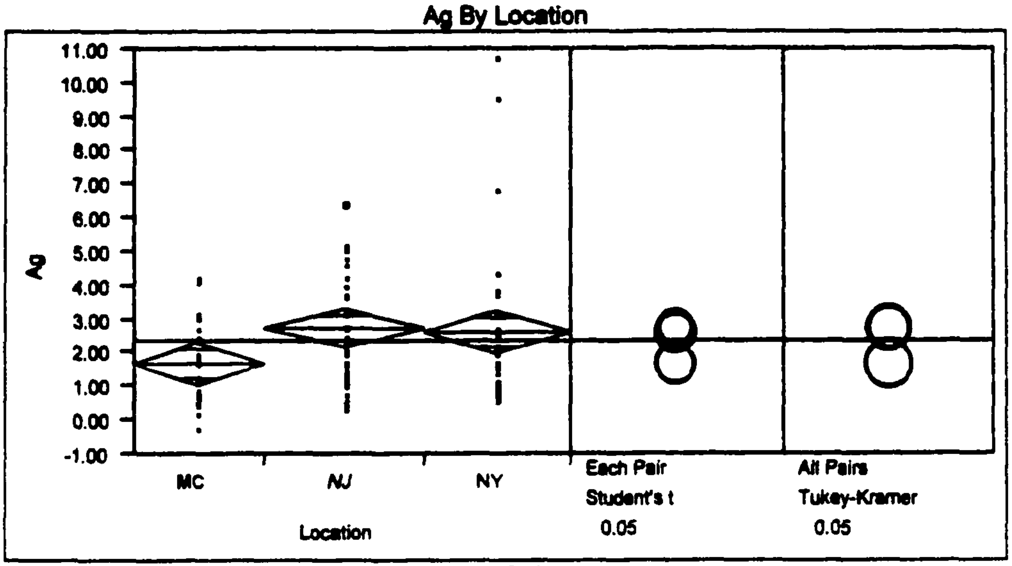

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                    Analysis of Variance
Source           DF      Sum of Squares        Mean Square      F Ratio
Model             2            21.54738            10.7737       3.2798
Error            95           312.06310             3.2849       Prob>F
C Total          97           333.61048             3.4393       0.0419
                    Means for Oneway Anova
            Level       Number        Mean      Std Error
            MC              30     1.66167        0.33090
            NJ              36     2.72944        0.30207
            NY              32     2.61031        0.32039
            Std Error uses a pooled estimate of error variance
                    Means Comparisons
     Dif=Mean[i]-Mean[j]              NJ            NY            MC
     NJ                          0.00000       0.11913       1.06778
     NY                         -0.11913       0.00000       0.94865
     MC                         -1.06778      -0.94865       0.00000

     Alpha=                         0.05
          Comparisons for each pair using Student's t
                        T = 1.98526
       Abs(Dif)-LSD                NJ            NY            MC
       NJ                    -0.84809      -0.75506      0.178295
       NY                    -0.75506      -0.89953      0.034243
       MC                    0.178295      0.034243      -0.92903

       Positive values show pairs of means that are significantly different.
        Comparisons for all pairs using Tukey-Kramer HSD
                        q*= 2.38102
       Abs(Dif)-LSD                NJ            NY            MC
       NJ                    -1.01715      -0.92933       0.00098
       NY                    -0.92933      -1.07885      -0.14804
       MC                     0.00098      -0.14804      -1.11424

       Positive values show pairs of means that are significantly different.
          Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level         Count      Score Sum      Score Mean            (Mean-Mean0)/Std0
MC               30           1192         39.7333                       -2.256
NJ               36         2047.5         56.8750                        1.954
NY               32         1611.5         50.3594                        0.205

1-way Test, Chi-Square Approximation
                    ChiSquare          DF       Prob>ChiSq
                       5.9982           2           0.0498
```

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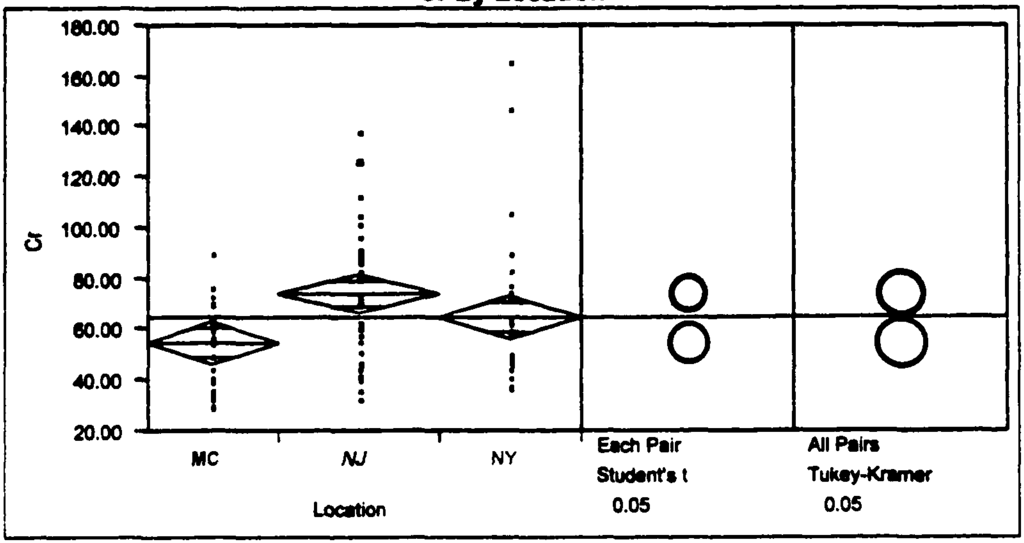

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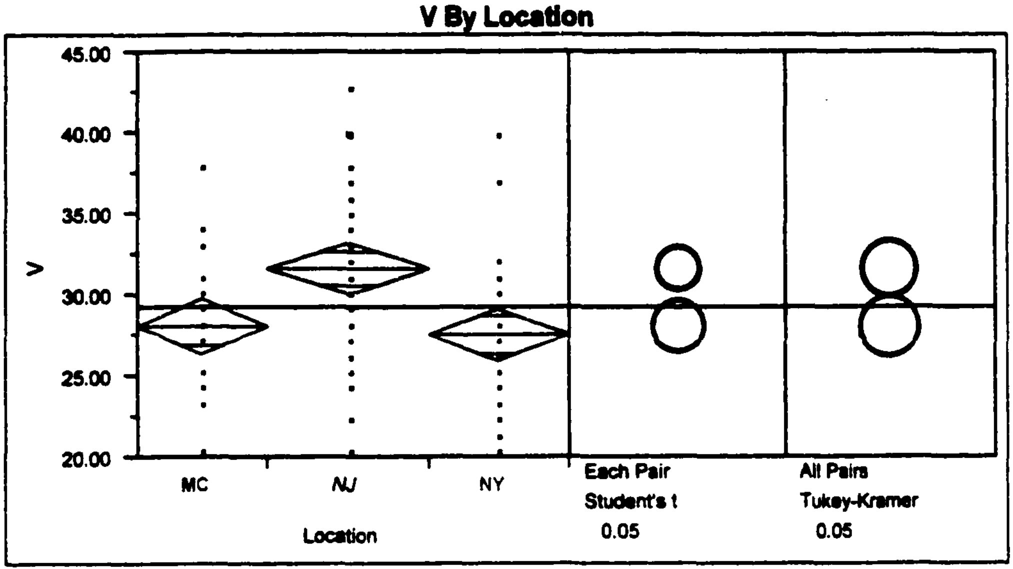
                         Analysis of Variance
Source          DF        Sum of Squares       Mean Square        F Ratio
Model            2              6171.197           3085.60         5.3269
Error           95             55029.021            579.25         Prob>F
C Total         97             61200.217            630.93         0.0064
                      Means for Oneway Anova
              Level       Number          Mean      Std Error
              MC              30       55.1617         4.3941
              NJ              36       74.5531         4.0113
              NY              32       64.8238         4.2546
              Std Error uses a pooled estimate of error variance
                         Means Comparisons
Dif=Mean[i]-Mean[j]                 NJ             NY             MC
NJ                              0.0000         9.7293        19.3914
NY                             -9.7293         0.0000         9.6621
MC                            -19.3914        -9.6621         0.0000
Alpha=                            0.05
            Comparisons for each pair using Student's t
                            T = 1.98526
Abs(Dif)-LSD                    NJ             NY             MC
NJ                        -11.2620        -1.8793         7.5797
NY                         -1.8793       -11.9452        -2.4805
MC                          7.5797        -2.4805       -12.3369

Positive values show pairs of means that are significantly different.
   Comparisons for all pairs using Tukey-Kramer HSD
                          q*= 2.38102
Abs(Dif)-LSD                    NJ             NY             MC
NJ                        -13.5071        -4.1935         5.2251
NY                         -4.1935       -14.3264        -4.9011
MC                          5.2251        -4.9011       -14.7962

Positive values show pairs of means that are significantly different.
          Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level        Count       Score Sum       Score Mean       (Mean-Mean0)/Std0
MC              30          1140.5          38.0167                  -2.653
NJ              36          2219.5          61.6528                   3.222
NY              32            1491          46.5938                  -0.701

1-way Test, Chi-Square Approximation
                    ChiSquare          DF         Prob>ChiSq
                      11.8135           2             0.0027
```



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                    Analysis of Variance
Source          DF       Sum of Squares       Mean Square        F Ratio
Model            2             334.0222           167.011         7.3245
Error           95            2166.1547            22.802         Prob>F
C Total         97            2500.1769            25.775         0.0011
                  Means for Oneway Anova
            Level       Number          Mean      Std Error
            MC              30       28.0790        0.87181
            NJ              36       31.6247        0.79585
            NY              32       27.5731        0.84413
            Std Error uses a pooled estimate of error variance
                      Means Comparisons
   Dif=Mean[i]-Mean[j]                NJ             MC             NY
   NJ                            0.00000        3.54572        4.05160
   MC                           -3.54572        0.00000        0.50588
   NY                           -4.05160       -0.50588        0.00000

   Alpha=                           0.05
          Comparisons for each pair using Student's t
                       T = 1.98526
     Abs(Dif)-LSD                   NJ             MC             NY
     NJ                       -2.23442        1.20224        1.74841
     MC                        1.20224       -2.44768       -1.90326
     NY                        1.74841       -1.90326       -2.36996

     Positive values show pairs of means that are significantly different.
      Comparisons for all pairs using Tukey-Kramer HSD
                       q*= 2.38102
     Abs(Dif)-LSD                   NJ             MC             NY
     NJ                       -2.67985        0.73508        1.28928
     MC                        0.73508       -2.93562       -2.38352
     NY                        1.28928       -2.38352       -2.84241

     Positive values show pairs of means that are significantly different.
         Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level          Count       Score Sum       Score Mean          (Mean-Mean0)/Std0
MC                30            1299          43.3000                     -1.434
NJ                36          2255.5          62.6528                      3.497
NY                32          1296.5          40.5156                     -2.181
1-way Test, Chi-Square Approximation
                       ChiSquare         DF        Prob>ChiSq
                         12.4026          2            0.0020
```

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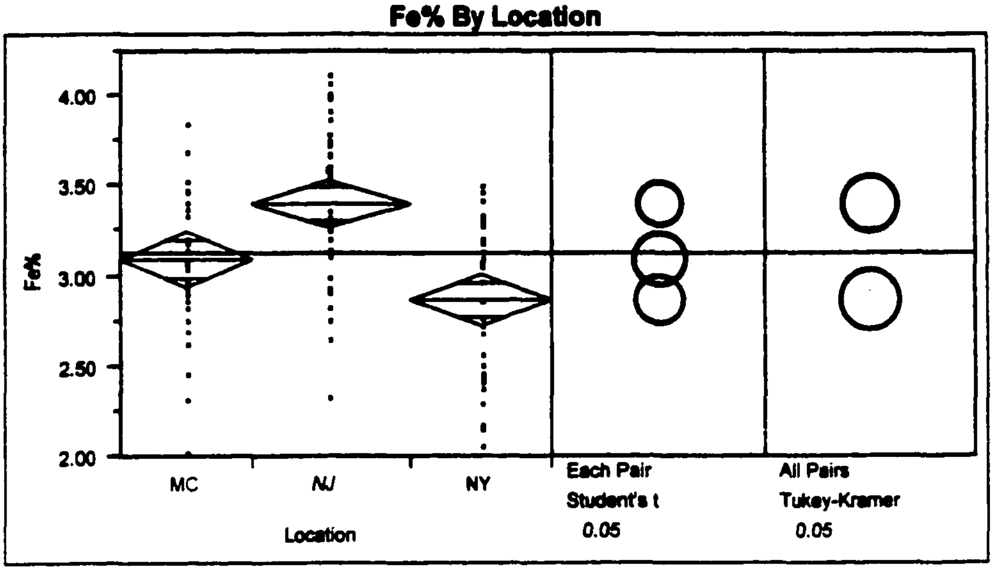

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                         Analysis of Variance
Source            DF       Sum of Squares       Mean Square      F Ratio
Model              2             4.922790           2.46139      13.4032
Error             95            17.448031           0.18364       Prob>F
C Total           97            22.368820           0.23061       <.0001
                       Means for Oneway Anova
            Level        Number          Mean      Std Error
            MC               30       3.09400        0.07824
            NJ               36       3.40694        0.07142
            NY               32       2.87219        0.07576

            Std Error uses a pooled estimate of error variance
                        Means Comparisons
 Dif=Mean[i]-Mean[j]                NJ              MC             NY
 NJ                           0.000000        0.312944       0.534757
 MC                           -0.31294        0.000000       0.221812
 NY                           -0.53476        -0.22181       0.000000
 Alpha=                           0.05
           Comparisons for each pair using Student's t
                          T = 1.98526
 Abs(Dif)-LSD                    NJ              MC             NY
 NJ                        -0.20052        0.102632       0.328061
 MC                        0.102632        -0.21966       0.005608
 NY                        0.328061        0.005608       -0.21269

 Positive values show pairs of means that are significantly different.
   Comparisons for all pairs using Tukey-Kramer HSD
                        q*= 2.38102
 Abs(Dif)-LSD                    NJ              MC             NY
 NJ                         -0.2405        0.060707       0.286856
 MC                        0.060707        -0.26345       -0.03749
 NY                        0.286856        -0.03749       -0.25509

 Positive values show pairs of means that are significantly different.
   Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level        Count      Score Sum      Score Mean        (Mean-Mean0)/Std0
MC              30         1408.5         46.9500                   -0.586
NJ              36           2336         64.8889                    4.079
NY              32         1106.5         34.5781                   -3.614
1-way Test, Chi-Square Approximation
                    ChiSquare         DF        Prob>ChiSq
                      19.6023          2            <.0001
```

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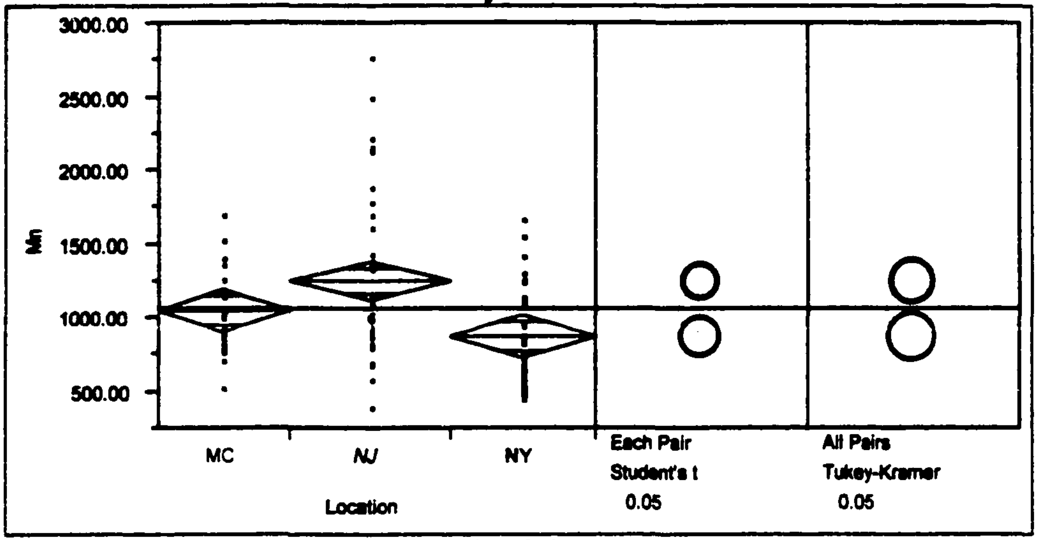

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                         Analysis of Variance
Source          DF       Sum of Squares       Mean Square        F Ratio
Model            2             2341975            1170987         6.8069
Error           95            16342795             172029         Prob>F
C Total         97            18684769             192626         0.0017
                      Means for Oneway Anova
            Level        Number         Mean       Std Error
            MC               30      1048.83          75.725
            NJ               36      1249.51          69.127
            NY               32       878.85          73.321
            Std Error uses a pooled estimate of error variance
                          Means Comparisons
    Dif=Mean[i]-Mean[j]               NJ             MC            NY
    NJ                             0.000        200.680       370.668
    MC                          -200.680          0.000       169.988
    NY                          -370.668       -169.988         0.000

    Alpha=                          0.05
          Comparisons for each pair using Student's t
                         T =1.98526
    Abs(Dif)-LSD                  NJ             MC            NY
    NJ                      -194.081         -2.874       170.614
    MC                        -2.874       -212.605       -39.268
    NY                       170.614        -39.268      -205.854

    Positive values show pairs of means that are significantly different.
      Comparisons for all pairs using Tukey-Kramer HSD
                         q = 2.38102
    Abs(Dif)-LSD                  NJ             MC            NY
    NJ                      -232.771        -43.452       130.734
    MC                       -43.452       -254.987       -80.983
    NY                       130.734        -80.983      -246.891

    Positive values show pairs of means that are significantly different.
           Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level         Count      Score Sum       Score Mean        (Mean-Mean0)/Std0
MC               30           1603          53.4333                    0.906
NJ               36         2096.5          58.2361                    2.314
NY               32         1151.5          35.9844                   -3.273

1-way Test, Chi-Square Approximation
                     ChiSquare          DF        Prob>ChiSq
                       11.2030           2            0.0037
```

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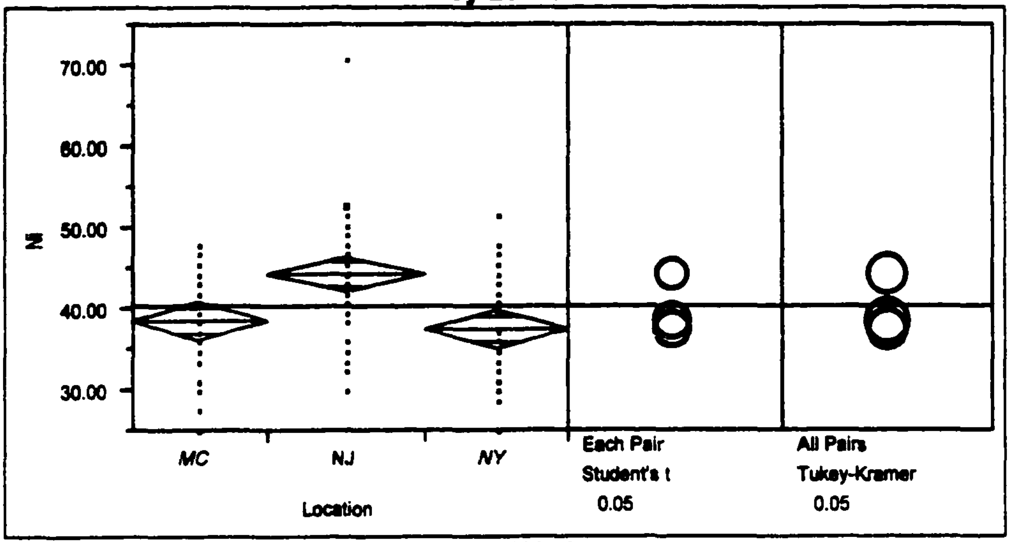

```
                    Analysis of Variance
Source          DF        Sum of Squares       Mean Square       F Ratio
Model            2              944.4602           472.230       10.0996
Error           95             4441.9414            46.757        Prob>F
C Total         97             5386.4016            55.530        0.0001

                Means for Oneway Anova
         Level          Number          Mean          Std Error
         MC                 30       38.5913             1.2484
         NJ                 36       44.4475             1.1397
         NY                 32       37.5684             1.2088

         Std Error uses a pooled estimate of error variance
                       Means Comparisons
    Dif=Mean[i]-Mean[j]                 NJ            MC             NY
    NJ                             0.00000       5.85617        6.87906
    MC                            -5.85617       0.00000        1.02290
    NY                            -6.87906      -1.02290        0.00000

    Alpha=                            0.05
          Comparisons for each pair using Student's t
                       T = 1.98526
      Abs(Dif)-LSD                   NJ            MC             NY
      NJ                       -3.19968       2.50032        3.58091
      MC                        2.50032      -3.50507       -2.42697
      NY                        3.58091      -2.42697       -3.39377

      Positive values show pairs of means that are significantly different.
       Comparisons for all pairs using Tukey-Kramer HSD
                       q*= 2.38102
      Abs(Dif)-LSD                   NJ            MC             NY
      NJ                       -3.83753       1.83133        2.92343
      MC                        1.83133      -4.20380       -3.11470
      NY                        2.92343      -3.11470       -4.07031
      Positive values show pairs of means that are significantly different.
         Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level        Count      Score Sum       Score Mean          (Mean-Mean0)/Std0
MC              30         1296.5          43.2167                     -1.451
NJ              36         2308.5          64.1250                      3.882
NY              32           1246          38.9375                     -2.561
1-way Test, Chi-Square Approximation
                    ChiSquare        DF        Prob>ChiSq
                      15.4490         2            0.0004
```

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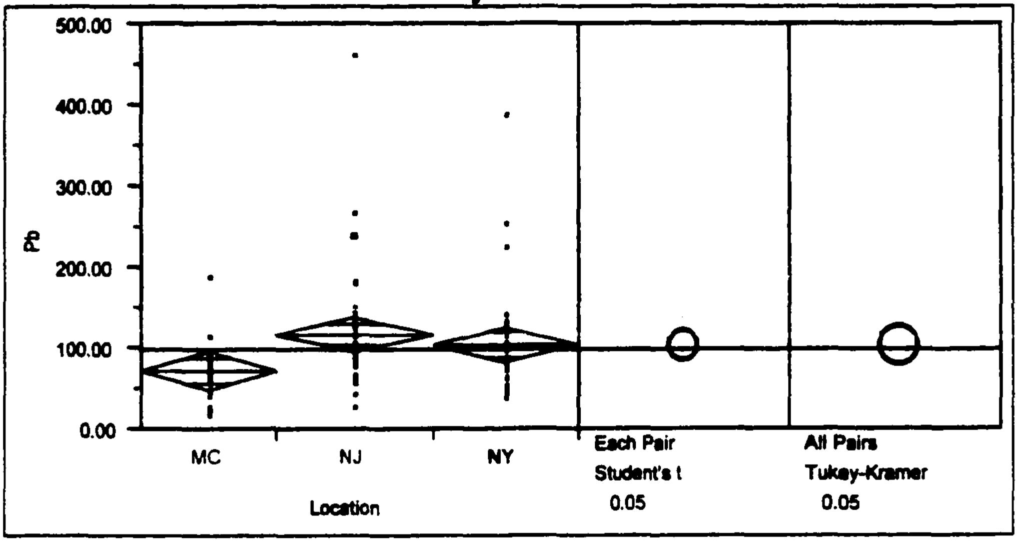
Pb By Location



```
                    Analysis of Variance
Source        DF      Sum of Squares       Mean Square      F Ratio
Model          2           33415.52            16707.8       3.8751
Error         95          409599.01             4311.6       Prob>F
C Total       97          443014.53             4567.2       0.0241

                 Means for Oneway Anova
          Level        Number          Mean       Std Error
          MC               30        72.838          11.988
          NJ               36       117.056          10.944
          NY               32       105.078          11.608

          Std Error uses a pooled estimate of error variance
                     Means Comparisons
Dif=Mean[i]-Mean[j]               NJ            NY            MC
NJ                            0.0000       11.9774       44.2176
NY                          -11.9774        0.0000       32.2401
MC                          -44.2176      -32.2401        0.0000

Alpha=                          0.05
        Comparisons for each pair using Student's t
                     T = 1.98526
  Abs(Dif)-LSD                  NJ            NY            MC
  NJ                      -30.7255      -19.6937       11.9924
  NY                      -19.6937      -32.5893       -0.8879
  MC                       11.9924       -0.8879      -33.6581

  Positive values show pairs of means that are significantly different.
   Comparisons for all pairs using Tukey-Kramer HSD
                     q*= 2.38102
  Abs(Dif)-LSD                  NJ            NY            MC
  NJ                      -36.8506      -26.0073        5.5683
  NY                      -26.0073      -39.0860       -7.4919
  MC                        5.5683       -7.4919      -40.3678
  Positive values show pairs of means that are significantly different.
      Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level       Count     Score Sum       Score Mean          (Mean-Mean0)/Std0
MC             30          1104          36.8000                     -2.933
NJ             36        2103.5          58.4306                      2.366
NY             32        1643.5          51.3594                      0.447
1-way Test, Chi-Square Approximation
                    ChiSquare         DF        Prob>ChiSq
                       9.6753          2            0.0079
```

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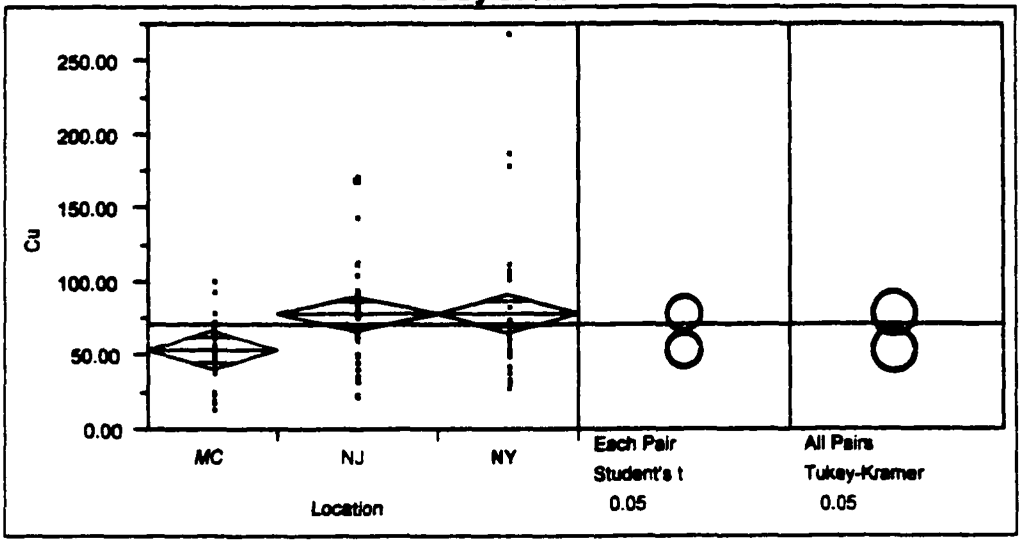
Cu By Location



```
                    Analysis of Variance
Source          DF        Sum of Squares      Mean Square       F Ratio
Model            2              12616.63          6308.31        4.2476
Error           95             141089.99          1485.16       Prob>F
C Total         97             153706.62          1584.60        0.0171

                 Means for Oneway Anova
              Level       Number         Mean     Std Error
              MC              30      54.0573        7.0360
              NJ              36      78.9967        6.4230
              NY              32      78.2987        6.8126

              Std Error uses a pooled estimate of error variance
                        Means Comparisons
       Dif=Mean[i]-Mean[j]                NJ            NY            MC
       NJ                             0.0000        0.6979       24.9393
       NY                            -0.6979        0.0000       24.2414
       MC                           -24.9393      -24.2414        0.0000

       Alpha=                           0.05
             Comparisons for each pair using Student's t
                          T = 1.98526
        Abs(Dif)-LSD                    NJ            NY            MC
        NJ                        -18.0330      -17.8901        6.0262
        NY                        -17.8901      -19.1269        4.7984
        MC                          6.0262        4.7984      -19.7542

        Positive values show pairs of means that are significantly different.
          Comparisons for all pairs using Tukey-Kramer HSD
                          q*= 2.38102
        Abs(Dif)-LSD                    NJ            NY            MC
        NJ                        -21.6278      -21.5955        2.2559
        NY                        -21.5955      -22.9398        0.9224
        MC                          2.2559        0.9224      -23.6921
        Positive values show pairs of means that are significantly different.
            Wilcoxon / Kruskal-Wallis Tests (Rank Sums)
Level          Count      Score Sum        Score Mean          (Mean-Mean0)/Std0
MC                30         1108.5           36.9500                     -2.899
NJ                36           2102           58.3889                      2.355
NY                32         1640.5           51.2656                      0.424
1-way Test, Chi-Square Approximation
                      ChiSquare          DF       Prob>ChiSq
                         9.4887           2           0.0087
```

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Appendix E

New York / New Jersey Water Pollution Control Plants Effluent Metal Loadings During The Time Period 1996, 1997 and 1998. Data Is Complied Based on The ISC, EPA, And DEC Monthly Reports.

Hoboken WPCP - 1996

1996	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (Kg/d))	Total Monthly (kg/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (Kg/d))	Total Monthly (kg/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (Kg/d))	Total Monthly (kg/d)	Daily Average (Kg/d))	Total Monthly (kg/d)
Action Limit	6.3		0.4		4.54		49.89		6.35		4.99		58.96	
	Ag		Cd		Cr		Cu		Ni		Pb		Zn	
Jan	0.1	3.1	0.1	3.1	0.10	3.1	0.8	24.8	0.2	6.2	0.3	9.3	1.3	40.3
Feb	0.12	3.6	0.16	4.7	0.16	4.7	1.23	35.6	2.78	80.7	0.41	11.9	0.41	11.9
Mar	0.1	3.1	0.2	6.2	0.20	6.2	0.1	3.1	0.2	6.2	0.5	15.5	1.8	55.8
Apr	0.34	10.2	0.0	0.9	0.85	25.5	0.6	17.4	0.2	5.1	0.0	0.6	0.85	25.5
May	0.1	3.1	0.2	6.2	0.20	6.2	0.3	9.3	0.2	6.2	0.4	12.4	1.2	37.2
Jun	0.07	2.1	0.2	4.5	0.15	4.5	0.3	10.2	0.2	5.4	0.4	10.8	0.13	3.9
July	0.1	3.1	0.1	3.1	0.01	0.3	0.5	15.5	0.2	6.2	0.4	12.4	1.1	34.1
Aug	0.13	4.0	0.1	4.2	0.24	7.4	0.5	17.0	0.2	6.2	0.3	10.6	0.97	30.1
Sep	0.13	3.9	0.1	4.0	0.24	7.2	0.5	16.5	0.2	6.0	0.3	10.2	0.97	29.1
Oct	0.13	4.0	0.1	4.2	0.24	7.4	0.5	17.0	0.2	6.2	0.3	10.6	0.97	30.1
Nov	0.13	3.9	0.1	4.0	0.24	7.2	0.5	16.5	0.2	6.0	0.3	10.2	0.97	29.1
Dec	0.13	4.0	0.1	4.2	0.24	7.4	0.5	17.0	0.2	6.2	0.3	10.6	0.97	30.1
SUM		48.1		49.4		87.1		200.0		146.6		125.1		357.1

West New York WPCP - 1998

1998	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	14	6.3		0.90	0.41		10	4.54		110	49.89	
	Ag			**Cd**			**Cr**			**Cu**		
Jan	8	3.6	112.5	0.24	0.11	3.4	2.70	1.22	38.0	25.7	11.66	361.3
Feb	6	2.7	84.4	0.22	0.10	2.9	4.0	1.81	52.6	27.0	12.24	355.1
Mar	12	5.4	168.7	0.18	0.08	2.5	3.0	1.36	42.2	25.0	11.34	351.5
Apr	6	2.7	81.6	0.33	0.15	4.5	1.0	0.45	13.6	25.0	11.34	340.1
May	8	3.6	112.5	0.24	0.11	3.4	2.7	1.21	37.5	25.7	11.64	360.8
Jun	6	2.7	81.6	0.15	0.07	2.0	2.0	0.91	27.2	31.0	14.06	421.8
July	2	0.9	28.1	0.12	0.05	1.7	0.0	0.00	0.0	27.0	12.24	379.6
Aug	8	3.6	112.5	0.10	0.05	1.4	2.0	0.91	28.1	32.0	14.51	449.9
Sep	8	3.6	108.8	0.20	0.09	2.7	2.2	0.98	29.5	27.3	12.38	371.4
Oct	8	3.6	112.5	0.58	0.26	8.2	6.0	2.72	84.4	22.0	9.98	309.3
Nov	5	2.3	68.0	0.28	0.13	3.8	7.0	3.17	95.2	22.0	9.98	299.3
Dec	9	4.1	126.5	0.79	0.36	11.1	9.0	4.08	126.5	31.0	14.06	435.8
SUM			**1197.7**			**47.6**			**574.8**			**4435.9**

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West New York WPCP - 1998

1998	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	14	6.35		11	4.99		130	58.96	
	Ni			Pb			Zn		
Jan	6.3	2.86	88.6	4.6	2.09	64.7	61.6	27.94	866.0
Feb	8	3.63	105.2	4	1.81	52.6	70	31.75	920.6
Mar	6	2.72	84.4	6	2.72	84.4	55	24.94	773.2
Apr	5	2.27	68.0	4	1.81	54.4	60	27.21	816.3
May	6.3	2.87	89.0	4.7	2.12	65.6	61.7	27.97	867.0
Jun	6	2.72	81.6	3	1.36	40.8	62	28.12	843.5
July	4	1.81	56.2	2	0.91	28.1	52	23.58	731.1
Aug	6	2.72	84.4	6	2.72	84.4	64	29.02	899.8
Sep	6.0	2.70	81.0	4.3	1.94	58.3	60.8	27.57	827.0
Oct	13	5.90	182.8	3	1.36	42.2	52	23.58	731.1
Nov	8	3.63	108.8	2	0.91	27.2	58	26.30	789.1
Dec	5	2.27	70.3	4	1.81	56.2	80	36.28	1124.7
SUM			1100.3			658.9			10189.5

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West New York -1997

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1997	Ag			Cd			Cr			Cu		
Jan	7	3.2	98.4	0.16	0.1	2.2	2.60	1.2	36.6	26.0	11.8	365.5
Feb	11	5.0	144.7	0.22	0.1	2.9	2.0	0.9	26.3	29.0	13.2	381.4
Mar	5	2.3	70.3	0.14	0.1	2.0	2.0	0.9	28.1	25.0	11.3	351.5
Apr	6	2.7	81.6	0.42	0.2	5.7	3.0	1.4	40.8	22.0	10.0	299.3
May	9	4.1	126.5	0.16	0.1	2.2	2.0	0.9	28.1	25.0	11.3	351.5
June	9	4.1	122.4	0.14	0.1	1.9	3.0	1.4	40.8	33.0	15.0	449.0
July	7	3.2	98.4	0.16	0.1	2.2	1.0	0.5	14.1	26.0	11.8	365.5
Aug	2	0.9	28.1	0.11	0.0	1.5	1.0	0.5	14.1	28.0	12.7	393.7
Sep	7	3.2	95.2	0.19	0.1	2.6	2.0	0.9	27.2	27.0	12.2	367.3
Oct	10	4.5	140.6	0.22	0.1	3.1	5.0	2.3	70.3	28.0	12.7	393.7
Nov	10	4.5	136.1	0.14	0.1	1.9	2.0	0.9	27.2	24.0	10.9	326.5
Dec	5	2.3	70.3	0.12	0.1	1.7	4.0	1.8	56.2	24.0	10.9	337.4
SUM			1212.7			30.0			409.8			4382.3

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West New York WPCP - 1997

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1997	**Ni**			**Pb**			**Zn**		
Jan	5.0	2.3	70.3	2.6	1.2	36.6	62.6	28.4	880.1
Feb	5	2.3	65.8	4	1.8	52.6	79	35.8	1039.0
Mar	4	1.8	56.2	2	0.9	28.1	56	25.4	787.3
Apr	5	2.3	68.0	3	1.4	40.8	70	31.7	952.4
May	4	1.8	56.2	2	0.9	28.1	72	32.7	1012.2
Jun	6	2.7	81.6	3	1.4	40.8	62	28.1	843.5
July	5	2.3	70.3	4	1.8	56.2	46	20.9	646.7
Aug	3	1.4	42.2	4	1.8	56.2	28	12.7	393.7
Sep	7	3.2	95.2	4	1.8	54.4	57	25.9	775.5
Oct	8	3.6	112.5	3	1.4	42.2	57	25.9	801.4
Nov	20	9.1	272.1	3	1.4	40.8	61	27.7	829.9
Dec	6	2.7	84.4	2	0.9	28.1	53	24.0	745.1
SUM			**1074.8**			**505.0**			**9706.8**

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West New York - 1996

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1996	**Ag**			**Cd**			**Cr**			**Cu**		
Jan	1	0.5	14.1	0.50	0.2	7.0	5.0	2.3	70.3	25.0	11.3	351.5
Feb	4.5	2.0	59.2	0.65	0.3	8.5	4.0	1.8	52.6	25.0	11.3	328.8
Mar	8	3.6	112.5	0.80	0.4	11.2	20.0	9.1	281.2	30.0	13.6	421.8
Apr	5	2.3	68.0	0.20	0.1	2.7	2.0	0.9	27.2	33.0	15.0	449.0
May	6.5	2.9	91.4	0.35	0.2	4.9	3.5	1.6	49.2	29.0	13.2	407.7
Jun	6.25	2.8	85.0	0.27	0.1	3.7	2.3	1.0	30.6	30.0	13.6	408.2
July	6	2.7	84.4	0.20	0.1	2.8	2.0	0.9	28.1	31.0	14.1	435.8
Sep	7	3.2	94.5	0.19	3.2	94.5	1.8	3.2	94.5	28.5	3.2	94.5
Oct	8	3.6	112.5	0.19	0.1	2.7	1.6	0.7	22.8	26.0	11.8	365.5
Nov	8	3.6	108.8	0.14	0.1	1.9	1.3	0.6	17.7	25.5	11.6	346.9
Dec	8	3.6	112.5	0.10	0.0	1.4	1.0	0.5	14.1	25.0	11.3	351.5
SUM			**942.8**			**141.4**			**688.3**			**3961.2**

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West New York WPCP - 1996

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1996	**Ni**			**Pb**			**Zn**		
Jan	8	3.6	112.5	4	1.8	56.2	80	36.3	1124.7
Feb	8.6	3.9	113.1	4.5	2.0	59.2	69.5	31.5	914.1
Mar	13	5.9	182.8	4	1.8	56.2	91	41.3	1279.4
Apr	14	6.3	190.5	21	9.5	285.7	65	29.5	884.4
May	11	5.0	154.6	4.1	1.9	57.6	78	35.4	1096.6
Jun	8.5	3.9	115.6	4.05	1.8	55.1	72	32.7	979.6
July	6	2.7	84.4	4	1.8	56.2	66	29.9	927.9
Sep	6.5	3.2	94.5	3	3.2	94.5	61.5	3.2	94.5
Oct	7	3.2	98.4	2	0.9	28.1	57	25.9	801.4
Nov	6	2.7	81.6	3.5	1.6	47.6	58	26.3	789.1
Dec	5	2.3	70.3	5	2.3	70.3	59	26.8	829.5
SUM			**1298.3**			**866.9**			**9721.0**

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Nodth River WPCP - 1997

1997	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	14	6.3		0.90	0.41		10	4.54		110.0	49.89	
	Ag			Cd			Cr			Cu		
Jan	5	2.27	70.29	0.18	0.08	2.53	4.0	1.81	56.24	33.0	14.97	463.95
Feb	11	4.99	144.67	0.22	0.10	2.89	2.0	0.91	26.30	29.0	13.15	381.41
Mar	5	2.27	70.29	0.14	0.06	1.97	2.0	0.91	28.12	25.0	11.34	351.47
Apr	6	2.72	81.63	0.42	0.19	5.71	3.0	1.36	40.82	22.0	9.98	299.32
May	9	4.08	126.53	0.16	0.07	2.25	2.0	0.91	28.12	25.0	11.34	351.47
Jun	9	4.08	122.45	0.14	0.06	1.90	3.0	1.36	40.82	33.0	14.97	448.98
July	7	3.17	98.41	0.16	0.07	2.25	1.0	0.45	14.06	26.0	11.79	365.53
Aug	2	0.91	28.12	0.11	0.05	1.55	1.0	0.45	14.06	28.0	12.70	393.65
Sep	7	3.17	95.24	0.19	0.09	2.59	2.0	0.91	27.21	27.0	12.24	367.35
Oct	10	4.54	140.59	0.22	0.10	3.09	5.0	2.27	70.29	28.0	12.70	393.65
Nov	10	4.54	136.05	0.14	0.06	1.90	2.0	0.91	27.21	24.0	10.88	326.53
Dec	5	2.27	70.29	0.12	0.05	1.69	4.0	1.81	56.24	24.0	10.88	337.41
SUM			1184.58			30.33			429.48			4480.73

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North River WPCP - 1997

1997	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	14	6.35		11	4.99		130	58.96	
	Ni			**Pb**			**Zn**		
Jan	12	5.44	168.71	2	0.91	28.12	48	21.77	674.83
Feb	5	2.27	65.76	4	1.81	52.61	79	35.83	1039.00
Mar	4	1.81	56.24	2	0.91	28.12	56	25.40	787.30
Apr	5	2.27	68.03	3	1.36	40.82	70	31.75	952.38
May	4	1.81	56.24	2	0.91	28.12	72	32.65	1012.24
Jun	6	2.72	81.63	3	1.36	40.82	62	28.12	843.54
July	5	2.27	70.29	4	1.81	56.24	46	20.86	646.71
Aug	3	1.36	42.18	4	1.81	56.24	28	12.70	393.65
Sept	7	3.17	95.24	4	1.81	54.42	57	25.85	775.51
Oct	8	3.63	112.47	3	1.36	42.18	57	25.85	801.36
Nov	20	9.07	272.11	3	1.36	40.82	61	27.66	829.93
Dec	6	2.72	84.35	2	0.91	28.12	53	24.04	745.12
SUM			**1173.24**			**496.60**			**9501.59**

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North River WPCP - 1998

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1998	**Ag**			**Cd**			**Cr**			**Cu**		
Jan	7.5	3.40	98.64	0.12	0.05	1.69	6.5	2.95	91.38	24.0	10.88	337.41
Feb	6	2.72	81.63	0.22	0.10	2.89	4.0	1.81	52.61	27.0	12.24	355.10
Mar	12	5.44	168.71	0.18	0.08	2.53	3.0	1.36	42.18	25.0	11.34	351.47
Apr	6	2.72	81.63	0.33	0.15	4.49	1.0	0.45	13.61	25.0	11.34	340.14
May	6	2.72	84.35	0.37	0.17	5.20	3.6	1.64	50.96	19.0	8.62	267.12
Jun	6	2.72	81.63	0.15	0.07	2.04	2.0	0.91	27.21	31.0	14.06	421.77
July	2	0.91	28.12	0.12	0.05	1.69	2.0	0.91	28.12	27.0	12.24	379.59
Aug	8	3.63	112.47	0.10	0.05	1.41	2.0	0.91	28.12	32.0	14.51	449.89
Sept	8	3.63	108.84	0.12	0.05	1.63	3.3	1.50	44.90	36.0	16.33	489.80
Oct	8	3.63	112.47	0.58	0.26	8.15	6.0	2.72	84.35	22.0	9.98	309.30
Nov	5	2.27	70.29	0.28	0.13	3.81	7.0	3.17	98.41	22.0	9.98	299.32
Dec	9	4.08	122.45	0.79	0.36	10.75	9.0	4.08	122.45	31.0	14.06	435.83
SUM			**1151.25**			**46.28**			**684.30**			**4436.73**

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North River WPCP - 1998

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1998	**Ni**			**Pb**			**Zn**		
Jan	5	2.27	70.29	4	1.81	56.24	48	21.77	674.83
Feb	8	3.63	105.22	4	1.81	52.61	70	31.75	920.63
Mar	6	2.72	84.35	6	2.72	84.35	55	24.94	773.24
Apr	5	2.27	68.03	4	1.81	54.42	60	27.21	816.33
May	8	3.63	112.47	4.5	2.04	63.27	65	29.48	913.83
Jun	6	2.72	81.63	3	1.36	40.82	62	28.12	843.54
July	4	1.81	56.24	2	0.91	28.12	52	23.58	731.07
Aug	6	2.72	84.35	6	2.72	84.35	64	29.02	899.77
Sept	5	2.27	68.03	3.3	1.50	44.90	62	28.12	843.54
Oct	13	5.90	182.77	3	1.36	42.18	52	23.58	731.07
Nov	8	3.63	108.84	2	0.91	27.21	58	26.30	789.12
Dec	5	2.27	70.29	4	1.81	56.24	80	36.28	1124.72
SUM			**1092.52**			**634.69**			**10061.68**

Yonkers WPCP - 1997

1997	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	3.80	1.72		49			125	56.87	
	Cd			**Cr**			**Cu**		
Jan	1.50	0.68	21.09	7.7	3.49	108.25	63.6	28.84	894.15
Feb	1.60	0.73	21.04	7.7	3.49	101.27	34.0	15.42	447.17
Mar	1.50	0.68	21.09	7.7	3.49	108.25	39.5	17.91	555.33
Apr	2.00	0.91	27.21	7.7	3.49	104.76	52.9	23.99	719.73
May	1.80	0.82	25.31	7.7	3.49	108.25	67.3	30.52	946.17
Jun	1.50	0.68	20.41	8.5	3.85	115.65	166.1	75.33	2259.86
July	1.40	0.63	19.68	8.2	3.72	115.28	22.0	9.98	309.30
Aug	1.40	0.63	19.68	7.7	3.49	108.25	48.2	21.86	677.64
Sept	1.50	0.68	20.41	7.8	3.54	106.12	74.3	33.70	1010.88
Oct	1.50	0.68	21.09	8.2	3.72	115.28	23.0	10.43	323.36
Nov	1.50	0.68	20.41	2.8	1.27	38.10	23.5	10.66	319.73
Dec	1.50	0.68	21.09	7.7	3.49	108.25	47.5	21.54	667.80
SUM			**258.50**			**1237.73**			**9131.11**

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Yonkers - 1997

1997	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	54.5	24.72		66			101.1	45.85	
	Ni			Pb			Zn		
Jan	21.2	9.61	298.05	38.4	17.41	539.86	32.5	14.74	456.92
Feb	16.2	7.35	213.06	38.4	17.41	505.03	40.4	18.32	531.34
Mar	15.3	6.94	215.10	38.4	17.41	539.86	67.5	30.61	948.98
Apr	20.3	9.21	276.19	38.4	17.41	522.45	42.7	19.37	580.95
May	18	8.16	253.06	38.4	17.41	539.86	45	20.41	632.65
Jun	15.3	6.94	208.16	38.4	17.41	522.45	41.4	18.78	563.27
July	16	7.26	224.94	38.4	17.41	539.86	22.7	10.29	319.14
Aug	20.1	9.12	282.59	38.4	17.41	539.86	35.4	16.05	497.69
Sep	18.9	8.57	257.14	38.4	17.41	522.45	34.6	15.69	470.75
Oct	15.3	6.94	215.10	38.3	17.37	538.46	32.9	14.92	462.54
Nov	15.3	6.94	208.16	38.4	17.41	522.45	35.1	15.92	477.55
Dec	15.3	6.94	215.10	38.4	17.41	539.86	72.1	32.70	1013.65
SUM			2866.67			6372.47			6955.42

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Yonkers - 1998

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1998									
	Cd			**Cr**			**Cu**		
Jan	1.70	0.77	23.90	14.0	6.35	196.83	120.5	54.65	1694.10
Feb	1.50	0.68	19.73	66.6	30.20	875.92	129.9	58.91	1708.44
Mar	1.50	0.68	21.09	20.7	9.39	291.02	111.6	50.61	1568.98
Apr	1.40	0.63	19.05	16.3	7.39	221.77	28.9	13.11	393.20
May	1.80	0.82	25.31	23.1	10.49	325.32	32.8	14.88	461.13
Jun	1.70	0.77	23.13	8.5	3.85	115.65	36.6	16.60	497.96
July	1.60	0.73	22.49	8.2	3.72	115.28	23.0	10.43	323.36
Aug	1.50	0.68	21.09	7.7	3.49	108.25	23.0	10.43	323.36
Sep	1.60	0.73	21.77	7.8	3.54	106.12	23.0	10.43	312.93
Oct	1.60	0.73	22.49	8.2	3.72	115.28	22.0	9.98	309.30
Nov	1.60	0.73	21.77	2.8	1.27	38.10	15.5	7.03	210.88
Dec	1.50	0.68	21.09	7.7	3.49	108.25	15.4	6.98	216.51
SUM			**262.90**			**2617.80**			**8020.14**

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Yonkers WPCP - 1998

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1998									
	Ni			**Pb**			**Zn**		
Jan	16.5	7.48	231.97	65.2	29.57	916.64	132.1	59.91	1857.19
Feb	78.5	35.60	1032.43	60.2	27.30	791.75	122.1	55.37	1605.85
Mar	24.5	11.11	344.44	51.3	23.27	721.22	104.1	47.21	1463.54
Apr	19.3	8.75	262.59	38.4	17.41	522.45	35.9	16.28	488.44
May	27.4	12.43	385.22	38.4	17.41	539.86	45.5	20.63	639.68
Jun	17.5	7.94	238.10	38.4	17.41	522.45	39.1	17.73	531.97
July	17.2	7.80	241.81	38.4	17.41	539.86	18	8.16	253.06
Aug	18.2	8.25	255.87	38.4	17.41	539.86	25.2	11.43	354.29
Sep	16.8	7.62	228.57	38.4	17.41	522.45	71.3	32.34	970.07
Oct	16.3	7.39	229.16	38.3	17.37	538.46	16.3	7.39	229.16
Nov	15.5	7.03	210.88	38.4	17.41	522.45	17.8	8.07	242.18
Dec	15.3	6.94	215.10	38.4	17.41	539.86	36.7	16.64	515.96
SUM			**3876.15**			**7217.32**			**9151.38**

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Orangetown WPCP - 1997

1997	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	4	2.01		4.74	2.15		24	10.88	
	Cu			**Ni**			**Zn**		
Jan	2.2	1.00	29.9	1.9	0.84	25.3	2	0.91	27.2
Feb	2.1	0.94	27.2	1.8	0.82	23.7	2	0.91	26.3
Mar	0.9	0.40	12.5	1.78	0.81	25.0	2	0.91	28.1
Apr	1.3	0.61	18.2	2.68	1.22	36.5	2	0.91	27.2
May	1.3	0.60	18.7	1.91	0.87	26.9	2	0.91	28.1
Jun	1.7	0.78	23.5	1.91	0.87	26.0	1.8	0.82	24.5
July	1.1	0.48	14.8	1.48	0.67	20.8	1.8	0.82	25.3
Aug	2.5	1.13	35.0	1.53	0.69	21.5	1.8	0.82	25.3
Sep	1.0	0.44	13.1	1.45	0.66	19.7	2	0.91	27.2
Oct	1.4	0.63	19.7	1.64	0.74	23.1	2	0.91	28.1
Nov	1.9	0.87	26.1	1.83	0.83	24.9	2	0.91	27.2
Dec	2.0	0.89	27.6	1.92	0.87	27.0	2	0.91	28.1
SUM			**266.3**			**300.3**			**322.7**

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Orangetown WPCP - 1998

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1998	**Cu**			**Ni**			**Zn**		
Jan	1.0	0.43	13.4	1.91	0.87	26.9	1.4	0.63	19.7
Feb	1.0	0.44	13.5	1.92	0.87	25.3	1.4	0.63	18.4
Mar	1.9	0.87	26.9	1.92	0.87	27.0	1.4	0.63	19.7
Apr	1.0	0.43	13.4	1.9	0.86	25.9	3.3	1.50	44.9
May	1.4	0.65	20.1	2.87	1.30	40.3	1.4	0.63	19.7
Jun	1.3	0.59	18.4	2.62	1.19	35.6	1.4	0.63	19.0
July	0.9	0.41	12.7	1.8	0.82	25.3	1.3	0.59	18.3
Aug	0.8	0.36	11.1	1.59	0.72	22.4	1.3	0.59	18.3
Sept	2.6	1.16	36.0	1.46	0.66	19.9	0.9	0.41	12.2
Oct	0.9	0.40	12.5	1.78	0.81	25.0	0.9	0.41	12.7
Nov	1.0	0.45	13.9	1.98	0.90	26.9	0.9	0.41	12.2
Dec	0.9	0.39	12.2	1.74	0.79	24.5	1.4	0.63	19.7
SUM			**204.0**			**324.9**			**234.8**

Ossining WPCP - 1997

1997	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
Action Limit	0.25	0.11		8.4	3.81		3.9	1.77		5.3	2.40	
	Cd			Cu			Ni			Zn		
Jan	0.03	0.01	0.35	0.3	0.11	3.56	0.253	0.11	3.56	0.594	0.27	8.35
Feb	0.03	0.01	0.33	0.3	0.11	3.33	0.253	0.11	3.33	0.594	0.27	7.81
Mar	0.03	0.01	0.35	0.3	0.11	3.56	0.253	0.11	3.56	0.594	0.27	8.35
Apr	0.03	0.01	0.34	0.3	0.11	3.44	0.253	0.11	3.44	0.594	0.27	8.08
May	0.03	0.01	0.35	0.3	0.11	3.56	0.253	0.11	3.56	0.594	0.27	8.35
Jun	0.03	0.01	0.34	0.3	0.11	3.44	0.253	0.11	3.44	0.594	0.27	8.08
July	0.03	0.01	0.35	0.3	0.11	3.56	0.253	0.11	3.56	0.594	0.27	8.35
Aug	0.03	0.01	0.35	0.3	0.11	3.56	0.253	0.11	3.56	0.594	0.27	8.35
Sep	0.07	0.03	0.95	1.5	0.69	20.82	0.75	0.34	10.20	2.57	1.17	34.97
Oct	0.07	0.03	0.98	1.5	0.69	21.51	0.75	0.34	10.54	2.57	1.17	36.13
Nov	0.03	0.01	0.34	0.3	0.11	3.44	0.253	0.11	3.44	0.594	0.27	8.08
Dec	0.03	0.01	0.35	0.3	0.11	3.56	0.253	0.11	3.56	0.594	0.27	8.35
SUM			5.39			77.32			55.74			153.26

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Ossining WPCP - 1998

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1998	**Cd**			**Cu**			**Ni**			**Zn**		
				0.70	0.34	10.50	0.747	0.34	10.50	4.11	1.86	57.78
Jan	0.07	0.03	1.04	0.70	0.34	9.82	0.747	0.34	9.82	4.11	1.86	54.05
Feb	0.07	0.03	0.97	0.70	0.34	10.50	0.747	0.34	10.50	4.11	1.86	57.78
Mar	0.09	0.04	1.27	0.10	0.05	1.36	0.09	0.04	1.22	0.41	0.19	5.58
Apr	0.09	0.04	1.22	0.10	0.05	1.41	0.09	0.04	1.27	0.41	0.19	5.76
May	0.09	0.04	1.27	0.10	0.05	1.36	0.09	0.04	1.22	0.41	0.19	5.58
Jun	0.10	0.05	1.36	1.00	0.45	14.06	1.00	0.45	14.06	2.70	1.22	37.96
July	0.10	0.05	1.41	1.00	0.45	14.06	1.00	0.45	14.06	2.70	1.22	37.96
Aug	0.10	0.05	1.41	1.00	0.45	13.61	1.00	0.45	13.61	2.70	1.22	36.73
Sep	0.07	0.03	1.01	0.70	0.34	10.50	0.747	0.34	10.50	4.11	1.86	57.78
Oct	0.07	0.03	1.04	0.70	0.34	10.16	0.747	0.34	10.16	4.11	1.86	55.92
Nov	0.07	0.03	1.01	0.70	0.34	10.16	0.747	0.34	10.16	4.11	1.86	55.92
Dec	0.07	0.03	1.04	0.70	0.34	10.50	0.747	0.34	10.50	4.11	1.86	57.78
SUM			**14.04**			**118.01**			**117.60**			**526.59**

Jt. Reg. Haverstraw WPCP - 1996

1996	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d	Total Monthly (kg/d)	Daily Average (lb/d	Daily Average (Kg/d	Total Monthly (kg/d)	Daily Average (lb/d	Daily Average (Kg/d	Total Monthly (kg/d)	Daily Average (lb/d	Daily Average (Kg/d	Total Monthly (kg/d)
Action Limit				4.4	2.01		4.74	2.15		45.77	20.76		24	10.88	
	Ag			Cu			Ni			Pb			Zn		
Jan	1.90	0.86	26.7	1.8	0.80	24.9	2.41	1.09	33.9	0.30	0.14	4.2	2.5	1.13	35.1
Feb	1.90	0.86	25.0	1.32	0.60	17.4	4.25	1.93	55.9	0.22	0.10	2.9	2.5	1.13	32.9
Mar	0.50	0.23	7.0	1.23	0.56	17.3	1.91	0.87	26.9	0.24	0.11	3.4	2.5	1.13	35.1
Apr	0.50	0.23	6.8	1.88	0.85	25.6	3.14	1.42	42.7	0.39	0.18	5.3	2.1	0.95	28.6
May	0.50	0.23	7.0	1.19	0.54	16.7	1.93	0.88	27.1	0.24	0.11	3.4	2.1	0.95	29.5
Jun	0.50	0.23	6.8	2.20	1.00	29.9	2.07	0.94	28.2	0.25	0.11	3.4	2.1	0.95	28.6
July	0.50	0.23	7.0	1.50	0.68	21.1	2.00	0.91	28.1	0.25	0.11	3.5	2.9	1.32	40.8
Aug	0.50	0.23	7.0	0.78	0.35	11.0	1.56	0.71	21.9	0.19	0.09	2.7	1.4	0.63	19.7
Sep	0.50	0.23	6.8	1.95	0.88	26.5	2.05	0.93	27.9	0.26	0.12	3.5	1.4	0.63	19.0
Oct	0.40	0.18	5.6	0.98	0.44	13.8	1.96	0.89	27.6	0.25	0.11	3.5	1.4	0.63	19.7
Nov	0.40	0.18	5.4	4.48	2.03	61.0	1.55	0.70	21.1	0.40	0.18	5.4	1.4	0.63	19.0
Dec	0.40	0.18	5.6	0.72	0.33	10.1	1.45	0.66	20.4	0.18	0.08	2.5	1.4	0.63	19.7
SUM			116.9			275.2			361.6			43.8			327.8

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Jt. Reg. Haverstraw WPCP - 1997

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1997	Ag			Cu			Ni			Pb			Zn		
Jan	0.4	0.18	5.62	1.3	0.60	18.56	2.0	0.90	27.98	0.25	0.11	3.51	2.2	1.00	30.93
Feb	0.4	0.18	5.26	2.1	0.94	27.22	1.8	0.82	23.67	0.67	0.30	8.81	2.2	1.00	28.93
Mar	0.7	0.32	9.84	0.9	0.40	12.51	1.78	0.81	25.02	0.22	0.10	3.09	2	0.91	28.12
Apr	0.7	0.32	9.52	1.3	0.61	18.23	2.68	1.22	36.46	0.33	0.15	4.49	2	0.91	27.21
May	0.7	0.32	9.84	1.3	0.60	18.70	1.91	0.87	26.85	0.24	0.11	3.37	2	0.91	28.12
Jun	0.4	0.18	5.44	1.7	0.78	23.54	1.91	0.87	25.99	0.24	0.11	3.27	1.8	0.82	24.49
July	0.4	0.18	5.62	1.1	0.48	14.76	1.48	0.67	20.81	0.18	0.08	2.53	1.8	0.82	25.31
Aug	0.4	0.18	5.62	2.5	1.13	35.01	1.53	0.69	21.51	0.22	0.10	3.09	1.8	0.82	25.31
Sep	0.3	0.14	4.08	1.0	0.44	13.06	1.45	0.66	19.73	0.18	0.08	2.45	1.8	0.82	24.49
Oct	0.3	0.14	4.22	1.0	0.44	13.50	1.45	0.66	20.39	0.17	0.08	2.39	1.8	0.82	25.31
Nov	0.4	0.18	5.44	0.9	0.42	12.52	1.83	0.83	24.90	0.23	0.10	3.13	2.2	1.00	29.93
Dec	0.4	0.18	5.62	1.0	0.44	13.50	1.92	0.87	26.99	0.24	0.11	3.37	2.2	1.00	30.93
SUM			76.15			221.10			300.30			43.51			329.07

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Jt. Reg. Haverstraw WPCP - 1998

	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)	Daily Average (lb/d)	Daily Average (Kg/d)	Total Monthly (kg/d)
1998	**Ag**			**Cu**			**Ni**			**Pb**			**Zn**		
Jan	0.5	0.23	7.03	1.0	0.43	13.36	1.91	0.87	26.85	0.24	0.11	3.37	1.4	0.63	19.68
Feb	0.5	0.23	6.58	1.0	0.44	12.63	1.92	0.87	25.25	0.24	0.11	3.16	1.4	0.63	18.41
Mar	0.5	0.23	7.03	1.9	0.87	26.85	1.92	0.87	26.99	0.24	0.11	3.37	3.3	1.50	46.39
Apr	0.5	0.23	6.80	1.0	0.43	12.93	1.9	0.86	25.85	0.24	0.11	3.27	3.3	1.50	44.90
May	0.5	0.23	7.03	1.4	0.65	20.10	2.87	1.30	40.35	0.24	0.11	3.37	3.3	1.50	46.39
Jun	0.4	0.18	5.26	1.3	0.59	17.82	2.62	1.19	35.65	0.54	0.24	7.35	1.3	0.59	17.69
July	0.4	0.18	5.62	0.9	0.41	12.65	1.8	0.82	25.31	0.54	0.24	7.59	1.3	0.59	18.28
Aug	0.4	0.18	5.62	0.8	0.36	11.11	1.59	0.72	22.35	0.2	0.09	2.81	1.3	0.59	18.28
Sep	0.4	0.18	5.44	2.6	1.16	34.83	1.46	0.66	19.86	0.19	0.09	2.59	0.9	0.41	12.24
Oct	0.4	0.18	5.62	0.9	0.40	12.51	1.78	0.81	25.02	0.22	0.10	3.09	0.9	0.41	12.65
Nov	0.5	0.23	6.80	1.0	0.45	13.47	1.98	0.90	26.94	0.25	0.11	3.40	1.4	0.63	19.05
Dec	0.5	0.23	7.03	0.9	0.39	12.23	1.74	0.79	24.46	0.22	0.10	3.09	1.4	0.63	19.68
SUM			**75.87**			**200.49**			**324.89**			**46.47**			**293.65**

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