HEAVY METALS IN ORGANIC-RICH MUDS OF THE NEUSE RIVER ESTUARINE SYSTEM

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LIST OF ABBREVIATIONS USED IN NEUSE RIVER REPORT

TERMS DEFINED IN THIS REPORT

ORM	Organic-rich Mud
EF	Enrichment Factor
MEF	Maximum Enrichment Factor
TM	Trimmed Mean
NRTM	Neuse River Trimmed Mean
PRTM	Pamlico River Trimmed Mean
AOC	Area of Concern
CAOC	Contaminated Area of Concern
NAOC	Noncontaminated Area of Concern

STANDARD ANALYTICAL TERMS

ICAPES	Inductively Coupled-Argon Plasma-Emission Spectrometry
AAS	Atomic Absorption Spectrometry
LLQ	Lower Limit of Quantification
NIST	National Institute of Standards and Technology
SRM	Standard Reference Material

STANDARD ENVIRONMENTAL TERMS

NPDES	National Pollution Disharge Elimination System
WWTP	Waste Water Treatment Plant
SIU	Significant Industrial User

GOVERNMENT OFFICES

A/P	Albemarle/Pamlico Estuarine Study
DEM	N.C. Division of Environmental Management
DEHNR	N.C. Department of Environment, Health and Natural Resources
DMF	N.C. Department of Marine Fisheries
EPA	U.S. Environmental Protection Agency

CHEMICAL ELEMENTS ANALYZED IN THIS STUDY

Al	Aluminum
As	Arsenic
Cd	Cadmuium
Ca	Calcium
Cr	Chromium
Co	Cobalt
Cu	Copper
Fe	Iron
F	Fluorine
Pb	Lead
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Ni	Nickel
P	Phosphorus
K	Potassium
Si	Silica
Na	Sodium
Sn	Tin
Ti	Titanium
V	Vanadium
Zn	Zinc

PART I: EXECUTIVE SUMMARY

HEAVY METALS IN ORGANIC-RICH MUDS OF THE NEUSE RIVER ESTUARINE SYSTEM

Increased human activity contributes ever increasing amounts of suspended sediment and chemical contaminants to the estuarine system. About 242 operating municipal and industrial facilities are presently permitted by the N.C. Division of Environmental Management (DEM) to discharge up to 206 million gallons of waste water per day into the Neuse River Basin. Permitted facilities include municipal waste water treatment plants (WWTP), large industrial facilities that discharge up to 40 million gallons per day, and numerous small municipal and industrial operations. Many of these facilities are permitted to discharge specific heavy metals; however, for many the concentration of heavy metal toxicants in their waste water discharge is poorly known.

Heavy metal contaminants may also come into the Neuse River estuarine system from nonpoint source activities such as the use of pesticides, fertilizers, and soil conditioners in the extensive, large-scale agriculture and forestry industries that occur in the eastern two thirds of the estuary. Historical facilities such as old industrial and dump sites may contribute heavy metal contaminants, particularly those sites that occur in estuarine lowlands around urban centers and that received poorly known types of waste for decades. Many sites occur along the east bank of Slocum Creek and along the New Bern and Bridgeton waterfronts and could be leaking toxic metals into the adjacent estuaries.

Discharge of apparently low concentrations of heavy metals from both natural and anthropogenic point and non-point sources into estuarine environments dominated by organic-rich muds leads to potential sediment contamination problems. High adsorption capabilities of clay minerals coupled with high chemical reactivity of organic matter, continuously strip trace metals from the water column. Enrichment of trace metals in sediments continues through time as storms, biological processes, and man (i.e., fish trawling, dredging, etc.) routinely resuspend the mud sediments into the water column. Thus, the cumulative effect of large volumes of waste water discharge and runoff, with low metal concentrations, over long time periods can lead to substantial metal enrichment within the sediments. Toxic metals are then potentially available for further concentration and movement through the food chain by abundant filter and detritus feeding organisms living within organic-rich mud environments. Kimerle (1987) concluded that some chemicals tend to strongly partition to sediments becoming sinks that may be "acutely and chronically toxic to aquatic organisms".

Thus, analysis of the estuarine mud sediments represents a relatively easy and reliable approach to help establish environmental quality for several reasons. First, concentrations of toxic heavy metals are considerably enriched in sediments compared to their dilute character within the water column; therefore they can be analyzed and monitored with much more reliable results. Second, sediments represent a long-term average and a temporal record of assimilation that smooths out the short-term variability associated with collecting water samples; therefore they can readily indicate enrichment areas associated with various types of heavy metal sources. Third, information obtained from heavy metal analyses of a few samples can often be more useful in defining potential problem areas than many analyses of water samples taken over space and time. These problem areas may also be enriched in other chemical components such as organic toxicants, many of which are more difficult and costly to quantify. Thus, for many areas, sediment analyses for trace elements can be a much more cost effective means of identifying potential problem areas.

The major objective for this study is to **determine the concentration and distribution of a series of trace elements associated with organic-rich mud within the Neuse River estuarine system.** Four sub-objectives are as follows:

a) establish present contaminant levels around a series of known point and non-point sources,
b) identify specific "areas of concern" within the estuarine system,
c) define a basin wide framework for determining migration paths of contaminants through time and space, and
d) determine the pre-industrial or "natural background" levels of contaminants and establish changing impact through time resulting from agriculture, urbanization, and industrialization.

A regional grid of 203 sites was sampled throughout the Neuse River estuarine system representing most geographic and geologic conditions and anthropogenic sources of contaminants. From these sites, 413 subsamples were analyzed for sediment grain size, sediment composition, and chemistry including 7 major elements and 15 trace elements that include the EPA's priority pollutant metals (Table 1). Elemental analysis is based on a partial extraction procedure that may approximate "bioavailability" of the elements. Quantitative concentrations of 20 elements were determined utilizing an inductively coupled-argon plasma-emission spectrometer (ICAPES); mercury analyses were done utilizing atomic absorption spectrometry (AAS), and fluorine measurements utilized an electrometric method.

TABLE 1. Quantitative analysis for 22 elements on 413 sediment subsamples from 203 sample stations within the Neuse River estuarine system.

TRACE ELEMENTS (15)				MAJOR ELEMENTS (7)	
Arsenic	(As)	Molybdenum	(Mo)	Aluminum	(Al)
Cadmium	(Cd)	Nickel	(Ni)	Calcium	(Ca)
Chromium	(Cr)	Phosphorus	(P)	Iron	(Fe)
Cobalt	(Co)	Tin	(Sn)	Magnesium	(Mg)
Copper	(Cu)	Titanium	(Ti)	Potassium	(K)
Lead	(Pb)	Vanadium	(V)	Silica	(Si)
Manganese	(Mn)	Zinc	(Zn)	Sodium	(Na)
Mercury	(Hg)				

The analytical data were entered into SYMPHONY worksheets, evaluated statistically utilizing SAS software, and stored in various data bases. A Neuse River trimmed mean (NRTM) was calculated for each element and used as the reference concentration for all subsequent data analysis. Enrichment factors (EF) were determined for each trace element in each sample by comparing the elemental concentration to the Neuse River trimmed mean (NRTM) for surface samples. Areas containing one or more sample sites in which one or more trace elements have enrichment factors equal to or greater than 2 X the Neuse River trimmed mean are defined as contaminated areas of concern (CAOC). Non-contaminated or pristine areas of concern (NAOC) are those areas in which all trace elements occur in concentrations within the sediment that are around or below the Neuse River trimmed mean. Identifying the pristine "areas of concern" is important for estuarine management purposes since these areas are coming under increasing pressure for major development.

Analyses of the analytical data for organic-rich muds within the Neuse River estuarine system have documented specific lateral and vertical distribution patterns of elemental concentration throughout the basin. Anthropogenic sources are believed to be largely responsible for heavy metal enrichment within the Neuse River estuarine system. Sediments in the vicinity of known point source discharges are often substantially enriched in specific metals compared to sediments in other portions of the Neuse River. Surface sediments have been enriched up to and occasionally in excess of 100 times the elemental concentrations occurring either in surface sediments in pristine portions of the estuary or in sediments deeper in the cores that represent pre-man estuarine conditions.

Seventeen contaminated areas of concern (CAOC) and five noncontaminated areas of concern (NAOC) have been identified with respect to the quality of the bottom sediments of the Neuse River estuarine system (Fig. 1 and Table 2).

TABLE 2. Contaminated and noncontaminated areas of concern with respect to the chemical quality of the bottom sediments within the Neuse River estuarine system.
MAJOR CONTAMINATED AREAS OF CONCERN (6)
1. New Bern: Trent River East and Lawson Creek Waterfront
2. New Bern: Neuse River Waterfront
3. New Bern: Waste Water Treatment Plant
4. Bridgeton: Neuse River Waterfront
5. Bridgeton: Mill Branch
6. Slocum Creek:
Upper Portion (Cherry Point)
East Prong (Havelock WWTP and Cherry Point)
Southwest Prong (Havelock WTP)
MINOR CONTAMINATED AREAS OF CONCERN (11)
1. Inner Neuse River
2. Outer Neuse River
3. Fairfield Harbor
4. Lower Slocum Creek
5. Oriental Area Creeks
6. Oriental Harbor
7. Scotts Creek
8. Swift Creek
9. Trent River West
10. Upper South River
11. Whittaker Creek
NONCONTAMINATED AREAS OF CONCERN (5)
1. Adams Creek
2. Beard Creek
3. Clubfoot Creek
4. Goose Creek
5. Hancock Creek

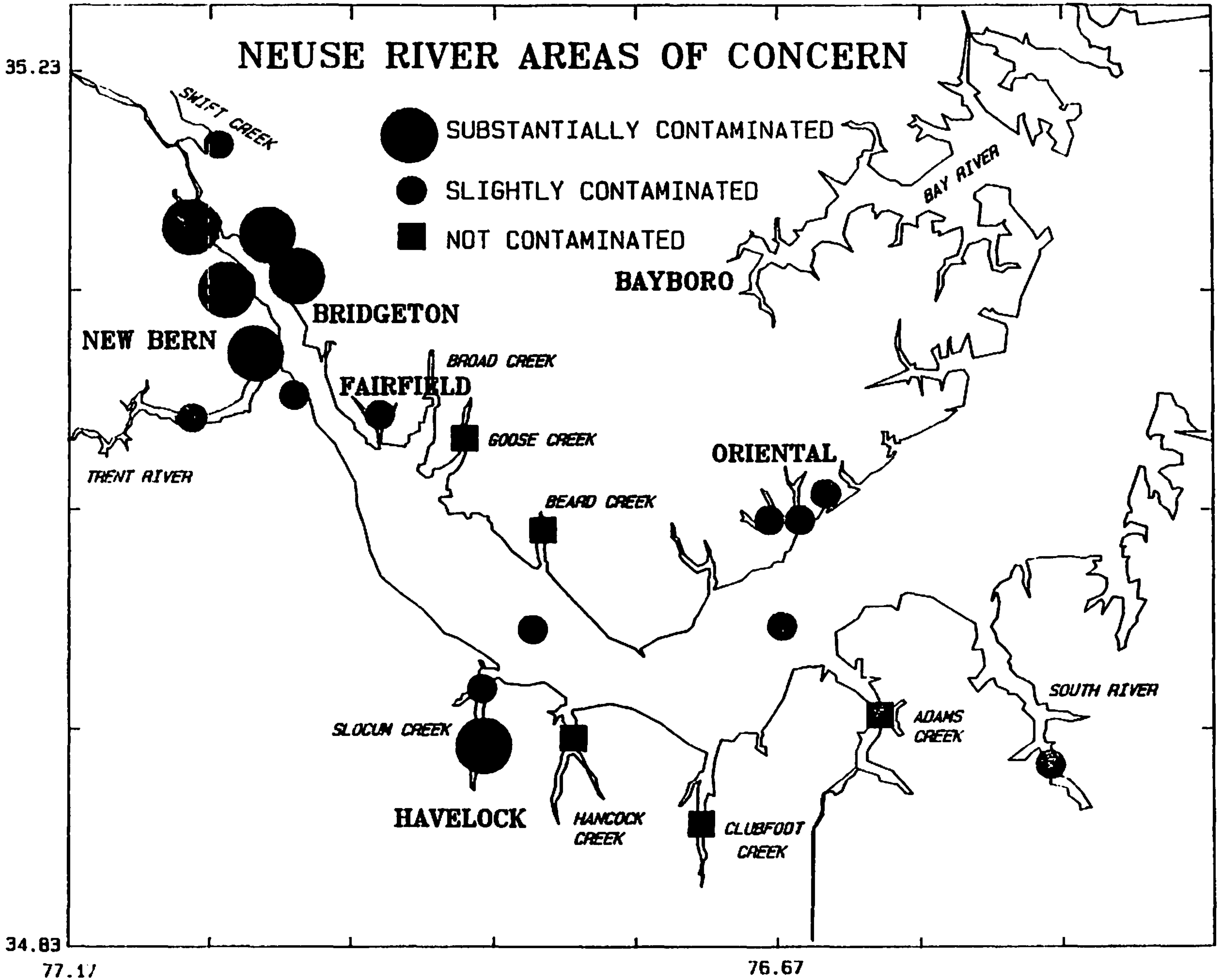

FIGURE 1. Map showing the Contaminated Areas of Concern and Noncontaminated Areas of Concern within the Neuse River estuarine system.

Six of the 17 CAOCs have major levels of sediment contamination with multiple sample sites that are substantially enriched in 3 or more trace elements with concentrations that exceed 2 X the Neuse River trimmed mean (Tables 3 and 4). Eleven COACs are characterized by minor levels of sediment contamination in which there are a) less than 3 trace elements at one or more sample sites with enrichment factors equal to or greater than 2 X the Neuse River trimmed mean and b) 2 or more trace elements with slight enrichment factors between 1.5 and 2 X Neuse River trimmed mean.

The 5 NAOCs are fairly pristine, estuarine tributaries with low levels of development and no substantial trace element enrichment within the sediments. The low trace element concentrations are similar to those occurring in deeper subsurface samples throughout the Neuse River estuarine system, excluding the highly contaminated areas around New Bern and in Slocum Creek. These NAOCs come closest to representing the pre-industrial character of the entire Neuse River estuarine system. However, increasing development pressures within these pristine estuaries could lead to the long-term cumulative degradation of their environmental quality if we don't recognize these important areas of concern.

TABLE 3. Maximum enrichment factors (MEF) for 15 trace elements in both surface and deep sediments of the substantially contaminated areas of concern in the Slocum Creek area. MEF values of 1 are equal to the Neuse River trimmed mean; therefore, values > 1 are slightly enriched, values = or > 2 are substantially enriched (underlined), and values < 1 are deficient relative to the Neuse River trimmed mean.

CRITICAL TRACE ELEMENTS (15)		MAXIMUM ENRICHMENT FACTORS (X NEUSE RIVER TRIMMED MEAN)					
		SLOCUM CREEK					
		Upper Slocum		East Prong		Southwest Prong	
		Surf	Deep	Surf	Deep	Surf	Deep
Arsenic	(As)	1.3	2.2	1.6	1.4	2.2	1.5
Cadmium	(Cd)	26.4	54.3	16.4	32.9	4.4	20.1
Chromium	(Cr)	9.3	11.2	6.5	17.8	1.7	11.0
Cobalt	(Co)	1.4	1.2	1.0	0.9	1.2	1.0
Copper	(Cu)	2.4	2.6	21.2	15.2	1.5	1.9
Lead	(Pb)	3.5	4.0	5.4	12.4	2.4	3.1
Manganese	(Mn)	1.6	1.0	1.0	1.5	1.8	1.1
Mercury	(Hg)	71.6	15.9	2.9	7.1	1.2	1.1
Molybdenum	(Mo)	6.2	18.2	10.5	4.4	6.8	3.5
Nickel	(Ni)	3.2	3.8	2.6	6.3	1.5	2.4
Phosphorus	(P)	2.5	1.5	4.6	2.9	3.6	2.9
Tin	(Sn)	2.0	2.1	0.6	0.9	0.7	0.5
Titanium	(Ti)	1.2	1.7	0.7	0.6	0.5	0.6
Vanadium	(V)	1.2	1.3	1.6	6.3	1.2	1.2
Zinc	(Zn)	2.3	2.1	3.4	7.3	1.6	1.7
NUMBER ENRICHED		10	10	9	10	5	6

TABLE 4. Maximum enrichment factors (MEF) for 15 trace elements in both surface and deep sediments of the substantially contaminated areas of concern in the New Bern--Bridgeton areas. MEF values of 1 are equal to the Neuse River trimmed mean; therefore, values > 1 are slightly enriched, values = or > 2 are substantially enriched (underlined), and values < 1 are deficient relative to the Neuse River trimmed mean.

CRITICAL TRACE ELEMENTS (15)	MAXIMUM ENRICHMENT FACTORS (X NEUSE RIVER TRIMMED MEAN)					
	NEW BERN WATERFRONT					
	Trent River East & Lawson Creek		Neuse River		Waste Water Treatment Plant	
	Surf	Deep	Surf	Deep	Surf	Deep
Arsenic (As)	2.2	2.0	2.8	2.0	2.3	1.8
Cadmium (Cd)	1.7	1.9	1.8	1.9	2.5	1.7
Chromium (Cr)	1.8	3.0	2.0	1.9	1.0	0.8
Cobalt (Co)	2.3	2.9	1.8	1.7	3.2	3.0
Copper (Cu)	12.8	18.3	1.9	1.5	4.6	3.3
Lead (Pb)	6.9	10.5	2.0	2.1	2.2	2.2
Manganese (Mn)	2.8	1.6	2.3	1.2	0.8	0.9
Mercury (Hg)	4.7	12.0	1.7	2.9	4.3	8.5
Molybdenum (Mo)	2.0	4.0	2.9	2.4	1.5	0.6
Nickel (Ni)	7.0	14.7	2.2	1.6	2.7	0.9
Phosphorus (P)	2.6	3.3	3.4	4.2	2.6	2.1
Tin (Sn)	2.1	2.3	2.0	1.7	1.2	1.3
Titanium (Ti)	1.6	1.9	1.5	1.9	1.5	1.6
Vanadium (V)	1.5	1.5	1.5	1.7	1.0	1.0
Zinc (Zn)	11.6	18.1	2.3	2.0	2.8	2.3
NUMBER ENRICHED	11	11	9	6	9	6

CRITICAL TRACE ELEMENTS (15)	BRIDGETON WATERFRONT			
	Mill Branch		Neuse River	
	Surf	Deep	Surf	Deep
Arsenic (As)	1.6	1.4	2.1	1.9
Cadmium (Cd)	30.4	1.4	4.4	2.6
Chromium (Cr)	3.9	1.6	7.0	2.7
Cobalt (Co)	1.6	0.6	2.1	1.8
Copper (Cu)	22.8	0.9	5.0	1.0
Lead (Pb)	1.8	0.9	2.3	2.1
Manganese (Mn)	0.4	0.4	3.1	1.2
Mercury (Hg)	0.7	0.7	1.2	1.3
Molybdenum (Mo)	1.3	2.0	1.3	1.7
Nickel (Ni)	178.7	2.8	6.6	5.3
Phosphorus (P)	2.5	1.1	2.7	1.0
Tin (Sn)	33.4	1.9	1.9	1.3
Titanium (Ti)	0.6	0.6	1.1	1.7
Vanadium (V)	0.9	1.0	1.4	1.4
Zinc (Zn)	4.5	0.7	2.9	1.3
NUMBER ENRICHED	7	2	10	4

CONCLUSIONS

1. Due to the mineralogy and chemistry of organic-rich muds occurring within the North Carolina estuarine system, low concentrations of trace elements within the water column can be sequestered and concentrated within the sediments through time. These bottom muds are continuously re-suspended into the water column by bottom disturbing activities and allow for the continued interaction with water column chemicals. Most sequestered trace elements are loosely bound to the fine-grained sediments and consequently are potentially available to filter- and bottom-feeding organisms living in these ecosystems.
2. All 15 trace elements analyzed in this study are substantially enriched within the bottom sediments at one or more sites in the vicinity of known point source discharges within the Neuse River estuarine system. The maximum enrichment factors for all samples analyzed are: Ni = 178X, Hg = 73X, Cd = 54X, Sn = 33X, Cu = 23X, Cr = 18X, Mo = 18X, Zn = 18X, Pb = 12X, Mn = 8X, V = 6.3X, P = 5.6X, Ti = 3.6X, Co = 3.2X, and As = 2.9X (times the Neuse River trimmed mean).
3. Based upon chemical quality of the bottom sediments of the Neuse River estuarine system, 17 contaminated areas of concern have been identified.
   A. Six of these areas have major levels of sediment pollution (multiple sample sites that are substantially enriched in 3 or more trace elements (enrichment factors = or >2X Neuse River trimmed mean) and include the following areas.
      a. New Bern: Trent River East and Lawson Creek Waterfront;
      b. New Bern: Neuse River Waterfront;
      c. New Bern: Waste Water Treatment Plant;
      d. Bridgeton: Neuse River Waterfront;
      e. Bridgeton: Mill Branch; and
      f. Slocum Creek: Upper Portion, East Prong, and Southwest Prong.
   B. Eleven contaminated areas of concern are characterized by minor levels of trace element enrichment (less than 3 trace elements at one or more sample sites (enrichment factors = or >2X Neuse River trimmed mean).
4. Based upon chemical quality of the bottom sediments of the Neuse River estuarine system, 5 noncontaminated areas of concern have been identified and include the following:
      a. Adams Creek;
      b. Beard Creek;
      c. Clubfoot Creek;
      d. Goose Creek; and
      e. Hancock Creek.

   These 5 areas are fairly pristine tributaries with low levels of development and no substantial enrichment of trace elements within the sediments.
5. With the exception of the major contaminated areas of concern, the surface sediments throughout the Neuse River estuarine system are enriched in 11 trace elements relative to the deeper sediments (Ni = 2.5X, P = 1.6X, Zn = 1.6X, Cu = 1.5X, Mn = 1.5X, Sn = 1.4X, Pb = 1.3X, Cr = 1.2X, As = 1.1X, Co = 1.1X, and V = 1.1X). Cadmium and mercury concentrations are generally the same with depth, while molybdenum and titanium have concentrations that generally increase with depth into the sediments.

6. Most substantially enriched trace elements in two major contaminated areas of concern (New Bern: Trent River West and Lawson Creek; and Slocum Creek) have concentration patterns that generally persist or increase with depth. This reflects either the discharge of trace elements over long time periods and/or disturbance and mixing by various anthropogenic activities. This pattern may also indicate that discharges have varied in volume and type of trace elements through time. All other contaminated areas of concern display major down core decreases in concentration for most of the 15 trace elements.
7. Anthropogenic sources are largely responsible for trace element contamination within the Neuse River estuarine sediments. NPDES permitted point source discharges appear to be the major contributors of enriched trace elements to bottom sediments. Nonpoint source discharges are also important, but they are generally more diffuse and difficult to evaluate.
8. Municipal waste water treatment plants and agricultural drainage outfalls appear to be supplying high levels of organic-matter to the tributary creeks with associated high levels of phosphorus. Resulting high organic concentrations probably increase the effectiveness of sequestering other trace elements from the waste discharge into the adjacent sediments. Major upward increases in phosphorus concentration in all cores suggest that these organic-rich muds may be an important source of "new" phosphorus, as well as amonia to the estuarine waters.
9. The waste water treatment plants at New Bern, Cherry Point, and Havelock appear to have contributed major amounts of trace elements to the sediments around their discharges. These discharge areas (with design flows from 4 to 1.5 MGD) show substantial sediment enrichment of 6 trace elements (maximum enrichment factors: Cd = 15X, Cu = 27X, Hg = 68X, P = 6X, Pb = 2.7X, and Zn = 2.8X the Neuse River trimmed mean) and variable enrichment of 4 trace elements (As = 2.3X, Co = 3.2X, Cr = 4.4X, and Ni = 2.7X). Five trace elements (Mn, Mo, Sn, Ti, and V) were not substantially enriched around any WWTP. The net impact of any specific WWTP upon sediment contamination appears to be dependent upon four interacting variables: a) population; b) number, size, and type of industrial facilities discharging to the WWTP; c) age, design, type and degree of treatment, and management of the WWTP; and d) sediment composition and dynamics of the discharge basin.
10. All marinas contribute substantial amounts of copper, and variable amounts of zinc and lead to the surrounding sediments. The total amounts appear to be direct functions of the size, age, and nature of the marina operation.
11. Industrial plating facilities on the Trent River West at New Bern, Mill Branch at Bridgeton, and Slocum Creek have contributed the highest levels of trace metals to Neuse River sediments. The worst contaminated of these is Slocum Creek, which also has numerous waste disposal sites along the banks; these waste sites could be major contributors of trace elements to the sediments.

12. Bottom sediments in the southern half of Slocum Creek are severely contaminated by 9 trace elements (maximum enrichment factors: Hg = 72X; Cd = 54X; Cu = 21X; Cr = 18X; Mo = 18X; Pb = 12X; Zn = 7.3X; Ni = 6.3X; P = 4.6X Neuse River trimmed mean) and locally by 3 other trace elements (maximum enrichment factors: V = 6.3X; As = 2.2X; and Sn = 2X Neuse River trimmed mean). Of the 15 trace elements, only Co, Mn, and Ti are not substantially enriched within Slocum Creek.
13. The general pattern of sediment contamination in Slocum Creek appears to reflect at least 5 specific point sources where trace elements are either discharged or leak into the estuarine system. The regional distribution of different trace elements, their downstream decrease to non-contaminated sediments at the mouth of Slocum Creek, and the composition of samples within the Neuse River generally suggest the following conclusions.
    a. Multiple point sources have contributed different trace element contaminants to Slocum Creek for long time periods.
    b. Only minimal redistribution of contaminated sediments has occurred within Slocum Creek; tidal or storm transport and mixing do not appear to be important processes with respect to trace element distribution.
    c. Contaminated sediments are not being transported into the Neuse River.
14. Based upon the present data, it is not clear how much of the trace element contamination problem in Slocum Creek is relict and due to historic processes and how much is ongoing today. However, modern accumulation of metals is probably taking place in the surface sediments of Slocum Creek from the following sources:
    a. ongoing discharges from the NPDES permitted waste water treatment plants at Cherry Point and Havelock and
    b. surficial groundwater leachates from the numerous waste disposal sites adjacent to Slocum Creek.
15. Permitting a relocation of a new discharge for Cherry Point into the Neuse River and allowing increased levels of metals to be discharged will lead to the development of trace element plumes of substantially enriched sediments within the Neuse River over time. This enrichment could contribute to the overall degradation of environmental quality within the main portion of the Neuse River estuarine system.
16. Ever increasing amounts of discharged waste water into the Neuse River will continue the systematic enrichment of trace elements within the sediments in the estuarine system. North Carolina should take the approach of requiring waste water treatment plants for industries and government agencies to design and incorporate more efficient treatment systems with the discharge of minimum amounts of potentially toxic elements into "Public Trust Waters". The increased costs are essential to maintaining a viable ecosystem and ensuring long-term protection of environmental quality.

PART II: INTRODUCTION

NEUSE RIVER DRAINAGE BASIN

The Neuse River drainage basin, the third largest drainage system in North Carolina, encompasses about 6,192 square miles within both the piedmont and coastal plain of North Carolina (Fig. 2). This drainage begins with the Eno and Flat Rivers in Durham County in the middle piedmont, north of the Raleigh-Durham-Chapel Hill triangle. The River flows southeast for over 220 miles through Goldsboro, Kinston, and New Bern to empty into Pamlico Sound. Only a small portion (328,700 acres, N.C. DEM, 1990a) of the eastern-most end of this drainage system has been drowned by the present level of the sea and constitutes the Neuse River estuarine system. Within the coastal plain, from Goldsboro southeastward to a few miles northwest of New Bern, the River operates as a river that meanders slightly within a narrow swamp forest floodplain. From this point east, the River becomes wider and deeper; it is over 6 miles wide and 5 meters deep at the mouth where it empties into Pamlico Sound. Throughout this eastern portion, the Neuse River and associated drowned tributaries operate as a drowned river estuarine system.

Estuarine waters in the area extending from a few miles northwest of New Bern to Northwest Creek (approximately equal to the "transition zone" on Figure 3) have been classified as "SC" ("saltwaters protected for secondary recreation, fishing and aquatic life including propagation and survival" by the N.C. DEM, 1990a). Waters in the area extending from Northwest Creek, eastward to Hancock Creek (approximately equal to the "inner estuarine zone" on Figure 3) have been classified as "SB" ("saltwaters protected for human contact such as swimming and all SC uses"). Waters in the area extending from Hancock Creek, eastward to the confluence with Pamlico Sound (approximately equal to the "outer estuarine zone" on Figure 3) have been classified as "SA" (saltwaters protected for shell fishing and all SB and SC uses"). Due to increasing problems with eutrophication within the lower Neuse River during the 1980's, the N.C. Environmental Management Commission classified the entire Neuse River Basin as "Nutrient Sensitive Waters" effective May 1, 1988 (N.C. DEM, 1990a). This classification requires development of a management plan with implementation strategies for all nutrient discharges from both point and nonpoint sources.

WATER QUALITY STATUS OF THE NEUSE RIVER ESTUARINE SYSTEM

There is little doubt that the North Carolina estuarine environment is now indelibly marked by products of human activity. Concerns about possible deleterious effects of this impingement by man on the well-being of this critical ecosystem bring renewed importance to the problems of the fate of anthropogenic chemical species within the estuarine environment. Man's activities in the Neuse River estuarine system contribute ever increasing amounts of suspended sediment and trace elements.

In a water quality study of the Neuse River, Harned (1980) stated that the Neuse River <u>water</u> is satisfactory for most uses with only a few water-quality parameters indicating problems and certain constituents occurring at undesirable levels. He found that trace metals generally occurred in low concentrations with only iron and manganese concentrations consistently above U.S. EPA (1976) criteria levels allowable for domestic water supplies and cadmium, selenium, and lead concentrations periodically above these levels. Harned (1980) concluded that "overall, ambient concentrations for toxic

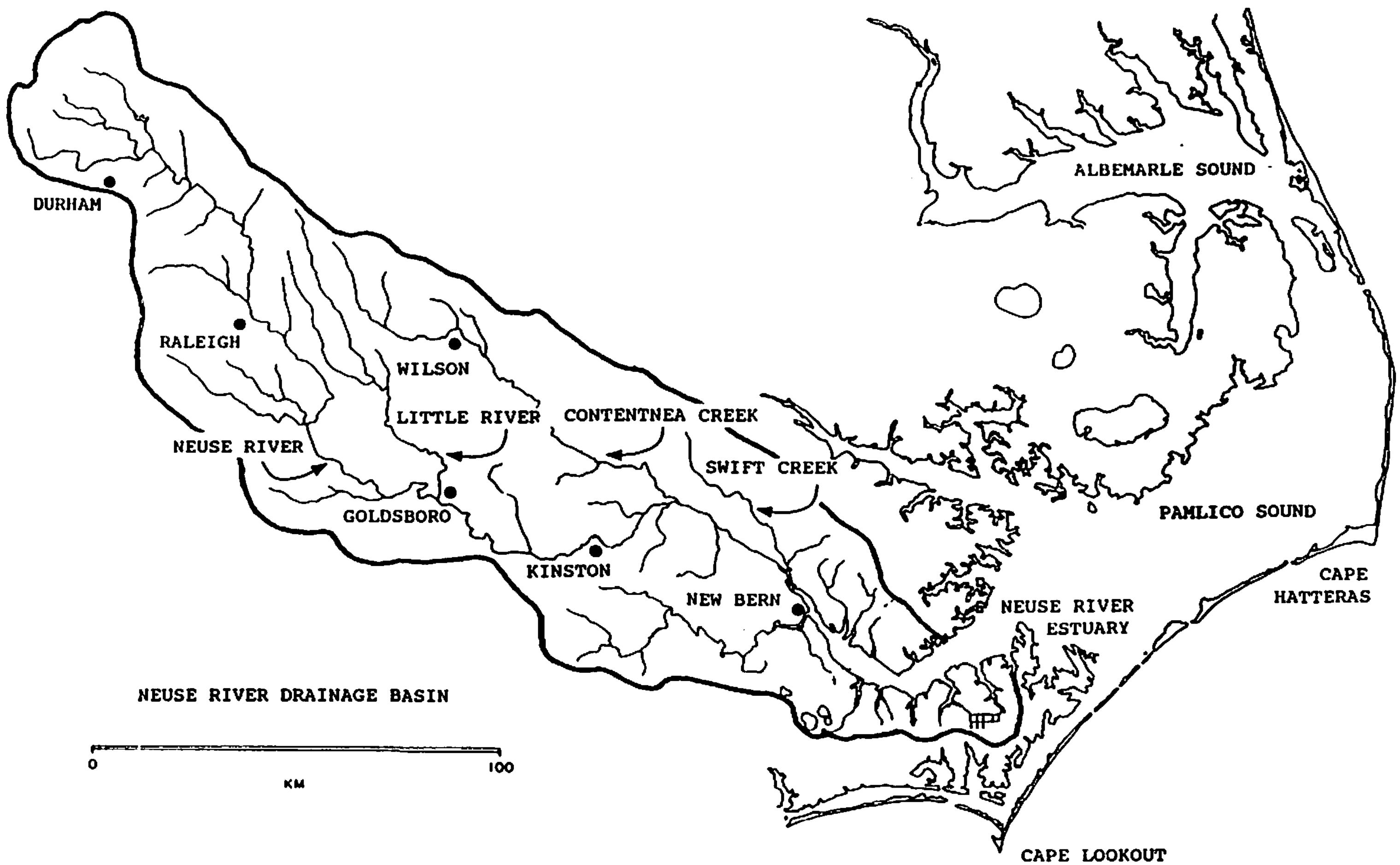

FIGURE 2. Map of the Neuse River drainage basin.

elements in Neuse River water at both stations are low. However, little is known about toxic element concentrations in bottom sediments or in aquatic organisms found in the Neuse River."

Low concentrations of toxic heavy metals in discharge waters or in estuarine water columns are not necessarily indications that the estuaries are free from metal contamination. Due to rapid changes in estuarine water chemistry, high adsorption characteristics of omnipresent inorganic clay minerals, and the chemical processes associated with metal complexing and organic matter, many trace metals are often enriched in the sediments at levels that are orders of magnitude above acceptable water level concentrations. Enrichment of trace metals within the sediments can continue as storms, biological processes, and man routinely resuspend the muds into the water column where they can chemically react with low concentrations of dissolved substances. Consequently, the cumulative effect of large discharge volumes with very low elemental concentrations over long time periods allows for continuous interaction with and significant enrichment of concentrations in the inorganic and organic sediment components. Thus, elemental enrichment within surficial sediments may become a factor in long-term, potential bioavailability of trace metals. As trace metal concentrations increase within surficial sediments, they potentially become more available to the food chain through abundant filter and detritus feeding organisms living within the organic-rich mud environments.

Site specific and regional baseline sediment data obtained for the Neuse River estuarine system represent an important first step. From this point, we can begin to determine if causal relationships exist between toxic trace metal sediment contamination, water quality, and the resultant health of the biological components of the estuary (i.e. shellfish, finfish, etc.). Only when these causal relationships are understood can effective management plans be developed to optimize the estuarine resources and minimize the potential detrimental impacts of increasing concentrations of metals in sediments resulting from rapid urbanization, industrialization, and chemical agriculture occurring within North Carolina's estuarine system. The National Academy of Sciences (1974) in a study on "Geochemistry and the Environment" concluded that finding realistic, workable means to mediate conflicts between human uses clearly depends upon understanding the complex interactions between heavy metals resulting from human activities and natural systems.

OBJECTIVES

The major objective and sub-objectives for this study entitled "Heavy Metals in Organic-Rich Muds of the Neuse River Estuarine System" are to:

Determine concentrations and distributions of a series of trace elements (i.e., toxic heavy metals and phosphorus contaminants) associated with organic-rich mud within the Neuse River estuarine system.

- **a. Establish present contaminant levels around a series of known point and non-point sources,**
- **b. Identify specific "areas of concern" within the estuarine system,**
- **c. Define a basin wide framework for determining migration paths of contaminants through time, and**

d. Determine the pre-man or "natural background" levels of contaminants and establish changing impact through time resulting from agriculture, urbanization, and industrialization.

This report presents the results from year two of a three year project. Each year will consider one of the main estuarine systems (i.e., the Pamlico River, Neuse River, and Albemarle Sound estuaries, respectively). This study will develop baseline information essential for generating a management plan concerning toxic metal contamination within the estuarine system and for addressing the following all important question:

What are the inter-relationships between sediment/water column and sediment/organism interactions and resultant chronic effects of heavy metal contaminants upon the North Carolina estuarine system?

THE NATURE OF TRACE ELEMENTS

Trace Elements and Health

Heavy metals and other trace elements are normal constituents of most ecosystems. However, natural concentrations are often being supplemented by, and the normal ratios among them are being altered by the activities of man, sometimes at an alarming rate. The dual role of many trace elements in biological systems (i.e., some acting as required nutrients within a restricted concentration range and all acting as potentially toxic contaminants at some level) is a well documented fact (National Academy of Sciences, 1974; Crounse et al., 1983a, 1983b).

Many factors affect the availability, transport, and concentration of metals into and through the natural coastal system. Ultimately, some of these metals get into the food chain and influence the well-being of many organisms, including man. Small excesses of specific metals in the food chain may have measurable health effects on organisms as demonstrated by the National Academy of Sciences report on "geochemistry and the environment" (1974) and the NOAA National Status and Trends Program report on "the potential for biological effects of sediment-sorbed contaminants" (Long and Morgan, 1990). Increases that can be tolerated depend largely on the natural background levels and subsequent rates and amounts of increased concentrations resulting from urbanization and agricultural and industrial development. Trace elements can enter the aquatic food chain in many ways including direct incorporation from soluble aqueous phases, ingestion and digestion of water and sediment, or by the transport across gill membranes, to name a few.

Accessibility of an element in the abiotic environment for incorporation into the biosphere is referred to as "bioavailability". Because of the magnitude of the concentrations encountered in sedimentary environments, the intimacy with which most benthic organisms are in contact with this environment, and the fact that many of these benthic organisms form the base of important food chains, bioavailability constitutes a very important, but poorly understood consideration. The bioavailability of any given element depends upon a host of complex factors. Principal among these factors are 1) the feeding habits, stage in the life cycle, and age and health of the particular organism in question; 2) the chemical form and manner in which a particular element is incorporated into the sediments; and 3) the physical and chemical conditions of the environment at the time of incorporation (e.g., temperature, salinity, Eh, pH, etc.).

Many studies document the direct and indirect effects of anomalous levels of heavy metals on organisms, many of which have been summarized in Long and Morgan (1990). For example, mercury, cadmium, arsenic, and lead are toxic to man and to other living things in various chemical forms. In most cases threshold limits for long-term, toxic effects are poorly understood, but they often tend to accumulate in the body (Sandstead et al., 1974). Mercury for example, "has long been recognized as one of the more toxic metals" (N.C. DEM, 1983). U.S. EPA (1980) states that "mercury and its various compounds have no known metabolic function and their presence in the cells of organisms represents some contamination from either natural or anthropogenic sources." On the other hand, chromium and zinc are trace elements known to be essential to animal and human health and additions to the environment may actually be beneficial; in these situations, deficiency is the major health concern (Mertz et al., 1974; Sandstead et al, 1974). In a third category are such elements as selenium, copper, and molybdenum which are both essential nutrient elements, but will cause severe health problems with either deficiencies or excesses (Davis et al., 1974; Oldfield et al., 1974). The importance of trace metals to human health concerns is reflected by the Federal standards for drinking water (U.S. EPA, 1986). The standards include 8 heavy metals in the primary restrictions, which have critical health effects, and five elements in the secondary restrictions, which are less critical to health (Table 5).

TABLE 5. Federal standards for elemental concentrations in drinking water (U.S. EPA, 1986).

PRIMARY RESTRICTIONS	SECONDARY RESTRICTIONS
As = 50 ug/L	Cl = 250,000 ug/L
Ba = 1,000 ug/L	Cu = 1,000 ug/L
Cd = 10 ug/L	Fe = 300 ug/L
Cr = 50 ug/L	Mn = 50 ug/L
Pb = 50 ug/L	Zn = 5,000 ug/L
Hg = 2 ug/L	
Se = 10 ug/L	
Ag = 50 ug/L	

Trace Elements in the Estuarine Environment

The transient nature of estuarine water column characteristics and the dilution factors frequently engineered into point source discharges often maintain trace metal concentrations in water below "safe" or even detectable limits. On the other hand, the sedimentary regime is much less transitory with regard to both the medium as well as the organisms inhabiting it. Furthermore, heavy metals and other trace elements can become incorporated into sediments by several different mechanisms and can be partitioned among a variety of sedimentary phases as follows:

1. Dissolved in interstitial pore waters;
2. Adsorbed or chelated by organic matter (often occurring as surface coatings);
3. Adsorbed or occluded with oxy-hydroxy precipitates of iron or manganese (occurring as discreet particles or surface coatings);
4. Precipitated as distinct metal salts (e.g., hydroxides, sulfides, carbonates, etc.) or other mineral species;
5. Adsorbed or occluded in carbonates of inorganic origin (calcite, aragonite, etc.) or of biogenic origin (shell hash);
6. Adsorbed at ion exchange or adsorption sites of mineral grains;
7. Bound at interlayer sites of clay minerals; and
8. Incorporated into the crystalline lattice of minerals.

As a result of these many concentrating mechanisms, benthic sediments are often envisioned as the ultimate sink for much of the soluble and nearly all particulate matter entering aquatic environments. Consequently, heavy metal concentrations in sediment are often orders of magnitude greater than those in the overlying waters, even for uncontaminated systems (Wolfe and Rice, 1972).

The partition of many elements between solution and suspended particles in fresh water undergoes drastic changes during estuarine mixing in response to major changes in pH, ionic strength, solution composition, salinity, etc. (Li et al., 1984). During estuarine mixing, some elements form strong complexes with humic acids and are coagulated into particles (Sholkovitz, 1978; Sholkovitz and Copland, 1981). Other heavy metals are scavenged from the water column by the fine-grained, suspended clay components (Turekian, 1971). Aller (1980) demonstrated extensive scavenging of reactive elements dissolved in the overlying water column by fine-grained estuarine bottom sediments within time scales of days. Turekian (1971) demonstrated that many heavy metals are maintained at low levels within the estuarine water column as a result of scavenging action of suspended particles. Consequently, Turekian et al. (1980) found that estuarine bottom sediments are strongly impacted by the trace metals from industry and that the primary mode of concentration and transportation within the estuarine zone is via sediment particles.

It has been well established that fine-grained sediments represent the largest reservoir for heavy metals within an estuarine system (Renfro, 1973). This reservoir, which occurs both in suspended and bottom sediments, obviously has the potential of conveying large quantities of anthropogenically derived metals to estuarine biota, particularly filter and detritus feeding macrofauna. In efforts to assess the relative importance of bioaccumulation of heavy metals by estuarine organisms, Cross and Sunda (1978) and Jenne and Luoma (1975) concluded that the "utility of continuing to conduct bioaccumulation and toxicity experiments based solely on total dissolved concentrations in the water must be severely questioned." Knowledge of the concentrations, chemical form, and bioavailability of metals in the sediment and organic matter reservoirs is essential before the consequences of metal additions, both in terms of bioaccumulation and toxicity, can be predicted (Cross and Sunda, 1978).

Turekian et al. (1980) concluded that "a strong correlation exists between high metal concentrations in all components of the coastal system (water, sediment, and organisms) and the proximity of polluted fresh-water stream and sewer discharges." They demonstrated a direct correlation between increasing heavy metal concentration with decreasing grain size in the estuarine sediments. Aller (1980) found that fine grained sediments were more efficient scavenging agents and that during mixing they exchanged low-activity for high-activity elements within the overlying water column. Thus, from the standpoint of particle interaction with geochemically reactive elements in the water column, a source of heavy metals and a fine-grained sediment are extremely important.

Horizontal dispersal during deposition and vertical redistribution after deposition result from storm and current processes affecting particles suspended in the water column, and physical and biological mixing of particles in the sediment column. Turekian et al. (1980) found strong horizontal distribution patterns of specific heavy metals which they believe demonstrates that complete homogenization does not proceed fast enough to obliterate the point sources of metals.

Tidal and storm resuspension of the organic-rich muds that floor the bottom of a large portion of the Albemarle-Pamlico-Neuse estuarine system, are important for sedimentological, biological, and geochemical processes. The physical stability and resuspension of bottom muds are important to water transparency and hence photosynthesis (Rhoads et al., 1978). Resuspended material often contains microbial coatings which are important food resources for both zooplankton and benthic organisms (Rhoads et al., 1975; Tenore, 1977) and estuarine chemical processes associated with adsorption and desorption of heavy metals and radionuclides (Benninger, 1976; Aller and Cochran, 1976; and Turekian, 1977; Aller, 1980; Li et al., 1984).

Sediment transport and resuspension within estuarine water bodies are often tied directly to major storm events. Storm processes that affect coastal sedimentation include storm surges, wave action, and flooding resulting from heavy rainfall (Hayes, 1978). Single storms can cause more erosion, bottom resuspension, and deposition in estuaries within a few hours than would occur in decades under normal conditions. During these same storm periods, there is a maximum contribution of heavy metals and other contaminants to the estuarine systems, in consort with maximum turbidity levels for absorption and removal to the bottom sediment regime. For example, urban runoff and industrial waste is often processed through waste water treatment plants (WWTP). However, during periods of high discharge, treatment plants are often bypassed and unprocessed effluent is discharged directly into the rivers, resulting in enrichment of the sediment surrounding the outfall in organic carbon and heavy metals (Turekian et al., 1980) as demonstrated for sewage outfalls in Long Island Sound.

Potential Sources of Trace Element Contaminants

Human (metabolic) waste products often have high concentrations of phosphorus and various metals such as zinc (1,000 ppm), lead, and copper (400 to 500 ppm each) (Horvath, 1972). Without industrial waste, raw municipal waste water generally contains concentrations of many heavy metals that are lower than the EPA drinking water standards (Crites et al., 1979). However, sewage sludge generally contains high metal contents as indicated in Table 6. Actual concentrations for any sewage treatment plant are extremely variable and depend upon the amount and composition of industrial waste that is treated. All too often, during peak use periods, mechanical breakdowns, and periods of storms and high rainfall runoff, untreated effluent is discharged directly into the environment from waste water treatment plants. Two recent reports indicate that this type of discharge is common within the Neuse and Pamlico River systems (Clean Water Fund-NC, 1990; EDF and PTRF, 1989).

TABLE 6. Concentrations of metals in sewage sludge (Regan and Peters, 1970).

ELEMENT	CONCENTRATION RANGE
Fe	9,800 to 11,000 ppm
Zn	4,300 to 7,690 ppm
Cr	2,100 to 3,200 ppm
Cu	1,200 to 2,100 ppm
Ni	790 to 1,200 ppm
Pb	650 to 1,100 ppm
Cd	290 to 520 ppm

The shorelines along North Carolina's estuaries contain a few major industrial plants such as pulp and paper mills, metal plating operations, chemical plants, textile mills, synthetic fiber plants, and mining operations. Some of these industrial facilities have large waste-water discharges that contain varying amounts of different heavy metals. In addition, many small industrial municipal operations have point source discharges (App. C) with the potential for containing specific trace elements and producing localized or cumulative impacts upon the estuarine system.

A poorly known, but potentially important contributor of heavy metals to the estuaries are the many historic waste disposal and industrial sites scattered through the marshes and lowlands of eastern North Carolina. Since these waste facilities and dump sites generally predate the time of environmental awareness, their locations and the chemicals dispensed into them are also poorly known.

A major source of lead in the environment has been from the combustion of lead-containing fuel, most of which either ends up in the atmosphere or falls on or near roads. Lead is removed from the atmosphere by rain and is washed off the roadways, parking lots, and commercial and industrial sites by rainwater. Much of this lead is insoluble and is quickly removed from the water by sediment adsorption. Carr et al. (1983) found storm water runoff from seven storms in three different urban settings had the ranges of concentrations of dissolved heavy metals presented in Table 7.

Use of heavy metal pesticides has generally increased with the decline in use of chlorinated hydrocarbon pesticides through the years (Nat. Acad. of Sci., 1974). In 1970 there were 96 pesticides commercially available that had heavy metal bases including Li, Cr, Pb, Cd, Zn, Se, Cu, F, and I. The National Academy of Science concluded that "knowledge of toxicity levels at relatively low-level long-term dosages for many of these pesticides are completely lacking. Furthermore, the ultimate depository in nature for many of these elements is at present unknown."

Based on limited available data, Gale and Adams (1984) concluded that peat mining activity in North Carolina and subsequent land use changes will significantly increase fluxes of trace metals. Various peat mining EIS studies have demonstrated mercury concentrations are consistently high in examined sediments (0.01 to 1.0 ppm) from drainage canals and in the Pungo River. Nine percent of 368 water samples obtained with the Ambient Water Monitoring Program (AWMP) from 1979 through 1981 contained detectable mercury (N.C. DEM, 1983). However, "at this point in time, little information exists

TABLE 7. Concentrations of metals in urban storm-water runoff (Carr et al., 1983).

ELEMENT	CONCENTRATION RANGE
Hg	<0.3 to 5 ug/L
As	<5 to 90 ug/L
Cd	<10 to 950 ug/L
Ni	30 to 5,900 ug/L
Cr	25 to 8,470 ug/L
Cu	100 to 20,100 ug/L
Pb	250 to 64,600 ug/L
Zn	130 to 37,600 ug/L
Fe	61,302 to 970,000 ug/L

to address the critical question of the impacts of such increases in drainage waters on biota of the receiving estuarine systems" (Gale and Adams, 1984). They believe that determining the potential for impacts is an important research need and "if impacts do occur, they are not likely to be the result of a single material, such as mercury or Alachlor, but rather the result of the cumulative effects of a variety of trace metals, pesticides, and other substances."

TRACE ELEMENTS IN THE NEUSE RIVER ESTUARINE SYSTEM

Point and Nonpoint Source Discharges

The Albemarle-Pamlico estuarine system acts as a large settling basin for sediments, organic matter, heavy metals, and other contaminants resulting from agriculture, urbanization, and industrialization within the drainage basin (Copeland et al., 1983, 1984). For example, Harned (1980) sampled general Neuse River water at two stations repeatedly between 1974-77 and found the ranges of heavy metal concentration listed in Table 8. Heavy metal concentrations at two stations were above the U.S. EPA (1976) domestic raw water supply criteria levels as follows: iron (28% and 39% of the time), manganese (100% and 88% of the time), cadmium (22% and 17% of the time), selenium (15% and 25% of the time), and lead (25% and 20% of the time).

Harned (1980) calculated the "inorganic pollution load" or man-made contribution to the natural load of dissolved solids of the Neuse River system. This calculation was developed by subtracting estimated natural loads, based upon data from other comparatively unpolluted streams, from measured total loads of the Neuse River. He concluded that the pollution load contributed by man constitutes approximately 53% of the total dissolved material transported by the Neuse River at the Kinston station and 51% at the Clayton station.

TABLE 8. Ranges of dissolved heavy metal concentrations (in ug/L) in the water column at two stations in the fluvial portion of the Neuse River (at Clayton and Kinston) from 1974-1977 (Harned, 1980).

ELEMENT	RANGE (ug/L)	ELEMENT	RANGE (ug/L)
As	0 to 50	Cd	0 to 50
Co	0 to 100	Cu	2 to 70
Fe	90 to 950	Pb	0 to 500
Mn	20 to 2200	Hg	0 to 2.2
Se	0 to 12	Zn	0 to 1400

Pollution and population are wed in an intimate relationship. Demographic increases generally lead to increases in man-produced waste, much of which is discharged into our rivers. The 1970 population in the Neuse River drainage was 709,900 or 14% of the total population of North Carolina and a 10% increase over 1960 (Harned, 1980). By 1980, the population for the Neuse River drainage basin had increased to approximately 1,069,000 (pers. comm., N.C. CGIA, 1990), representing over a 50% growth rate for the decade of the 1970's. The greatest proportion of this population is in the upper portion of the Neuse River drainage basin and includes the high growth triangle area of Raleigh, Durham, Chapel Hill.

NPDES (National Pollution Discharge Elimination System) industrial and municipal discharge permits for the Neuse River drainage basin are listed in Appendix C (as of May 1990). At this time there were 196 NPDES discharges within the fluvial portion of the Neuse River system (west of Streets Ferry and the beginning of the estuarine system) with a design flow of about 148 million gallons of waste water per day. Within the Neuse River estuarine system (east of Streets Ferry), there were an additional 46 NPDES discharge permits with a design flow of about 58 million gallons of waste water per day. Thus, 242 NPDES facilities are permitted to discharge up to 206 million gallons of waste water per day into the Neuse River. This known discharge represents approximately 35% (67% municipal and other domestic point sources and 33% industrial point sources) of the total pollution load to the Neuse River estuarine system. The largest source of contaminants into the Neuse River system is the additional 65% that comes from non-point sources (N.C. DEM, 1987).

Chemical composition of permitted discharge waters for anything other than basic nutrients, oxygen, suspended solids, and a few other parameters, is poorly known. For example, notice in Appendix C that only a very few of the permitted dischargers are required to monitor their waste water for other parameters such as a few heavy metals or toxic organic compounds. These NPDES permits are the sole source for the limited information that does exist from monitoring data gathered to fulfill individual permit requirements about chemical compositions of effluent from specific discharges.

The Clean Water Fund-NC (1990) studied the performance record of 23 of the largest dischargers to the Neuse River for a one year period during 1989-1990. These 23 plants had NPDES permits with a total design flow of about 179 million gallons of waste water per day and an actual flow of about 115 million gallons per day into the Neuse River drainage basin. Following is a partial summary of the conclusions of this study on these 23 plants.

1. Twelve plants reported problems regularly meeting their permit limits for flow.
2. Seventeen of the plants had maximum monthly flows that significantly exceeded their design capacity by amounts up to 235%.
3. Eight plants reported bypassing raw sewage.
4. Most plants had virtually no limits on the heavy metals they could discharge into their receiving waters. Since the majority of plants were not even required to test for heavy metals, their heavy metal load to the river cannot be determined.
5. Fifteen municipal WWTP's have pretreatment programs that monitor and regulate the discharges of 117 industries; the most recent semi-annual pretreatment reports show that 40% of these industries had permit violations.
6. The five worst plants in the study were classified as "ugly", four plants had serious problems and were classified as "bad", while only three plants were classified in the "good" category. The New Bern WWTP was included as one of the "ugly" plants.

The average concentration of toxic metals within any discharged waste water is generally very low. However, when the total volume of discharge is considered during a day, month or year, the total volume of metals delivered to the estuarine system can be quite large. For example, Table 9 summarizes data collected for 23 waste water dischargers that suggest significant volumes of heavy metals are contributed to the Neuse River system each year when the combined concentrations are considered.

TABLE 9. Combined effluent flow and pollutant loads for 23 major waste water dischargers in the Neuse River drainage basin from 4/89 through 3/90. Data are from the Clean Water Fund-NC, 1990.

ELEMENT	NO. OF PLANTS	DAILY AVERAGE	YEARLY AVERAGE
Cadmuim	7	0.69 lbs	252 lbs
Chromium	13	3.28 lbs	1,197 lbs
Copper	11	8.61 lbs	3,143 lbs
Lead	10	3.02 lbs	1,102 lbs
Mercury	4	0.11 lbs	40 lbs
Nickel	7	4.00 lbs	1,460 lbs
Silver	4	0.72 lbs	263 lbs
Zinc	10	27.20 lbs	9,928 lbs

Little is known about nonpoint source discharges into the Neuse River drainage systems. Sources of nonpoint discharges are extremely varied in space, time, volume, and chemical composition and include agricultural and urban runoff, peat mining and timbering, groundwater discharge associated with historic waste dump sites and landfills, land and shoreline erosion, and atmospheric fall out. In addition, there are numerous impoundment projects and various types of channel alterations and stream modifications, all of which directly impact the sediment characteristics of the estuarine system. For example, during the 1960's and 70's at least 8 Neuse River coastal plain tributaries were channelized by the U.S. Soil Conservation Service and over 310 miles of channel modification projects have been carried out by the U.S. Army Corps of Engineers since 1896 with an additional 75 miles scheduled for flood protection (Harned, 1980).

Trace Element Contaminants: Problems with Monitoring Water Quality

The EPA STORET Data Base System for the North Carolina estuaries and associated drainage basins contain information from monitoring sites for the Ambient Water Monitoring Program administered by the N.C. DEM. Measured monthly, data at each site consist of chemical and physical parameters for water samples including heavy metals. In 1987, a North Carolina state agency (Rader et al.) concluded that heavy metals were not a problem in the Pamlico River estuary. The main basis for their heavy metal conclusion was that most water analyses within the STORET data base were below detection limits. Only copper and zinc were detected with any frequency, out of a group of metals that included Pb, Hg, Ni, and Cr.

Table 10 compares analytical detection limits for 5 heavy metals reported for rivers and estuaries in N.C. (Barker et al, 1986) compared to concentrations for the Mississippi River (Shiller and Boyle, 1987). Analytical detection limits for these five metals in N.C. are significantly higher than ambient concentrations in the Mississippi, a river heavily influenced by anthropogenic input of heavy metals. However, the high detection limits used in analyses for the North Carolina data base have lead to misinterpretations. Cadmium for example, may be 500 times higher in concentration compared to background or non-contaminated waters; however, this would not be detected using the present techniques in North Carolina.

TABLE 10. Comparison between detection limits for trace metal samples from North Carolina rivers (Barker et al., 1986) and average metal concentrations in the Mississippi River (Shiller and Boyle, 1987). > X = amount detection limits used for N.C. rivers are above average of Mississippi values.

ELEMENT	MISS RANGE nmol/kg	MISS AVE nmol/kg	NC DETECT LIMITS nmol/kg	> X
Cu	18.3 - 30.9	22.7	160	7
Ni	20.5 - 26.2	23.4	890	38
Zn	1.7 - 4.2	3.2	154	48
Cr	.4 - 2.8	1.6	470	294
Cd	.08- .2	0.13	80	615

Two possible explanations for the use of the high detection limits depicted in Table 10 are: 1) the methods used routinely by many labs studying North Carolina waters are not adequate for determining ambient trace metal concentrations, or 2) some State agencies set analytical detection limits for heavy metal concentrations in ambient water at fairly high levels only to detect violation of standards and keep analytical costs low. In either case, using these types of data to conclude that water quality problems do not exist because metal concentrations in water samples are below analytical detection limits are misleading.

Also, such analyses do not address the potential concentration and toxicity of metals that might occur within the riverine and estuarine sediments. Due to rapid changes in estuarine water chemistry and high chemical reactivity of the sediments, many metals become enriched in the sediments to levels that are orders of magnitude above acceptable water concentrations. For example, "of sixty-five classes of toxic pollutants for which EPA has issued water quality criteria, two-thirds of those classes have constituents that will bind to sediments" (Gilford and Zeller, 1987). Enrichment of trace metals continues through time as the mud sediments are routinely resuspended into the water column. Consequently, the cumulative effect of large discharge volumes over long time periods and continuous interaction with inorganic and organic sediment components are important factors on long-term concentrations and potential bioavailability of trace metals. Thus, trace metals may become increasingly more available to the food chain through time by abundant filter and detritus feeding organisms living within the organic-rich mud environments.

Long and Morgan (1990) summarized the biological studies "to assess the relative likelihood or potential for adverse biologial effects occurring due to exposure of biota to toxicants in sediments sampled and analyzed by the NOAA National Status and Trends Program". In this study they determined the apparent ranges in concentrations of individual chemicals in sediments in which various biological effects are likely to occur. Kimerle (1987) concluded that some chemicals tend to partition strongly to sediments becoming sinks that "are acutely and chronically toxic to aquatic organisms". Gilford and Zeller (1987) have found that polluted sediments have negatively impacted benthic organisms in areas where water column criteria were not violated.

Analysis of the estuarine mud sediments represents a screening tool that is an easy and reliable approach to determining general problem areas within the estuarine system for several reasons.

1. Concentrations of heavy metals are considerably enriched in the sediments compared to their dilute character within the water column; therefore they can be analyzed and monitored with much more reliable results.
2. Sediments represent a long-term average and a temporal record of assimilation that smooths out the extreme short-term variability associated with collecting water samples; therefore they can readily pinpoint problem areas associated with various types of heavy metal sources.
3. Problem areas defined by heavy metal enrichment have high potentials for being enriched in other chemical components that may cause more serious water quality problems (e.g., organic toxicants, many of which are difficult and costly to quantify). Thus, sediment analyses for trace

elements may be a much less expensive, more cost effective means of identifying potential problem areas.

Long and Morgan (1990) conclude that chemical data provide indications of the relative degrees of contamination among the sampling sites, but alone they provide neither a measure of adverse biological effects nor an estimate of the potential for effects. From chemical/sediment data bases, such as is presented in this Neuse River study, it is now critical to determine the effects of increasing heavy metal contamination in estuarine sediments upon the general health of biological systems within the North Carolina estuaries.

PART III: METHODOLOGY

FIELD SAMPLING

Design and Rationale

The general location and distribution of sample sites within the Neuse River estuarine system are presented in Figure 3. Since the types and sources of trace element contaminants within this system are highly varied, the sampling scheme reflects our attempt to describe as many of these variable conditions as possible:

1. Areas that have high levels of both modern and relict, man-influenced point source discharges such as industrial sites (i.e., metal plating facilities, shipyards, fertilizer plants, paper mills, and chemical treatment plants, etc.) and municipal facilities (i.e., waste water treatment plants, solid waste dump sites, coal burning power plants, etc.);
2. Areas that have high levels of man-influenced nonpoint source discharges such as marinas and surrounding areas of intense boating activity, urban areas and associated runoff, and agricultural farming and feed-lot operations and resulting runoff;
3. Areas that appear fairly pristine with limited man-influenced development, runoff, and discharges; and
4. Samples from deeper in the cores that contain sediment that is pre-anthropogenic and below the man influenced surface sediment.

The last two sample types provide two different "background" values for metals in the estuarine system while the first two sample types define the types and levels of heavy metal contaminants in the organic-rich estuarine muds. The research design specifically addressed the need to distinguish between these four types of areas and their respective levels of contamination within the estuarine sediments.

Regional sample sites were systematically located along the entire length of the trunk estuary and in all major tributaries within the Neuse River estuarine system. These sample sites provided the regional patterns of elemental distributions. Denser sampling grids were established around known sources of chemical and sediment contamination. Location of these sites was based upon the distribution of known point and nonpoint discharges as determined from surveying the literature and the NPDES waste water discharge permits within the Neuse River drainage (Appendix C). The regions with denser sampling grids provide information on the types and volumes of contaminants contributed by specific sources for comparison to the background contaminant levels within the sediments of the Neuse River estuarine system.

Delineation of the Neuse River Study Area

The study area includes the entire Neuse River estuarine system. It extends from the N.C. Highway 43 bridge at Streets Ferry, 7.5 miles west of New Bern, east to Point of Marsh on the south side of the mouth of the Neuse River and to the mouth of the Bay River on the north side (Fig. 3). Most major tributary creeks to the trunk estuary were also included within the study area (Table 11).

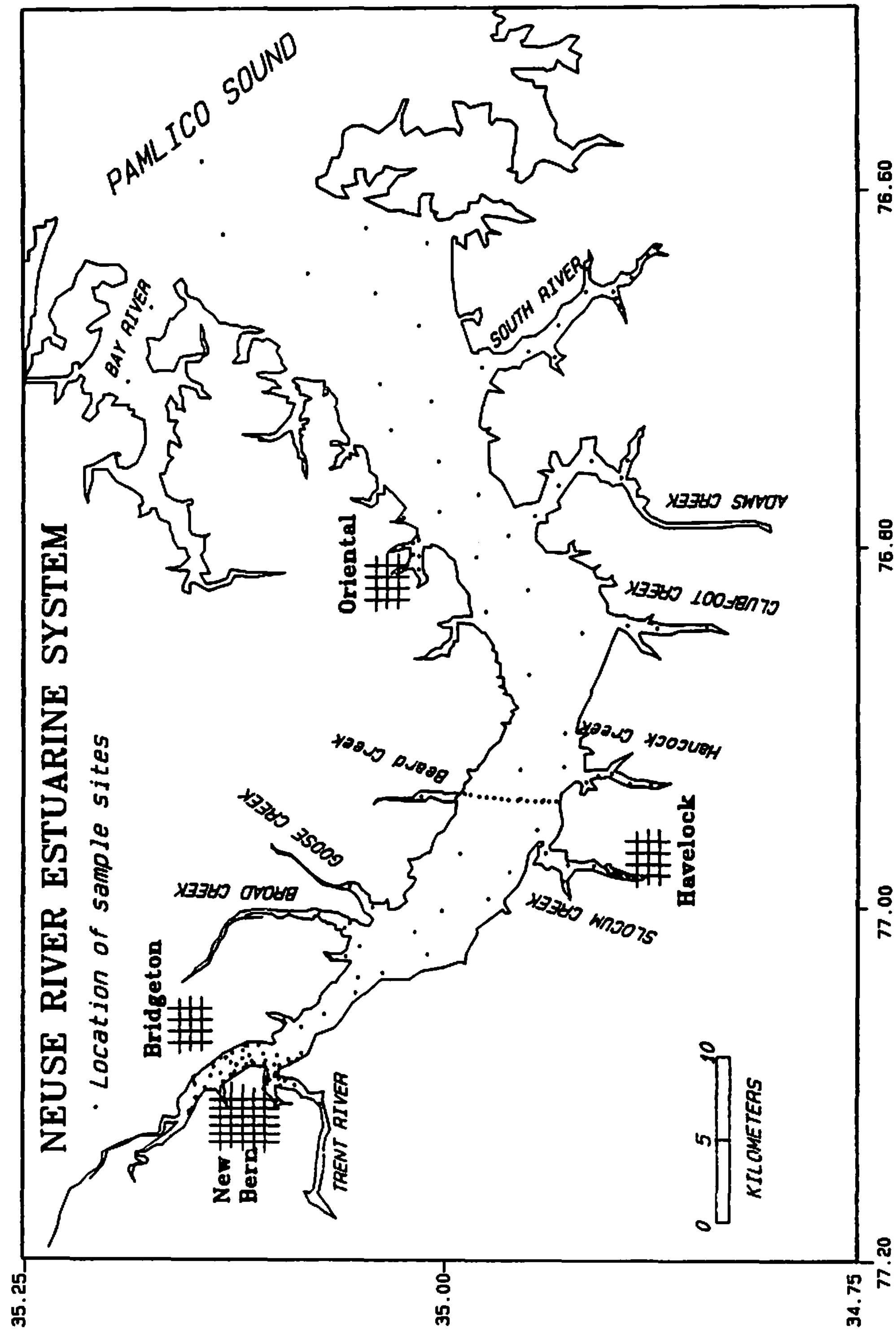

FIGURE 3. Map of the Neuse River estuarine system showing the general location and distribution of sample sites for this study. See Figures 10, 19, 20, 21, 23, 24, 34, 35, and 36 for sample numbers and more specific locations; Appendix A contains the exact location of each sample site.

TABLE 11. Distribution and numbers of sediment samples collected in the Neuse River estuarine system for subsequent sediment and elemental analysis. Sample areas are listed from west to east within each category.

SAMPLE AREAS	CORE NAME	NUMBER OF SITES OCCUPIED	NUMBER OF SUBSAMPLES
NEUSE RIVER TRUNK SYSTEM		94	189
Neuse River (upstream)	RIV	3	6
New Bern West	NBNW	27	59
New Bern East	NBNE	12	22
Neuse River West	NUS	33	63
Neuse River East	NUSE	19	39
TRIBUTARIES--NORTH SIDE		31	64
Swift Creek	SWT	2	6
Mills Branch Creek	NBNW	2	4
Duck Creek	DUC	1	2
Fairfield Harbour	FFD	3	6
Broad Creek	BRD	3	6
Goose Creek	GOS	2	4
Beard Creek	BRD	3	6
Oriental Harbor	CMP	3	6
Oriental Area Creeks	ORL	7	14
Whittaker Creek	WKR	3	6
Bay River	BAY	2	4
TRENT RIVER TRIBUTARY--SOUTH SIDE		21	44
Trent (West of US-70)	TNT	8	16
Trent (New Bern Area)	TNT	11	24
Lawson Creek	LSN	2	4
TRIBUTARIES--SOUTH SIDE		57	116
Scott Creek	SCT	2	4
Slocum Creek	SLO	25	50
Hancock Creek	HCK	6	12
Clubfoot Creek	CBF	3	6
Adams Creek	ADM	5	10
South River	STH	16	34
TOTALS:		SITES = 203	SAMPLES = 413

Development of Base Maps

Digital base maps were generated for the entire Neuse River estuarine system to plot pre-existing data and data generated by this study. The base maps were developed from National Ocean Service 1:40,000 and 1:80,000 scale nautical charts and from U.S. Geological Survey 7.5 minute quadrangle maps. A LORAN-C map was produced for location of most sampling sites in the field.

The LORAN-C map was produced by making repeated observations at known points to correct for ground-wave distortion throughout the study area; coordinates were calculated and plotted on the map. Core site positions were located utilizing LORAN-C coordinates that were plotted on the corrected LORAN-C map to obtain latitude and longitude coordinates. In areas where LORAN-C signals were unobtainable, compass bearings taken on available landmarks were used for navigational positioning.

Acquisition of Sediment Samples

One core was obtained at each site; these sites were located (Fig. 3) in areas that were 1) proximal to known point sources such as municipal and industrial discharges, 2) adjacent to non-point discharge sources such as marinas, urban runoff, and agricultural areas, and 3) areas that were assumed to be minimally influenced by human activity. Figure 3 and Table 11 summarize the number and distribution of core sites within the Neuse River estuarine system. Appendix A presents core hole location data for all samples acquired for the present study.

Each sample site was occupied on only one occasion. Most sampling was done over a 17-day field period during the late spring and early summer of 1989. An additional 10 sites (SLO-16 through SLO-25) were sampled within the upper reaches of Slocum Creek during late spring 1990. All but the latter samples were collected from the R/V NITRO, a 34 foot, diesel powered, converted navy personnel boat belonging to the ECU Department of Geology. The following sample and field data were collected at each of the 203 core sites:

1. Station number;
2. Location: LORAN-C coordinates or compass bearings and descriptive landmarks;
3. Weather conditions;
4. Hydrographic conditions: water depth, visibility, salinity, and temperature;
5. Bottom sediment description;
6. Bottom core and associated samples with assigned numbers and size.

Sediment cores were collected at the 203 sample sites and ranged from 20 cm up to 1 meter in length. These sediment cores were obtained by divers using either SCUBA or surface supplied air, or by free diving. The diver-collected cores were taken by hand-forcing a 9 cm diameter, clear polybuterate pipe into the sediment, the ends of the core pipe and included sediment were covered with plastic caps and the core pipe withdrawn. As soon as the core was aboard the boat, it was measured, trimmed, sealed, labeled, and stored vertically for transport to the laboratory. In the lab the cores were frozen in a vertical position and freezer-stored until they could be subsampled.

Additional sediment surface or 'floc' samples were collected at selected stations within the estuarine system to obtain more detailed information about the vertical distribution of heavy metals in the surface sediments. Floc samples were diver-collected by skimming the upper 1 to 2 cm of sediment from the river bottom into a clear polybuterate container which was then sealed with plastic caps, and brought to the surface and treated according to the same flow sheet as the cores. Samples collected in this manner were denoted with an 'F' at the end of the sample number (i.e., NUS-15F).

SEDIMENT ANALYSIS

All analytical procedures were carried out in accordance with following quality assurance reports prepared according to the U.S. EPA guidelines (Werme, 1985):

1. "Quality Assurance/Quality Control Report" submitted when the Pamlico River project was accepted for funding in June 1987; and
2. Upgraded in the "Revised Quality Assurance Project Plan" submitted in December 1989 (Riggs et al., 1989a).

All procedures associated with sample preparation and storage were done in a trace-element clean manner for avoidance of sample contamination.

Sub-sampling involved production of two sets of uniform and homogenous samples for the purposes outlined in the flow sheet in Figure 4. The first sample set was used for sedimentological lab analyses according to the procedures outlined in Appendix B. The second sample set was prepared for chemical analyses according to procedures outlined in Appendix B and summarized below. All remaining sample material from both sample sets were archived for future reference and subsequent analyses. Following sub-sampling, remaining core material was not saved due to lack of storage facilities.

A total of 203 cores (Fig. 3) were described and subsampled. This resulted in 413 subsamples distributed regionally as outlined in Table 11. These 413 subsamples were analyzed as follows (Fig. 4):

1. Core and sediment descriptions;
2. Sediment compositions (% water, % organic, % inorganic, % organic in mud (silt plus clay) fraction, and % organic in sand fraction);
3. Grain size analysis (% sand, % silt, and % clay); and
4. Chemical analysis for 30 elements as follows (Table 12):
    - A. Mild acid leach (2 N HNO_3 for 48 hours) extract of all sediment samples:
        - a. Inductively coupled-argon plasma-emission spectroscopy (ICAPES) determinations were made for 28 elements on the acid leachate. Due to particular instrumental conditions (e.g., available wavelength, type of photo-multiplier tube, the ability to identify and appropriately correct for inter-element interferences, as well as the order of magnitude of actual concentrations encountered) reliable results (based on acceptable lower limits of quantitation and reproducibility) were obtained for only 21 of the 28 elements examined.
        - b. Electrometric techniques (specific ion electrode) were utilized to determine the concentration of extractable fluorine in all sediment samples. Because of the necessity to dilute out interfering effects of high levels of acid, iron, and aluminum prior to actual electrode measurement, the resultant lower limit of quantitation (LLQ) for fluorine is unusually high. Consequently, no samples from the Neuse River exhibited

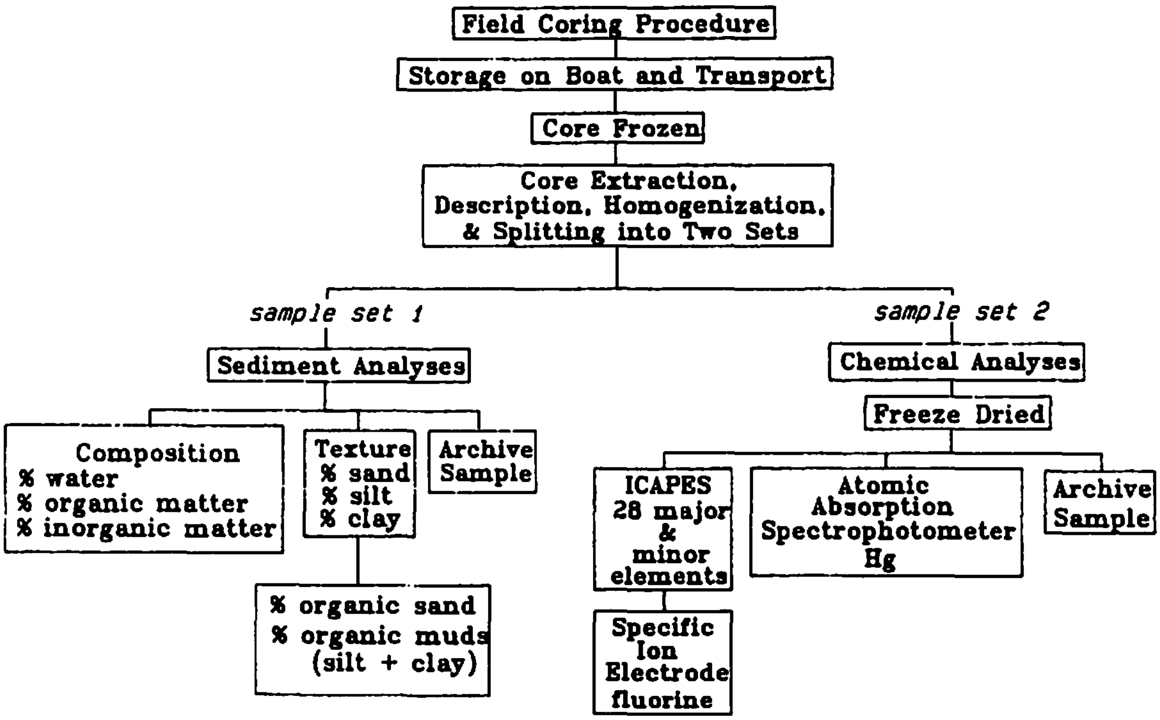

FIGURE 4. Laboratory flow sheet for sediment and chemical analyses.

extractable fluorine levels above the LLQ. This is in great contrast to many sediment samples from the Pamlico River estuary that had enriched fluorine concentrations resulting from waste discharges of a phosphate mining and processing facility (Riggs et al., 1989b).

B. Autoclave digestion and mercury analysis (U.S. EPA, 1979) of sediment samples was performed utilizing a cold vapor atomic absorption spectrometric (AAS) technique.

TABLE 12. Analytical data were obtained for 30 elements in this study. However, only the 22 elements listed in the first three columns are quantitative and analytically reliable. The 8 elements listed in the fourth column were either based upon wavelength channels that were not very sensitive or were in concentrations below the lower limit of quantitation (LLQ) within the Neuse River samples. Consequently, the analytical data for these elements are unreliable and are excluded from further discussion in this report.

RELIABLE ANALYTICAL DATA			UNRELIABLE ANALYTICAL DATA
EPA PRIORITY POLLUTANT METALS	OTHER TRACE ELEMENTS	MAJOR ELEMENTS	TRACE ELEMENTS
Inductively Coupled-Argon Plasma-Emission Spectroscopy (ICAPES)			
Arsenic	Cobalt	Aluminum	Beryllium
Cadmium	Manganese	Calcium	Lithium
Chromium	Molybdenum	Iron	Selenium
Copper	Phosphorus	Magnesium	Silver
Lead	Tin	Potassium	Thallium
Nickel	Titanium	Silica	Uranium
Zinc	Vanadium	Sodium	Yttrium
Atomic Absorption Spectrometry (AAS)			
Mercury			
Specific Ion Electrode			
			Fluorine

CHEMICAL ANALYSIS

Rationale for Extraction Procedure Utilized

Numerous attempts have been made to approximate "bioavailability" by identifying relationships between whole body or organ specific trace metal levels in biota and metal levels in the surrounding water and sediments (Pringle et al., 1968; Cross et al., 1970; Huggett et al., 1973; Valiela et al., 1974; Wharfe and Van Den Broek, 1977; Pesch et al., 1977). However, such studies usually develop an estimate of what is more accurately called "bioaccumulation" or "biomagnification" rather than "bioavailability".

Other investigators, concentrating exclusively on sediments, have applied various selective or sequential extraction schemes that are intended to identify the partitioning of elements among the various sedimentary phases previously identified (Chester and Hughes, 1966; Gupta and Chen, 1975; Engler et al., 1977; Agemian and Chau, 1977; Tessier et al., 1979; Salomons and Forstner, 1980; De Groot and Zschuppe, 1981; Mahan et al., 1987). Typically these extraction schemes are based on some variation of the following phase groupings:

1. Extraction with a salt solution to liberate metals at adsorption or ion exchange sites;
2. Mild acid treatment to free carbonate bound metals;
3. Reduction treatment to obtain oxide bound metals;
4. Nitric acid-peroxide treatment to release organic bound metals; and
5. Total digestion to solubilize all residual metals bound within the crystal lattice of minerals.

Interpretations of the results of these various extraction procedures remains somewhat controversial (Kheboian and Bauer, 1987; Tessier and Campbell, 1988; Bauer and Kheboian, 1988).

A few investigators have attempted to look at both the composition of the organisms and associated sediments utilizing selective extraction procedures (Luoma and Jenne, 1976a, 1976b, 1977; Jenne and Luoma, 1977; Luoma and Bryan, 1979a, 1979b). The overall results from these studies are not unequivocal either. Still other investigators (Sinex et al., 1980; Cantillo et al., 1984) argue that the only true reference point for extractions that are to be used to make comparisons over time or between different systems is one that involves very vigorous attack of the sediment to result in a total or very nearly total digestion (such as hot nitric acid, hydrofluoric-boric acid mixtures, bomb digestions or fusion-dissolution techniques). It is argued that such a reference point is the only truly reproducible extraction that would allow for intercomparisons.

No matter what particular extraction procedure is followed, other than total or near total digestion, unless exacting specifications are described and followed, reproducibility or compatibility of the data suffers. Many small details that are seldom if ever published, are very important with respect to the results of an extraction. This includes such parameters as temperature; length of time of extraction; solid to solution ratios; and those things that affect the degree of agitation such as the particular agitation technique (e.g., magnetic stirrer, reciprocating shaker, wrist action shaker, etc.) speed or excursion rates for each of these, volume of the extraction compared with the vessel size, etc.

However, with appropriate control over all such laboratory aspects, the level of reproducibility needed for intercomparison purposes can be achieved. Of course, the less complex the procedure, the easier it is to exercise the necessary control. The results obtained with the procedure utilized in this study support this contention. The extraction procedure applied in this study was based on compromises among the following scientific as well as practical considerations:

1. Cost effectiveness,
2. Probability of future use,
3. Reproducibility, and
4. Capability for determining the
    a. Anthropogenic derived fraction and
    b. "Bioavailable" fraction.

This study is not the first to investigate heavy metals in the Albemarle-Pamlico-Neuse Estuarine systems. However, the purpose and sheer scope of this research project guarantees that it will serve as an important base-line or reference study against which future data both from within this system as well as from other estuarine systems will be compared. Any analytical extraction procedure that is intended for potentially widespread, routine application by other investigators and by governmental research and regulatory agencies must, of necessity, be cost effective. It must also be sufficiently easy to perform so that it can be readily applied in more than the rare "research" setting. No sequential extraction procedure can satisfy these two criteria; every added extraction step requires an added analysis step with its associated costs in manpower, instrument time, and reagents.

An absolute differentiation between naturally derived and anthropogenically derived trace metals in sediments is likely never to be possible. However it can be argued that, because of both time (on a geological reaction scale) and the nature of most inputs (as discharges of dissolved metals into the water column), the fraction of the total that is anthropogenically derived is likely to be present in those phases subject to attack by milder extraction techniques. Anthropogenic metals are not likely to be incorporated into the mineral or crystallographic lattices; likewise, metals that are biologically available are not likely to be incorporated into the mineral or crystallographic lattices. Consequently, a milder extraction that would liberate metals from pore water, easily exchangeable sites, carbonates (which are more readily formed and highly susceptible to pH conditions both in the environment and in digestive tracts of organisms), chelated in surface organic coatings, and coprecipitated with iron oxy-hydroxy precipitates, would more accurately model anthropogenic and bioavailable metals.

Like all such procedures, this is a defined procedure and is intended for use as a first approximation only. No claims are made as to the absolute meaning of the results, which are expressed as micrograms of element extractable from a gram of freeze dried sediment. No accounting is made for potential redistribution (i.e., solubilization from one phase with subsequent occlusion by some means into another) during the extraction process. The procedure is a slight modification of one described by W.S. Boothman (pers. comm., Jan. 1988) that has been applied by the U.S. EPA in Narragansett Bay and Booth Bay Harbor. It involves extracting 2.5 g dry sediments with 50 ml of 2N nitric acid for two days at room temperature but with very little agitation.

Although we have yet to find any other investigations which describe the action of a HNO_3 extraction exactly like this one, Pickering's (1986) comprehensive review article describes:

1. The extraction recovery of 0.1N HNO_3 on Zn, Cd, Pb, and Cu from various clay matrices for which the metals were loaded onto the clays from 10^{-4} M M^{+2} Chloride solutions and
2. The extraction recovery of 1N HNO_3 on the same metals loaded in the same fashion onto various humic, carbonate, and hydrous oxide phases.

With but one exception (Zn on montmorillonite extracted at pH 5 with 0.1N HNO_3), recoveries were all at least 50% of the loaded amount, and usually much greater. It was further pointed out by Pickering that 1N HNO_3 was effective in dissolving out most of these same metals present in soils augmented with sewage sludge. Based on the foregoing arguments, the 2N HNO_3 extraction procedure appears to meet all the criteria regarding cost, probability of use, reproducibility, as well as ability to approximate the "anthropogenic" and "bioavailable" fractions.

A detailed description of procedures utilized for sample pre-treatment and elemental extraction, as well as comparison of various extraction procedures were presented in the Pamlico River report (Riggs et al., 1989b). For the sake of completeness, this same material is included in Appendix B of the present Neuse River report.

ICAPES Analyses

The inductively coupled-argon plasma-emission spectrometer (ICAPES) used for the major analyses in this project is a Jarrell-Ash Plasma AtomComp (Mark II System), modified with the Ward Scientific, Ltd., WICS and MDA (Multiple Data Acquisition) hardware and software upgrades. Analyses are made with a five point, simultaneous scan of all element profiles in order that sufficient information is obtained to provide on-peak and off-peak (baseline) readings for each element. The system is calibrated with appropriate matrix matched multi-element standards and corrections are made for inter-element interferences. Table 13 presents a list of the 21 elements analyzed by ICAPES for which reliable results were obtained and are reported in the Neuse River study along with the analytical wavelengths (in nm) that were used in the ICAPES analyses. The 7 other trace elements (Table 12) for which unreliable data were obtained (Be, Li, Se, Ag, Tl, U, and Y) have been excluded from any further discussion in this report.

TABLE 13. Analytical wavelengths (in nm) for 21 elements analyzed by ICAPES and included in this report.

Al	Aluminum	308.215	Mn	Manganese	257.6
As	Arsenic	193.6	Mo	Molybdenum	202.0
Ca	Calcium	317.9	Na	Sodium	588.99
Cd	Cadmium	228.8	Ni	Nickel	231.6
Co	Cobalt	228.6	P	Phosphorus	213.6
Cr	Chromium	267.7	Pb	Lead	220.3
Cu	Copper	324.7	Si	Silicon	288.1
Fe	Iron	259.9	Sn	Tin	283.9
K	Potassium	766.5	Ti	Titanium	334.9
Mg	Magnesium	279.5	V	Vanadium	292.4
			Zn	Zinc	213.8

ICAPES analyses for the Neuse River estuarine system consisted of 11 batches that included 413 samples and 97 controls that were subjected to the HNO_3 extraction. The 97 controls represent 47 blanks, 36 internally prepared reference samples (APES D), and 14 reference standard samples (NIST SRM-1646: Estuarine Sediment).

Control Samples

The APES D internal control is a composite sample of organic-rich muds collected at several locations in the Pamlico River during the first year of this investigation. The APES D sample was freeze dried and passed through a 60 mesh polyester screen with gentle rubbing. Particles that did not pass through the screen were discarded. Sieving was used since there were several different types of sediments and an overall finer grain size lends itself to greater homogeneity. The resulting 1.5 kg sample was tumbled for nearly 20 hours on a Patterson-Kelly, twin shell, dry blender. It was then split into nine 250-mL plastic bottles. This control, identified as APES D, was intended to last through the completion of all phases of this project. In order to provide information on more accessible and universal standards, two standard reference materials (SRM) from the National Institute of Standards and Technology (NIST) were utilized. The Pamlico River study utilized sediment standards SRM 1645 (River Sediments) and SRM 1646 (Estuarine Sediments). Throughout the Pamlico study it became apparent that SRM 1645 (River Sediment) was inappropriate because of its trace element composition. Consequently only SRM 1646 (Estuarine Sediment) was used as a reference control in the Neuse River study.

Limit of Quantitation and Reproducibility

The instrumental lower limit of quantitation (LLQ), or lower limit of detection, is defined for purposes of this study as three times the standard deviation about the process blanks, expressed in the same concentration terms as the samples (viz., $\mu g/g$ extractable). Process blanks are taken through the complete extraction, filtration and analytical process. Overall reproducibility for the entire analytical process, including actual precision of the instrumental measurement combined with precision of the extraction process was determined by running at least three replicate samples of APES D with each analytical batch. Fourteen replicates of SRM 1646 (Estuarine Sediments) were run randomly throughout the entire Neuse study and at least three blanks were run with each batch. Table 14 presents the estimate for the lower limit of quantitation as well as both the mean and two times the standard deviation about the means for APES D controls for both the Pamlico and Neuse River studies. Table 14 also presents the means of element concentrations extracted from the NIST Standard Reference Material expressed as a percent of the total value reported on the NIST certificate.

Comments on the Quality of Analytical Numbers

Due to the nature of the mild extraction procedure prior to ICAPES analyses, 100% recovery of all elements is highly unlikely. However, Table 14 does demonstrate a general agreement between the percent recoveries for each

TABLE 14. Quality assurance data for ICAPES and AAS determinations for samples from the Neuse River study as compared to samples from the Pamlico River study (Riggs et al., 1989b).

	LOWER LIMIT OF QUANTITATION (LLQ) = 3 x s.d. OF BLANKS µg/g		REPRODUCIBILITY ON APES D CONTROL SPL MEAN = ± 2 x s.d. µg/g		RECOVERY OF NIST SRM 1646 (ESTUARINE SEDIMENT) MEAN RECOVERY percent	
Element	Pamlico n = 27	Neuse n = 47	Pamlico n = 15	Neuse n = 36	Pamlico n = 6	Neuse n = 14
Al	9.8	33.0	3808 ± 243	3906 ± 235	8	8
As	2.3	1.4	8.8 ± 5.2	2.4 ± 3.2	120	72
Ca	19.6	44.3	5815 ± 352	6060 ± 240	38	39
Cd	0.5	0.4	0.4 ± 0.3	0.4 ± 0.2	28	83
Co	0.2	0.4	4.0 ± 0.3	4.2 ± 0.3	40	45
Cr	0.2	0.3	6.7 ± 0.4	6.8 ± 0.4	20	20
Cu	0.3	0.3	9.2 ± 0.7	8.8 ± 0.6	59	60
Fe	4.7	119.9	8927 ± 456	9651 ± 542	42	45
K	45.1	51.3	463 ± 178	496 ± 76	14	15
Mg	35.7	33.3	1312 ± 91.3	1309 ± 88	47	46
Mn	0.9	1.1	77.0 ± 4.2	79.2 ± 4.4	36	37
Mo	0.3	0.5	0.4 ± 0.7	0.4 ± 0.1	40	45
Na	9.8	16.6	1985 ± 126	1955 ± 120	48	49
Ni	1.1	1.0	0.9 ± 0.7	1.8 ± 0.4	21	29
P	18.0	21.4	598 ± 110	514 ± 30	65	59
Pb	1.6	0.9	28.1 ± 4.0	22.9 ± 1.6	86	65
Si	26.2	40.2	1109 ± 60.5	1053 ± 91	0.4	0.4
Sn	*	3.7	*	9.1 ± 3.6	*	NR
Ti	0.4	0.6	30.0 ± 1.7	29.5 ± 1.3	4	4
V	0.2	0.3	15.3 ± 1.0	15.0 ± 0.8	27	27
Zn	1.2	1.8	54.3 ± 3.2	53.3 ± 3.9	61	62
Hg				0.11 ± 0.04		#108 (n=5)

= Recovery of NIST SRM 1645 (River Sediment)
* = Elements were not analyzed
NR = Elements were not reported

element within the Pamlico and Neuse River studies. Substantial discrepancies do exist between studies for As, Pb and Cd. The As and Pb discrepancies result from additional inter-element interference corrections that were applied to these elements in the Neuse study. The discrepancy for Cd is due to the fact that absolute concentrations for Cd in the standard is below the limit of quantitation (.36 = ± 0.07 µg/g). Consequently, any slight variation results in a large relative difference.

It should be noted that there are substantially greater LLQ's for Al, Ca, Fe, Na and Si in the Neuse River study as compared to the LLQ's in the Pamlico River study (Table 14). Very high concentrations of these elements caused the emission signals to go off-scale for nearly every sample during the Pamlico River study; this required a dilution and second analysis with appropriate recalibration for all samples. During the Neuse River study, analytical sensitivities for these five elements were reduced by changing the electrical resistance in the photomultiplier circuit. This resulted in greater analytical efficiency but in higher LLQ's for these elements. Nothing was lost, however, since at no time did the values for any of these elements approach the detection limit.

Reproducibility is defined as two times the standard deviation about all of the replicate APES D internal control samples processed through the entire analytical procedure (Table 14). In general, excellent agreement occurs in reproducibility for the control samples, both within runs and between runs, which is indicative of the excellent reproducibility of the extraction procedure. Studies on inter-element interferences for As and Pb resulted in greater correction factors being applied to the Neuse River samples than the Pamlico River samples. This caused not only the discrepancies in percent recovery of these two elements between the studies, but also caused the LLQ's and reproducibilities on As and Pb to be different as well.

AAS Mercury Analyses

Atomic absorption spectrometry (AAS) was utilized for the mercury analyses. The analytical technique is EPA's Method 245.5 outlined in "Methods for the Chemical Analysis of Water and Wastes" Procedural Manual (U.S. EPA, 1979) with slight modifications. This is a manual cold vapor technique for mercury in sediments and includes the alternate autoclave digestion procedure. The modifications involved 1) use of a commercially available cold vapor generator (IL model AVA 440), 2) use of one gram samples due to the low concentrations of Hg expected, and 3) an increase in the volume of the $KMnO_4$ reagent to 25 ml deemed necessary due to the increase in sample size. These differences in procedure as compared with the procedure originally applied to the Pamlico River samples (Riggs et al., 1989b) was not only more efficient but provided much better quality data for the Neuse River samples.

With an appropriate autoclave, up to 100 samples could be digested simultaneously to permit processing a large number of samples. The reproducibility obtained on 36 replicates of the APES D internal control sample, which is comparatively low in Hg concentration, is .11 ± 0.04 μg/g (Table 14). The mean recovery on five replicates of the NIST SRM 1646 (Estuarine Sediment) is 108%. Because the estuarine sediment standard has even lower concentrations of Hg than the internal control, five replicate determinations were also run on the NIST SRM 1645 (River Sediment) sample. The mean and 2 x s.d. for those determinations were 1.38 ± 0.30 μg/g for a mean recovery of 96%.

Additional quality control-quality assurance measurements are being made along with a complete redetermination of all Pamlico River samples (Riggs et al., 1989b) by the method outlined above for the Neuse River samples. When complete, an addendum to the Pamlico River Report (Riggs et al., 1989b) will be published providing better analyses of the Hg concentrations.

Electrochemical Fluorine Analyses

An electrometric method was used for determination of extractable fluorine. This analysis was based on specific ion electrode measurements in a procedure adapted from standard F^- electrode techniques. Extractable F^- was analyzed in the acid extracts for each sample remaining after the ICAPES analyses. These acid extracts had to be diluted 1:200 in order to minimize the Fe and Al interference and for buffering purposes in the fluoride analysis; consequently, the lower limit of quantitation is at about 30 µg/g extractable. Unlike the Pamlico River samples (Riggs et al., 1989b), none of the Neuse River samples exhibited extractable fluorine concentrations above this limit.

DATA ANALYSIS

Data Management and Statistical Analysis

All field, sedimentological and chemical data are permanently stored in two formats: 1) in data base spreadsheets using SYMPHONY software that are compatible with IBM PC type computers and 2) in Statistical Analysis System software (SAS) data sets on the East Carolina University IBM 4381 mainframe computer disks with backup copies stored on PC hard disks and floppy disks. These data can be transferred to other formats via 7-bit ASCII format files. Formatting is flexible so that selected portions of the total data base can be separated and printed. All raw data from the Pamlico, Neuse, and Albemarle studies are also presently being put into the Albemarle/Pamlico Study data base being established in the Raleigh office or are available from the senior author.

Data transcriptions were routinely triple checked. The chemical data were first checked by J.T. Bray and J.C. Hamilton in the laboratory generating the data. The second check was by E.R. Powers, K.L. Owens, and D.V. Ames who had the primary responsibility for data transcription and manipulation. The final check was by S.R. Riggs who had the primary responsibility for data interpretation. The sedimentological data were first checked by D.D. Yeates and D.V. Ames in the laboratory generating the data. The second check was by E.R. Powers, K.L. Owens, and D.V. Ames who had the primary responsibility for data transcription and manipulation. The final check was by S.R. Riggs who had the primary responsibility for sediment interpretation.

All field, sedimentological and chemical data were compiled and merged using a combination of SAS programs and SYMPHONY worksheets and data bases. The data matrix consist of sample identifiers listed against all parameters measured on each sample. Each sample number had a location with respect to latitude and longitude, LORAN-C coordinates, and name of water body (Table 11 and Appendix A). Additional information assigned to each sample number includes depth below sediment/water interface, hydrographic parameters (water depth, salinity, and temperature), concentrations of major, minor and trace elements in µg/g extractable, organic content, and concentrations of sediment size components (sand, silt, and clay).

Data manipulations were accomplished on the IBM 4381 mainframe computer using SAS software. Simple statistics (mean, standard deviation, maximum and minimum values, etc.) were calculated for the following categories:

1. All samples,
2. Surface versus subsurface samples,
3. Specific sediment types,
4. Groups of samples within specific tributaries and river segments, and
5. Specific types of point and non-point source areas (i.e., urban regions, marinas, waste water treatment facilities, agricultural regions, etc.).

These analyses provide for stratigraphic, sedimentologic, and regional comparisons of both sediment characteristics and elemental concentrations. Results of these analyses are presented and discussed in subsequent sections.

Rationale and Definitions for Data Analysis

Fifteen trace elements were utilized in this study (Table 15) and include the 8 U.S. EPA "priority pollutant metals" plus seven other environmentally important trace elements. An estimate of background levels was determined for each of the 15 trace elements within the Neuse River sediments. This estimate was derived by the following procedure and results in a value hereafter referred to as the Neuse River trimmed mean (NRTM).

1. Mean concentrations and standard deviations were computed for each trace element in all surface samples within the Neuse River estuarine system.
2. Those samples with values greater than two standard deviations from this original mean were then excluded. These 'outliers' were assumed to represent either anthropogenically contaminated sediments or depleted relict sediments and should not be incorporated into any process intended to derive a general background value.
3. Mean values were then calculated for these trimmed data sets resulting in the NRTM for each element (Table 15).
4. The NRTM for each element serves as a reference point against which every sample, including the surface outliers excluded from the trimmed data set and samples from depth, were compared.
5. This comparison represents the enrichment factor (EF) for each element in each sample (EF is the ratio of actual concentration for the sample to the NRTM). This provides a measure of either excess or depletion compared to an approximate 'background' level. It also provides a convenient and uniform method to graphically depict spatial distributions of concentrations of the elements.

The term enrichment factor is often used differently in the geochemical literature. For example, Zoller et al. (1974), Bruland et al. (1974), and Schropp et al. (1990) develop enrichment factors by calculating the ratio of the element to either Fe or Al within the analyzed air, water, or sediment and to some reference material such as crustal abundance. In this procedure, Fe or Al are used as normalizing factors because anthropogenic sources are generally considered to be negligible; therefore, the primary source would be from crustal weathering. The advahtage of utilizing this definition is that it minimizes variations due to grain size of the sediments. Harding and Brown (1974), in a trace metal study of the middle Pamlico River area, normalized their elemental data to the concentration of clay plus organic matter. This

TABLE 15. Neuse River trimmed mean (NRTM) data for all surface samples that are less than 2 standard deviations from the mean total population. The standard deviation, coefficient of variation, and the minimum and maximum concentration values used in this calculation for 22 elements (in µg/g or ppm) in surface sediments of the Neuse River estuarine system, are also included.

ELEMENT	N	NEUSE RIVER TRIMMED DATA: TRIMMED MEAN µg/g	COEFFICIENT OF VARIATION %	STANDARD DEVIATION µg/g	MINIMUM VALUE µg/g	MAXIMUM VALUE µg/g
TRACE ELEMENTS						
As *	197	5.98	46.5	2.78	0.8	12.7
Cd	201	0.77	136.4	1.05	0.10	7.6
Cr	196	16.8	61.9	10.4	3.4	65.3
Co	198	4.66	45.1	2.10	1.2	8.5
Cu	197	19.3	84.5	16.3	3.4	89.4
Hg	161	0.15	66.7	0.10	0.04	0.5
Ni	200	4.64	56.9	2.64	0.8	12.2
Pb	197	34.9	54.4	19.0	6.0	117.
Mn	197	288.	49.0	141.	74.1	649.
Mo	200	0.54	59.3	0.32	0.1	1.5
P	197	876.	66.3	581.	126.	2230.
Sn *	197	21.5	40.4	8.69	5.4	43.4
Ti	197	31.8	34.6	11.0	8.2	52.4
V	197	22.5	41.8	9.41	4.7	41.3
Zn	197	95.0	56.3	53.5	14.1	248.
MAJOR ELEMENTS						
Al	197	6910.	32.3	2240.	1900.	10300.
Ca	197	5040.	46.9	2360.	1650.	12600.
Fe	197	16200.	39.8	6470.	3870.	29400.
K	197	1030.	48.3	497.	142.	2020.
Mg	197	3220.	36.7	1180.	654.	5480.
Na	197	6200.	57.1	3540.	584.	13800.
Si	197	1050.	13.1	138.	580.	1300.

* Analyses have poor reproducibility, hence somewhat less reliability.

resulted in an enrichment inversion whereby the highest anomalies occurred in the shallow waters dominated by quartz sand sediments. The small amount of mud that occurs within these quartz sand environments may be richer in metals; however, there is so little mud that it becomes insignificant with respect to the metal concentration in the total sediment.

Application of general normalization or correction factors based upon metal/iron and metal/aluminum ratios, similar to Zoller et al. (1974), Bruland et al. (1974), and Schropp et al. (1990) is not appropriate for this study. In these cited studies, enrichment factors were calculated with concentrations obtained by total digestion techniques. However, the present study utilized a partial extraction procedure and it is not known how consistent the percent extraction for each metal is for different sediment types. In addition, the sedimentological data suggest the following:

1. Different parts of the Neuse River and adjacent tributaries operate independently of each other,
2. Metals are generally concentrated within the mud sediments, and
3. Local enrichment is primarily related to anthropogenic sources rather than natural variations in concentration between organic matter and the clay component.

Also, the criteria used within this study suggest that if a specific trace element has relatively high concentrations within the natural system and is released by the partial digestion procedure used in this study, it is equally 'bioavailable' and represents the same potential problem as its anthropogenic counterpart.

The uncertainty surrounding the EF values for the 15 trace elements was explored by techniques comparable to those used to examine the propagation of errors (Daniels et al., 1962; Caulcutt and Boddy, 1983; Miller and Miller, 1984). For this discussion, several definitions, assumptions, and clarifications are in order.

The term 'uncertainty' is used to clearly distinguish this entity from rigorous statistical terms such as variance, standard deviation, and confidence interval. Similarly, the NRTM, though arrived at in a semi-statistical fashion, is not used as a statistical parameter; it is merely a reference point against which to compare all other sediment concentrations. A median value of all the data or of the trimmed set of data could just as easily have been selected. Since a) the sampling scheme was setup to encounter areas likely to be anthropogenically altered and b) the trimmed data set still included some of these elevated values, the NRTM reference value is probably relatively 'high' in comparison to values derived by a totally random sampling pattern and a weighted mean based on volume of sediment type. Therefore, the EF's utilized in this report are very conservative estimates of enrichment over 'background' conditions.

The uncertainty about the measured sample concentrations, presented in Table 14, is defined as two times the standard deviation about the mean of all replicate APES-D internal controls run throughout the various analytical batches. This is a conservative estimate in that most often in the analysis of propagation of errors, simple single standard deviation is used. Since the NRTM is not a true statistical parameter, the uncertainty about this value was taken to be the same value as the measurement uncertainty. This is likewise a very conservative estimate. Because of the way it is used in the calculations, it could be considered a constant, in which case there would actually be no uncertainty ascribed to it. Using δ as the symbol for uncertainty and treating this quantity the same as a true standard deviation of replicate measurements in determining the propagation of random errors, the equations used to calculate the percent uncertainty in EF, are as follows.

1. EF = C/NRTM

2. $\%\delta(EF) = \delta(EF)/EF \times 100 = \{[\delta(C)/C]^2 + [\delta(NRTM)/NRTM]^2\}^{1/2} \times 100$

Where: EF = enrichment factor
C = extractable concentration in the sample
NRTM = Neuse River trimmed mean
δ = uncertainty

The level of uncertainty is dependent on the actual EF value. For example, the uncertainty is 3.4% when the EF of Cr = 1 (Cr concentration = NRTM = 16.8 μg/g). However, the uncertainty is only 2.4% for the maximum enrichment factor (MEF) of Cr = 17.9 (Cr concentration = 300 μg/g). Of course, as the measured concentration decreases, the uncertainty increases so that for the very low values, those approaching the lower limit of quantitation, uncertainties over 100% are common. However, EF values below 1 are not so critical since the main objective is to identify anthropogenic sources (i.e., concentrations elevated over background). The enrichment factor uncertainties when EF = 1 and for the maximum enrichment factor (MEF) for the 15 trace elements are presented in Table 16. Note that the uncertainties for As, Cd, Mo, Sn, and Hg are relatively high, reflecting the poorer reproducibility of these concentration measurements.

TABLE 16. Level of uncertainty for enrichment factors equal to 1 (or the NRTM) as compared to the maximum enrichment factor (MEF) for each of the 15 trace elements utilized in the Neuse River sediment study.

TRACE ELEMENT	PERCENT UNCERTAINTY EF = 1	MEF
As	75.7	56.6
Cd	36.7	25.9
Co	9.1	6.7
Cr	3.4	2.4
Cu	4.4	3.1
Hg	37.7	26.7
Mn	2.2	1.6
Mo	26.2	18.5
Ni	12.2	8.6
P	4.8	3.5
Pb	6.5	4.6
Sn	23.7	16.8
Ti	5.8	4.4
V	5.0	3.6
Zn	5.8	4.1

With respect to estuarine sediment quality, there are two types of areas of concern (AOC). The following definitions will be used to characterize the level of sediment contamination within the Neuse River estuarine system. Portions of the Neuse River estuarine system that contain multiple sample sites with trace elements that have enrichment factors between 1.5 X and 1.99 X the Neuse River trimmed mean (NRTM), are considered to be "slightly enriched". Considering the conservative nature of the above definitions and calculations, it is appropriate that an EF of 2 X the NRTM be achieved or surpassed in multiple sample sites in order to be defined as "substantially enriched" and a contaminated area of concern (CAOC). Also, we believe that it is equally as important to recognize those estuarine areas that are still relatively pristine as it is to define those areas in which the sediments are contaminated in response to long-term, cumulative impacts of man's waste discharges. These pristine or 'noncontaminated' areas of concern (NAOC) are just beginning to feel major development pressures and have high potentials for becoming contaminated if proper management procedures are not implemented.

1. Contaminated Areas of Concern (CAOC) are those portions of the estuarine system that contain substantially elevated levels of trace element contaminants associated with known anthropogenic point or nonpoint sources. CAOCs are those areas containing multiple sample sites with one or more trace element that are substantially enriched (EFs that are = or > 2 X the NRTM).
   a. Major Contaminated Areas of Concern: CAOCs with major levels of sediment contamination (multiple sample sites that are substantially enriched in 3 or more trace elements. EFs that are = to or > 2 X the NRTM).
   b. Minor Contaminated Areas of Concern: CAOCs with minor levels of sediment contamination (multiple sample sites that are substantially enriched in less than 3 trace elements. EFs that are = to or > 2 X NRTM).
2. Noncontaminated Areas of Concern (NAOC) are those portions of the estuarine system that are relatively free of trace element loading within the sediments. NAOCs are those areas in which mean concentrations for all trace elements are near or below the NRTM. NAOCs may have an occasional sample with anomalous concentrations of one or more trace elements; however, such anomalies could be due to laboratory or analytical error or due to minor spurious character of an individual sample (i.e., presence of a nail, fishing weight, or trash within or adjacent to the sample).

Thus, based upon the chemical quality of bottom sediments in the Neuse River estuarine system, the present study has identified 17 CAOCs and 5 NAOCs (Table 2 and Fig. 1). Six of the 17 CAOCs have major levels of sediment contamination with substantial levels of enrichment of multiple trace elements. These 6 areas are listed in Table 2 and located with large circles in Figure 1. The other 11 CAOCs have minor levels of sediment contamination, are listed in Table 2, and located with small circles in Figure 1. The 5 identified NAOCs are free of substantial levels of enrichment of all trace elements, are listed in Table 2, and located with small squares in Figure 1.

Contour Mapping of Data

Contour maps were assembled to provide a graphical illustration of the spatial distribution of metal concentrations in the sediment samples. Data for the maps were processed using the following procedure. Results of chemical analyses (reported in μg/g) were merged with the location data for each site. Samples representing the surface sediments at each site (from 0 to -7 cm) were sorted from the data set. Ratios of elemental concentration to the Neuse River trimmed mean were calculated for each individual sample within the study area to yield enrichment factors (EF). Enrichment factors are either equal to 1 (the value of the trimmed mean), greater than 1 (enriched relative to the trimmed mean), or less than 1 (deficient relative to the trimmed mean).

The enrichment factors, along with latitude and longitude, were then entered as xyz coordinates into files processed by a computer mapping program entitled SURFER (Golden Software, Golden, CO.). SURFER produces two-dimensional representations of three-dimensional data consisting of xyz coordinates. The x and y data are longitude and latitude, respectively and z value is the enrichment factor. An inverse distance square method, or in some cases inverse distance cube method, was used to interpolate z-grid values between points. Sparseness of data points in some portions of the study area necessitated use of a splinning procedure or artificial thickening of the grid matrix to obtain reasonable results. Adjacent land areas were given a z value of close to zero so that no contours would be plotted in these regions. Each surface was contoured at appropriate contour intervals and shaded to clearly show the distribution of each range of z values.

Contour maps showing very general lateral distributions of enrichment factors were produced for some of the most enriched trace elements within specific CAOC. Due to the following factors, certain limitations to the contour maps should be pointed out.

1. Most of the tributary estuaries have a narrow and irregular, linear geometry.
2. The mud sediments are restricted to specific depths and geometries within each estuarine system.
3. These factors determined the location, distribution and density of sample sites.
4. Computer contouring software packages have major limitations in handling these geometric constraints, sample patterns and necessary boundary conditions for this type of contouring.

Therefore, the contour maps are only a generalized visual representation of the data and may not accurately reflect the absolute relationships that exist between metal enrichment, distribution of sediment type, and the estuarine shoreline, morphology and depth.

PART IV: RESULTS

NEUSE RIVER ESTUARINE SEDIMENTS

Two important factors dictate the level of heavy metal contamination in the North Carolina estuarine sediments. First, there must be a source for trace metals and second, there must be fine-grained sediments that are chemically able to sequester the metals from the water and concentrate them within the sediment system. The source factor was discussed in an earlier section of the report. The present section will consider the morphology of the estuarine basin and then will consider the character of sediments filling this depositional basin.

The distribution, concentration, and composition of organic matter and inorganic clay mineral components are extremely variable throughout the Neuse River estuarine system. However, there are some definite patterns that probably have significant effects upon determining a) which trace elements are concentrated in the sediment, b) their specific levels of concentration and chemical state, as well as c) their potential chemical availability to the biological system. These factors are poorly understood at present and are a major part of ongoing research efforts.

Morphology of the Estuarine System

The Neuse River estuarine system can be subdivided into a group of geographic components that to a large extent determine the physical, chemical, and biological processes operating within the system. First, the estuarine system can be divided into the trunk and tributary estuaries (Fig. 5). The trunk estuary is the flooded portion of the main channel of the Neuse River; it is a major piedmont stream that drains a 6,192 mi^2 basin that extends across the North Carolina coastal plain and well into the red clayey soils of the piedmont. The tributary estuaries are the smaller, coastal plain streams that have also been flooded by a rising sea level and flow into the flooded trunk estuary.

Second, the Neuse River trunk estuary can be subdivided along its length into the following categories depicted in Figure 5. The fluvial zone is that portion of the Neuse River that is a narrow water body characterized by river flow conditions, bounded by fresh water swamp forest floodplains, and dominated by fresh water. This zone occurs on the western end of the estuarine system. The transitional zone is that portion of the Neuse River that is slightly wider due to the permanent drowning of the swamp forest floodplains; this produces dominantly sediment bank shorelines. The transitional zone is characterized by fluctuating water flow and salinity conditions that range from fresh to low brackish salinity. The inner estuarine zone has an intermediate width, but is still somewhat protected from high the wave energy of Pamlico Sound due to the geographic shape of the Neuse River system (Fig. 5). The shoreline of this zone is dominated by high to low sediment banks that are being actively eroded by increasing wave energy. The water is characterized by low brackish conditions. The outer estuarine zone is the very wide, northeast trending portion of the Neuse River that opens into Pamlico Sound on its eastern end (Fig. 5). This high wave energy portion of the Neuse River is dominated by rapidly eroding low sediment bank shorelines and intermediate brackish water conditions.

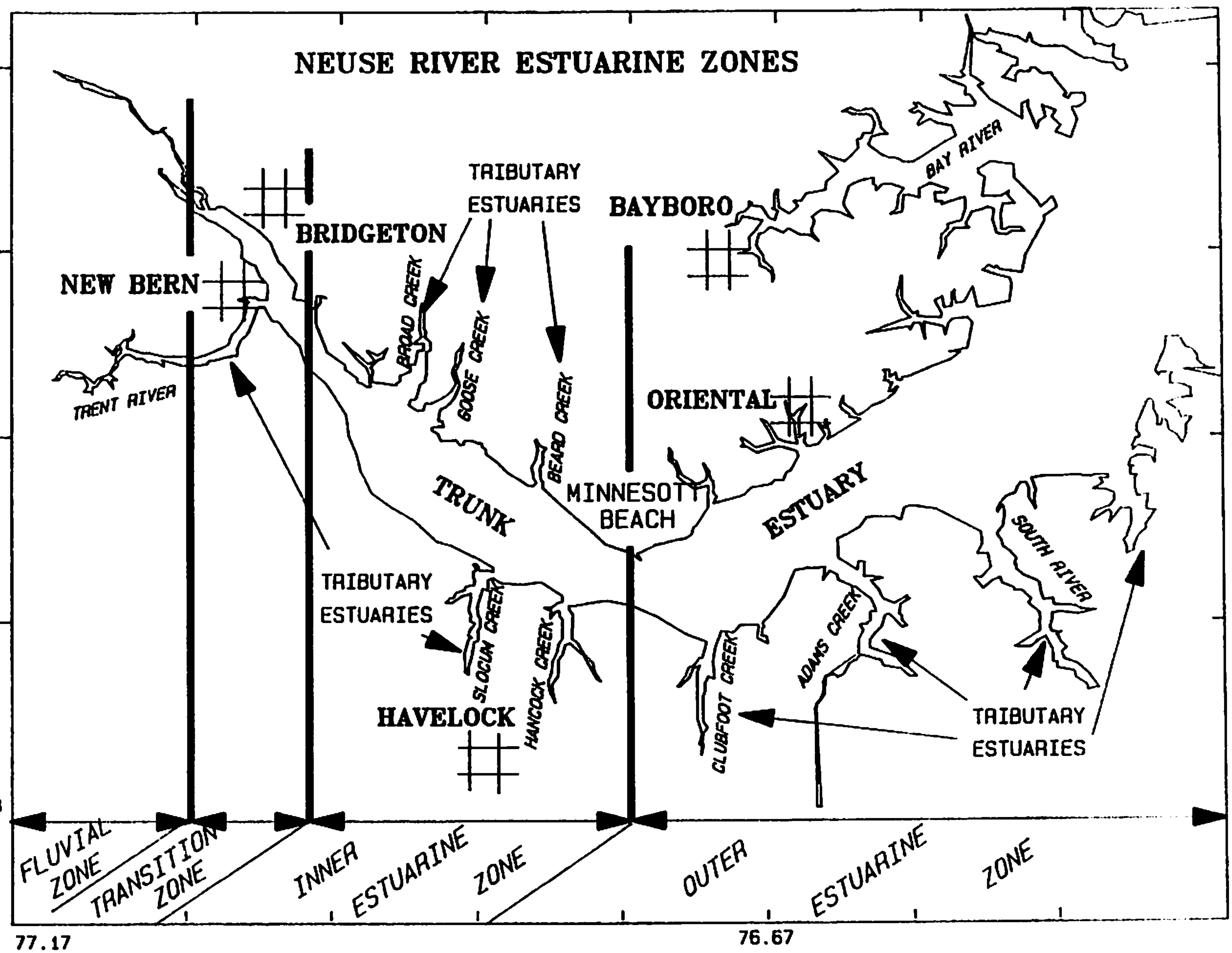

FIGURE 5. Map delineating the fluvial and estuarine zones within the Neuse River system.

The cross-sectional morphology of the Neuse River estuary is much like a shallow dish. The shoreline perimeter has a narrow, shallow platform that slopes gradually down to between 4 to 6 feet and then slopes more abruptly to the broad, flat floor of the basin. A bathymetric profile across the inner estuarine zone of the Neuse River is presented in panel A of Figure 6; location of this profile is along the NP sample line in Figure 21. The entire trunk estuary has this same basic cross-sectional morphology except that the flat basin floor gradually shallows upstream and deepens downstream.

Sediment Composition and Distribution Patterns

The composition and distribution patterns of sediment types within the Neuse River estuarine system are distinct and are directly related to basin morphology and associated estuarine processes. Surface distribution of the sand and mud content is displayed in panels B and C along the bathymetric profile in Figure 6. Notice that the shoreline platforms are dominated by sand with little mud and organic matter present. As the profile drops off into the basin, the sand content decreases as the mud and organic contents increase. The gradual decrease in sand content from both shorelines to a minimum within the estuarine center suggests that most of this sand is being derived from erosion of adjacent shorelines. Panel D of Figure 6 shows a strong relationship between the concentration of organic matter and percent mud within estuarine basin sediments. Consequently, due to the potential for chemical reaction between discharge waste and reactive sediments, major consideration should be given by managers to the location of waste water discharges with respect to basin morphology and associated sediment type.

The morphology and sediment distribution patterns within the Neuse River estuarine system are basically the same as those described in the Pamlico River estuary (Riggs et al., 1989b). The general distribution of sand and organic-rich mud is similar throughout the entire estuarine system with minor lateral variations as outlined below. Samples collected for chemical analysis in this study were generally organic-rich muds obtained from below the edge of the narrow shoreline platform.

Sediments within the Neuse River estuarine system can be subdivided into three general types: sand, peat, and organic-rich mud. Table 17 summarizes the average organic and inorganic composition of these three main sediment types.

TABLE 17. Average composition of total sediment for the three major sediment types occurring within the Neuse River estuarine system. The mud includes both the silt plus clay fractions.

AVERAGE COMPOSITION SEDIMENT TYPE	N	INORGANIC SAND %	ORGANIC SAND %	INORGANIC MUD %	ORGANIC MUD %
SANDS	48	86.5	2.1	9.2	2.1
PEATS	17	32.4	29.7	14.5	23.5
ORGANIC-RICH MUDS	318	29.4	4.6	56.8	8.9
ALL SEDIMENTS	389	36.7	5.4	49.1	8.8

Neuse River Profile

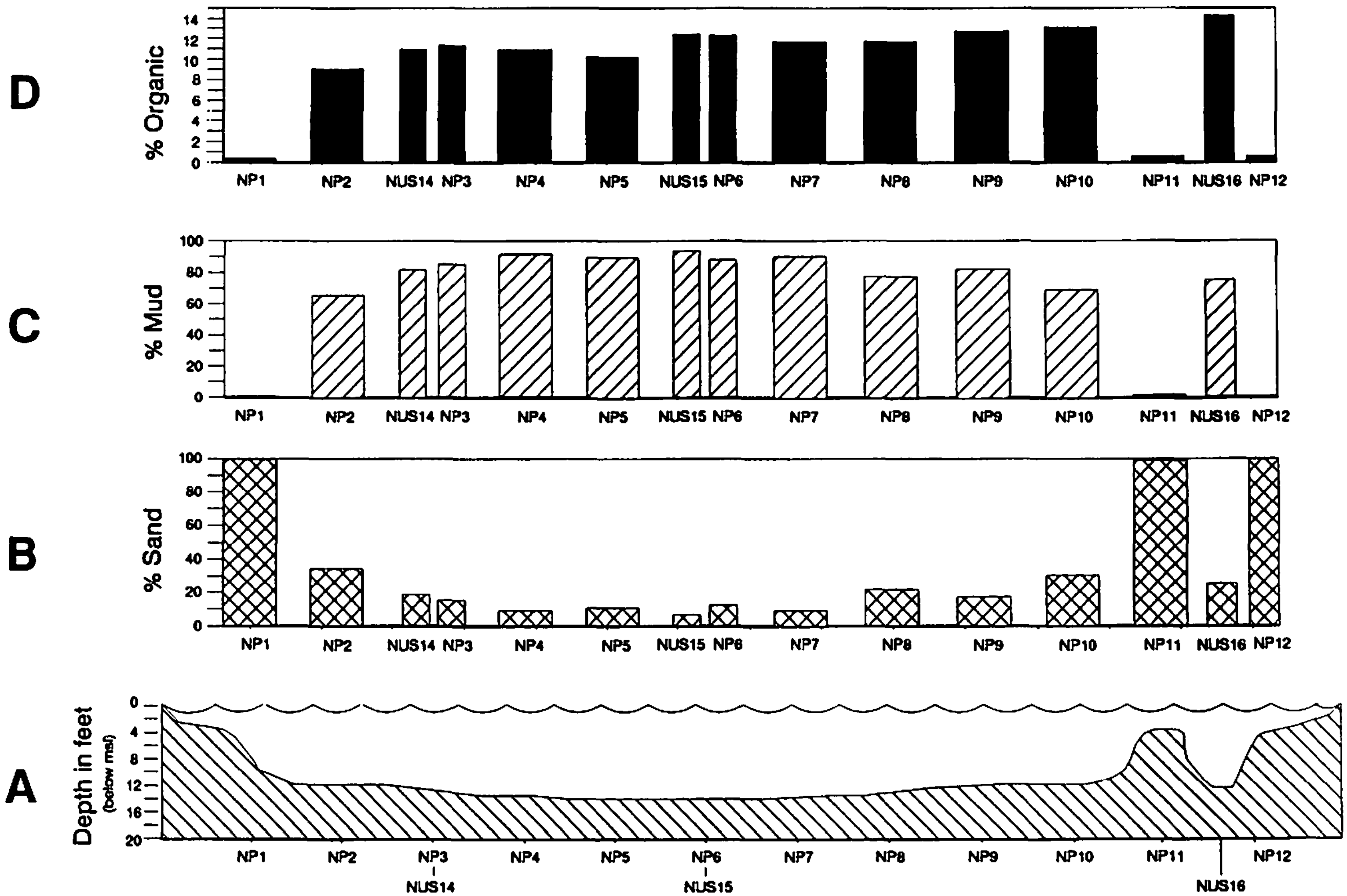

FIGURE 6. South to north (left to right) cross-sectional bottom profile across the Neuse River (Panel A) in feet below mean sea level. Panels B, C, and D show changing distributional patterns of percent sand, mud, and organic content, respectively. Samples and cross-sectional profile are located on Figures 21 and 23

Table 18 summarizes, by region and tributary, the distribution of sediment particle size and organic/inorganic composition of all sediment types within 396 subsamples analyzed throughout the Neuse estuarine system. Table 19 summarizes the organic and inorganic composition of all organic-rich mud (silt plus clay) samples on the basis of Table 18. Table 20 summarizes the distinctive patterns that occur through the estuarine system based upon data in Table 19. Within the main trunk of the Neuse River, the inorganic sand fraction increases downstream towards Pamlico Sound. The inorganic mud fraction generally shows the inverse pattern, but not so dramatically. Both the organic sand and organic mud fractions systematically increase upstream in the trunk estuary. This distribution pattern reflects the dominantly inorganic suspended sediment source coming down the Neuse River with an absence of inorganic sand. The inorganic sand that does occur within the trunk estuary is related to either the proximity of Pamlico Sound on the east or adjacent sediment banks that are actively eroding to supply an internal source of sand. The organic fractions, which decrease downstream, are probably largely derived from the extensive upstream fluvial swamp forests.

Within the tributary systems, there is a dramatic decrease downstream in both inorganic and organic sand fractions in consort with a general increase downstream in both the inorganic and organic mud fractions. The tributaries within the transition zone (Fig. 5) are dominated by inorganic sand, whereas those in the outer estuarine zone are dominated by inorganic mud. Likewise, the organic component follows a similar pattern; tributaries within the transition zone are dominated by organic sand, whereas those in the outer estuarine zone are dominated by inorganic mud. These patterns probably reflect the occurrence of high sediment banks and fresh water swamp forests within the western portion of the estuaries, whereas the eastern portions are dominated by low sediment banks with fringing salt marshes that are eroding on the seaward side. Thus, much of the internally derived sediment consists of fine organic marsh detritus which combines with suspended sediments that settle out as storm waters are trapped in the protected tributary embayments.

TABLE 18. Summary of sediment particle size and the inorganic/organic composition of the total sediment for all samples of the Neuse River estuarine system. Sample areas are listed by regions of the Neuse River trunk (from W to E) and by tributaries that drain into each region (also from W to E).

REGION	N	% SAND	% SILT	% CLAY	%ORGANIC	%INORGANIC
		TOTAL SEDIMENT			TOTAL SEDIMENT	
NEUSE RIVER TRUNK REGIONS						
Fluvial Floodplain	4	39.2	28.4	32.4	11.2	88.8
Transition Zone West	55	37.2	30.6	32.2	19.6	80.4
Transition Zone East	22	37.2	28.1	34.7	11.9	88.1
Inner Estuarine Zone	57	37.2	29.4	33.3	9.6	90.4
Outer Estuarine Zone	37	40.7	32.8	26.5	9.1	90.9
N = 175 MEANS =		38.0	30.3	31.7	13.0	87.0
TRIBUTARIES TO THE FLUVIAL NEUSE RIVER						
Swift Creek	8	44.7	21.7	33.6	9.2	90.8
TRIBUTARIES TO THE NEUSE RIVER IN THE TRANSITION ZONE						
New Bern WWTP	7	62.2	21.0	16.7	19.9	80.1
Trent (West of US-70)	16	58.6	22.7	18.6	19.5	81.5
Trent (New Bern Area)	27	56.2	23.8	20.0	17.2	82.8
Duck Creek	2	55.8	24.7	19.9	20.8	79.2
Scott Creek	4	56.4	28.0	15.6	17.9	82.1
N = 56 MEANS =		57.6	23.5	18.9	18.4	81.6
TRIBUTARIES TO THE INNER NEUSE RIVER ESTUARINE ZONE						
Fairfield Harbour	6	61.7	20.6	17.9	13.1	86.9
Broad Creek	6	30.0	33.0	37.0	15.4	84.6
Goose Creek	4	55.8	20.9	23.4	25.8	74.2
Beard Creek	6	56.1	21.9	22.0	9.6	90.4
Slocum Creek (Main)	30	37.8	35.1	27.1	6.2	93.8
Slocum Creek (Tribs)	16	56.6	22.1	21.4	17.1	82.9
Hancock Creek	10	50.6	25.2	24.3	13.2	86.8
N = 78 MEANS =		46.9	28.1	25.0	11.8	88.2
TRIBUTARIES TO THE OUTER NEUSE RIVER ESTUARINE ZONE						
Clubfoot Creek	6	13.5	45.9	40.7	10.0	90.0
Oriental Harbour	6	33.4	33.8	32.8	10.0	90.0
Oriental Area Creeks	13	29.0	36.1	34.9	9.0	91.0
Whittaker Creek	6	48.6	26.5	24.8	8.2	91.8
Adams Creek	10	25.4	35.5	39.1	11.0	89.0
South River (North Part)	8	35.0	33.1	31.8	9.6	90.4
South River (South Part)	26	45.5	25.2	29.1	25.8	74.2
Bay River	4	31.0	33.4	35.5	11.9	88.1
N = 79 MEANS =		35.3	31.8	32.9	16.1	83.9
SUMMARY N = 396 MEANS =		42.2	29.0	28.8	14.1	85.9

TABLE 19. Summary of composition for all organic-rich mud sediment (silt plus clay fractions) components and their inorganic and organic composition for subsamples within the Neuse River estuarine system. Sample areas are listed by regions of the Neuse River trunk (from west to east) and by tributaries that drain into each trunk region (also listed from west to east). These organic analyses were done on the sand and mud fractions and are different than the total organic analyses for total sediment in Table 18.

REGION	N	INORGANIC SAND %	ORGANIC SAND %	INORGANIC MUD %	ORGANIC MUD %
NEUSE RIVER TRUNK REGIONS					
Fluvial Floodplain	6	27.6	3.9	61.6	7.0
Transition Zone West	36	20.4	5.4	65.6	8.6
Transition Zone East	21	27.3	5.0	58.9	8.8
Inner Estuarine Zone	45	24.6	2.0	64.9	8.4
Outer Estuarine Zone	32	29.8	1.0	59.2	6.9
N = 140	MEANS =	25.2	3.2	62.8	8.1
TRIBUTARIES TO THE NEUSE RIVER IN THE TRANSITION ZONE					
Swift Creek	3	11.1	3.7	84.5	7.3
New Bern WWTP	4	31.0	19.6	42.0	7.4
Trent (West of US-70)	9	32.4	6.6	50.6	10.8
Trent (New Bern Area)	20	41.0	7.6	43.6	7.8
Scott Creek	4	46.4	10.0	35.8	7.9
N = 40	MEANS =	36.4	8.5	47.3	8.4
TRIBUTARIES TO THE INNER NEUSE RIVER ESTUARINE ZONE					
Fairfield Harbour	3	28.2	6.7	49.5	15.6
Broad Creek	6	25.0	5.0	59.6	10.4
Goose Creek	3	52.3	8.8	29.8	9.1
Beard Creek	5	46.3	3.7	42.7	7.3
Slocum Creek	40	33.6	6.0	51.2	9.1
Hancock Creek	9	41.8	5.2	44.5	8.6
N = 66	MEANS =	35.9	5.8	49.4	9.3
TRIBUTARIES TO THE OUTER NEUSE RIVER ESTUARINE ZONE					
Clubfoot Creek	6	12.0	1.4	78.0	8.6
Oriental Harbour	6	31.2	2.2	58.8	7.8
Oriental Area Creeks	13	27.5	1.5	63.6	7.4
Whittaker Creek	6	47.0	1.6	44.8	6.6
Adams Creek	9	17.2	2.3	70.8	9.5
South River	28	30.1	7.5	48.2	14.0
Bay River	4	29.8	1.3	58.4	10.6
N = 72	MEANS =	28.0	4.0	57.5	10.5
SUMMARY N = 318	MEANS =	29.4	4.6	56.9	9.0
		Inorganic Components = 86.4%			
		Organic Components = 13.6%			

TABLE 20. Changing patterns of sediment particle size and composition of organic-rich mud samples through the Neuse River estuarine system. Samples are summarized by regions from upstream to downstream in the main Neuse River trunk estuary and by tributaries occurring within each region of the trunk estuary. Mud includes the silt plus clay size fractions. These organic analyses were done on the sand and mud fractions and are different than the organic analyses for the total sediment in Table 18. Each of the arrows point in the direction of increasing concentration of that component.

REGION	N	INORGANIC SAND %	ORGANIC SAND %	INORGANIC MUD %	ORGANIC MUD %
NEUSE RIVER TRUNK SYSTEM (W to E)					
Transition Zone	57	22.9	5.3	63.1	8.7
Inner Neuse River	45	24.6	2.0	64.9	8.4
Outer Neuse River	32	29.8	1.0	59.2	6.9
NEUSE TRIBUTARY SYSTEM (W to E)					
Transition Zone	40	36.4	8.5	47.3	8.4
Inner Neuse River	66	35.9	5.8	49.4	9.3
Outer Neuse River	72	28.0	4.0	57.5	10.5

Organic-Rich Mud (ORM) Sediment

Organic-rich mud (ORM) sediments are the dominant sediment type within the Neuse River estuarine system. Tables 17, 18, and 19 summarize the general textural and organic composition and show the regional lateral variations in ORM, which occupies the entire slope and basin environment throughout both the trunk and tributary estuaries. Consequently, ORM constitutes over 80% of the bottom environments within the estuarine system (Fig. 5).

Actual concentrations of organic matter within individual samples ranges from 0.4% up to 81% of the total sediment and generally occurs in several different forms. Major differences occur in sediment types within estuarine systems depending upon the organic concentration. Sediments that contain greater than 20% organic matter are generally some form of peat or muddy peat deposit. Peat deposits form in two ways. First, they can represent in situ growth in either swamp forests or grass marshes containing discrete plant components such as roots and stems in growth position, along with large pieces of logs, leaves, seeds, and inorganic sediments that have accumulated within the in situ organic framework. Second, peats can result totally from secondary accumulations of transported organic detritus eroded out of swamp forests and grass marshes. Within the Neuse River estuarine system, both of these types of peat deposits contain fairly high concentrations of inorganic clay components. Inorganic clays settle out in the swamp forests and marshes from turbid storm waters that contain high concentrations of suspended sediments.

Swamp forest peat sediments tend to be coarser grained and are dominant in the fluvial and transition zones of the Neuse River and headwaters of associated tributary estuaries. Within the fluvial zone, organic material

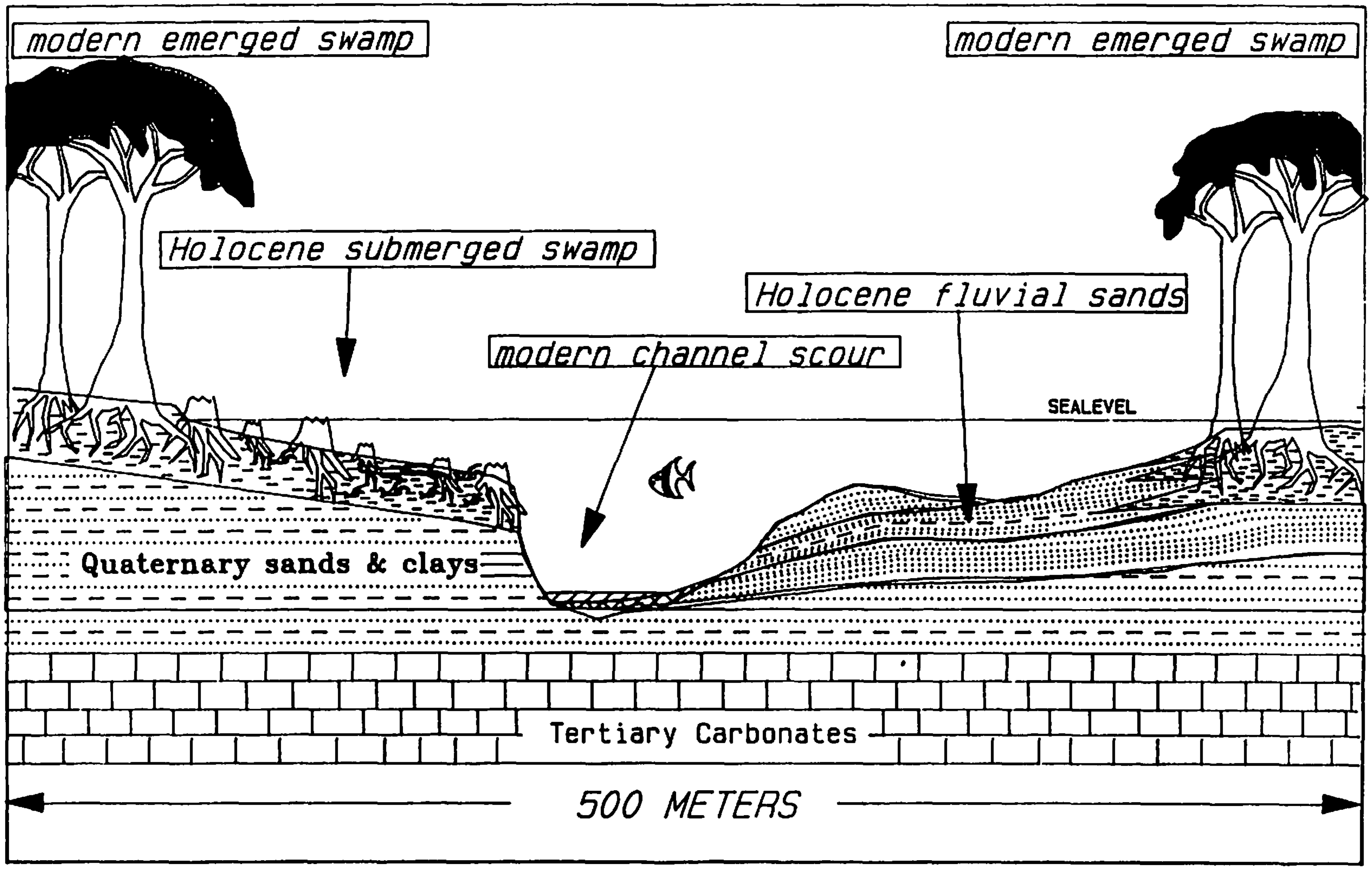

FIGURE 7. Schematic cross-section of the upper transition zone of the Neuse River during the initial stages of flooding by rising sea level. Notice the general relationship of different sediment components to the various fluvial environments.

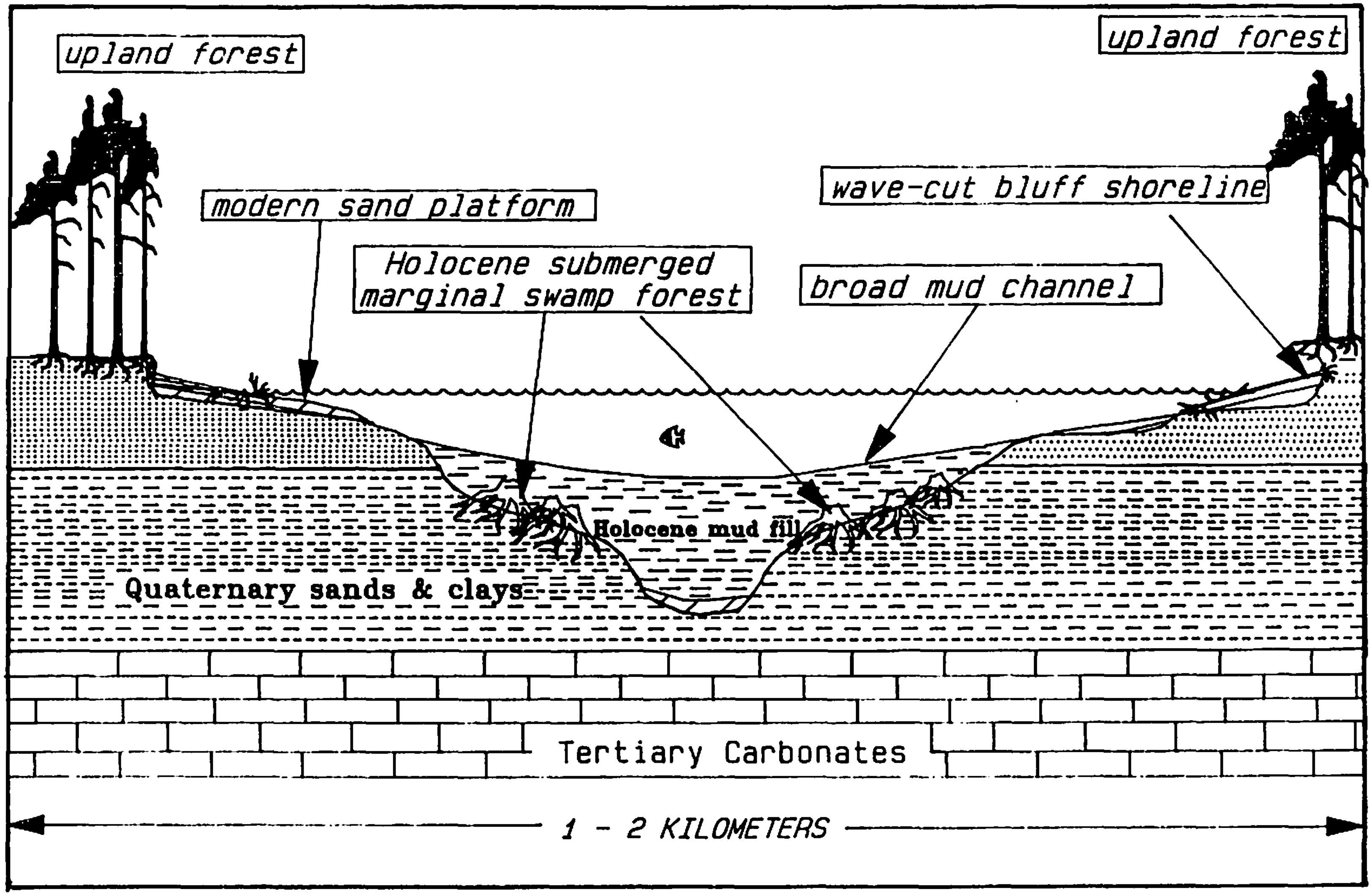

FIGURE 8. Schematic cross-section of the upper transition zone of the Neuse River about 400 meters east of Figure 7 This section shows a major shift in sedimentation as organic-rich muds fill the fluvial channel and bury the swamp-forest peats in response to continued flooding by rising sea level.

occurs as swamp forest peats on the channel flanks and as coarse organic detritus mixed with coarse sand within the channel proper (Fig. 7). Within the transition zone into a flooded estuary, there is a major sediment inversion (Riggs, 1985). The swamp forest is drowned and mud, containing high concentrations of fine-grained organic detritus, begins to accumulate on top of swamp forest peats on the channel flanks and in the channel (Fig. 8). Swamp forest peats become buried beneath increasingly thicker accumulations of ORM within the main portions of the tributary and trunk estuaries. The shoreline platforms have been eroded into tight Quaternary sediment units by wave and current action that produce a thin and highly variable layer of well-sorted sand cover (Fig. 8) (Hartness, 1977; Hardaway, 1980; Riggs et al., 1989b). Within the broad, deeper portions of the Neuse River estuary, ORM sedimentation occurs. Thus, these mud-filled, depositional basins are incised into the shallow platforms composed of older, more indurated Quaternary sediment units.

Table 17 demonstrates that ORM sediments generally have considerably less than 20% organic matter (average = 13.6%), are generally dominated by inorganic mud (average = 56.8%), and contain lesser amounts of inorganic sand (average = 29.5%). The mud-size fraction is composed of mixtures of various clay minerals and organic matter. Park (1971) found the relative concentration of five common clay minerals within the Neuse River sediments to be as follows: kaolinite (46%), illite (23%), chlorite-intergrade (17%), chlorite (8%), and smectite (5%). These clay minerals are derived from the erosion of sediment bank shorelines and river drainage off the upland portions of the drainage basin. Various workers have shown a downstream increase in illite and decrease in kaolinite (Brown and Ingram, 1954; Griffin and Ingram, 1955; Allen, 1964; Petree, 1974). Chemically inert quartz is the main mineral component within the sand-size fractions of the sediments within the Neuse River system.

Total organic matter content of ORM sediments that fill the estuarine basins ranges from lows of 1% to 2% in sandier sediments to highs of about 30% to 44% in muddy sediments around sewage outfalls and areas of intense agricultural development (Table 19). The concentration of this organic matter is generally highest in the tributaries and decreases into the trunk estuary and seaward down the trunk estuary (Table 20). Grass marsh peats, which contain much finer-grained organic matter than swamp forest peats, form around low-energy shorelines in the outer portions of the tributary and trunk estuaries. As these fringing marshes erode, they supply abundant fine-grained organic detritus as a major component of the suspended sediment along with clay minerals (Bellis et al., 1975; Copeland et al., 1983, 1984). This suspended sediment settles out of the water column by flocculation, aggregation, or via filter-feeding organisms to produce the ORM that dominate the estuarine system. The lateral distribution and thickness of organic-rich mud increases as the basin widens and deepens in the downstream direction within both the trunk estuary and tributary channels (Hartness, 1977; Duque, 1978; Riggs et al., 1989b).

Benthic environments associated with the ORM contain an oxidized zone of loose floc material that is of variable thickness. The presence or absence and degree of development of this loose floc at the sediment/water interface appears to be a direct function of the biological productivity, salt-water wedges, and storm energy levels, all of which vary greatly at scales ranging from daily to seasonal cycles. Sediments become reduced and increasingly compacted with depth below the sediment/water interface. In addition to a large population of micro-organisms, this sediment/water interface zone contains a large community of filter-feeding macrobenthos, particularly polychaetes and clams (Tenore, 1977), that appear to be important in concentrating, pelletizing, and depositing the mud sediment.

Rates of Sedimentation

Wells (1989) and Wells and Kim (1989) believe that most of the surface sediments within the Neuse River trunk estuary will be deposited and resuspended many times before permanent accumulation on the bottom. This is due to the combination of the fine-grained nature of the sediments, the shallow water character of the sediment basin, and the high levels of wind stress on the basin. They found that sedimentation of fine-grained components was accelerated by the formation of large particulate aggregates or "marine snow" of suspended sediment that are at least an order of magnitude larger than the discrete sediment particles themselves. This process of aggregate formation accelerates the transport of sediments to the bottom with fairly high settling rates of 50 to 200 meters/day (Wells and Kim, 1989). Thus, small amounts of suspended sediment are rapidly aggregated and deposited within the turbidity maxima as flocculent particulates (either biologically or electrochemically). Nevertheless, fine-grained sediments are readily disturbed from the bottom by biological processes, storm energy, and activities of man, and resuspended within the water column. Wells and Kim (1989) also found that the residence time of fine-grained sediments in the estuarine turbidity maximum is increased due to a persistent upstream current flow near the bottom, and ultimately are permanently deposited on the bottom and buried.

Benninger and Martens (1983) used lead 210, in combination with carbon 14 age dates to determine preliminary rates of sedimentation within the Neuse River estuary. They estimated a sedimentation rate of about 5 mm/year for the main trunk of the Neuse River near New Bern over the last 60 to 100 years, whereas accumulation rates were relatively low (and possibly zero) at the mouth of the Neuse River during the last 100 years.

Riggs et al. (1989b) produced a sea-level curve for the last 5,000 years for the inner portion of Blounts Bay in the Pamlico River estuary based upon carbon 14 age dates. This curve begins with in situ swamp forest peat at the base of the core that formed in a fresh water fluvial system at or slightly above sea level. The peat grades upward into ORM that represent deposition in an aquatic, inner estuarine environment seaward of the transition zone. The resulting curve reflects the systematic rise in sea level, flooding up the tributary stream to form a lateral estuary, and deposition of ORM sediments. Riggs et al. (1989b) calculated the mean rate of deposition of the ORM as 0.61 mm/year (with a range from 0.45 mm/year to 0.7 mm/year).

In addition, a sequence of 11 samples from the upper one meter of the Blounts Bay core were analyzed for lead-210 and cesium-137 (W.C. Burnett, Florida State University, Tallahassee; personal communication, 1990). The lead concentrations were very low and with an irregular upsection concentration. This suggests low lead accumulation with the distribution being a result of alternate periods of moderate sediment accumulation followed by periods of major resuspension and mixing by irregular pulsing events on very small time scales. Storm events could produce such a distribution pattern. Cesium, which was first introduced into the natural system during atmospheric nuclear bomb testing during the 1950's and reached a maximum in 1963, also supports the storm mixing interpretation. Cesium was first detected at 17 to 17.5 cm below the sediment/water interface with an irregular distribution upsection and maximum concentration in the uppermost sample (5 to 5.5 cm). Rates of sedimentation based upon the first occurrence of cesium suggest ongoing depositional rates between 0.5 to 0.75 mm/year which corroborates the carbon-14 rates of sedimentation.

The Neuse River depositional rate of 5 mm/year of Benninger and Martens (1983) is an order of magnitude higher than the 0.61 mm/year rate for the Pamlico River of Riggs et al. (1989b). This difference may reflect several different effects upon sedimentation as follows:

1. The Neuse River core is located within the transition zone and turbidity maxima of the trunk estuary and may actually have slightly higher rates of sediment deposition. Whereas the Blounts Bay core in the Pamlico River estuary is located on the inner portion of a tributary estuary within the inner estuarine zone. This bay is an area of active erosion and embayment expansion and could have slightly lower rates of sediment deposition.
2. Rapid sedimentation of the young surface sediments in the Neuse River may reflect local, short-term deposition of loose, fluid-like muds that form on the surface. Such loose sediments tend to be ephemeral and can be readily resuspended many times. During resuspension and before permanent burial, the sediments can become mixed with older carbon and with varying lead and cesium concentrations in response to storm events.

A slower rate of sedimentation for the Neuse-Pamlico estuarine system is also supported by the rate of sediment infill calculations of Wells and Kim (1989). Based upon the present volume of river sediment input alone and assuming no dramatic short-term climatic changes and a very modest rate of sea-level rise of 1 mm/year, Wells and Kim concluded that the present North Carolina estuarine system would never reach a sediment-filled state.

The net slow sedimentation of ORM as discussed, suggests that the anthropogenic effects of metal contaminants should be well mixed and homogenized in the upper 5 to 15 cm. Actual depth of impact within any specific portion of the estuarine system would ultimately be dependent upon secondary mixing processes such as bioturbation by benthic organisms, wave and current processes resulting from major storm events, and mixing by man's activities such as fishing trawlers and dredging. Areas that are highly impacted by man and old industrial development, enriched metal concentrations could extend much deeper below the sediment/water interface. The latter distribution is supported by the data presented and discussed in the next section.

Organic-Rich Muds and Heavy Metals

Discharge of apparently low concentrations of heavy metals from both natural and anthropogenic point and non-point sources into the Neuse River estuarine environments dominated by ORM may lead to potential contamination problems. High adsorption capabilities of clay minerals coupled with high chemical reactivity of organic matter, continuously sequester trace metals from the water column. Resuspension of mud sediments by storms, biological processes and man, present multiple opportunities to further concentrate metals within bottom sediments. Thus, the cumulative effect of large discharge volumes with low concentrations over long time periods can lead to substantial metal enrichment. Lightly bound metals are then potentially available for further concentration and movement through the food chain by abundant filter and detritus feeding organisms living within organic-rich mud environments.

Chemical analyses of major, minor, and trace element compositions have been done on the samples of ORM cored at 203 stations (Table 11 and Fig. 3) within the Neuse River estuarine system. Subsampling of these cores produced 413 samples (Table 11) representing at least the surface (uppermost 7 cm) and deep sediments (lowermost 7 cm) (see Appendix B for detailed procedure). Analysis of these sediment samples documents specific lateral and vertical distribution and concentration of metals within the basin and define environmental conditions favoring heavy metal enrichment. As discussed in the subsequent sections, sediments in the vicinity of known point source discharges are often substantially enriched in specific metals compared to sediments in other portions of the Neuse River irregardless of organic and clay concentrations within the sediments (Table 21). The wide variation of organic matter and clay constituents within the most and least contaminated portions of the Neuse River estuary suggest that anthropogenic sources are largely responsible for heavy metal enrichment within this estuarine system.

TABLE 21. Comparison of organic and clay concentrations (in %) within all sediment samples (surface and deep) of the most and least contaminated portions of the Neuse River estuarine system.

ESTUARINE AREA	N	% ORGANIC MATTER Mean	Range	% CLAY-SIZE MATTER Mean	Range
MOST CONTAMINATED AREAS					
Bridgeton: Neuse	15	26	4 to 61	24	3 to 63
New Bern: WWTP	7	20	7 to 43	17	3 to 34
New Bern: Trent	27	17	4 to 59	20	5 to 51
New Bern: Neuse	19	19	9 to 66	36	13 to 59
Oriental: Harbor	6	10	7 to 14	33	22 to 44
Slocum Creek	40	16	4 to 35	25	1 to 58
MEANS	114	18	4 to 66	25	1 to 63
LEAST CONTAMINATED AREAS					
Adams Creek	10	11	3 to 15	39	10 to 61
Beard Creek	6	10	2 to 17	22	8 to 45
Clubfoot Creek	6	10	8 to 12	41	30 to 48
Goose Creek	4	26	16 to 50	23	12 to 32
Hancock Creek	10	13	4 to 21	25	5 to 47
MEANS	36	13	2 to 50	31	5 to 61

Vertical Distribution of Metals

Throughout most of the Neuse River estuarine system, surface sediments appear to have been enriched in many of the metals relative to the deeper sediments. This is demonstrated in Table 22 which compares mean concentrations for 15 trace elements in all deep samples with mean concentrations for all surface samples within the Neuse River estuarine system. These data suggest that there might be a general upcore increase in concentration as follows. Eleven of the elements show upcore increases that range from 1.1 X up to 2.5 X enrichment in the surface sediments. Lead (1.3 X), tin (1.4 X), copper and chromium (1.5 X), zinc and phosphorus (1.6 X), and nickel (2.5 X) appear to be substantially enriched in the surface sediments. Cadmium and mercury are relatively uniform through the cores, whereas molybdenum and titanium (0.8 X and 0.9 X) are enriched in the deeper portions of the cores. This apparent upcore increase in trace metal concentration was also documented in the Pamlico River estuary by Riggs et al. (1989b).

TABLE 22. Comparison of mean concentrations for 15 trace elements (in μg/g or ppm) between surface and deep sediment samples in the Neuse River estuarine system. The deep samples have an average depth of 30 cm below the sediment/water interface. Bold print indicates those samples for each element with the highest mean value; underlined enrichment values indicate those elements that are enriched at the surface relative to the deep samples.

TRACE ELEMENTS	NEUSE RIVER MEANS				RATIO OF MEANS	
	N	SURFACE SEDS.	N	DEEP SEDS.		SURFACE/DEEP
Ni	217	**8.99**	189	3.66	**	2.5 ± 2.1
Zn	217	**105.**	189	65.8	**	1.6 ± 0.6
P	217	**924.**	189	563.	**	1.6 ± 0.3
Cu	217	**27.2**	189	17.6	**	1.5 ± 0.6
Mn	217	**299.**	189	200.	**	1.5 ± 0.2
Sn *	217	**25.0**	189	18.3	**	1.4 ± 0.4
Pb	217	**39.4**	189	30.1	**	1.3 ± 0.4
Cr	216	**19.9**	189	16.8	**	1.2 ± 0.4
As *	217	**6.06**	189	5.55	**	1.1 ± 0.1
Co	217	**4.74**	189	4.23		1.1 ± 0.1
V	217	**22.6**	189	21.1		1.1 ± 0.1
Cd	217	1.28	189	1.31	**	1.0 ± 0.6
Hg	169	0.24	119	0.23		1.0 ± 0.6
Ti	217	32.0	189	**36.9**	**	0.9 ± 0.1
Mo	217	0.64	189	**0.84**	**	0.8 ± 0.2

* = Analyses have poor reproducibility, hence somewhat less reliability
** = Numbers are significantly different when $p < 0.05$ using the SAS Wilcoxon Signed Rank test.

Higher concentrations of trace elements do occur at greater depths in two types of depositional areas. First, some cores from the inner Neuse River grade from ORM at the surface to peat deposits at depth. These peats have extremely high contents of organic matter (ranging from 25% to 81%) that increases the ability to sequester trace metals (Evans et al., 1984; Linebach, 1990). Second, areas with a long history of extensive human activity, often show high or higher concentrations of most trace elements with depth. The latter situation may be caused by the following circumstances: a) extensive discharge of metal-bearing wastes over long time periods in consort with extensive bottom disturbing and sediment mixing processes by man, and/or b) discharges that have varied in volume and type of trace elements through time.

The amount of surface enrichment of heavy metals is directly related to the total elemental concentration; cores with low total concentrations (i.e., from the least contaminated areas) have small upcore changes whereas cores with high total concentrations (i.e., from the most contaminated areas) have large upcore changes. The nutrient element phosphorus shows distinct surface enrichments (1.6 X). Phosphorus data suggest that decomposition of the ORM in surface sediments represents an important source of nutrient input into the water column within the estuarine system. If this is the situation, nitrogen would also be derived from the decomposition of ORM and potentially available to the aquatic system. This corroborates the results of Matson et al. (1983) for both the Pamlico and Neuse River estuaries.

Comparison of Trace Elements in the Neuse and Pamlico River Sediments

Table 23 compares trimmed means of surface samples within the Neuse River with those of the Pamlico River (Riggs et al., 1989b) and presents the relative enrichment of the Neuse River estuarine system as compared to the Pamlico River system. Comparison of these trimmed means demonstrates several interesting points. First, the Neuse River has higher background levels of concentrations for 10 of the 15 trace elements; five of these elements have higher background levels and include cadmium (2.1 X), manganese (1.9 X), mercury and nickel (1.7 X), and chromium (1.6 X). On the other hand, only arsenic and lead have background concentrations within the Pamlico River that are higher than in the Neuse; of these, only arsenic is substantially enriched (2.1 X).

Second, background concentrations for all major elements are fairly similar for both estuarine systems except for calcium and sodium. Both elements are enriched in the background composition of the Neuse River sediments by 1.4 X. This is interpreted to reflect slightly higher salinities within the estuarine waters and associated sediment pore waters as compared to the Pamlico River. Calcium enrichment in the Neuse River reflects higher concentrations of $CaCO_3$ shells in the sediments as compared to the Pamlico system; this probably also reflects slightly higher salinities throughout the Neuse River estuarine system.

Third, differences in the other 5 major elements including aluminum, silica, potassium, magnesium, and iron are slight and range between 0.9 X and 1.2 X. The slight variations that do exist probably reflect relative variations in concentrations of organic matter, inorganic clay, and quartz silt/sand contents.

TABLE 23. Comparison of trimmed mean concentrations for 22 elements (in μg/g or ppm) in surface sediments of the Neuse River (this study) and the Pamlico River (Riggs et al., 1989b) estuarine systems. Bold print indicates the estuarine system which has the higher background levels for each element.

ELEMENT	NEUSE RIVER TRIMMED MEANS	PAMLICO RIVER TRIMMED MEANS		RATIO OF TRIMMED MEANS NEUSE R./PAMLICO R.
TRACE ELEMENTS				
Cd	**0.77**	0.36	**	2.1 ± 0.5
Mn	**288.**	154.	**	1.9 ± 0.2
Hg	**0.15**	0.09	**	1.7 ± 0.3
Ni	**4.64**	2.66	**	1.7 ± 0.3
Cr	**16.8**	10.5	**	1.6 ± 0.2
Cu	**19.3**	13.6	**	1.4 ± 0.2
Zn	**95.0**	77.0	**	1.2 ± 0.2
Mo	**0.54**	0.50		1.1 ± 0.1
P	**876.**	805.		1.1 ± 0.2
V	**22.5**	21.4		1.1 ± 0.1
Pb	34.9	**35.9**		1.0 ± 0.1
Co	4.66	**5.55**	**	0.8 ± 0.1
Ti	31.8	**38.6**	**	0.8 ± 0.1
As *	5.98	**12.8**	**	0.5 ± 0.0
Sn *	21.5	NA		---
MAJOR ELEMENTS				
Ca	**5039.**	3679.	**	1.4 ± 0.1
Na	**6203.**	4519.	**	1.4 ± 0.2
Mg	**3220.**	2707.	**	1.2 ± 0.1
Fe	**16236.**	14692.	**	1.1 ± 0.1
K	**1029.**	932.		1.1 ± 0.1
Al	**6912.**	6664.		1.0 ± 0.1
Si	1052.	**1174.**	**	0.9 ± 0.0

* = Analyses have poor reproducibility, hence somewhat less reliability.
NA = Not analyzed
** = Numbers are significantly different at the 95% confidence interval using the Student-t Test (Marsal, 1987).

NEUSE RIVER AREAS OF CONCERN

Table 24 is an outline of the specific regional areas and associated maps that will be the basis for presentation and discussion of all analytical data in the remainder of this report. Figure 9 is an index map showing the location of all area maps used in the remainder of this report.

TABLE 24. Outline of the regional areas of the Neuse River estuarine system and the associated figures.

AREAS OF THE NEUSE RIVER ESTUARINE SYSTEM	ASSOCIATED FIGURES
Neuse River Transition Zone: New Bern--Bridgeton Area	9 through 18
New Bern: Trent River East and Lawson Creek	10 through 18
New Bern: Trent River West	9 and 19
New Bern: Neuse River	10 through 18
New Bern: Waste Water Treatment Plant	10 through 18
Bridgeton: Mill Branch	10 through 18
Bridgeton: Neuse River	10 through 18
Neuse River Summary in New Bern--Bridgeton Area	10 through 18
Neuse River Zone: West of New Bern--Bridgeton Area	9 and 20
Inner Neuse River Estuarine Zone	9 and 21
Inner Neuse River: East of New Bern--Bridgeton Area	21
Scotts Creek	21
Duck Creek	21
Cherry Point Area: Slocum Creek	9, 23 through 33
Cherry Point Area: Hancock Creek	9 and 23
Goose and Beard Creeks	21
Fairfield Harbor: Northwest and Upper Broad Creeks	21
Outer Neuse River Estuarine Zone	9, 34 through 35
Outer Neuse River: East of Minnesott Beach	34 and 35
Adams Creek	34
Bay River	1 and 9
Clubfoot Creek	34
South River	35
Oriental Area	9, 34, 36, and 37

Neuse River Transition Zone: New Bern--Bridgeton Area

The New Bern--Bridgeton area occurs in the uppermost portion of the estuarine system in the transition zone from the Neuse River fluvial system to the west and the Neuse River estuarine system to the east (Figs. 5 and 9). Figure 10 and Appendix A present the locations of all sediment samples collected within the Neuse River Transition Zone and utilized for the following discussion.

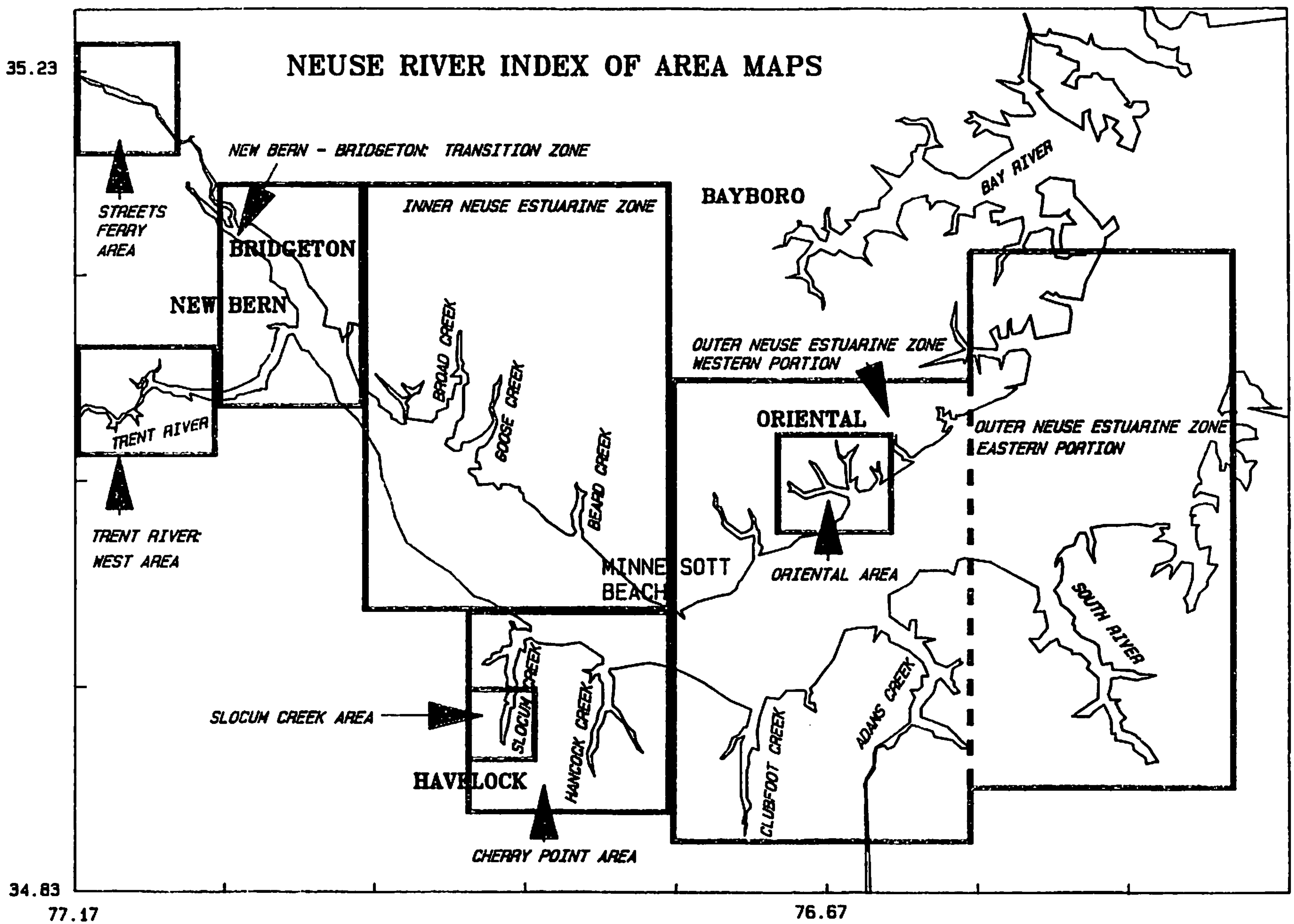

FIGURE 9. Index map of the Neuse River showing the location of specific regional maps used in the text.

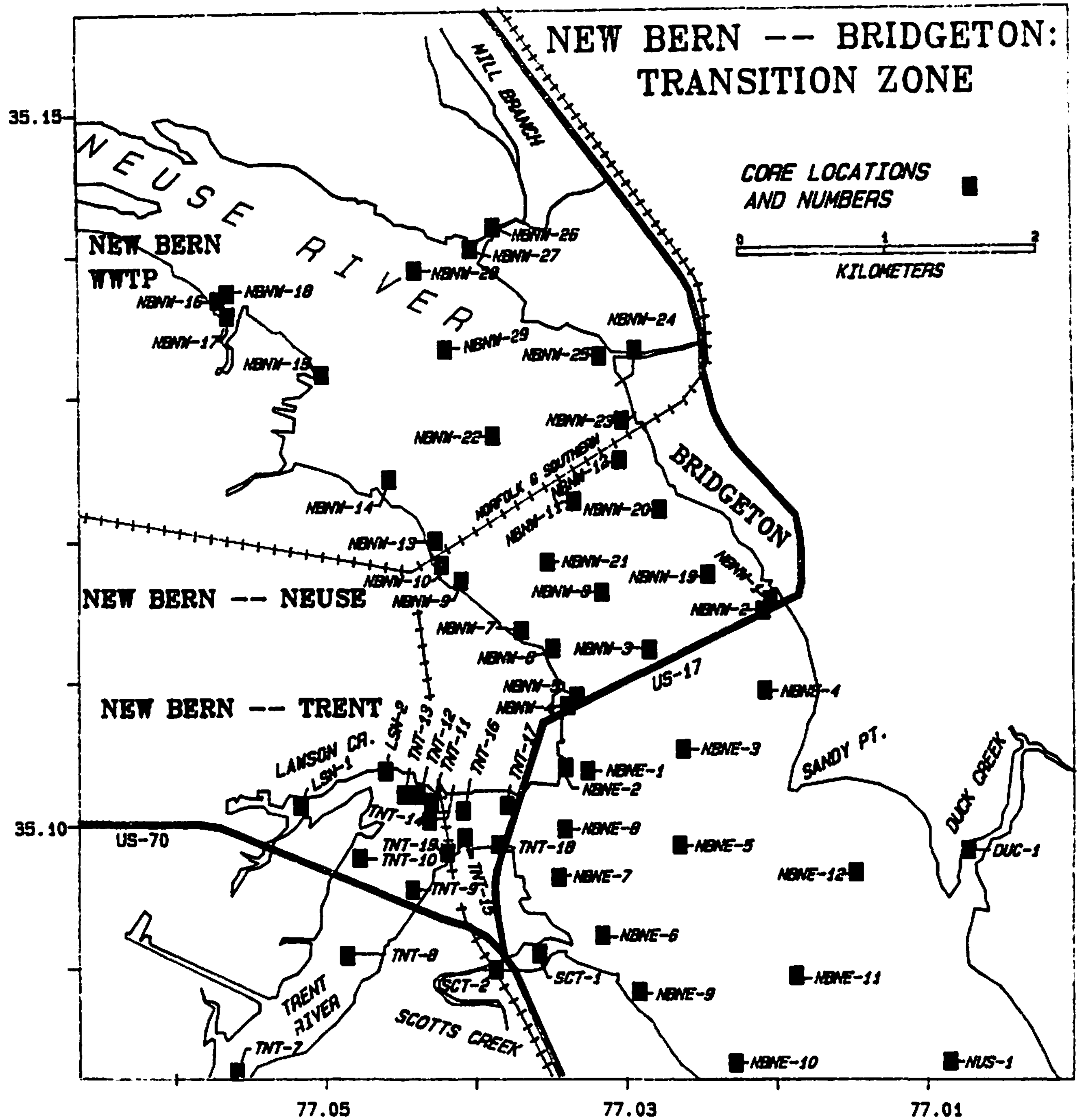

FIGURE 10. Sample location map of the Neuse River Transition Zone: New Bern--Bridgeton Area.

New Bern is situated on a peninsula between the confluence of the Neuse and Trent Rivers. It is the largest city within the Neuse River estuarine system with the highest degree of industrial development. Nineteen active NPDES discharge permits in the New Bern area contribute up to 16,627,500 million gallons of industrial and municipal waste water per day to the estuarine system (App. C). Bridgeton is a smaller town on the northeast side of the Neuse River. Seven NPDES discharge permits discharge up to 125,000 gallons of industrial and municipal waste water per day to the estuarine system in the Bridgeton area (App. C).

The entire New Bern--Bridgeton urban area is characterized by a large number of potential point and nonpoint sources of trace element contaminants that either runoff or are discharged directly into the estuarine system. Some known sources are located on Figure 11 and include the following.

1. One municipal waste water treatment plant;
2. Abundant active and historic industrial sites including plants for metal plating, fertilizer production, lumber and wood processing, chemical distributors, and soft drink manufacturing;
3. A major shipyard and boat manufacturing plant, and numerous marinas and boatyards of all sizes;
4. Several major rock quarries;
5. Several utility companies;
6. Extensive street and parking lot pavement with curbs, gutters, and storm sewers; and
7. Vast areas of shoreline residential development with manicured lawns, gardens, and septic systems.

In addition, both the Neuse and Trent Rivers are used extensively for recreational boating and commercial shipping with dredged channels and basins cut into the natural river bottom and adjacent areas filled with resultant dredge spoils. Extensive broken dock remnants and old pilings along much of the shoreline area reflect almost three centuries of maritime activity.

Consequently, the estuaries in the New Bern--Bridgeton area reflect high levels of anthropogenic influence. Substantial levels of elemental enrichment occurs in samples collected along the waterfront areas of New Bern and Bridgeton and small tributary creeks that drain these areas (Table 10). Six COAC have been delineated in the estuaries surrounding New Bern--Bridgeton urban areas (Fig. 1); five of these are considered to be major COAC.

<u>New Bern: Trent River East and Lawson Creek</u>

The Trent River between the new US highway 70 highrise bridge and the old highway 70 swing bridge is characterized by extensive industrial development (Fig. 11). Several active industrial docks, marinas, hotels, and a shipyard occur in this area. Historic industrialization is evidenced by abundant ruined docks, pilings, and shipwrecks. The shoreline and portions of the harbor region have been, and still are being modified by dredging, filling and bulkheading.

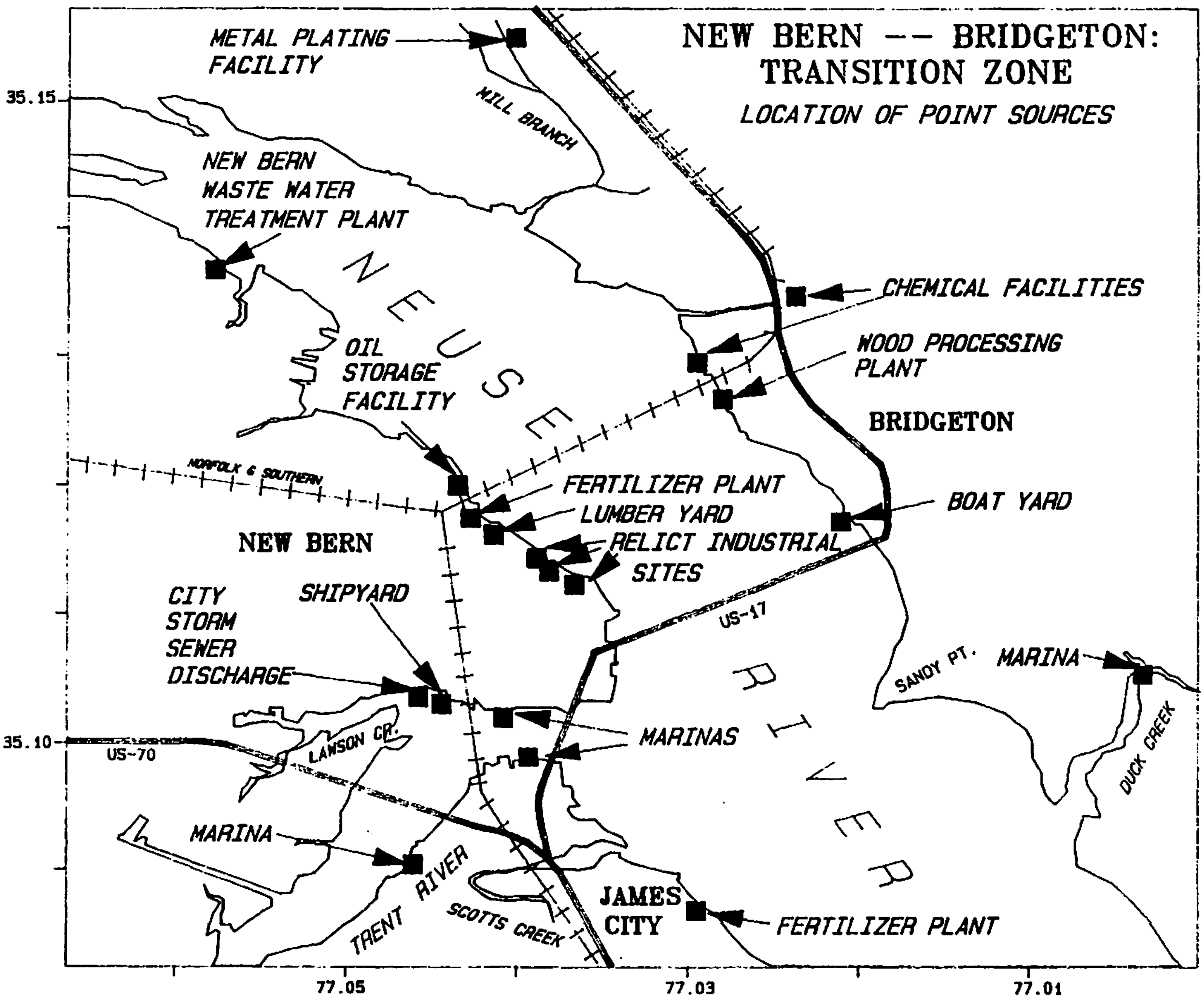

FIGURE 11. Location of some of the more important and known potential point sources of metal contaminants in the New Bern--Bridgeton Area.

Samples collected along the north shore and extending from Lawson Creek east to the old highway 70 bridge (Fig. 10) are substantially enriched in 11 trace elements (Table 25). Figures 12 through 18 present the regional distributions for 7 major metal contaminants. Copper, zinc, nickel, lead, and mercury are substantially enriched in the surface sediments (up to 12.8 X, 11.6 X, 7.0 X, 6.9 X, and 4.7 X, respectively) with trace elements manganese, phosphorus, cobalt, arsenic, tin, and molybdenum having enrichment factors between 2.8 X and 2.0 X. Chromium, cadmium, titanium, and vanadium are slightly enriched relative to the Neuse River trimmed mean.

TABLE 25. Concentrations and enrichment factors of 15 trace elements in surface sediments from New Bern: Trent River East and Lawson Creek. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold type are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (µg/g or ppm) MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS MEAN	MAXIMUM
NEW BERN: TRENT RIVER EAST AND LAWSON CREEK						
Cu #	15	63.2	9.6	248.	3.3	12.8
Zn #	15	248.	47.9	1104.	2.6	11.6
Ni #	15	7.6	0.8	32.5	1.6	7.0
Pb #	15	92.1	19.0	242.	2.6	6.9
Hg #	13	0.31	0.05	0.72	2.0	4.7
Mn	15	399.	75.7	819.	1.4	2.8
P	15	1391.	300.	2264.	1.6	2.6
Co	15	5.4	1.5	10.7	1.2	2.3
As *	15	6.1	0.2	13.4	1.0	2.2
Sn *	15	26.8	5.4	45.1	1.2	2.1
Mo	15	0.49	0.0	1.1	0.9	2.0
Cr #	15	16.6	3.5	30.1	1.0	1.8
Cd #	15	0.69	0.2	1.3	1.2	1.7
Ti	15	27.1	15.2	52.0	0.9	1.6
V	15	19.8	5.1	32.8	0.9	1.5

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses have poor reproducibility, hence somewhat less reliability.

The most enriched sediments occur in a broad zone around the shipyard operations and railways and along the New Bern waterfront (Figs. 12 through 18). Metal contaminants generally decrease in concentration in all directions away from the New Bern waterfront. In fact, metal concentrations are generally around or below the trimmed means west up the Trent River, along the southern portion of the New Bern area, and east into the Neuse River. The only exception to this is a mercury high that occurs off the motel along the southern Trent River shore (Fig. 16). It should be noted that all samples were taken prior to recent development of new marinas along the south shore.

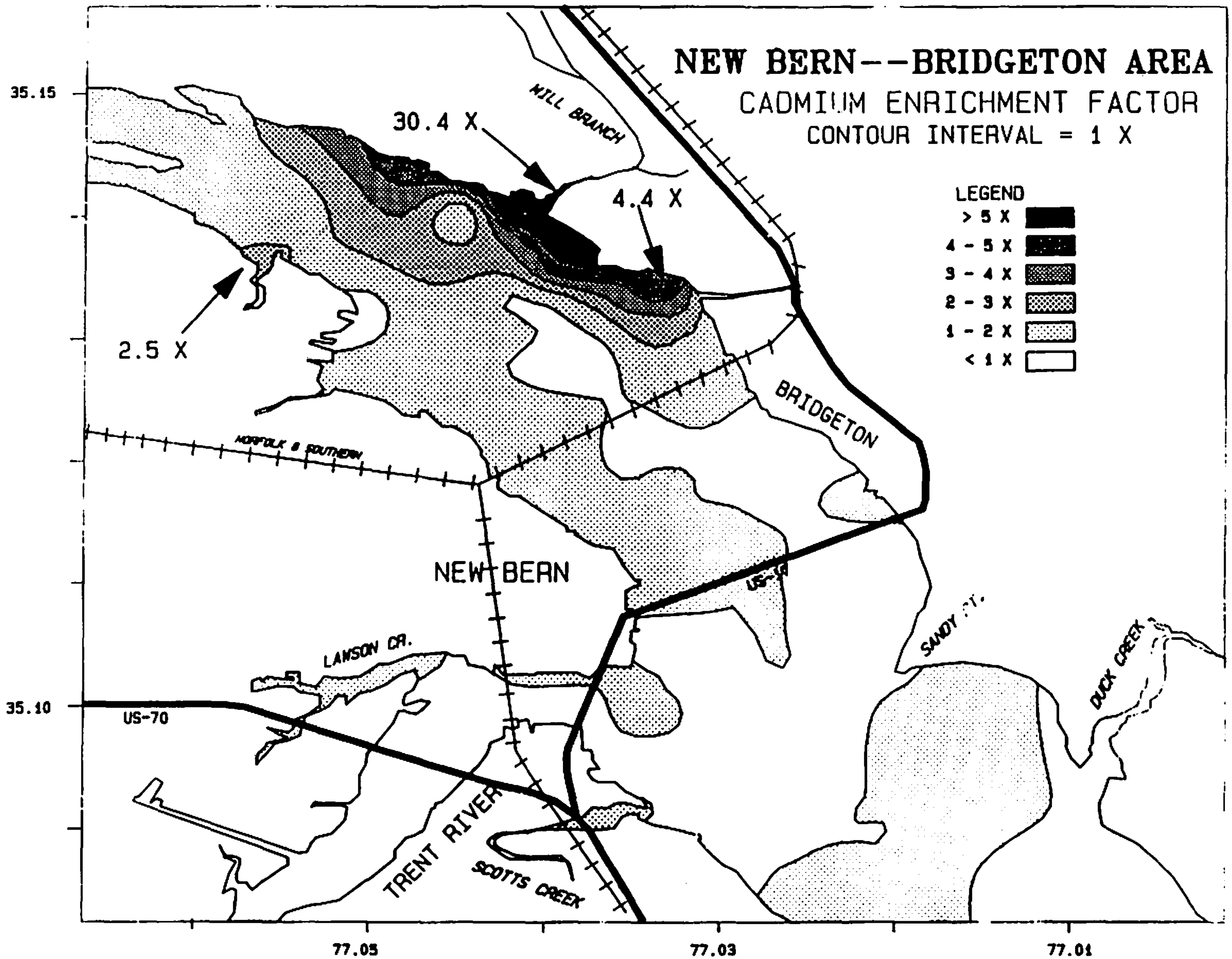

FIGURE 12. Schematic contour map of the cadmium enrichment factors in the New Bern--Bridgeton Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

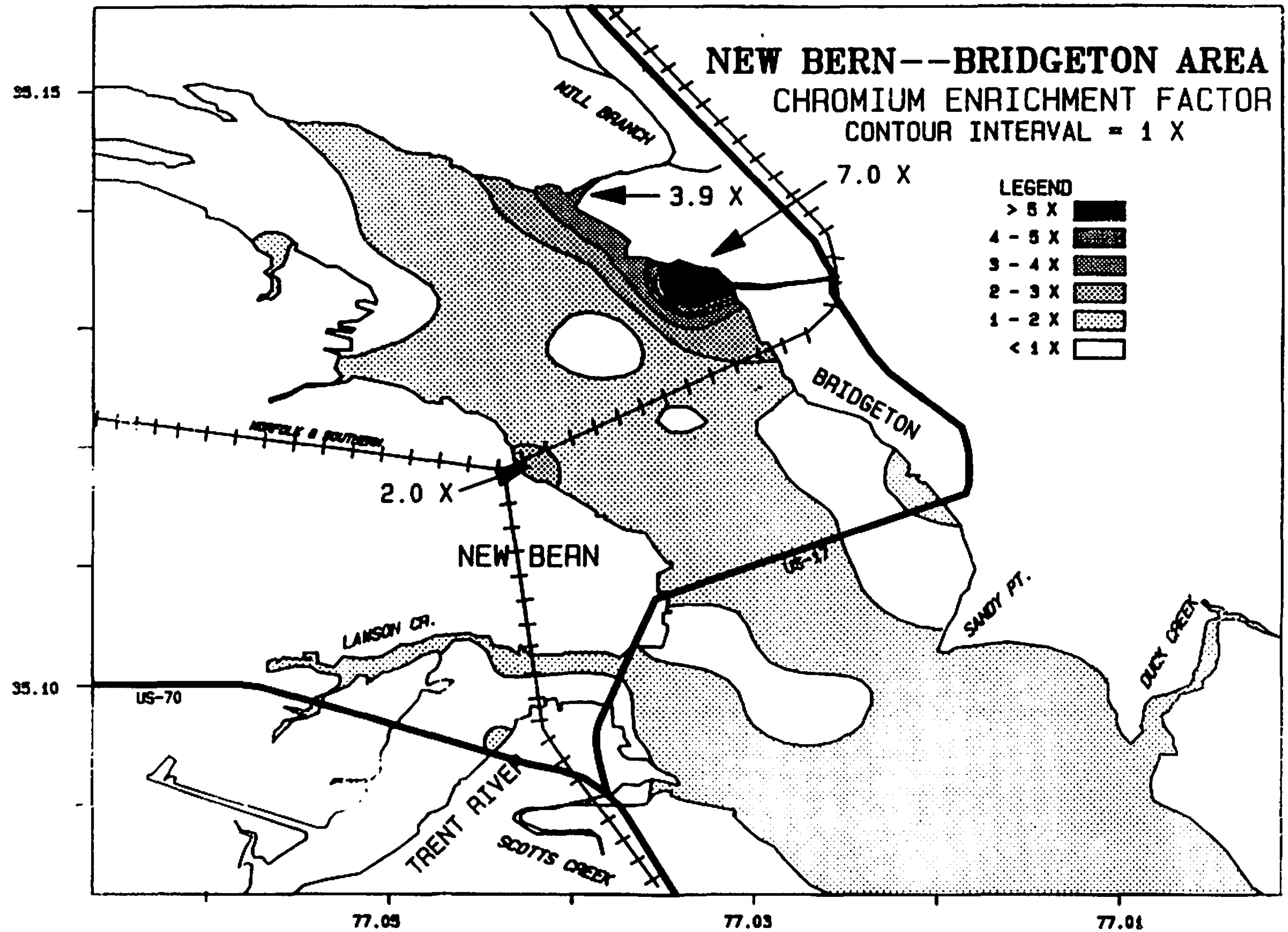

FIGURE 13. Schematic contour map of the <u>chromium</u> enrichment factors in the <u>New Bern--Bridgeton Area</u>. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

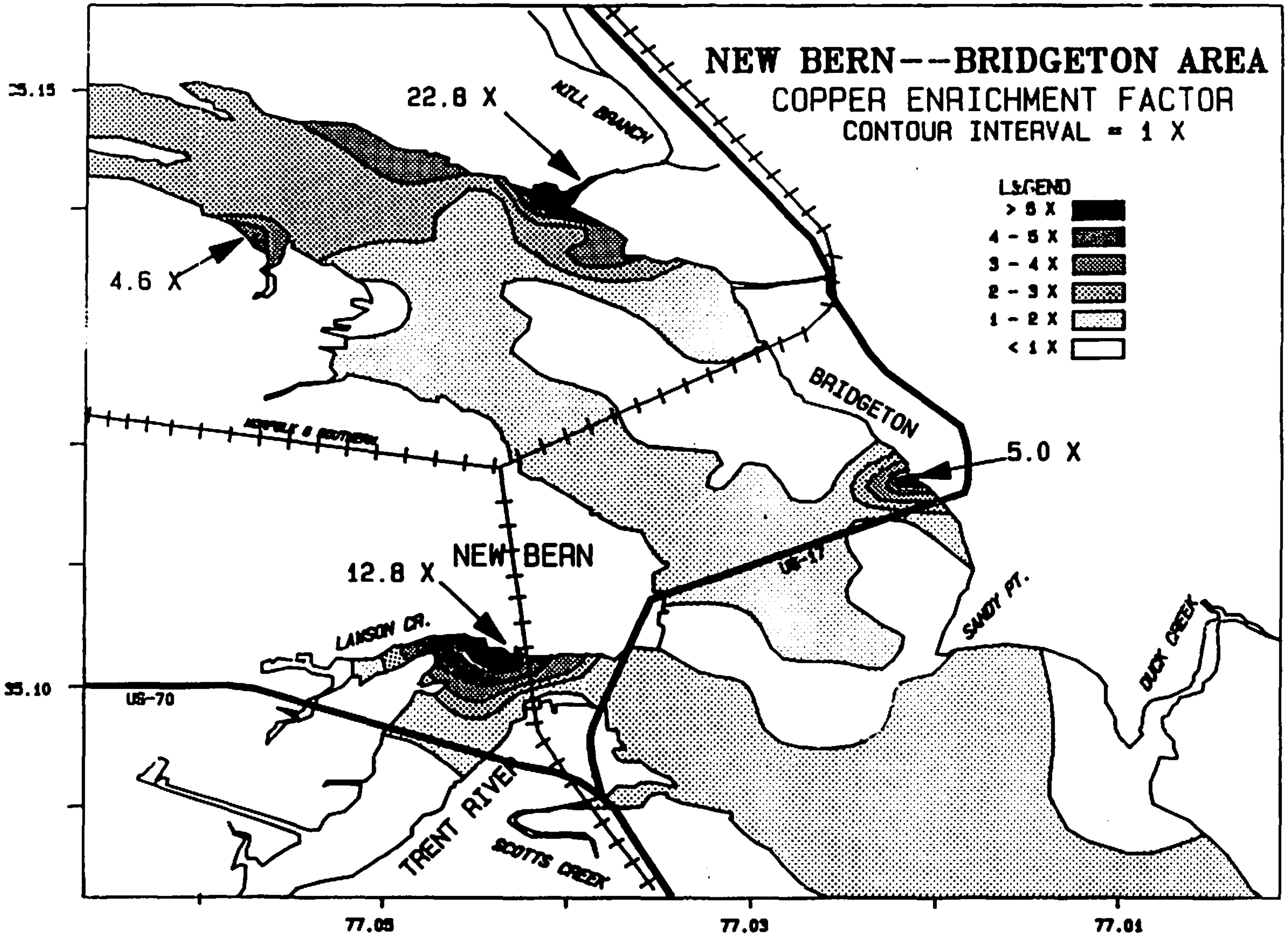

FIGURE 14. Schematic contour map of the copper enrichment factors in the New Bern--Bridgeton Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

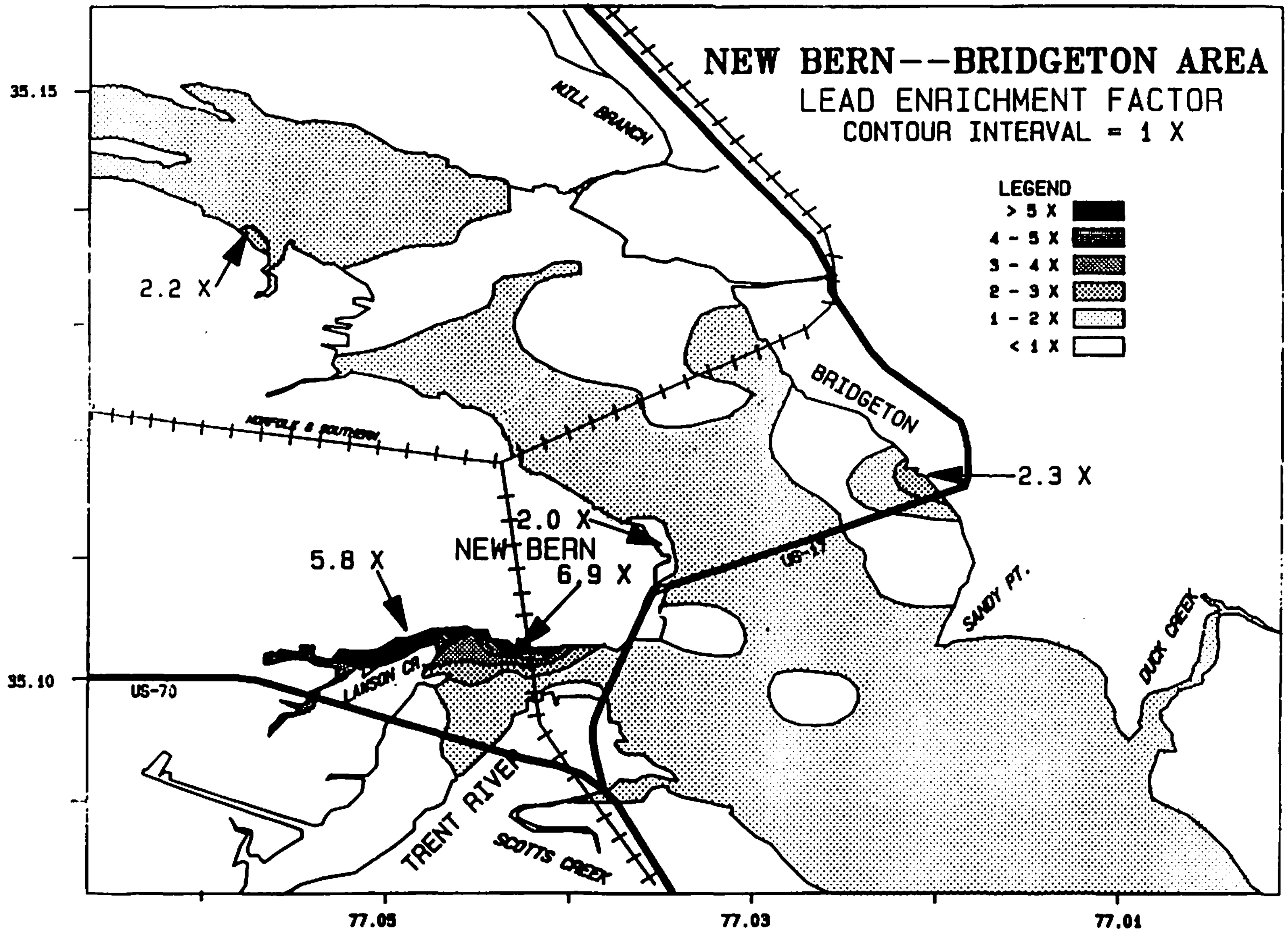

FIGURE 15. Schematic contour map of the lead enrichment factors in the New Bern--Bridgeton Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

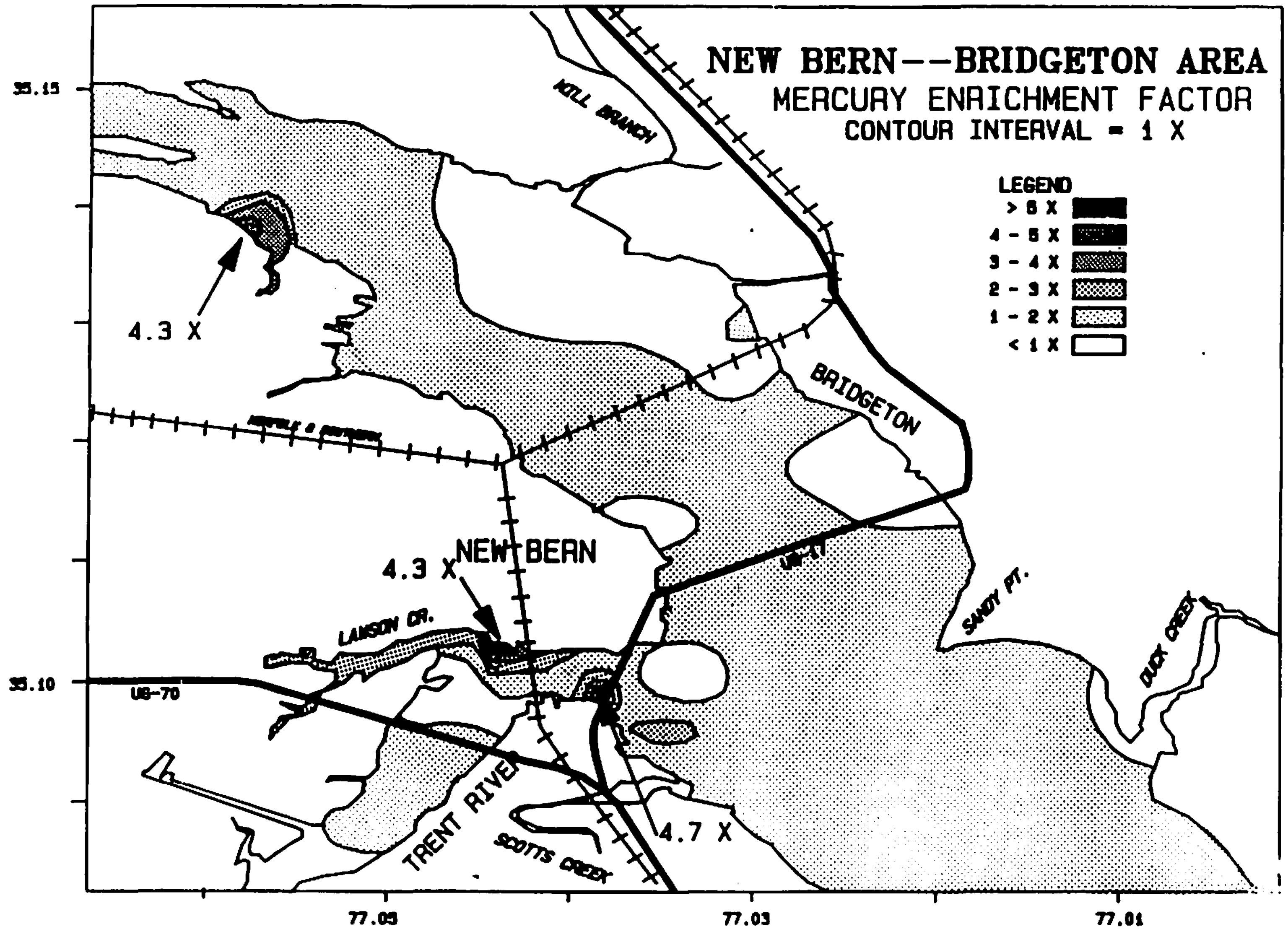

FIGURE 16. Schematic contour map of the mercury enrichment factors in the New Bern--Bridgeton Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

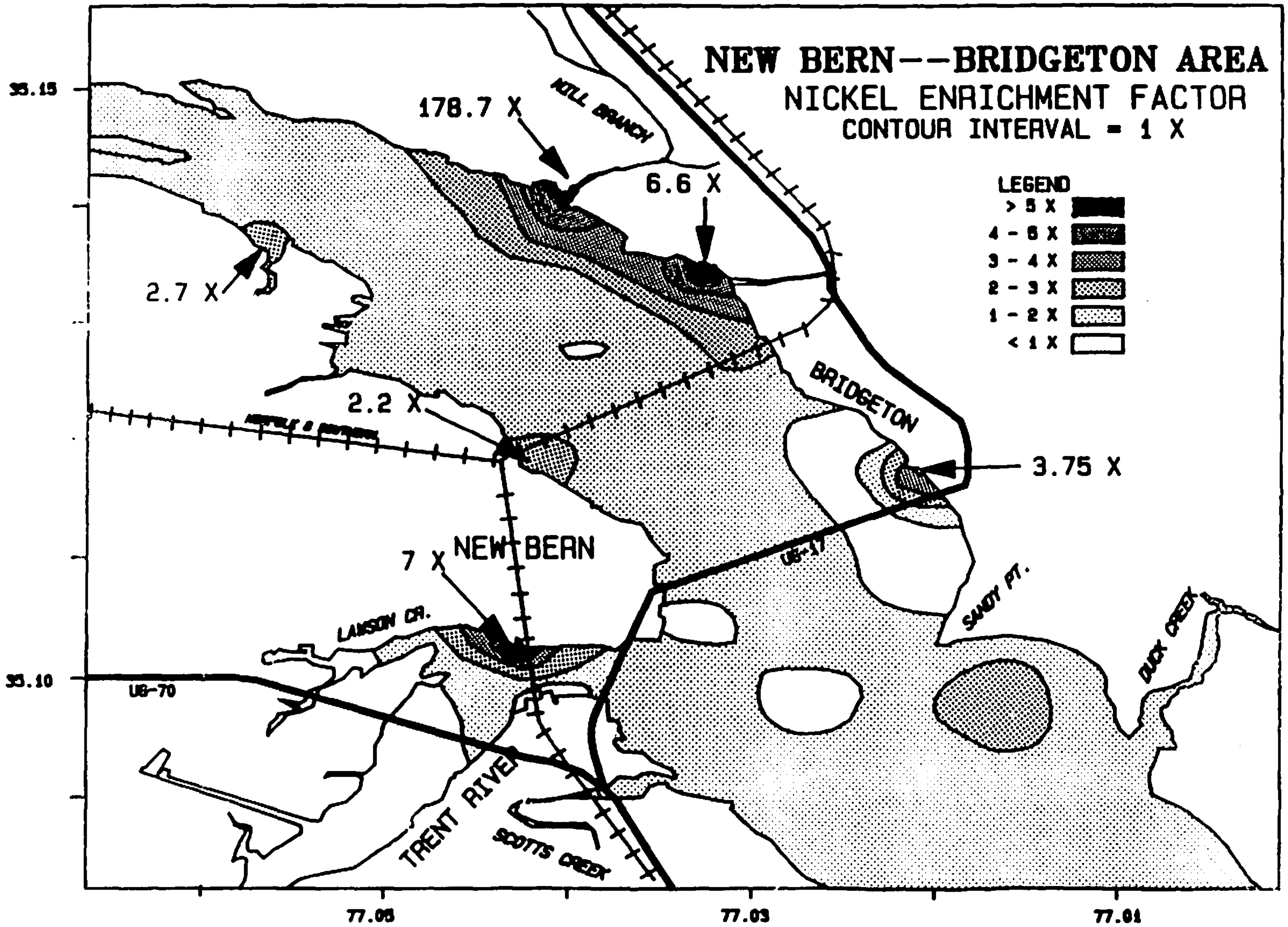

FIGURE 17. Schematic contour map of the nickel enrichment factors in the New Bern--Bridgeton Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

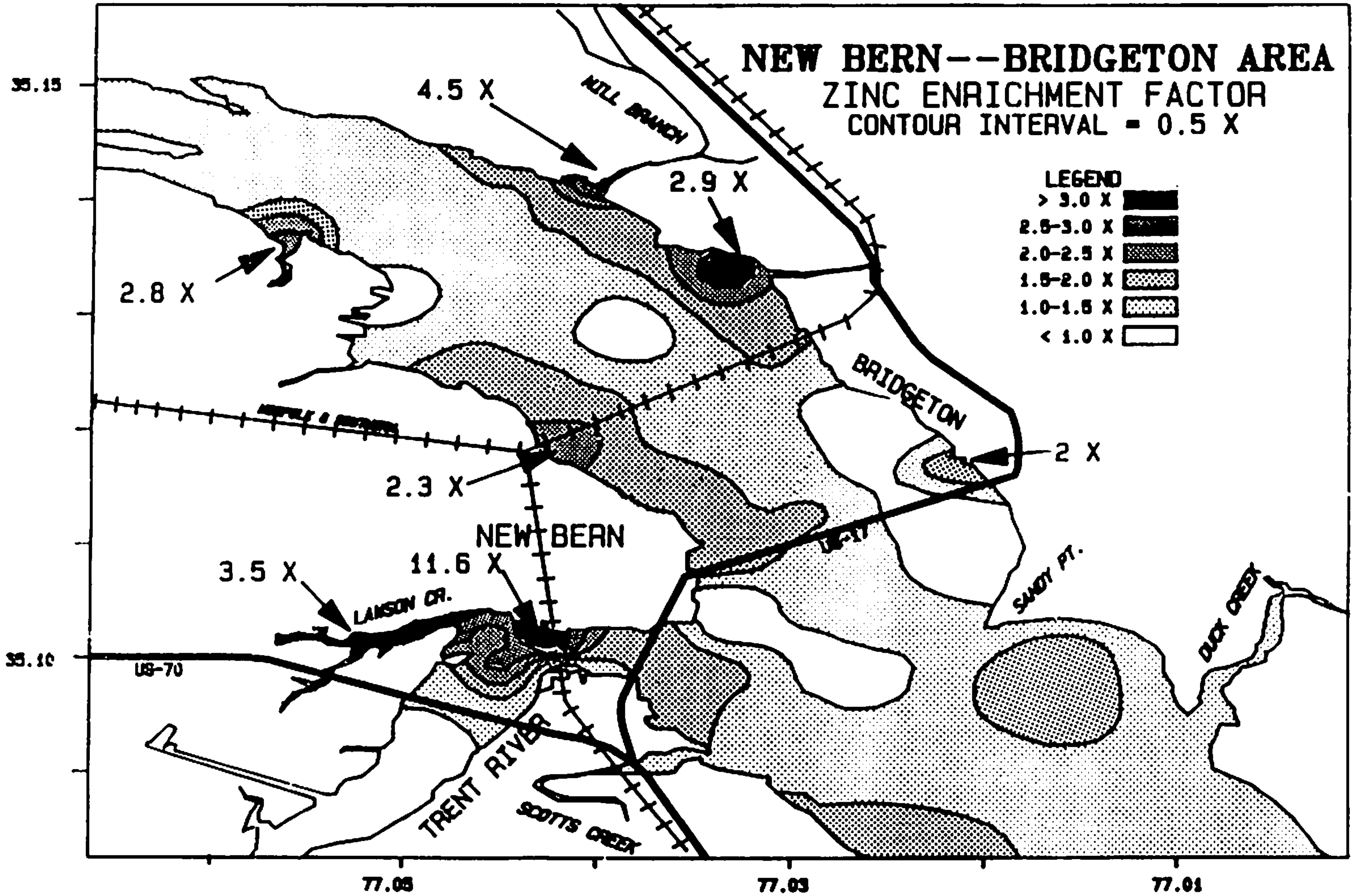

FIGURE 18. Schematic contour map of the <u>zinc</u> enrichment factors in the <u>New Bern--Bridgeton Area</u>. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

The patterns of metal enrichment along the north shore suggest that the shipyard is probably the largest contributor of cadmium, mercury, and nickel, whereas both the shipyard and marina complex to the east appear to be contributing to the copper, lead, and zinc loading in the sediments. However, it is not clear as to how much of the metal contamination is relict and products of prior industrial operations or how much represents a product of ongoing activities.

Lawson Creek is a small tributary that flows through the town of New Bern and into the Trent River at the New Bern waterfront (Fig. 10). It flows through densely populated housing projects with numerous storm sewers and other discharge points along the north shore and enters the Trent River near the shipyard and old industrial waterfront docks. Substantially elevated levels of 4 trace elements occur in the two cores taken in Lawson Creek (Fig. 10 and Table 25) (Pb = 5.8 X, Cu = 4.5 X, Zn = 3.5 X, and Hg = 2.5 X). Concentration of these elements persist in a core taken upstream from the waterfront industries (Fig. 10) suggesting that at least some of the metals in Lawson Creek may be coming from urban runoff, as well as from the New Bern waterfront industrial activity.

Table 26 compares trace element data from surface sediments and from sediments deeper below the sediment surface for the Trent River east and Lawson Creek (Fig. 10). Notice that 9 elements in Table 26 increase substantially with depth. Only manganese decreases substantially with depth; phosphorus, chromium, and cadmium display mixed patterns of change with depth; and arsenic and vanadium tend to remain fairly uniform with depth.

These patterns of mean concentration and maximum enrichment factors with depth for the different elements could reflect several effects. First, the substantial increase with depth for most elements could result from high levels of mixing due to a multitude of man's activities over the decades in active industrial harbors such as New Bern. This mixing would result from periodic dredging; construction activity associated with the building and tearing down of many bridges, piers, and bulkheads; tugboat propellers; anchors from boats, channel markers and piers; etc. Second, this vertical distribution pattern could reflect changing patterns of discharge and accumulation of contaminant elements through the long period of time that the harbor has been active. Third, the patterns of some elements could reflect specific chemical characteristics that are controlling subsequent movement and concentration of these elements within the sediment. Data from the rest of the Neuse River suggest that these elemental distribution patterns are largely the result of man's activities and represent a combination of the first two factors. The New Bern: Trent River East and Slocum Creek areas are the only two regions within the Neuse River that show substantial element enrichment with depth; both are characterized by major impacts of man.

TABLE 26. Comparison of mean concentrations and maximum enrichment factors in surface and deep sediment samples in the New Bern: Trent River East and Lawson Creek. Surface samples represent the upper 7 cm while deep samples come from the bottom of sediment cores and represent depths ranging from 14 to 47 cm below the sediment surface (mean depth = 23 cm). The highest mean concentration and maximum enrichment factor for each element is indicated in bold print.

TRACE ELEMENTS	N S/D	MEAN CONCENTRATIONS (µg/g or ppm) SURFACE	DEPTH	MAXIMUM ENRICHMENT FACTORS SURFACE	DEPTH
NEW BERN: TRENT RIVER EAST AND LAWSON CREEK					
Cu #	15/13	63.2	**69.2**	12.8 X	**18.3 X**
Zn #	15/13	247.6	**288.1**	11.6 X	**18.1 X**
Ni #	15/13	7.6	**10.2**	7.0 X	**14.7 X**
Pb #	15/13	92.1	**100.1**	6.9 X	**10.5 X**
Hg #	13/12	0.31	**0.49**	4.7 X	**12.0 X**
Co	15/13	5.4	**5.5**	2.3 X	**2.9 X**
Sn *	15/13	26.8	**28.4**	2.1 X	**2.3 X**
Mo	15/13	0.49	**0.58**	2.0 X	**4.0 X**
Ti	15/13	27.1	**32.4**	1.6 X	**1.9 X**
P	15/13	**1390.6**	1240.4	2.6 X	**3.3 X**
Cr #	15/13	**16.6**	15.2	1.8 X	**3.0 X**
Cd #	15/13	**0.69**	0.62	1.7 X	**1.9 X**
Mn	15/13	**398.9**	227.2	**2.8 X**	1.6 X
As *	15/13	6.1	6.1	**2.2 X**	2.0 X
V	15/13	**19.8**	17.4	**1.5 X**	**1.5 X**

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses with poor reproducibility, hence somewhat less reliability.

New Bern: Trent River West

The upstream portion of the Trent River, west of the New Bern waterfront and U.S. 70 highrise bridge (Figs. 9 and 19), is characterized by scattered urban development. The banks of the river are generally dominated by low-density individual homes (many with individual septic tanks), several small boat marinas, a golf course, and scattered agricultural land. Development pressures are increasing with a few high-density housing developments beginning to appear on the river banks and up tributary creeks, some with their own sewage treatment facilities. This area receives surface runoff from numerous residential communities situated along both shores of the river and effluent from a waste water treatment facility located near the mouth of

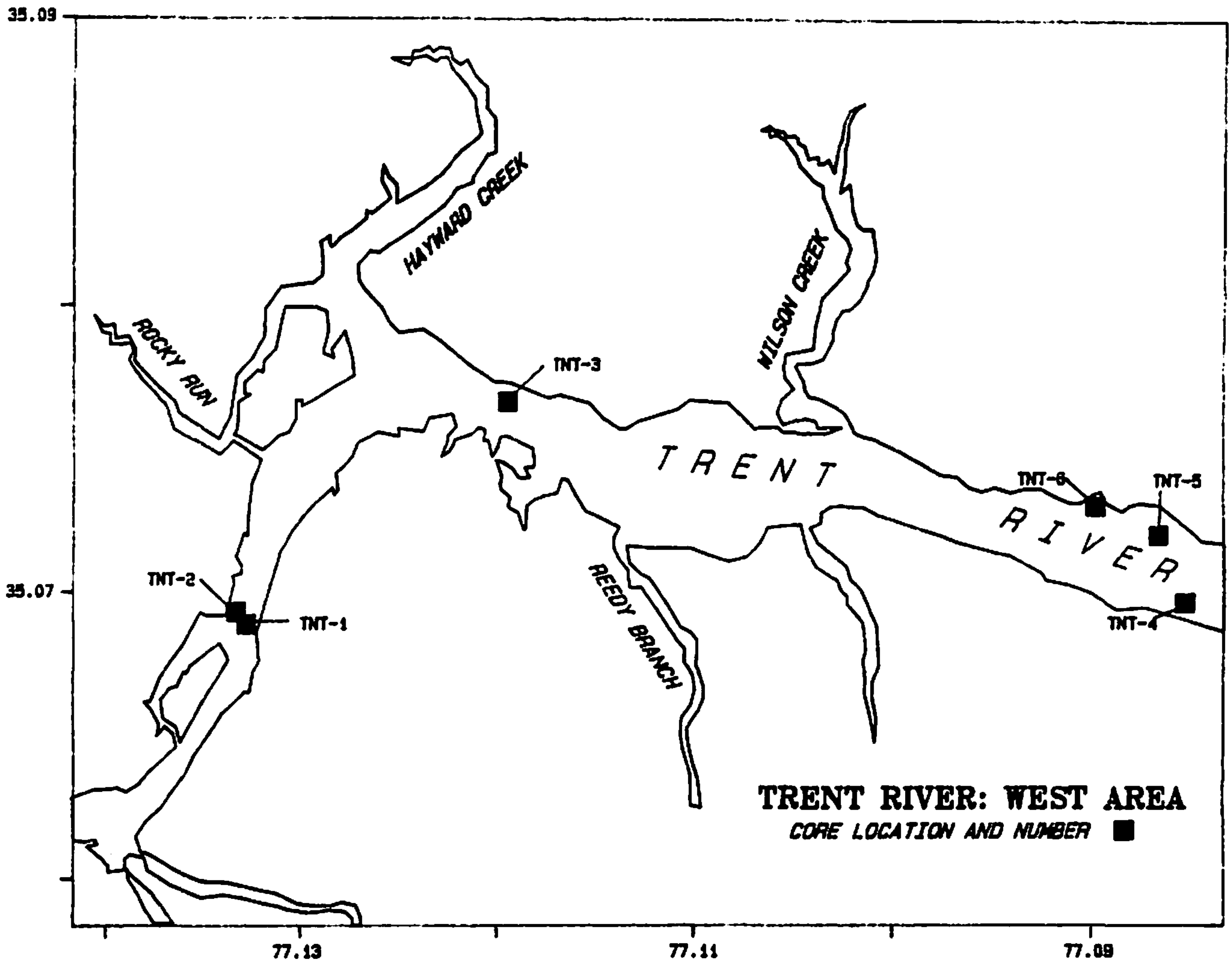

FIGURE 19. Sample location map of the Neuse River Transition Zone: Trent River West Area.

Hayward Creek (Fig. 19). A country club facility with golf courses and boat docks is located on the north shore east of Wilson Creek.

In the Trent River, west of the U.S. 70 bridge, all trace elements except phosphorus were around the Neuse River trimmed mean for all sites sampled. Phosphorus enrichment occurs in 5 out of the 8 cores taken within this portion of the Trent River (Table 27), three of which are off the golf course and marina complex. Phosphorus enrichment factors range from 2.1 X to 2.7 X the Neuse River trimmed mean and probably reflect general runoff from fertilized lawns, agricultural fields, septic tanks, and marina discharges.

TABLE 27. Phosphorus concentrations and enrichment factors in surface sediments from New Bern: Trent River West (EF = or >2X NRTM). See Figure 19 for sample locations.

SAMPLE NUMBER AND LOCATION	PHOSPHORUS CONCENTRATION (μg/g or ppm)	ENRICHMENT FACTOR
<u>NEW BERN: TRENT RIVER WEST</u>		
TNT-1 (mid-channel off small WWTP)	1850.	2.1
TNT-3 (mid-channel downstream of WWTP)	2050.	2.3
TNT-4 (mid-channel off golf course)	2170.	2.5
TNT-5 (at marina)	2360.	2.7
TNT-6 (at golf course)	2000.	2.3

<u>New Bern: Neuse River</u>

The Neuse River shoreline segment of the New Bern waterfront (Fig. 10) is an area of mixed industrial sites and residential areas with the largest number on known point sources in the region (Fig. 11). Along the river banks are the remains of multiple generations of waterfront occupation that reflect relict industrial utilization. Industries within this area that presently have NPDES waste water discharge permits include a fertilizer plant and a wood processing plant immediately southeast of the Norfolk and Southern Railroad. In addition, there is a petroleum storage facility immediately northwest of the railroad.

Consideration of the samples obtained just off and parallel to this New Bern waterfront, demonstrate that every sample was enriched in almost all trace elements (Table 28) relative to the Neuse River trimmed mean. This enrichment is substantial for 9 elements (= to or greater than 2 X the NRTM) and is greatest for phosphorus (3.4 X). The other 8 elements range from 2.0 X up to 2.9 X background while 6 other elements are slightly enriched between 1.5 X and 1.9 X the NRTM. This is in marked contrast to sediments immediately water-ward which all show elemental concentration levels around or below the Neuse River trimmed mean.

A major industrial zone occurs in the region between samples NBNW-7 through NBNW-13 (Fig. 10). All samples within this region generally contain the highest concentrations of most of the trace elements listed in Table 28. Concentrations of almost all trace elements decrease systematically both to the northwest and to the southeast into areas that are dominantly residential.

TABLE 28. Concentrations and enrichment factors of 15 trace elements in surface sediments of the New Bern: Neuse River waterfront and the New Bern: waste water treatment plant site. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold type are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (µg/g or ppm) MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS MEAN	MAXIMUM
NEW BERN: NEUSE RIVER WATERFRONT						
P	11	2000.	711.	3020.	2.3	3.4
Mo	11	0.72	0.2	1.6	1.3	2.9
As *	11	8.9	6.0	16.5	1.5	2.8
Zn #	11	166.	74.0	218.	1.7	2.3
Mn	11	394.	197.	677.	1.4	2.3
Ni #	11	8.1	4.9	10.3	1.8	2.2
Cr #	11	26.6	11.9	33.0	1.6	2.0
Pb #	11	55.5	23.3	69.3	1.6	2.0
Sn *	11	27.0	14.6	43.0	1.3	2.0
Cu #	11	27.4	14.7	36.4	1.4	1.9
Cd #	11	1.05	0.6	1.4	1.4	1.8
Co	11	7.8	6.9	8.6	1.7	1.8
Hg #	7	0.19	0.11	0.26	1.2	1.7
Ti	11	38.5	33.3	48.1	1.2	1.5
V	11	28.4	24.1	33.2	1.3	1.5
NEW BERN: WASTE WATER TREATMENT PLANT						
Cu #	4	41.8	18.1	89.4	2.2	4.6
Hg #	3	0.5	0.27	0.66	3.3	4.3
Co	4	10.1	7.7	14.9	2.2	3.2
Zn #	4	189.	128.	269.	2.0	2.8
Ni #	4	7.2	4.8	12.5	1.6	2.7
P	4	1470.	724.	2260.	1.7	2.6
Cd #	4	1.17	0.8	1.9	1.5	2.5
As *	4	9.7	5.0	14.0	1.6	2.3
Pb #	4	46.0	28.5	75.9	1.3	2.2
Mo	4	0.5	0.3	0.8	0.9	1.5
Ti	4	33.4	14.1	47.4	1.1	1.5
Sn *	4	17.6	6.8	26.2	0.8	1.2
Cr #	4	13.5	10.6	16.7	0.8	1.0
V	4	14.6	4.7	23.3	0.6	1.0
Mn	4	148.	62.4	217.	0.5	0.8

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.

* analyses have poor reproducibility, hence somewhat less reliability.

Lead is the main exception to this. Lead has the same trend, but concentrations remain fairly high and uniform throughout the entire area between the highway 17 and railroad bridges (NBNW-4 through NBNW-13 on Fig. 10) and then decreases to the northwest and southeast. This shoreline enrichment suggests that most low-level enrichment of elemental contaminants reflects a general long-term urban runoff with a major industrial imprint occurring along the shoreline between samples NBNW-7 and NBNW-13 (Fig. 10).

New Bern: Waste Water Treatment Plant

The city of New Bern has an NPDES permit to discharge up to 4 million gallons per day from their waste water treatment plant into a small, wide-mouthed embayed tributary creek at the western-most end of the Neuse River estuary (Figs. 10 and 11). A recent study by the Clean Water Fund-NC (1990) classified the New Bern WWTP in their scheme of "the good, the bad, and the ugly" as an "ugly" and among the worst of the 23 major waste water treatment plants in their study". This classification was based upon the permit records for a one year portion of 1989-1990 in which they found the following conditions:

1. over capacity usage;
2. flow violations;
3. high BOD5, TSS, residual chlorine, NH3, fecal coliform, total nitrogen and total phosphorus levels;
4. low percent BOD5 and TSS removal rates;
5. low effluent DO; and
6. no up- or downstream monitoring requirements.

According to the Clean Water Fund (1990), on March 19, 1990, the New Bern WWTP processed 90% domestic effluent and 10% industrial effluent from five significant industrial users (SIU's). Four of these 5 SIU's are required by North Carolina Division of Environmental Management to test their effluent for cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc as well as other organic components. The New Bern WWTP must test for all of these metals except mercury, however, there are no concentration limits on any of these metals. Table 29 summarizes the metal concentrations at the New Bern WWTP. Most of these metals will end up in the sewage sludge and are removed from the system. However, during times of equipment malfunction or storms, these metals could be discharged to the estuary. Even though the monthly average flow is only 74.5% of the design flow, the monthly maximum flow has been up to 142.5% of the design flow (Clean Water Fund-NC, 1990).

The present sediment study analyzed three sample sets plus a floc sample from the area off the WWTP as follows: NBNW-16 is about 40 feet in front of the point of discharge; NBNW-17 is about 600 feet up the tributary creek above the WWTP discharge point, and NBNW-18 and NBNW-18F are in the mouth of the tributary creek and about 200 feet in front of the discharge point (Fig. 10).

Nine trace elements are substantially enriched (EF = or >2X the NRTM) in the sediments adjacent to the New Bern WWTP discharge (Table 28). Four of the elements (Cu, Hg, P, and Pb) are most enriched in the sediments directly in front of the discharge point. The other five metals (As, Cd, Co, Ni, and Zn) are most enriched in sediments about 600 feet up the tributary creek. The latter distribution probably represents the direction of flow of flood water and associated clay sediments with their subsequent entrapment up the tributaries; this situation would occur during periods of rising water and high water flow conditions on the Neuse River. All nine elements are diminished in concentration at the station in the wide-mouth of the tributary creek. However, all of these elements except phosphorus are still enriched at this site. The other five elements (Mo, Ti, Sn, Cr, and Mn) occur in concentrations that are similar to the Neuse River trimmed mean.

TABLE 29. Monthly averages for concentrations of trace metals in the effluent at the New Bern WWTP during the period 4/89 to 3/90 (data are from the Clean Water Fund-NC, 1990).

ELEMENT	LIMITS	MO. AVG. µg/l	MO. AVG. lbs/day
Cd	none	0*	0*
Cr	none	0*	0*
Cu	none	35	0.870
Pb	none	9	0.224
Hg	none	NTR	NTR
Ni	none	48	1.193
Ag	none	5	0.124
Zn	none	60	1.491
P	?	3.84	95.5

NTR = no test required
* 0 is not really zero, it only means that it is below detection limit of the analytical technique, which actually could be quite high. For a discussion on this, see the section entitled "Trace Element Contaminants: Problems with Monitoring Water Quality".

Bridgeton: Mill Branch and Neuse River

Mill Branch is a minor tributary to the Neuse River that drains the lowland areas west of Bridgeton. A major metal plating facility, located less than a kilometer upstream on Mill Branch, has an NPDES permit to discharge up to 100,000 gallons of waste water per day into Mill Branch. Only minor residential development exists in this small drainage basin without any other permitted discharges.

Two samples (NBNW-26 and NBNW-27) inside the mouth of Mill Branch (Fig. 10) have the highest metal enrichment factors for 6 trace elements (Table 30) encountered in the entire study area. Exceptionally high enrichment values occur in the core taken several hundred meters upstream from the creek mouth where nickel, tin, cadmium, and copper are enriched 178.7 X, 33.4 X, 30.4 X, and 22.8 X the NRTM. Substantial enrichment factors also occur for zinc (4.5 X), chromium (3.9 X), and phosphorus (2.5 X); lead (1.8 X), arsenic (1.6 X) and cobalt (1.6) are slightly enriched in this core. Enrichment values

TABLE 30. Concentrations and enrichment factors of 15 trace elements in surface sediments of Bridgeton: Mill Branch and Bridgeton: Neuse River waterfront. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold type are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (μg/g or ppm) MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS MEAN	MAXIMUM
BRIDGETON: MILL BRANCH						
Ni #	2	439.	48.1	829.	94.6	178.7
Sn *	2	367.	17.2	718.	17.1	33.4
Cd #	2	12.7	2.0	23.4	16.5	30.4
Cu #	2	233.	25.3	440.	12.0	22.8
Zn #	2	274.	119.	428.	2.9	4.5
Cr #	1	65.3	65.3	65.3	3.9	3.9
P	2	1270.	328.	2200.	1.5	2.5
Pb #	2	37.8	11.9	63.6	1.0	1.8
As *	2	6.6	3.9	9.3	1.2	1.6
Co	2	5.4	3.4	7.5	1.2	1.6
Mo	2	0.6	0.5	0.7	1.1	1.3
V	2	13.2	6.7	19.8	0.6	0.9
Hg	2	0.07	0.04	0.1	0.5	0.7
Ti	2	16.8	15.5	18.6	0.6	0.6
Mn	2	98.3	93.4	103.	0.4	0.4
BRIDGETON: NEUSE RIVER WATERFRONT						
Cr #	6	43.3	3.5	118.	2.6	7.0
Ni #	6	13.5	2.4	30.7	2.9	6.6
Cd #	6	1.48	0.8	3.4	1.9	4.4
Cu #	6	35.7	18.6	96.1	1.8	5.0
Mn	6	449.	86.6	879.	1.6	3.1
Zn #	6	161.	55.5	272.	1.7	2.9
P	6	1600.	326.	2360.	1.8	2.7
Pb #	6	41.6	22.6	81.6	1.2	2.3
As *	6	9.2	2.8	12.7	1.5	2.1
Co	6	6.7	0.9	9.9	1.4	2.1
Sn *	6	27.3	13.8	40.5	1.2	1.9
V	6	21.5	6.5	30.8	1.0	1.4
Mo	6	0.47	0.2	0.7	0.8	1.3
Hg #	5	0.10	0.05	0.18	0.7	1.2
Ti	6	30.9	25.8	35.9	1.0	1.1

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses have poor reproducibility, hence somewhat less reliability.

generally decrease downstream in Mill Branch and into the Neuse River (Figs. 12 through 18). Based upon the types of metals in the sediments, the metal plating facility is the probable source for these high enrichment factors observed downstream of the plant.

Even though metal concentrations decrease downstream towards the mouth of Mill Branch, some elevated trace element concentrations persist into the Neuse River and appear to form an elongate plume that extends southeast along the Neuse River shoreline (Table 30 and Figs. 12 through 18). Concentrations of cadmium, chromium, nickel, and tin continue to decrease southeast along the Neuse River shoreline suggesting that they originated from Mill Branch. However, some of this elemental enrichment plume could result from discharge of a chemical distributor and wood processing plants that have NPDES discharge permits in this portion of the coast (Fig. 11). Both copper and zinc have high values at either end of the Neuse River waterfront (i.e., towards Mill Branch and at the boat yard/marina at the highway 17 bridge) with lower values in between. Arsenic and lead increase in concentrations away from Mill Branch to maximums off the boat yard/marina. This clearly suggests that their contributions are related to the boat yard and possibly urban runoff while the copper and zinc have contributions from both Mill Branch and the boat yard/marina. The regional distribution patterns of these elements are presented in Figures 12 to 18.

Metal contamination occurs primarily in Mill Branch and in intermediate depth waters along the shoreline from Mill Branch to the highway 17 bridge. The next set of samples within the Neuse River that occur in deeper water, further off the shoreline (samples NBNW-28, NBNW-29, NBNW-22, NBNW-12, NBNW-20, NBNW-19, and NBNW-2 in Fig. 10) generally show decreasing levels of metal contamination. Also, concentrations of all trace elements in both Mill Branch and along the Neuse River shoreline are highest in the surface sediments and decrease substantially with depth. This suggests that there is little to no mixing of the sediments, rates of sedimentation are very slow, and that the zone of metals accumulation is in the active biologic zone.

Neuse River Summary in the New Bern--Bridgeton Area

Table 31 compares the contamination problem resulting from 15 trace elements in the New Bern--Bridgeton portion of the Neuse River. This table plots the deeper water samples obtained from further offshore in the western portion of the Neuse River (west of the highway 17 bridge) with samples obtained closer to shore and adjacent to anthropogenic inputs. The following relationships are apparent in Table 31.

1. The central portion of the Neuse River (west of the highway 17 bridge) has the following characteristics:
   a. low mean concentrations of all 15 trace elements;
   b. cadmium, copper, lead, manganese, and tin concentrations are below the NRTM (Cd = 0.9 X, Cu = 0.8 X, Pb = 0.9 X, Mn = 0.9 X, and Sn = 0.9 X);
   c. phosphorus concentrations are equal to the NRTM (EF = 1.0 X);
   d. the other 9 elements are slightly enriched relative to the NRTM (Cr = 1.1 X, Mo = 1.1 X, Ti = 1.1 X, V = 1.1 X, Zn = 1.1 X, As = 1.2 X, Co = 1.3 X, Hg = 1.3 X, and Ni = 1.3 X).

TABLE 31. Summary of mean concentrations of the 15 trace elements that occur within the surface sediments of the Neuse River in the New Bern--Bridgeton Area as compared to the central portion of the Neuse River in this area. Bold print indicates those elements within each region that have mean concentrations below the Neuse River trimmed mean; an underline indicates those elements within each region that have mean concentrations that are slightly (EF >1.5X to <2X NRTM) or substantially (EF = or >2X NRTM) enriched over the Neuse River trimmed mean.

TRACE ELEMENTS	MEAN CONCENTRATIONS (μg/g or ppm)				
	NEW BERN		CENTRAL NEUSE	BRIDGETON	
	WWTP N = 4	NEUSE RIVER N = 11	N = 11	NEUSE RIVER N = 6	MILL BR N = 2
Sn *	**18**	27	**20**	27	367
Cr #	**14**	27	18	43	65
Ni #	7	8	6	14	439
Zn #	189	166	104	161	274
Cd #	1.2	1.0	**0.7**	1.5	13
Cu #	42	27	**15**	36	233
P	1480	2000	**863**	1600	1270
As *	10	9	7	9	7
Co	10	8	6	7	5
Hg #	0.5	0.2	0.2	**0.1**	**0.1**
Pb #	46	56	33	42	38
Mn	**148**	394	**223**	449	**98**
Mo	0.5	0.7	0.6	0.5	0.6
Ti	33	38	34	31	**17**
V	15	28	24	22	**13**

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses have poor reproducibility, hence somewhat less reliability.

2. The six most enriched trace elements [tin, chromium (Fig. 13), nickel (Fig. 17), zinc (Fig. 18), cadmium (Fig. 12), and copper (Fig. 14)] appear to come from a major input through Mill Branch with high mean concentrations that systematically decrease away from this point source. In the Neuse River area, this appears to be the only major source for tin, chromium, and nickel; the lowest mean concentrations of each of the latter three elements occur adjacent to the New Bern WWTP.
3. Four trace elements [zinc (Fig. 18), cadmium (Fig. 12), copper (Fig. 14), and phosphorus] have multiple sources along both the New Bern and Bridgeton waterfront areas with the lowest mean concentrations generally within the central portion of the Neuse River.
4. The most important input of arsenic, cobalt, and mercury (Fig. 16) appears to be the New Bern WWTP with the highest mean concentrations that generally decrease into all other regions; the lowest mean concentrations occur within Mill Branch. Lead is also slightly enriched around the New Bern WWTP.
5. Lead and manganese are slightly enriched along the Neuse River waterfront areas of both New Bern and Bridgeton. The other areas are well below the Neuse River trimmed mean.
6. Molybdenum, titanium, and vanadium are not enriched within any portion of this area and concentrations everywhere are around the Neuse River trimmed mean.

<u>Neuse River Zone: West of The New Bern--Bridgeton Area</u>

A large paper pulp mill is located at Streets Ferry (Figs. 9 and 20) with an NPDES discharge permit for up to 35 million gallons of waste water per day. This waste water is discharged through a disseminator pipe laid across the northeastern portion of the Neuse River. Two sites were cored near the NPDES discharge pipe (Fig. 20).

This portion of the Neuse River generally operates as a fluvial system since it is well above the normal level of estuarine influence. However, major estuarine influence does occur at irregular intervals that are generally related either to periods of very low river flow or periods of high estuarine storm tides or both. During periods of high river water flow, current velocities through this area are high. Consequently, the main river channel is floored with fairly clean quartz sands that are chemically inert. Minor and variable amounts of ephemeral organic-rich mud do accumulate locally on the channel flanks during low flow periods or in the floodplain during high flow periods. The former are removed during subsequent periods of high flow and carried on downstream with no long-term accumulation. Ultimately, any trace elements that might accumulate within the organic-rich muds would be transported either laterally into the swamp forest or downstream and disseminated throughout the Neuse River estuarine sediments.

No trace elements were enriched in either of two samples obtained near the paper mill discharge site (RIV-1 and RIV-2). This does not mean that this paper mill discharge is of little concern with respect to its contribution of toxic components to the downstream estuarine system. As noted earlier, the trimmed mean or background levels of six trace elements (Cd = 2.1 X, Mn = 1.9 X, Hg = 1.7 X, Ni = 1.7 X, Cr = 1.6 X, and Cu = 1.4 X) are enriched throughout

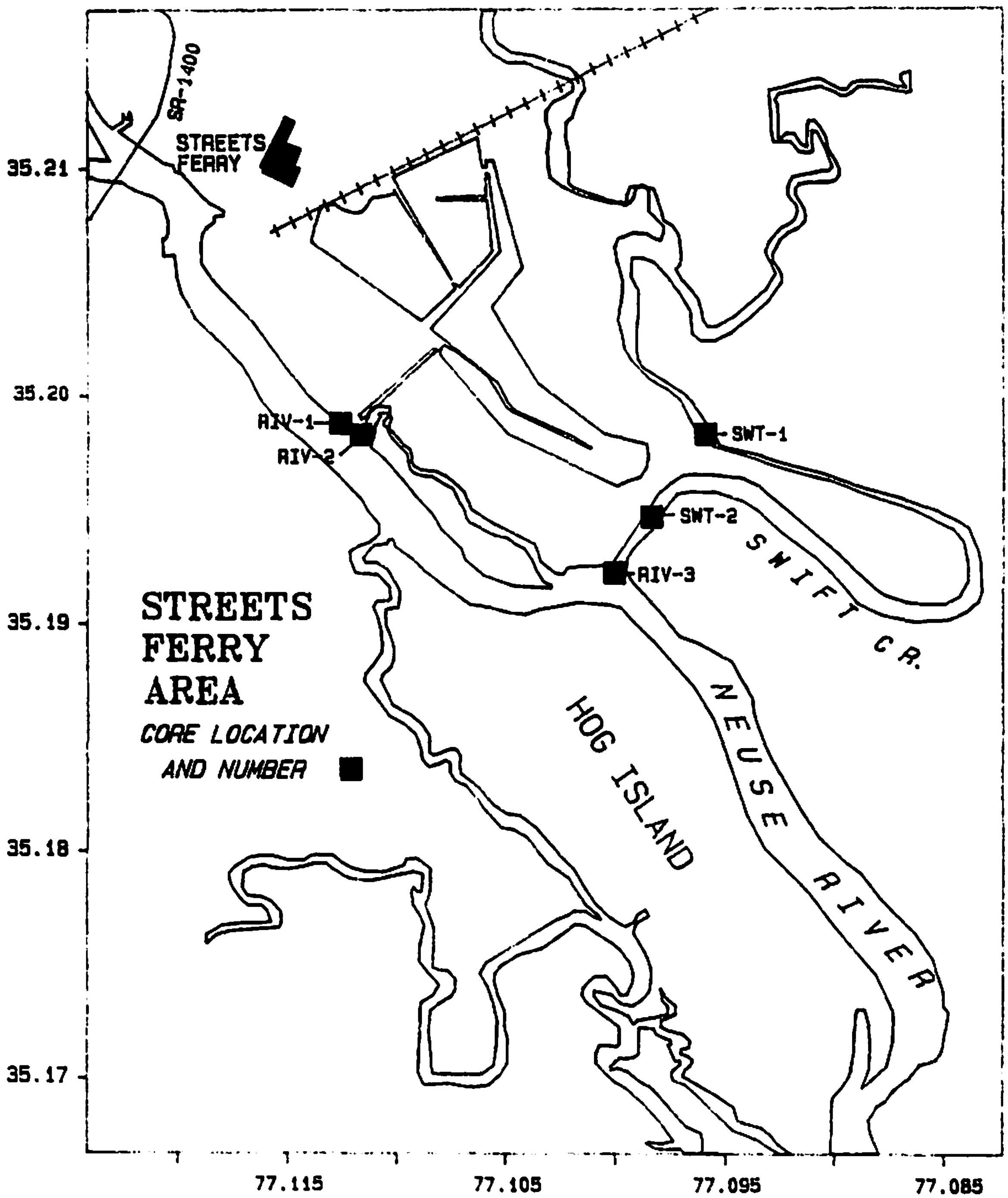

FIGURE 20. Sample location map of the Neuse River: Streets Ferry Area.

the entire Neuse River estuarine system as compared to the Pamlico River estuarine system (Table 23). This difference may reflect generally higher levels of major industrial development throughout the upstream drainage basin. Toxic components would be carried in solution until they reach the estuarine system where saltier water, slower velocities, and chemically active sediments systematically sequester these components from the water column and concentrate them to form the higher background levels throughout the system.

Sediments from three stations located in Swift Creek, slightly downstream of the paper mill (Fig. 20), have minor enrichments in only three trace elements. Cobalt is slightly enriched (1.9 X) at the uppermost sample site (SWT-1) and is substantially enriched (2.1 X the NRTM) in the lower two sample sites (SWT-2 and RIV-3). Phosphorus (1.8 X) and mercury (1.6 X) are each slightly enriched at one sample site (RIV-3 and SWT-2, respectively). No persistent patterns occur with any of these data and it is not clear why these anomalies exist in Swift Creek.

Inner Neuse River Estuarine Zone

Inner Neuse River: East of the New Bern--Bridgeton Area

The Inner Neuse River estuarine zone is a fairly narrow, shallow (mean water depth = 3 m) trunk estuary that is oriented northwest-southeast. It extends from the southeastern edge of the transition zone (the New Bern--Bridgeton area) southeast to Minnesott Beach (Figs. 5 and 9). East of Minnesott Beach the estuary makes a right angle turn, is oriented northeast-southwest and becomes considerably wider (Fig. 5). This outer NE-SW oriented estuary becomes increasingly deeper with mean water depths of 3.4 m in the western portion and 5.3 m in the eastern portion.

The southwest side of the inner Neuse River is generally characterized by high sediment bank shorelines with no major tributaries, scattered low-density residential areas, and an extensive portion of Croatan National Forest. However, the northeast side is generally characterized by low to medium sediment bank shorelines with four major tributaries containing extensive marsh and swamp forest shorelines. Since the late 1970's and early 1980's, the community of Fairfield Harbor has become a moderate-density region of urban development with several large marinas within the Northwest and Upper Broad Creeks. These development pressures will probably continue to expand eastward into the presently undeveloped drainages of Goose and Beard Creeks.

Minor industrial development exists along the inner Neuse River except for the immediate vicinity of James City which has a fertilizer plant and small industrial harbor. The only NPDES discharge permit in this section of the Neuse River is for the Fairfield Harbor WWTP (App. C). This permit allows for up to 100,000 gallons of municipal waste water to be discharged per day into Upper Broad Creek.

Figure 21 and Appendix A present the locations of all sediment samples collected within the Inner Neuse River Area and utilized for the following discussion. The sediments throughout the inner Neuse River are very uniform organic-rich mud. Figure 6 demonstrates the relationship of the organic-rich muds to the deeper, central basin portion of the estuary, below the shallow sandy perimeter platforms. This broad, deeper basin portion of the estuary is dominated by sediments that have mean mud (clay plus silt) concentrations of 65% and mean total organic concentrations of 10.4%.

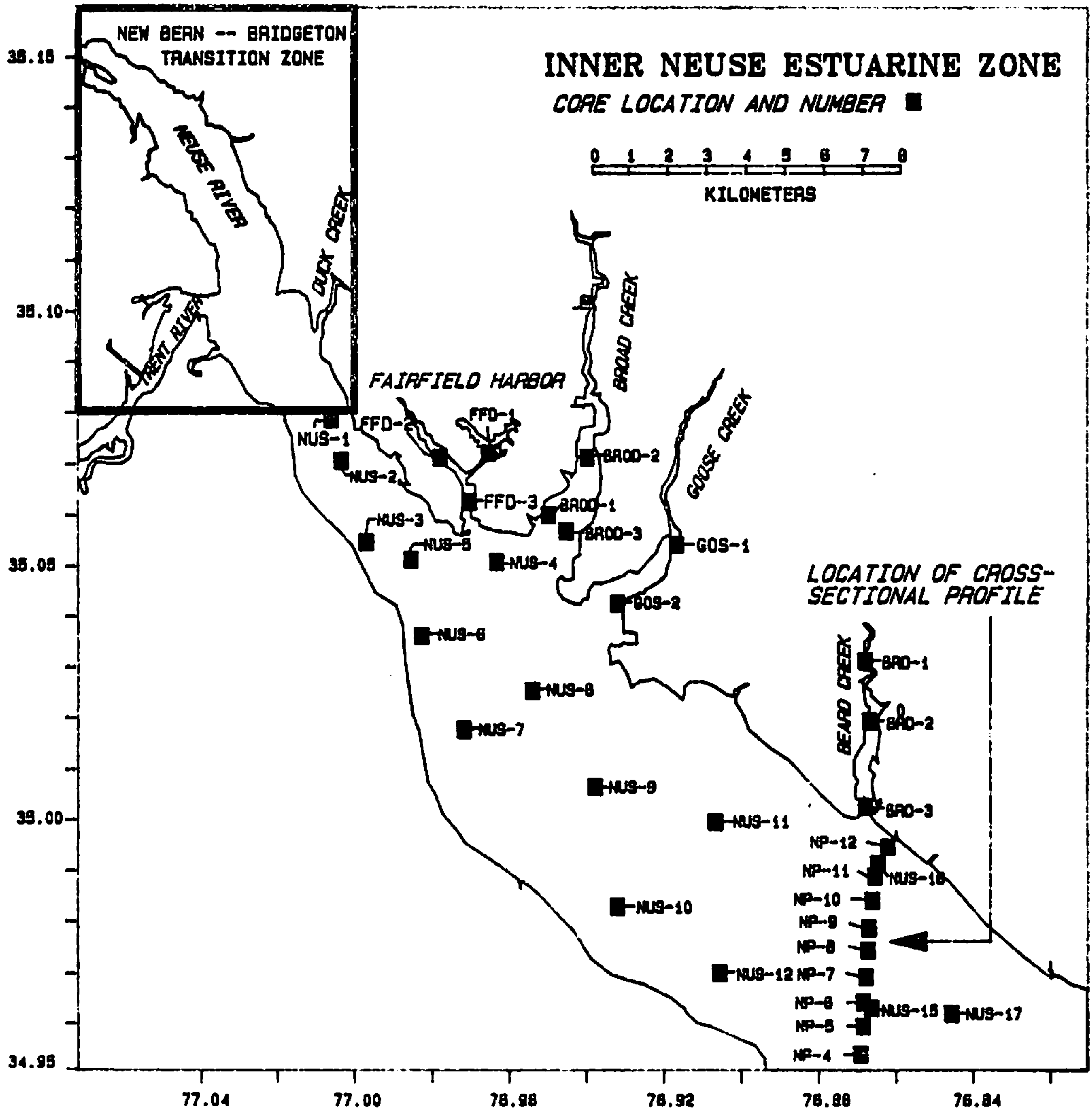

FIGURE 21. Sample location map of the Inner Neuse River Area.

Overall, the mud sediments in the inner Neuse River are generally at or near the Neuse River trimmed mean with mean EF ranging from 0.7 to 1.3 X NRTM (Table 32). A cross-estuarine profile of 15 cores (NP samples in Fig. 21) demonstrates that there is a general elemental enrichment for chromium, copper, lead, and zinc, as well as the other 11 trace elements, into the central portion of the basin. This regional distribution pattern of element enrichment is probably a direct function of two factors. First, it reflects the increased concentration of organic-rich muds in the deeper, central basin portion of the estuary as depicted in Figure 22. Second, this suggests that the regional background enrichment in all trace elements is not due to local point or nonpoint sources; rather, it appears to reflect a broad, low-magnitude impact of combined trace element contributions from upstream sources that include the following (see Appendix C).

1. About 25 industrial and municipal facilities in the New Bern-Bridgeton area have NPDES permits to discharge up to 16.83 million gallons of waste water per day into the estuarine system.
2. A major paper mill facility discharges up to 35 million gallons of waste water per day into the Neuse River at Streets Ferry.
3. Approximately 196 industrial and municipal facilities have NPDES permits to discharge up to 148.05 million gallons of waste water per day into the Neuse River in the upstream areas of the Neuse River.
4. The upstream portion of the drainage basin has a rapidly growing population that has increased by approximately 50% from 710,000 in 1970 to 1,069,000 in 1980.

Even though the inner Neuse River sediments generally have low concentrations of trace elements, there are elements and portions of this area that do contain elemental enrichments (Table 32). Five trace elements are substantially enriched (EF = >2X NRTM) at multiple sites (Sn = 9 sites, Mo = 8 sites, V = 6 sites, Mn = 4 sites, and As = 2 sites) and slightly enriched (EF = >1.5 and <2X NRTM) at multiple sites (V = 18 sites, Mn = 16 sites, Mo = 5 sites, As = 4 sites, and Sn = 4 sites). An additional 6 trace elements are slightly enriched (EF = >1.5 and <2X NRTM) at multiple sites (Ti = 13 sites, Co = 6 sites, Ni = 5 sites, Cr = 2 sites, Hg = 2 sites, and Zn = 2 sites); 2 elements (Pb and P) are slightly enriched (EF = >1.5 and <2X NRTM) at only one sample site each; and 2 elements (Cd and Cu) show no enrichment at any sample sites. Mean concentrations for 10 of the 15 trace elements in the Inner Neuse River (Table 32) are slightly lower than the equivalent sediments within the central portion of the Neuse River in the New Bern--Bridgeton Area (Table 31). This regional pattern may be the result of rapidly increasing salinity that produces a turbidity maximum within the transition and inner estuarine zones (Benninger and Martens, 1983; Filer, 1979; Giese et al., 1979; Griffin and Ingram, 1955; Hobbie and Smith, 1975; Knowles, 1975; and Wells and Kim, 1989). This results in rapid flocculation and sedimentation of suspended organic and clay particles which sequester the various trace elements dissolved in the water column. Five of the elements (Sn, Mn, Mo, Ti, and V) have higher mean concentrations in the downstream Inner Neuse River (Table 32) as compared to the central portion of the New Bern--Bridgeton Area (Table 31). Consequently, the sediments in the inner portion of the trunk estuary have relatively higher background levels of these 5 trace elements. This pattern probably results from the specific chemistry of these five elements and their interactions with

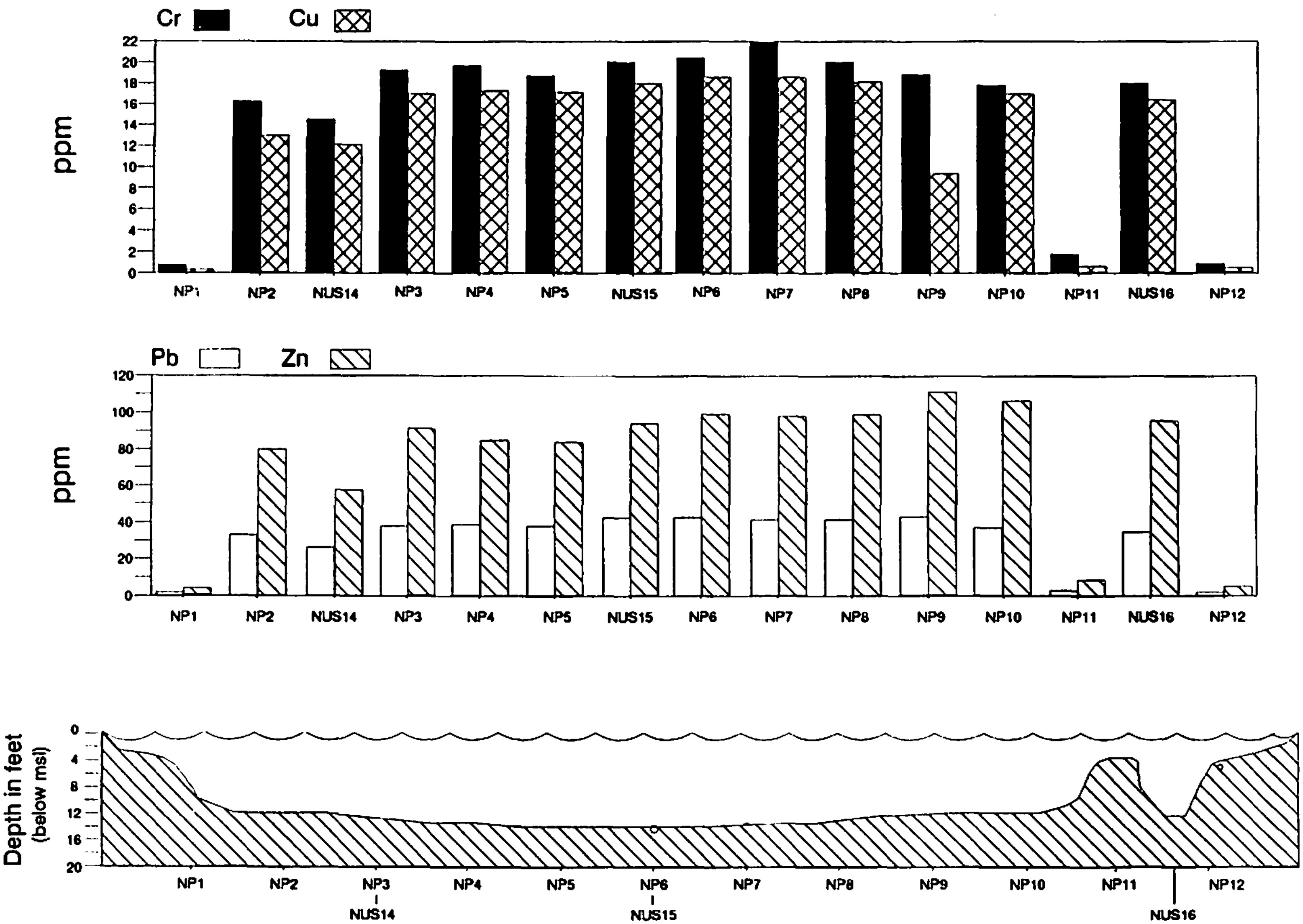

FIGURE 22. South to north (left to right) cross-sectional bottom profile across the Neuse River (Panel A) in feet below mean sea level. Panels B and C show the changing patterns in concentration of four trace elements (lead, zinc, chromium, and copper, respectively). Samples and cross-sectional profile are located on Figures 21 and 23.

the water column and associated bottom sediments and is not directly related to specific point sources.

TABLE 32. Concentrations and enrichment factors of 15 trace elements in surface sediments in the Inner Neuse River. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold type are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (µg/g or ppm) MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS MEAN	MAXIMUM
INNER NEUSE RIVER: EAST OF NEW BERN--BRIDGETON AREA						
Sn *	40	28.1	0.5	63.5	1.3	3.0
Mo	40	0.65	0.0	1.6	1.2	2.9
Mn	40	388.	58.9	782.	1.3	2.7
As *	40	6.2	0.0	12.2	1.0	2.0
V	40	30.3	0.3	46.1	1.3	2.0
Ni	40	4.4	0.1	8.4	0.9	1.8
Ti	40	37.3	3.5	57.1	1.2	1.8
Co	40	5.1	0.3	7.9	1.1	1.7
Hg	28	0.16	0.04	0.25	1.0	1.6
P	40	600.	45.7	1376.	0.7	1.6
Zn	40	79.5	3.7	155.	0.8	1.6
Cr	40	16.0	0.7	25.5	0.9	1.5
Pb	40	31.7	1.7	51.4	0.9	1.5
Cd	40	0.53	0.0	1.1	0.7	1.4
Cu	40	13.6	0.3	23.6	0.7	1.2

* analyses have poor reproducibility, hence somewhat low reliability.

Scotts Creek

Scotts Creek (Fig. 10) drains the largely urban area north and west of James City. An industrial wharf is located immediately inside the mouth of the creek with abundant logging and barge activity. The creek into the wharf has been dredged and deepened for commercial vessels. U.S. highway 70 overpass crosses the creek on the west side of the harbor allowing passage of water from upstream through a large concrete pipe to the Neuse River. Most developments along the shores of the creek are small-scale industries.

Two samples were collected in Scotts Creek; one sample was located in the middle of the harbor and another between the railroad trestle and the US-70 overpass (Fig. 10). Trace element concentrations in these samples are mostly around the Neuse River trimmed mean. However, phosphorus is substantially enriched (2.0 X NRTM). This higher concentration of potentially available phosphorus in the harbor sediments is probably related to decomposition of abundant organic detritus derived from pulp logs stored and barged from this site. Zinc and lead are slightly enriched within the harbor with maximum enrichment factors of 1.8 X and 1.6 X NRTM, respectively.

Enrichment of these two metals is common around boat yards and marinas and is probably related to the commercial shipping activity within the Creek.

Duck Creek

One sample was collected in Duck Creek, a very small tributary on the northeast side of the Neuse River and about 3 km east of New Bern (Fig. 10). A small marina is located near the headwaters of the creek; however, our sample location is well below the marina site. Consequently, the sample was not substantially enriched in any trace elements. Concentrations for all elements are around the trimmed mean for Neuse River sediments except for phosphorus which is slightly enriched (1.9 X NRTM).

Cherry Point Area: Slocum Creek Data

Slocum Creek is a tributary of the Inner Neuse River (Figs. 9 and 23). Throughout most of the length of the creek, facilities associated with Cherry Point Marine Corps Air Station dominate the adjacent land areas. East and Southwest Prongs of Slocum Creek are dominated by urban development associated with the town of Havelock, along with water and waste water treatment plants. Wastes of many varieties from industrial aircraft operations at the air station have been disposed of at sites adjacent to Slocum Creek (Fig. 24) since the base was established in 1941. Numerous contracted studies have been done on the types and amounts of wastes disposed of at these sites including Schnabel (1981), Putnam et al. (1982), Soil and Materials (1983), and NUS (1984). The air station has an NPDES permit to discharge up to 3.5 million gallons of waste water per day from a waste water treatment facility. This permitted site discharges into Slocum Creek just south of the Slocum Road bridge (Fig. 24). The town of Havelock operates a WWTP that releases up to 1.5 million gallons per day of treated municipal waste through a discharge pipe located in the upper reaches of East Prong Creek. The exact nature, extent and effects of waste spills and waste discharge into Slocum Creek have been the subject of numerous studies conducted during the 1980's and are summarized in the next section.

A suite of 25 sediment samples were collected in Slocum Creek from the uppermost tributaries, northward to the Neuse River; their locations are indicated on Figures 23 and 24 and in Appendix A. For the purposes of this discussion, Slocum Creek will be subdivided into four subregions as follows (Figs. 23 and 24): East Prong (6 sample sites; Table 33), Southwest Prong (2 sample sites; Table 34), upper Slocum Creek (14 sample sites; Table 35), and lower Slocum Creek (3 sample sites; Table 36). The sediments in the southern half of Slocum Creek (Fig. 23) are substantially contaminated by many trace elements as summarized in Tables 33 through 36. This entire map area has generally elevated values; however, specific portions have plumes of higher enrichment of certain groups of elements suggesting multiple point sources. The following discussion will be centered around these plumes within four subregions and will begin in the southern headwaters and progress northward towards the Neuse River. Figures 25 through 33 are schematic contour maps that use enrichment factors to display specific trace element concentration and their general distribution within the southern portion of Slocum Creek.

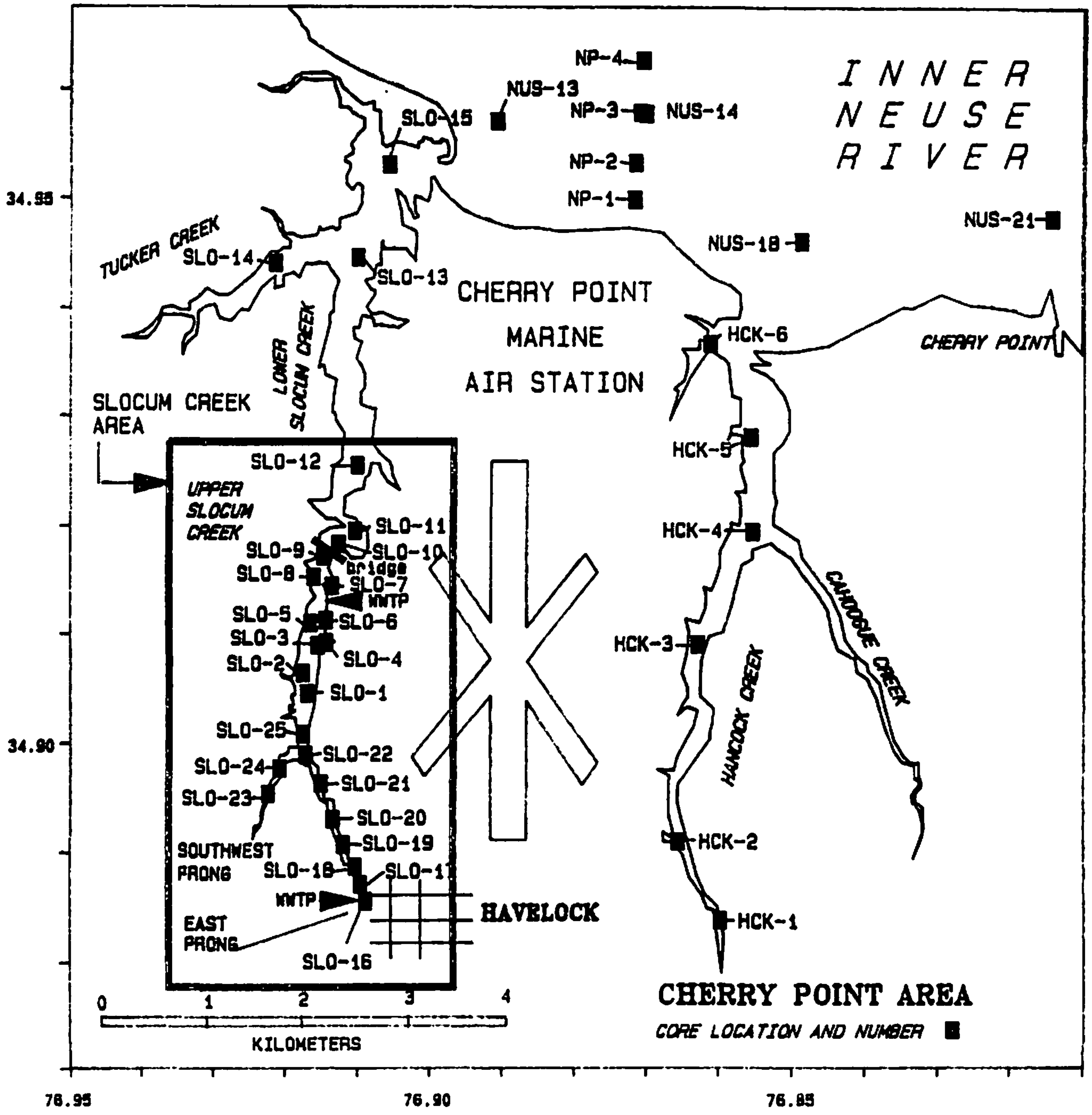

FIGURE 23. Sample location map of the Cherry Point, Slocum Creek, Hancock Creek, and Inner Neuse River Areas.

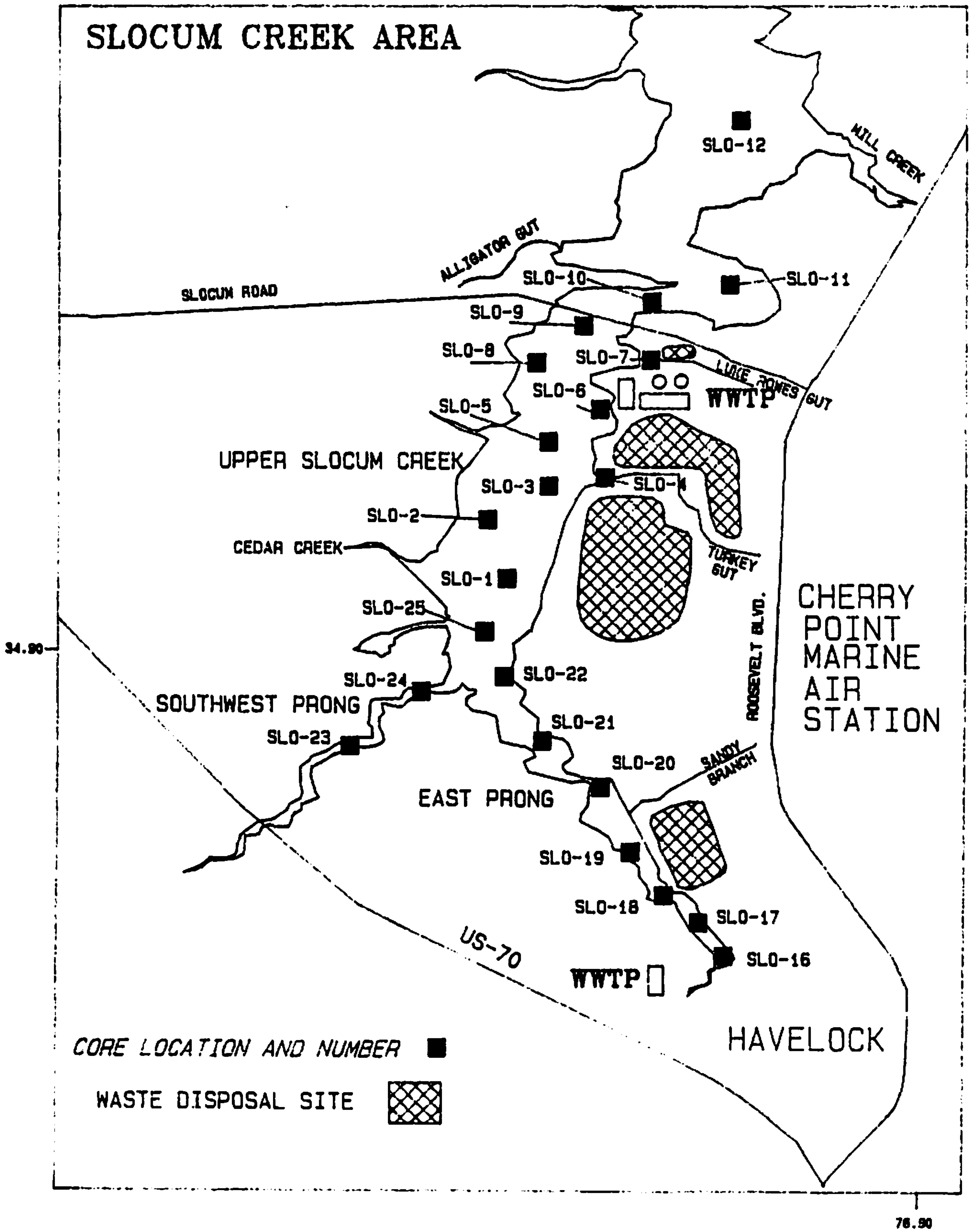

FIGURE 24. Sample location map of the <u>Slocum Creek Area</u>.

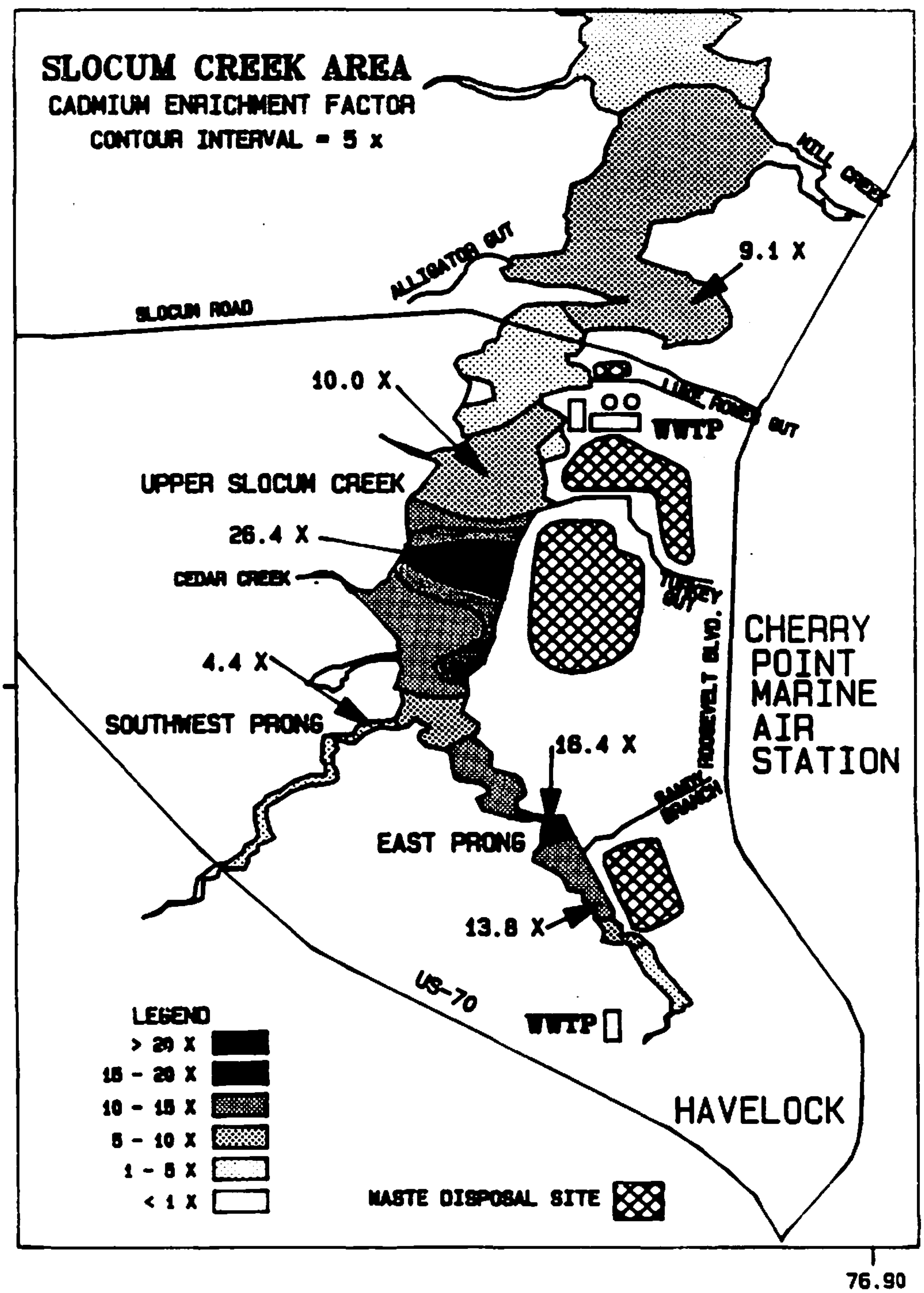

FIGURE 25. Schematic contour map of the cadmium enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

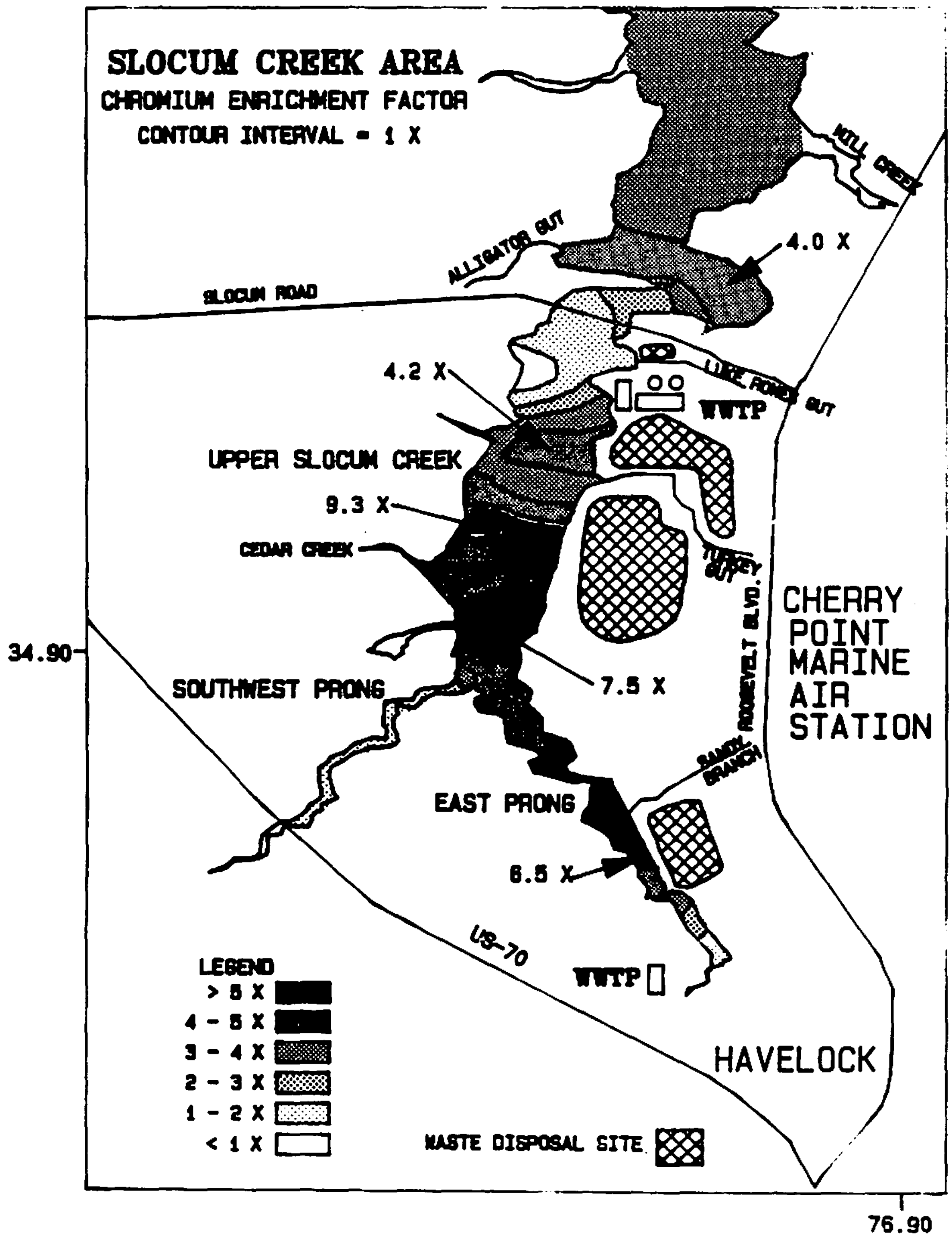

FIGURE 26. Schematic contour map of the chromium enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

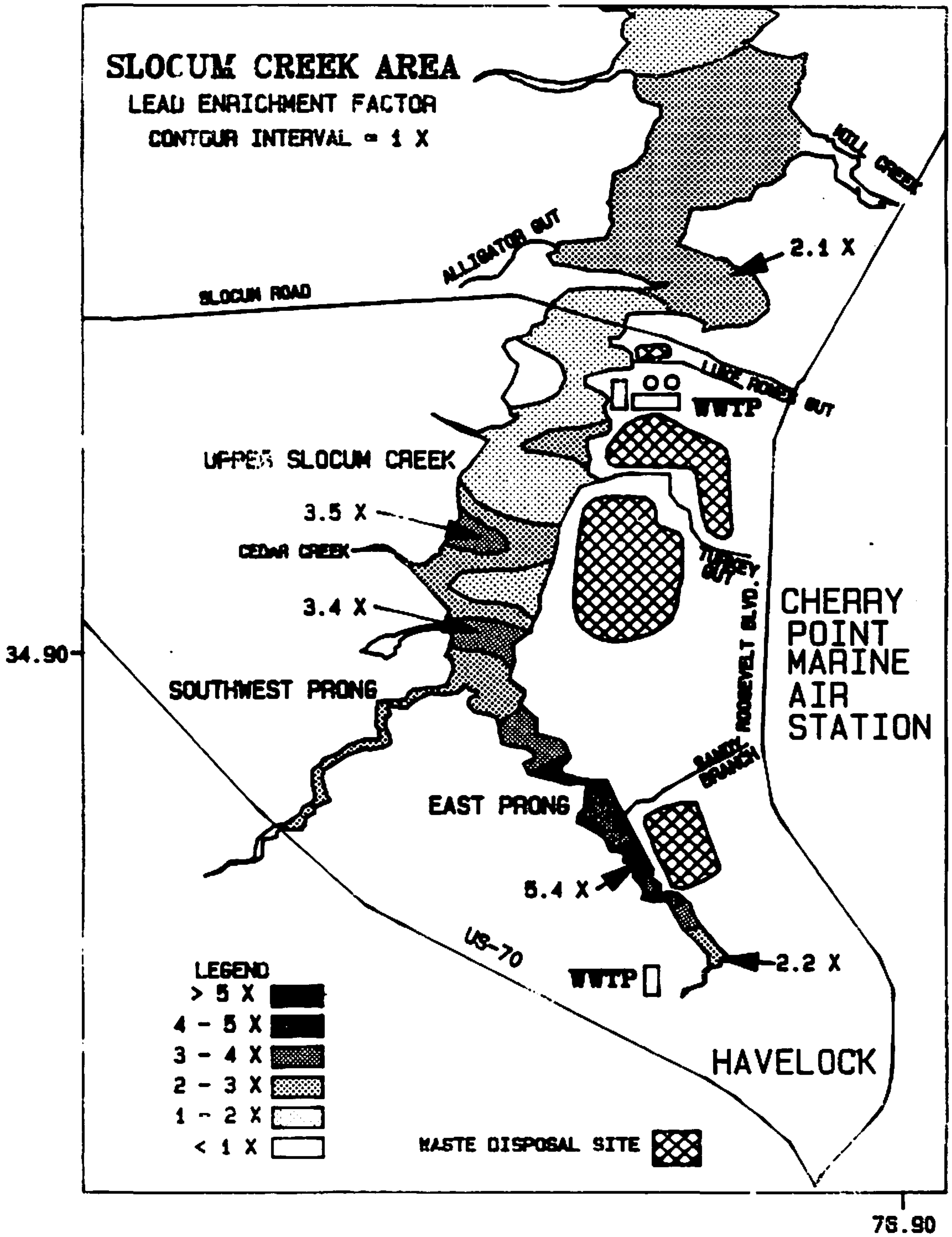

FIGURE 27. Schematic contour map of the lead enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

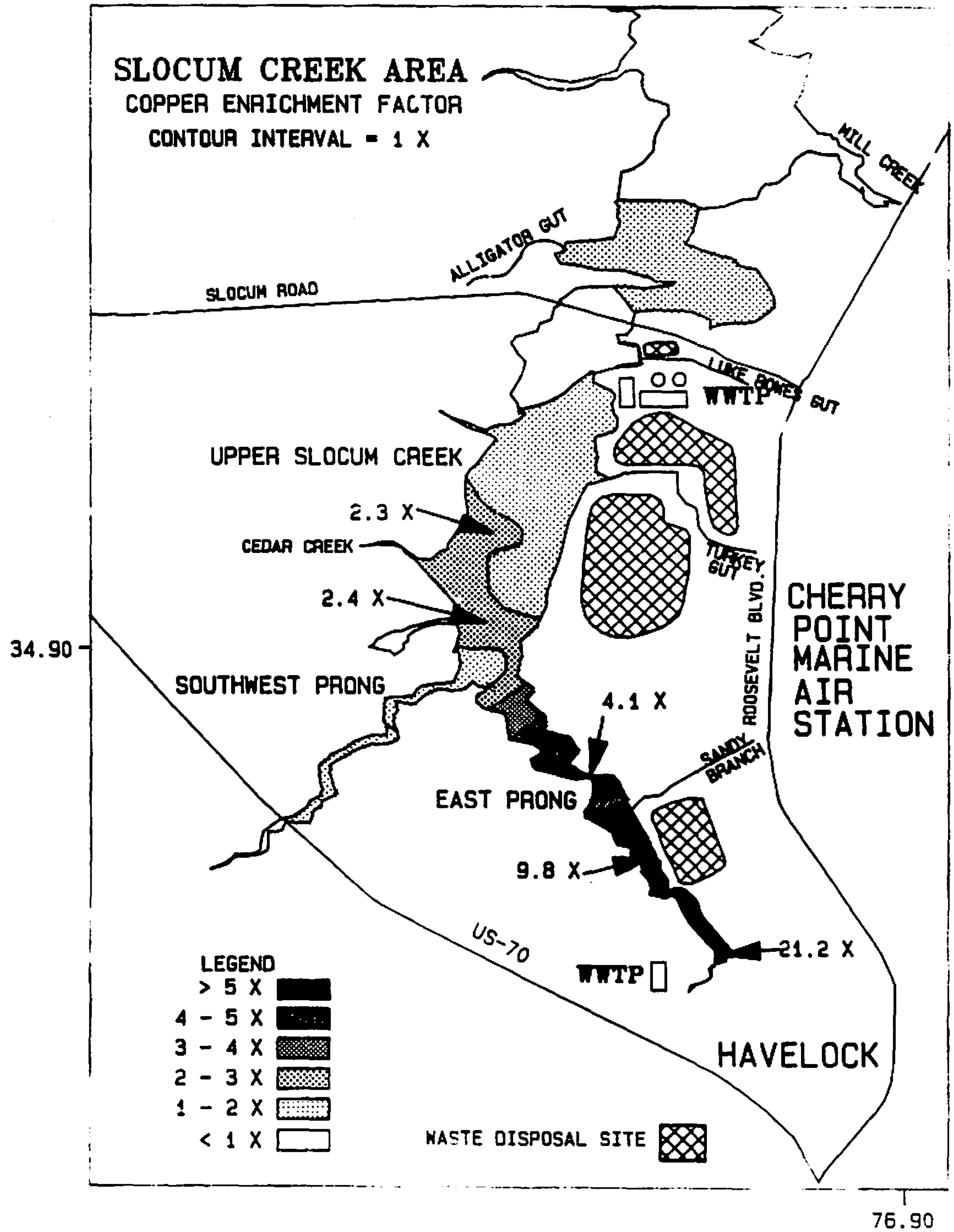

FIGURE 28. Schematic contour map of the copper enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

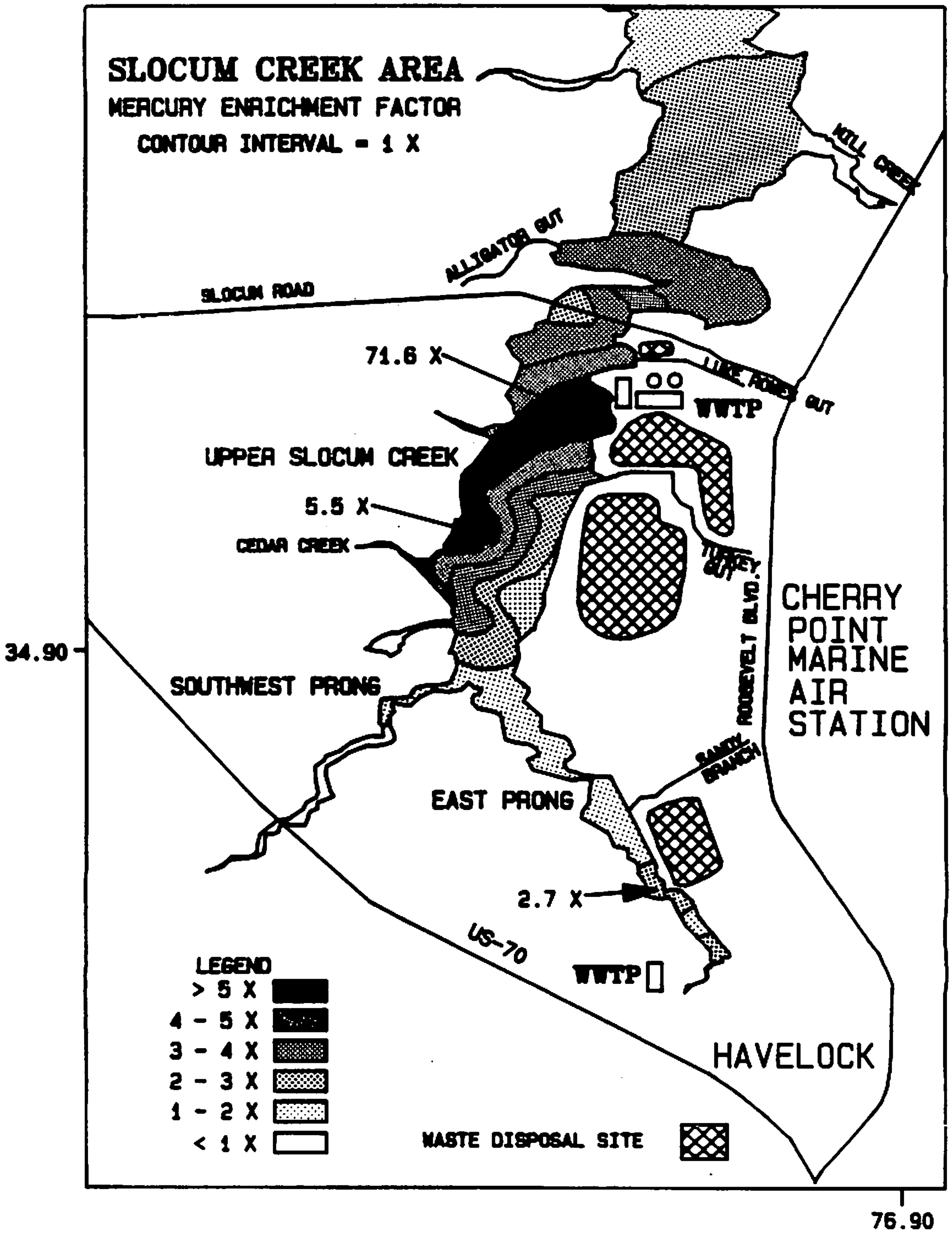

FIGURE 29. Schematic contour map of the mercury enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

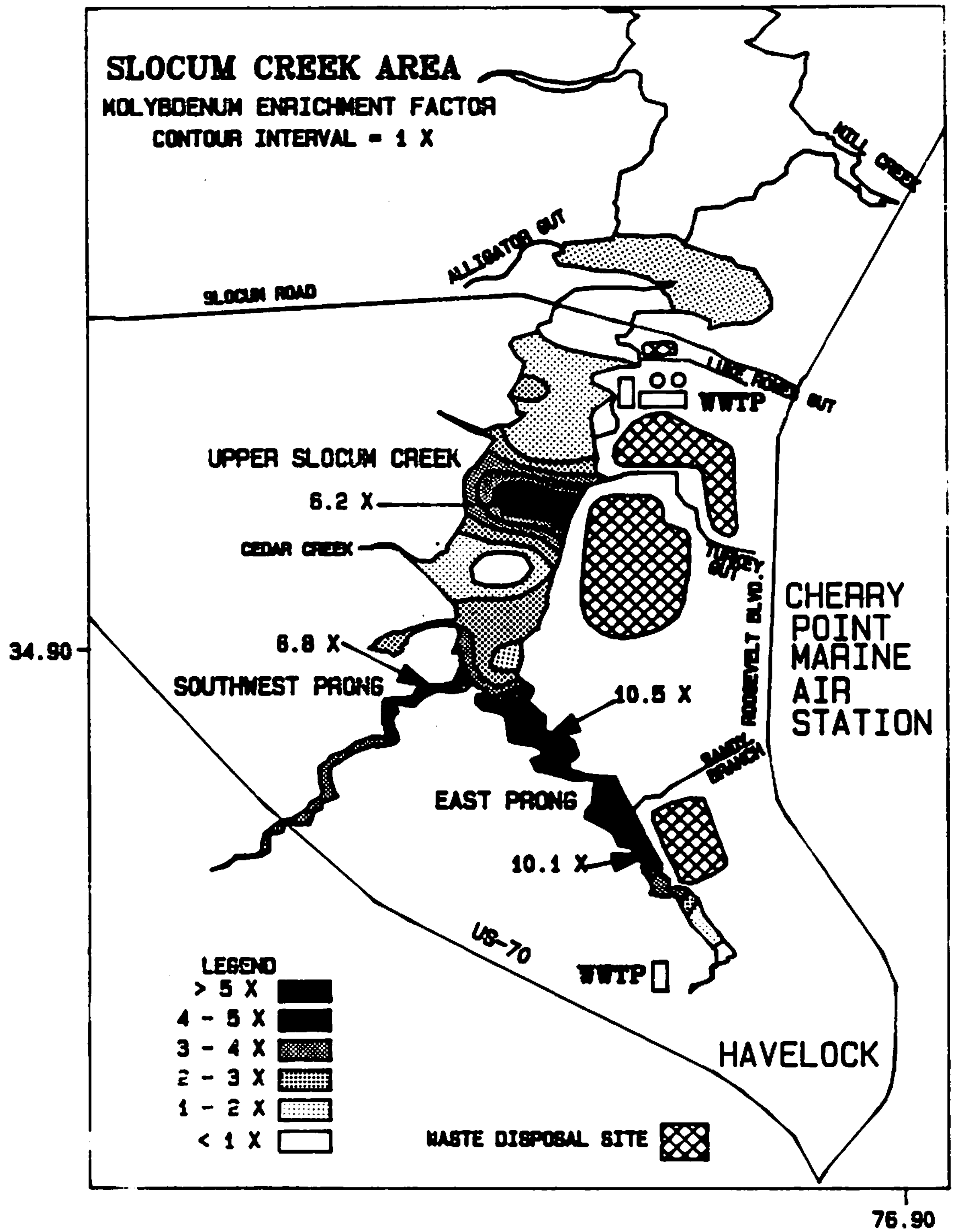

FIGURE 30. Schematic contour map of the molybdenum enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

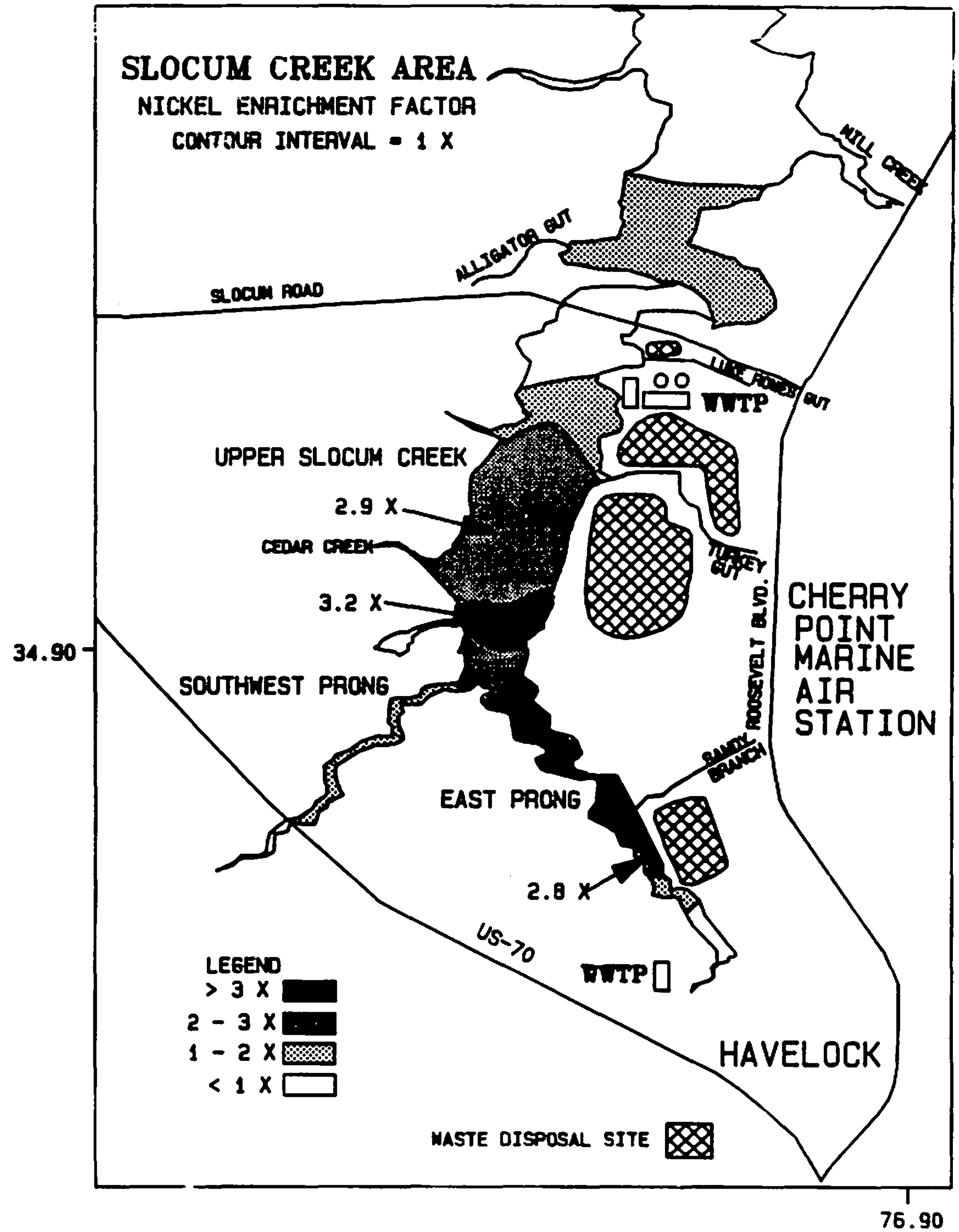

FIGURE 31. Schematic contour map of the nickel enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

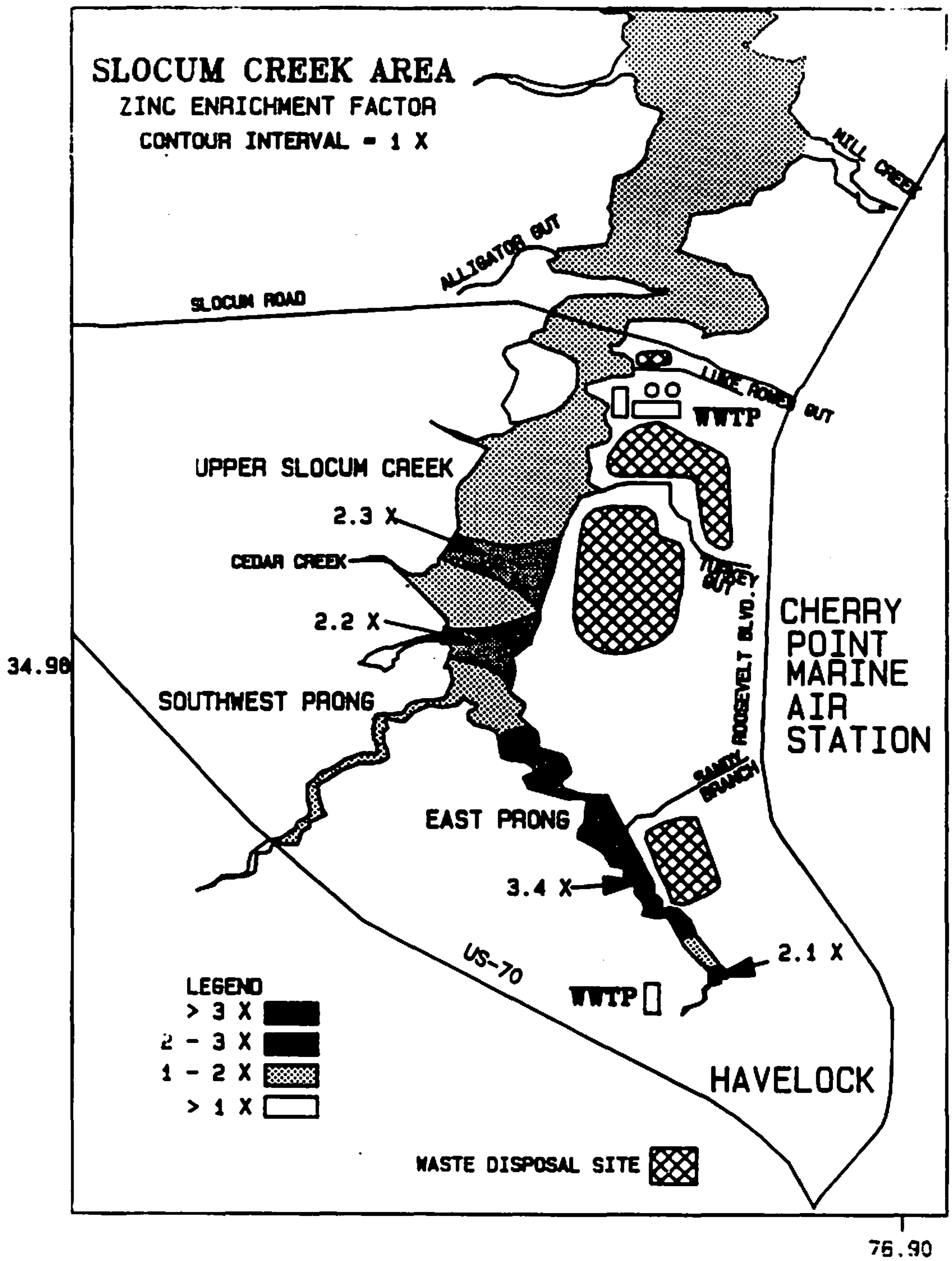

FIGURE 32. Schematic contour map of the <u>zinc</u> enrichment factors in the <u>Slocum Creek Area</u>. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

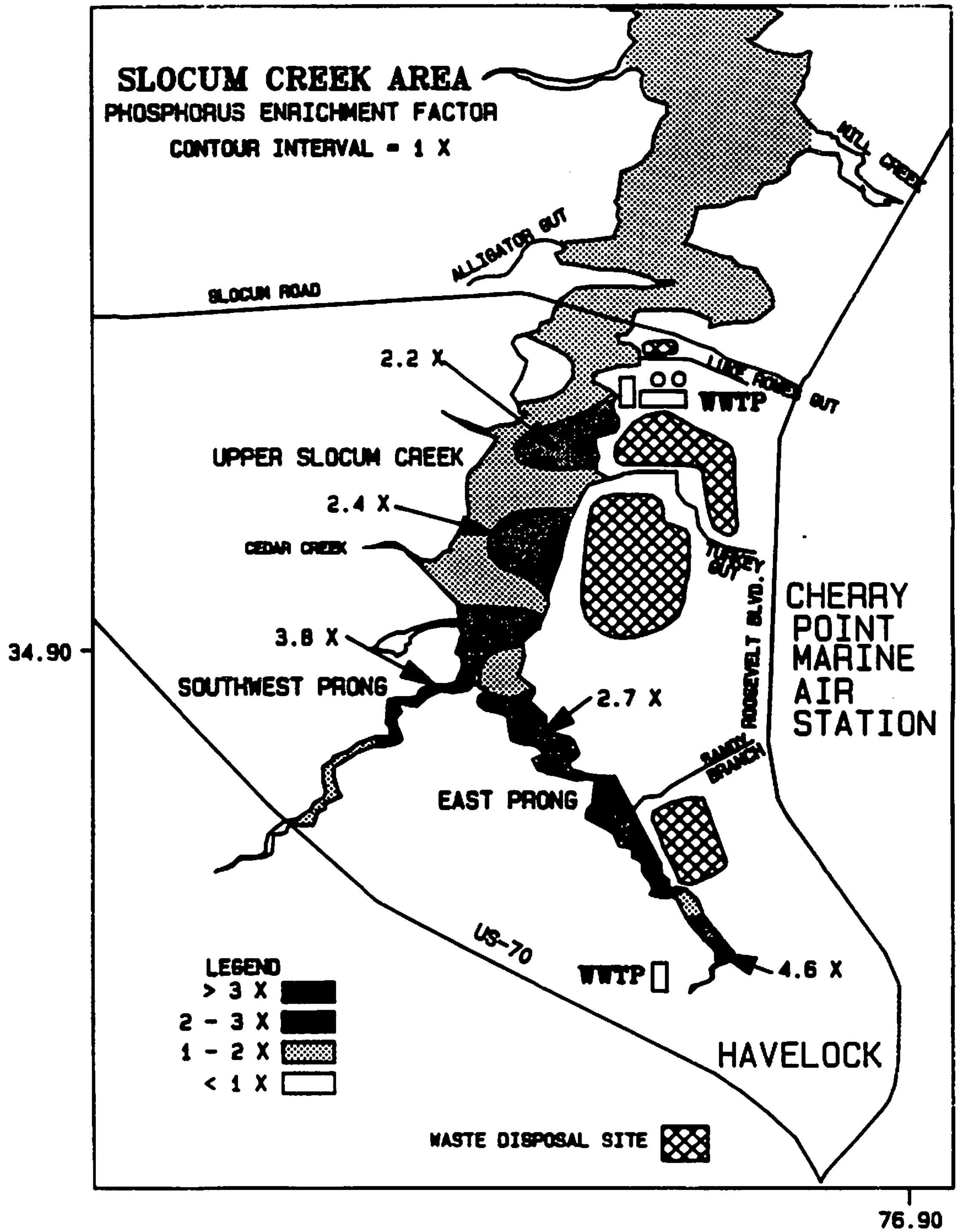

FIGURE 33. Schematic contour map of the phosphorus enrichment factors in the Slocum Creek Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

East Prong of Slocum Creek (Table 33). The first enriched area is in the upper portion of East Prong and adjacent to the Havelock waste water treatment plant that discharges up to 1.5 million gallons of waste water per day (SLO-16 in Fig. 24). Seven trace elements are substantially enriched at this site (EF: Cu = 21.2 X; Cd = 14.6 X; Zn = 7.3 X; Hg = 7.1 X; Cr = 5.7 X; Pb = 4.9 X; P = 4.6 X NRTM). These concentrations are considered to be high and they occur in both the surface and deep samples. The direct source of these metal contaminants is not clear. Copper, zinc, and phosphorus generally decrease in concentration downstream away from the WWTP suggesting that they may be derived from the WWTP discharge. Cadmium, chromium, lead, and molybdenum generally increase downstream suggesting sources other than the Havelock WWTP.

TABLE 33. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in the East Prong portion of Slocum Creek. Depths of the deep samples range from 9 to 25 cm below the sediment surface for an average depth of 22 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (μg/g or ppm) SURFACE SAMPLES MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS DEEP SAMPLES N = 6 MEAN	MAXIMUM	SURFACE SAMPLES N = 6 @ MEAN	MAXIMUM
EAST PRONG--SLOCUM CREEK								
Cu	12	144.	18.3	409.	6.7	15.2	8.3	21.2
Cd #	12	11.1	1.6	25.3	19.5	32.9	9.4	16.4
Mo	12	2.3	0.4	5.7	3.1	4.4	5.3	10.5
Cr #	12	109.	17.4	300.	9.1	17.8	3.8	6.5
Pb #	12	168.	59.5	432.	6.1	12.4	3.6	5.4
P	12	2026.	352.	4072.	2.1	2.9	2.6	4.6
Zn	12	280.	65.5	693.	3.5	7.3	2.4	3.4
Hg	11	0.42	0.11	1.08	3.5	7.1	1.9	2.9
Ni	12	10.1	2.7	29.3	2.6	6.3	1.7	2.6
V	12	32.4	4.9	142.	2.0	6.3	0.9	1.6
As *	12	5.2	1.5	9.3	0.8	1.4	0.9	1.6
Mn	12	180.	45.1	421.	0.6	1.5	0.7	1.0
Co	12	3.1	1.4	4.7	0.7	0.9	0.7	1.0
Ti	12	16.2	5.9	22.2	0.5	0.6	0.5	0.7
Sn *	12	10.5	5.4	19.4	0.5	0.9	0.4	0.6
Ca	12	8205.	4125.	17370.	1.4	2.4	1.8	3.4

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses have poor reproducibility, hence somewhat low reliability.
@ except for mercury (n = 5).

The second enriched area is midway down East Prong and continues southward to the confluence with Slocum Creek. At least one waste disposal site (Murray and Daniel, 1990) and a hazardous chemical facility occur along the Cherry Point side of the creek (SLO-18 through SLO-22 in Fig. 24). Ten trace elements are substantially enriched through this area (MEF: Cd = 54.3 X; Mo = 18.2 X; Cr = 17.8 X; Pb = 12.4 X; Cu = 9.6 X; Ni = 6.3 X; V = 6.3 X; Hg = 4.7 X; Zn = 4.5 X; P = 2.7 X NRTM). These high levels of cadmium, molybdenum, chromium, and lead occur in almost all samples and are the highest levels found in the North Carolina estuarine system to date. Also, this is the only area where substantial concentrations of vanadium have been found (in three samples). Concentrations generally decrease into the uppermost portion of upper Slocum Creek.

<u>Southwest Prong of Slocum Creek (Table 34).</u> Only two cores were obtained in the lower portion of Southwest Prong (SLO-23 and SLO-24; Fig. 24). The only known discharge into this branch is the Havelock water treatment plant.

Seven trace elements are substantially enriched in this creek, but only irregularly in some of the samples (MEF: Cd = 20.1 X; Cr = 11.0 X; Mo = 6.8 X; P = 3.6 X; Pb = 3.1; Ni = 2.4 X; As = 2.2 X NRTM). Concentration levels for cadmium, chromium, and molybdenum are relatively high, but they are considerably lower than in East Prong and don't occur in all samples. The other four elements are enriched in just 1 or 2 samples each. These data suggest that Southwest Prong does not have its own point sources of contaminants, but rather the contamination has been derived from the lower portion of East Prong and the upper portion of Slocum Creek.

<u>Upper Slocum Creek (Table 35).</u> A major area of sediment contamination occurs adjacent to a large area containing polishing lagoons, sanitary landfills, and buried sludge pits at Cherry Point (Fig. 24) (Murray and Daniel, 1990). The highest trace element enrichments occur in this area (SLO-2, SLO-3, and SLO-5 in Fig. 24). Ten trace elements are substantially enriched in the surface sediments and include the following (MEF: Cd = 29.0 X; Hg = 15.9 X; Cr = 9.3 X; Mo = 6.2 X; Pb = 3.5 X; Ni = 2.9 X; Cu = 2.6 X; P = 2.4 X; Zn = 2.3 X; Sn = 2.1 X NRTM). In 2 of the cores (SLO-2 and SLO-3) all elements, except molybdenum, are only enriched in the surface samples. Whereas in core SLO-5, enrichment of 9 elements continues down core to at least 33 cm. The latter suggests that either SLO-5 is nearer a main site of waste discharge or that this area has been physically disturbed over the years. Contamination levels in this area do not seem to be as high as the lower portion of East Prong.

A second area of sediment contamination occurs adjacent to the Cherry Point waste water treatment facility (SLO-6 in Fig. 24), which discharges up to 3.5 million gallons of waste water per day. Six trace elements are substantially enriched in these sediments and include the following (MEF: Hg = 71.6 X; Cd = 11.0 X; Cr = 3.5 X; Pb = 4.0 X; Mo = 2.6 X; P = 2.2 X NRTM). The mercury concentration (10.9 ppm) in this area is the highest level recorded in any of our samples within the North Carolina estuarine system to date. This concentration is high enough that these sediments should probably be considered a hazardous toxic waste. Sediments off the Cherry Point WWTP discharge have only slight enrichments of copper and zinc (1.9 X; 1.8 X NRTM; respectively) and much lower levels of phosphorus (2.2 X NRTM) compared to very high levels (21.2 X; 7.3 X; 4.6 X NRTM; respectively) for sediments adjacent to the Havelock WWTP discharge.

TABLE 34. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in the Southwest Prong of Slocum Creek. Depths of the deep samples range from 12 to 31 cm below the sediment surface for an average depth of 22 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (µg/g or ppm) SURFACE SAMPLES MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS DEEP SAMPLES MEAN (N = 2)	DEEP SAMPLES MAXIMUM	SURFACE SAMPLES MEAN (N = 2)	SURFACE SAMPLES MAXIMUM
SOUTHWEST PRONG--SLOCUM CREEK								
Mo	4	2.1	1.1	3.7	2.8	3.5	5.1	6.8
Cd #	4	5.6	1.4	15.5	11.0	20.1	3.6	4.4
P	4	1857.	182.	3160.	1.6	2.9	2.7	3.6
Pb #	4	74.2	30.6	108.	2.0	3.1	2.3	2.4
As *	4	7.4	2.7	13.1	1.0	1.5	1.5	2.2
Cr #	4	63.0	14.9	185.	5.9	11.0	1.6	1.7
Ni	4	6.6	2.0	11.0	1.4	2.4	1.5	1.5
Zn	4	122.	41.1	162.	1.1	1.7	1.5	1.6
Cu	4	22.7	6.8	37.3	1.1	1.9	1.2	1.5
Mn	4	269.	47.2	523.	0.6	1.1	1.2	1.8
V	4	22.4	14.0	27.1	0.9	1.2	1.1	1.2
Hg	4	0.13	0.8	1.2	0.8	1.1	1.0	1.2
Co	4	4.3	2.0	5.6	0.7	1.0	1.1	1.2
Sn *	4	9.7	5.3	15.1	0.4	0.5	0.5	0.7
Ti	4	14.2	9.6	17.5	0.4	0.6	0.5	0.5
Ca	4	8230.	5727.	12600.	1.2	1.3	2.1	2.5

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses have poor reproducibility, hence somewhat low reliability.

A third area of sediment contamination extends over a broad region north of Slocum Road bridge to the mouth of Mill Creek (SLO-10, SLO-11, and SLO-12 in Fig. 24). This area is situated adjacent to and north of a series of fly ash ponds and incinerator and sludge disposal sites (Murray and Daniel, 1990). Four trace elements are substantially enriched in these sediments and include the following (MEF: Cd = 11.8 X; Cr= 4.0 X; Hg = 4.0 X; and Pb = 2.1 X NRTM). Mercury levels, even though still high, systematically decrease downstream from the Cherry Point WWTP. The other three metals increase to maximum concentrations in cores SLO-10 and SLO-11 and then decrease systematically downstream. Due to the road access and geography of the peninsula just north of Slocum Road bridge, this area is a favorite family park for picnicking, swimming, and boating.

TABLE 35. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in the upper portion of Slocum Creek. Depths of the deep samples range from 26 to 42 cm below the sediment surface for an average depth of 33 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (μg/g or ppm) SURFACE SAMPLES MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS DEEP SAMPLES MEAN N = 12 @	DEEP SAMPLES MAXIMUM N = 12 @	SURFACE SAMPLES MEAN N = 12 @	SURFACE SAMPLES MAXIMUM N = 12 @
UPPER SLOCUM CREEK								
Hg	22	1.0	0.06	10.9	3.2	15.9	9.4	71.6
Cd #	24	7.8	0.2	41.8	5.9	54.3	10.2	26.4
Cr #	24	56.1	5.2	188.	2.6	11.2	4.0	9.3
Mo	24	1.45	0.1	9.9	3.7	18.2	1.6	6.2
Pb #	24	57.7	4.9	140.	1.4	4.0	2.0	3.5
Ni	24	7.2	1.7	17.6	1.2	3.8	1.8	3.2
P	24	1096.	302.	2157.	0.8	1.5	1.7	2.5
Cu	24	21.6	4.9	49.8	0.9	2.6	1.3	2.4
Zn	24	109.	23.4	216.	0.9	2.1	1.5	2.3
Sn *	24	23.3	10.9	44.4	1.0	2.1	1.1	2.0
As *	24	4.6	0.0	13.1	0.8	2.2	0.7	1.3
Mn	24	252.	90.0	451.	0.7	1.0	1.1	1.6
Ti	24	25.9	9.0	53.3	1.0	1.7	0.7	1.2
Co	24	4.4	1.0	6.4	1.0	1.2	0.9	1.4
V	24	18.8	4.8	28.3	0.8	1.3	0.9	1.2
Ca	10	74800.	3871.	209800.	9.9	40.7	19.8	41.6
Ca	14	5860.	3585.	6282.	1.0	1.3	0.9	1.1

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses have poor reproducibility, hence somewhat low reliability.
@ except for mercury (n = 11) and Ca (n = 5 for the top and 7 for the bottom entries).

Two samples were obtained within drainage ditches (SLO-4 in Turkey Gut; and SLO-7 in Luke Rowes Gut; Fig. 24) that drain through areas of several hazardous waste disposal sites on Cherry Point. However, the resulting three samples contained no enriched levels of any trace elements for the following reasons. The two samples from SLO-4 are quartz silty sands with only 9% and 14% clay component and 4% organic matter. The one sample from SLO-7 was collected behind a delta lobe of carbonate sediments and is a carbonate-rich sand (97%) with only 3% clay. Source of the carbonate is probably from lime discharged by the WWTP. Both quartz and calcite are chemically nonreactive minerals and overwhelmingly diluted any chemically reactive fraction of the sediment. Therefore, low trace element concentrations within the total sediment of these samples tells us little about the potential source of contaminants draining the hazardous waste disposal sites on Cherry Point.

Lower Slocum Creek (Table 36). The northern portion or lower Slocum Creek (Fig. 23) is generally away from the industrial portion of Cherry Point and is characterized by low-density housing, offices, and recreational facilities with golf courses and small marinas, etc. The three cores (SLO-13, SLO-14, and SLO-15 in Fig. 23) contain minimal levels of trace element contamination in the sediments. Only 3 trace elements are substantially enriched in sediments in lower Slocum Creek and they only in core SLO-13 (MEF: Sn = 2.2 X; Cd = 3.5 X; and Cr = 2.1 X NRTM). Concentrations of all trace elements in core SLO-15, located further downstream at the mouth of Slocum Creek, are either at or below the Neuse River trimmed mean.

TABLE 36. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in the lower portion of Slocum Creek. Depths of the deep samples range from 19 to 34 cm below the sediment surface for an average depth of 25 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (μg/g or ppm) SURFACE SAMPLES MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS DEEP SAMPLES N = 3 MEAN	MAXIMUM	SURFACE SAMPLES N = 3 MEAN	MAXIMUM
LOWER SLOCUM CREEK								
Sn *	6	27.6	9.2	47.9	1.4	2.2	1.2	2.0
Cd	6	1.2	0.3	2.7	1.6	3.5	1.4	1.9
Cr	6	18.4	6.0	34.9	1.2	2.1	1.0	1.3
Ti	6	35.4	16.6	57.8	1.4	1.8	0.8	1.0
Mo	6	0.55	0.3	0.7	1.0	1.3	1.0	1.3
Mn	6	260.	105.	384.	0.9	1.1	0.9	1.3
Ni	6	3.2	1.1	5.1	0.6	0.9	0.7	1.1
Hg	6	0.12	0.07	0.2	0.9	1.3	0.7	1.0
Co	6	4.0	2.0	5.5	0.9	1.2	0.8	1.0
Pb	6	26.4	10.7	41.4	0.7	1.2	0.8	1.0
V	6	20.0	7.6	27.8	1.0	1.2	0.7	1.0
As *	6	4.6	2.4	7.6	0.8	1.3	0.7	0.9
Zn	6	58.9	29.6	87.1	0.6	0.8	0.7	0.9
Cu	6	12.0	4.4	18.0	0.6	0.9	0.6	0.8
P	6	459.	192.	755.	0.5	0.9	0.6	0.8
Ca	6	3680.	1980.	5308.	0.6	0.7	0.9	1.1

# indicates that there is a map displaying regional distribution patterns of enrichment factors for this element.
* analyses have poor reproducibility, hence somewhat low reliability.

Cherry Point Area: Slocum Creek Discussion

Much rhetoric has occurred in the news media during the past several years concerning sediment contamination problems in Slocum Creek. This concern revolves around the activities of the U.S. Marine Corps and the request by the U.S. Marine Corps at Cherry Point for a new NPDES Permit (No. NC0003816). The permit requests a change in location of their main (001) outfall of treated domestic and industrial waste water from Slocum Creek to the Neuse River in concert with significant modifications in effluent limitations.

Numerous studies have already been done, or are presently being done on the water, sediments, and biota in Slocum Creek by the U.S. Marine Corps, various Federal and State agencies, and some individuals. All of these studies are basically corroborative and demonstrate that there is a potential problem concerning sediment contamination within Slocum Creek. At present it is not definitely known whether these contaminated sediments are impacting the water quality or the biota within the estuary. However, thorough consideration should be given to all data before a long-term decision is made on moving the discharge site to the Neuse River or modifying the effluent limitations. A brief summary of some of the more important aspects of these studies follows.

The present study has evaluated sediments within Slocum Creek (Figs. 23 and 24). This study has found that broad portions of the surface sediments in upper Slocum Creek, East Prong, and Southwest Prong are substantially enriched in 9 trace elements and slightly enriched in 5 trace elements, which are summarized in Tables 4 and 37. Within the contaminated area, both surface and deep sediments contain substantially high concentrations of cadmium, molybdenum, chromium, mercury, lead, phosphorus, copper, nickel, and zinc with enrichment factors that range up to 71.6 X the Neuse River trimmed mean. Only cobalt is not substantially or slightly enriched within the sediments of Slocum Creek.

All data from the present study represent a weak leach analysis technique suggesting that these metals are loosely bound within the surface sediments and thus, are potentially "bioavailable" (Riggs et al., 1989b and this report). Table 38 compares the data from this report with Slocum Creek trace element data from the USMC (U.S. FWS, 1985) and N.C. DEM study of 1983. These latter two sets of analyses represent total metal concentrations in the sediments; consequently, they are somewhat higher than the metal concentrations in the present study. In total metals analyses, some proportion of the metal content is probably being structurally bound within the sediments and therefore not potentially bioavailable.

TABLE 37. Mean enrichment factors for 15 trace elements and numbers of samples displaying slight or substantial levels of enrichment in all surface and deep sediments within Slocum Creek. Elements with underlined mean enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold print are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	LOWER SLOCUM CREEK		UPPER SLOCUM CREEK		EAST PRONG SLOCUM CREEK		SOUTHWEST PRONG SLOCUM CREEK	
	MEAN EF (N=6)	NO SPL ENRICH	MEAN EF (N=24)	NO SPL ENRICH	MEAN EF (N=12)	NO SPL ENRICH	MEAN EF (N=4)	NO SPL ENRICH
ELEMENTS SUBSTANTIALLY ENRICHED IN SOME PORTION OF SLOCUM CREEK								
Cd	1.5	1	10.1	18	14.4	12	7.3	4
Mo	1.0	0	2.7	15	4.2	11	3.9	4
Cr	1.1	0	3.3	16	6.5	10	3.7	2
Hg	0.8	0	6.4	16	2.8	6	0.9	0
Pb	0.8	0	1.7	12	4.8	12	2.1	3
P	0.5	0	1.3	11	2.3	10	2.1	3
Cu	0.6	0	1.1	9	7.5	11	1.2	2
Ni	0.7	0	1.5	10	2.2	7	1.4	3
Zn	0.6	0	1.1	7	2.9	10	1.3	2
ELEMENTS THAT ARE LOCALLY ENRICHED IN SOME PORTION OF SLOCUM CREEK								
As *	0.8	0	0.8	1	0.9	1	1.2	1
Mn	0.9	0	0.9	2	0.6	1	0.9	1
Sn *	1.3	2	1.1	4	0.5	0	0.5	0
Ti	1.1	1	0.8	0	0.5	0	0.4	0
V	0.9	0	0.8	0	1.4	3	1.0	0
ELEMENTS WITH NO ENRICHMENT WITHIN SLOCUM CREEK								
Co	0.9	0	0.9	0	0.7	0	0.9	0

* analyses have poor reproducibility, hence somewhat low reliability.

TABLE 38. Summary of concentration and maximum enrichment factors for trace elements in sediments in the upper portions of Slocum Creek and comparison with data from previous studies. The analyses from this study are of surface sediments utilizing a partial leach technique, whereas the other studies represent total metals. Enrichment factors of 2 or more times the trimmed mean are considered to be substantial and are indicated by underlining.

	THIS STUDY (Partial Leach Technique)		USMC DATA (US FWS, 1985) (Total Metals)		N.C. DEM (1983)
TRACE ELEMENT	Concentration in ppm's Min to Max	Maximum Enrichment Factor	Concentration in ppm's Min to Max	Maximum Enrichment Factor	in ppm's Maximum Reported
Hg	0.1 to 10.9	71.6 X	0.2 to 2.2	14.7 X	1.6
Cd	0.2 to 20.3	26.4 X	<8.0 to 46.8	80.7 X	0.7
Cu	5.3 to 409.	21.2 X	<8.0 to 154.	8.9 X	50.0
Mo	0.1 to 5.7	10.5 X			
Cr	9.0 to 157.	9.3 X	3.8 to 440.	28.4 X	66.0
Pb	6.0 to 188.	5.4 X	9.6 to 264.	8.1 X	81.0
Zn	23.6 to 324.	3.4 X	7.2 to 416.	4.6 X	130.0
Ni	2.5 to 14.9	3.2 X	<80.0		19.0
V	4.9 to 36.1	1.6 X			
Sn	5.4 to 42.3	2.0 X			
P	302. to 4072.	4.6 X			
As	2.5 to 13.1	2.2 X			

Two recent U.S. Geological Survey reports (Murray and Daniel, 1990; Murray and Keoughan, 1990) summarize the most recent water-quality studies on groundwater wells clustered around the waste water treatment plant at Cherry Point. Their work demonstrated that 1) groundwater in the surficial aquifer flows toward Slocum Creek and 2) trace metals occur in concentrations above minimum detectable limits in all wells (Table 39), but have higher concentrations in the downgradient wells. According to the U.S. EPA (1986; Table 5), only iron, manganese, and chromium concentrations are substantially above standards for drinking water. However, groundwater containing low concentrations of these trace elements, discharging into Slocum Creek over long-terms, could represent important potential sources for heavy metal loading within the estuarine sediments.

The sediments in the inner Neuse River, in front of the U.S. Marine Corps Cherry Point facility (Fig. 23), are mineralogically and chemically similar to those occurring both in Slocum Creek and within the analogous portion of the Pamlico River estuary. In the Pamlico River, major industrial waste from a large phosphate mining and chemical operation (Texasgulf, Inc.) is discharged directly into the Pamlico River estuary. Over the past 25 years this discharge has produced a large plume of surface sediment contamination that extends across the entire trunk estuary and over 5 miles in the upstream-downstream direction (Riggs et al., 1989b). The sediments within this plume are substantially enriched in 8 trace elements (Cd = 5.2 X; Mo = 5.0 X;

P = 3.2 X; As 2.7 X; Mn = 2.6 X; V = 2.5 X; Ti = 2.0 X PRTM; and fluorine with concentrations up to 280 ppm) as well calcium enrichment up to 34 X the Pamlico River trimmed mean (see Riggs et al., 1989b).

TABLE 39. Maximum level of trace metals found in groundwater of the surface aquifer in well clusters around the Cherry Point WWTP. Data are from Murray and Daniel (1990).

TOTAL RECOVERABLE (µg/L or ppb)				DISSOLVED (µg/L or ppb)	
Arsenic	= 36	Lead	= 21	Barium	= 73
Antimony	= 8	Mercury	= 0.5	Boron	= 140
Cadmium	= 5	Nickel	= 52	Cobalt	= 240
Chromium	= 140	Silver	= 4	Iron	= 76,000
Copper	= 200	Zinc	= 320	Manganese	= 4,700
		Tin	= 25	Vanadium	= 38

Numerous preliminary studies are being carried out on both diseased fish and crabs within the Pamlico River by various independent researchers and the N.C. DMF and N.C. DEM (Hawkins, 1987; Levine, 1988; Engel and Noga, 1989; Levine et al., 1989; Noga et al., 1989; McKenna et al., 1990; and Miller et al., 1990). This work is beginning to suggest that there may be a higher incidence of diseased finfish and blue crabs occurring within those portions of the Pamlico River where toxic metal enrichment is greatest. Also, there is yet controversial evidence that some clams and diseased crabs may be enriched in various elements including cadmium and fluorine; but a direct link between the disease and metal concentrations has NOT yet been established. However, metal enrichment within these estuarine sediments may reflect a general degradation in overall environmental quality within the Pamlico River estuarine system.

Texasgulf, Inc. has a major NPDES permit to discharge waste water directly into the Pamlico River. When time came for the renewal of this permit some years ago, N.C. DEM considered conditions serious enough that they spent several years working with Texasgulf to redesign a water recycling system that would substantially decrease the contaminants discharged into the River. With the final approval of this new system, a new discharge permit was awarded during 1990.

The physical location of the Cherry Point facility on the Neuse River is analogous to the phosphate operations on the Pamlico River. A discharge of metal-bearing waste waters into the Neuse River will probably increase the trace metal concentration within the organic-rich mud sediments of the Neuse River similar to that which has already occurred in the Pamlico River. Dilution does NOT solve the pollution problem in an estuarine system dominated by chemically reactive sediments that can sequester and loosely bind trace metals within the biologically active surface sediments. The proposed increase in industrial (metal finishing) waste water discharge with increased effluent limitations for 7 toxic metals (Cd, Cr, Cu, Pb, Ni, Ag, and Zn) will continue to slowly degrade environmental quality within the estuarine system, only now on a larger scale. This is particularly true in light of previous studies done within Slocum Creek concerning the nature of the waste water discharge and the discharge history. A brief summary of some of the more important findings follows.

1. The NPDES permit (no. NC0003816) states that effluent from the 3.5 MGD waste water treatment system that will be discharged at the 001 outfall into the Neuse River can contain greater amounts of 7 toxic metals (Cd, Cr, Cu, Pb, Ni, Ag, and Zn) in the effluent than the present discharge into Slocum Creek. Table 40 outlines the amount of toxic metals that will be permitted for discharge into the Neuse River as compared to the present permit in Slocum Creek.

TABLE 40. Comparison of NPDES waste water discharge limits for major trace metals in the USMC Cherry Point main (001) outfall in the existing permit that presently discharges to upper Slocum Creek and the proposed permit to discharge to the Neuse River. Data are from the NPDES permit no. NC0003816.

METAL	SLOCUM CREEK PERMIT (existing)		NEUSE RIVER PERMIT (new)		INCREASE
	lbs/day max	lbs/yr total	lbs/day max	lbs/yr total	
Cd	0.133	48.5	3.62	500.1	10.3 X
Cr	0.534	194.9	14.57	3,281.4	16.8 X
Cu	11.6	2,608.7	17.75	3,974.9	1.5 X
Pb	0.667	243.5	3.62	821.3	3.4 X
Ni	1.334	486.9	15.06	4,558.9	9.4 X
Ag	1.45	294.6	2.25	459.9	1.6 X
Zn	10.3	2,130.1	13.69	2,832.4	1.3 X

2. On Nov. 3, 1988, the N.C. EMC issued a Special Order of Consent (SOC) to the USMC stating that they were out of compliance in effluent concentrations of cadmium, chromium, and zinc as well as several other items. As a direct result of the SOC, the USMC contracted C.T. Main, Inc. to prepare a report entitled Engineering Report for Sewage and Industrial Waste Treatment (1989). According to this report, industrial waste water is derived from work on aircraft, weapons systems, equipment and accessories and comes primarily from electroplating, conversion coating of aluminum, metal cleaning, stripping, and testing of engines. "Industrial waste water can be characterized by low concentrations of heavy metals such as cadmium, chromium, copper, lead, nickel and zinc. Also present are cyanide, high concentrations of free and emulsified fuels, oils and greases as well as moderate concentrations of phenolics and other toxic organics." The industrial waste water is treated first at the Industrial Waste Water Treatment Plant (IWTP) and is then further treated at the Sewage Treatment Plant (STP) with the treated effluent being discharged into Slocum Creek. Conclusions of this report include the following:
   a. The existing IWTP cannot comply with federal pretreatment standards or projected pretreatment requirements (based on the new NPDES permit) for Total Toxic Organics (TTO includes phenol, chromium, cadmium and possibly cyanide).

b. The existing STP cannot comply with the new NPDES permit limits for chromium, zinc, lead, nickel, cadmium, ammonia and BOD5 nor will it comply with the expected BOD5 or ammonia limit if the discharge is directed to the Neuse River.
c. The STP sludge is now classified as non-hazardous but will be classified as hazardous if the electroplating waste or other hazardous waste is pretreated at the IWTP before final treatment at the STP.
d. The report states that "comparison of the long term average effluent concentrations with the projected pretreatment requirements based on the new NPDES permit indicates that the chromium concentrations would have been excessive on all but one occasion and the phenol and cadmium concentrations would have been excessive on numerous occasions." "This indicates that the existing IWTP cannot comply with the federal pretreatment standards and the pretreatment requirements projected based on the new NPDES permit. This will require an increase in treatment efficiency for the IWTP which in turn requires IWTP equipment modifications." Analyses of industrial waste samples by the consulting company "indicate the necessity of more efficient treatment for metals such as chromium, cadmium, zinc, nickel and lead."
e. In addition, the report summarizes "a number of military construction projects at various stages of completion or planned in the near future" that will have an effect upon the composition of future discharges associated with the NPDES permit. These facilities include a new plating shop (project P-913) with an average industrial waste water flow of 5 million gallons per month, a blade/vane rework shop (project P-940) with almost 1 million gallons of waste water per month, and a cleaning shop (project P-917) that will contribute 1.3 million gallons of waste water per month to the IWTP.

3. Several studies have been done in conjunction with the USMC on the effects of metalliferous sediments on the biological community in Slocum Creek. These studies are inconclusive, but do suggest that various finfish and crabs in Slocum Creek have higher incidence of lesions and have bioaccumulated elevated levels of specific metals including Ag, Cd, Cr, Cu, Hg, Ni, Pb, and Zn (N.C. DEM, 1983; U.S. FWS, 1985; Gallagher and Di Giulio, 1989). In addition, a recent memo from the N.C. Dept. of Epidemiology (Nov., 1990) to the N.C. DEM stated that "fish fillet samples taken in Slocum Creek off Mill Creek...indicate elevated levels of copper, zinc, and lead."

<u>Cherry Point Area: Slocum Creek Conclusions and Recommendations</u>

The concentrations of trace elements, their distribution patterns, downstream decrease of all trace elements, and presence of noncontaminated sediments at the mouth of Slocum Creek, lead to the following conclusions.

1. Bottom sediments in the entire southern half of Slocum Creek are substantially contaminated with 9 trace elements and locally by 5 additional trace elements (Table 37).

a. Cobalt is the only one of the 15 trace elements considered in this study that is not enriched within Slocum Creek.
b. The general distribution pattern appears to reflect specific point sources where trace elements are either discharged or leak into the estuarine system.
c. There appears to be only local movement and redistribution of trace element contaminated sediments within Slocum Creek.
d. It does not appear that any contaminated sediments are presently being transported out of Slocum Creek and into the adjacent Neuse River. Sediment samples within the Neuse River generally support this latter conclusion.

2. A much more detailed sampling grid associated with each point source discharge is necessary to demonstrate without a question the source and timing of major contaminants into the estuary.
3. The U.S. Marine Corps at Cherry Point appears to be presently discharging substantial amounts of metals into the Slocum Creek and they plan to increase the metal loading with their new discharge permit into the Neuse River.
4. Based upon the present knowledge, it is not clear how much of the sediment contamination problem in Slocum Creek is relict and due to historic processes and how much is a product of modern processes.
5. Modern accumulation of metals is probably taking place in the surface sediments as a direct result of:
   a. ongoing discharges from the USMC NPDES permitted waste water treatment plant and
   b. surficial groundwater leachates from the numerous waste disposal sites adjacent to Slocum Creek.

It is our opinion that the presence of high concentrations of numerous trace metals in bottom sediments of Slocum Creek reflect a substantial impact upon the overall environmental quality of the Slocum Creek estuarine system. If this is true, permitting a relocation of a new discharge into the Neuse River and an increase in levels of metal discharges will lead to development of a large plume of substantial enrichment of potentially bioavailable metals around the discharge point. This enrichment will continue to lead towards the overall degradation of environmental quality within the main portion of the Neuse River estuarine system. It is our opinion that the State of North Carolina should take a similar approach to discharge permits in the Neuse River as taken with Texasgulf, Inc. in the Pamlico River. Discharge permits should require designing the most efficient treatment systems possible for discharging absolutely minimum amounts of toxic elements into "Public Trust Waters".

Cherry Point Area: Hancock Creek

Hancock Creek is bounded along the western perimeter by the Cherry Point Marine Corps Air Station and along the eastern perimeter by the Croatan National Forest (Fig. 23). Development by Cherry Point along the shoreline of Hancock Creek is considerably less than along Slocum Creek. Near the mouth of Hancock Creek there is a small marina for pleasure boats and a U.S. Navy dock facility. The heavily forested eastern shore lies mostly within the Croatan National Forest and is entirely undeveloped.

Core HCK-5 (Fig. 23) was lost in transit. None of the other five samples taken in Hancock Creek had levels of enrichment greater than 1.1 X, except for molybdenum and titanium. Three samples in upper Hancock Creek (HCK-1, 2, and 3 in Fig. 23) were slightly enriched in molybdenum (EF = 1.8, 1.5, and 1.7 X NRTM) and one sample (HCK-3) was slightly enriched in titanium (EF = 1.5 X NRTM). Sediments around the marina facilities at the mouth of the Creek are dominated by sands and consequently, no muds were sampled. Core HCK-6 was a mud sample obtained inside the mouth of Still Gut. However, no trace elements commonly associated with marinas (copper, lead, and zinc) were enriched in this core. Table 41 compares the low concentrations of trace elements in Hancock Creek to concentrations in Beard and Goose Creeks, which are also fairly pristine tributary estuaries.

Goose and Beard Creeks

Goose and Beard Creeks are small, south-flowing tributaries to the inner Neuse River (Fig. 21). Much of the shoreline of both creeks are fringed by Juncus marsh and upland forest with some bordering farmland and minor low-density residential development. One NPDES permit exists within each creek for waste discharge from fish processing plants located on the creek banks. The majority of shoreline is uninhabited and undisturbed.

Two samples were obtained in Goose Creek and three samples in Beard Creek (Fig. 21). Concentrations of trace elements were generally at or around the Neuse River trimmed mean at all sites, except two samples in Beard Creek had enriched concentrations of molybdenum (EF up to 2.2 X NRTM), two samples in Goose Creek were slightly enriched in molybdenum (EF up to 1.7 X NRTM), and one sample in Goose Creek was slightly enriched in nickel (EF = 1.5 X NRTM) (Table 41).

In summary, Goose, Beard and Hancock Creeks are characterized by the following conditions.

1. Minimal levels of small scale development are scattered around the estuarine perimeter with vast portions of the shoreline occurring in a forested condition.
2. Concentrations of all trace elements, except for molybdenum and locally nickel and tin, are at or around the Neuse River trimmed mean at all sites.
3. No obvious sources exist to explain the minor enrichment that does occur in molybdenum, nickel, and tin; consequently, it is assumed that this reflects natural variations and is not related to anthropogenic contributions.
4. Goose, Beard and Hancock Creeks are considered to be fairly pristine with respect to heavy metal contamination within the sediments (Table 41).

Fairfield Harbor: Northwest and Upper Broad Creeks

Fairfield Harbor is a moderate-density residential community developed along the banks of Northwest Creek and extending eastward to the west side of Upper Broad Creek (Fig. 21). It represents a recently and extensively man-modified estuarine system in which the geologic, hydrologic, and biologic make-up has been dramatically altered. During the early stages of this development (early 1970's), there was extensive dredging and filling to create a network of finger canals and a boat-basin harbor. These finger canals were dredged up a small, unnamed tributary creek and into the adjacent upland areas. Wetlands were filled and the entire region bulkheaded to create extensive waterfront property. Consequently, all organic-rich mud that is now accumulating within this sand-bottomed harbor is very recent. Homes now surround the basin with individual boat docks and manicured lawns and gardens that generally extend to the bulkheaded basin edge with no natural fringing vegetation zones.

TABLE 41. Mean concentrations and maximum enrichment factors of 15 trace elements in surface sediments from Goose, Beard and Hancock Creeks, three uncontaminated tributaries to the Inner Neuse River. Elements with underlined enrichment factors are substantially enriched (EF = or > 2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold are slightly enriched (EF > 1.5X to <2X NRTM).

TRACE ELEMENTS	GOOSE CREEK (n = 2) MEAN CONC. (µg/g or ppm)	MAX EF	BEARD CREEK (n = 3) MEAN CONC. (µg/g or ppm)	MAX EF	HANCOCK CREEK (n = 5) MEAN CONC. (µg/g or ppm)	MAX EF
As *	5.7	1.4	3.7	0.8	5.6	1.1
Cd	0.35	0.6	0.23	0.4	0.38	0.6
Co	5.3	1.4	4.7	1.3	3.6	0.9
Cr	9.3	0.8	6.9	0.6	8.9	0.8
Cu	11.2	0.8	9.1	0.7	9.4	0.6
Hg	0.04	0.3	0.06	0.6	0.05	0.5
Mn	220.	1.1	112.	0.6	172.	0.9
Mo	0.9	1.7	0.8	2.2	0.54	1.8
Ni	4.6	1.5	2.7	0.9	2.7	0.9
P	440.	0.7	345.	0.5	578.	0.8
Pb	22.9	0.9	19.5	0.8	23.6	1.0
Sn *	22.0	1.4	14.8	1.2	20.8	1.5
Ti	25.3	1.1	21.7	0.9	26.3	1.1
V	21.4	1.3	13.5	0.9	16.5	1.0
Zn	66.1	1.0	43.9	0.6	42.7	0.6

* analyses with poor reproducibility, hence somewhat low reliability.

One sample was collected from within the dredged portion of the unnamed creek, adjacent to the main urban development within the Fairfield Harbor complex (FFD-1 in Fig. 21). Molybdenum (EF = 4.2 X NRTM), copper (EF = 3.4 X NRTM), and manganese (EF = 2.3 X NRTM) are substantially enriched above the Neuse River trimmed mean. Three other trace elements (As = 1.6 X, P = 1.7 X, and V = 1.7 X NRTM) are slightly enriched in the surface sediments compared to the Neuse River trimmed mean.

A large marina facility was dredged near the mouth of Northwest Creek with slips, fuel dock, and support facilities. One sample collected off this relatively new marina (FFD-3 in Fig. 21) shows a slight amount of enrichment of copper (EF = 1.9 X NRTM) and molybdenum (EF = 1.8 X NRTM). Another marina is located east of the community at the mouth of Upper Broad Creek. Fairfield Harbor has an NPDES permit for a municipal waste water treatment plant that discharges up to 100,000 gallons of treated waste water per day into Broad Creek. The one sample collected off the relatively new WWTP (BROD-1 in Fig. 21) does not show any enrichment of trace elements.

Table 42 compares trace element concentrations between 3 deep samples (from 21 to 30 cm below the surface sediments) and 3 surface sediments at Fairfield Harbor. Fourteen of 15 elements are substantially enriched in the surface sediments (EF = > 2 X the mean concentration of the deep sediments) including those elements commonly associated with marinas (Cu = 29.4 X, Zn = 20.6 X, and Pb = 14.4 X) and fertilizer (P = 12.0 X). Since mercury was not analyzed in the three deep samples, the surface enrichment is unknown. The substantial upcore increase in concentration of these 14 trace elements is interpreted to represent the direct impact of recent development of large marinas and an extensive urban environment without natural vegetation fringes around the manicured lawns and gardens.

TABLE 42. Surface enrichment of 15 trace elements resulting from the comparison of mean concentrations in deep sediments (ave. depth = 26 cm) with mean concentrations in surface sediments from Fairfield Harbor: Northwest Creek. The right-hand column presents the surface enrichment over the deep samples for each element. Elements with underlined maximum enrichment factors in the surface sediments are substantially enriched relative to the Neuse River trimmed mean (EF = or >2X NRTM), whereas those in bold print are slightly enriched (EF = >1.5X to <2X NRTM).

TRACE ELEMENTS	DEEP SAMPLES (n = 3) MEAN CONC. (μg/g or ppm)	SURFACE SAMPLES (n = 3) MEAN CONC. (μg/g or ppm)	MAX EF	SURFACE ENRICH-MENT
FAIRFIELD HARBOR: NORTHWEST CREEK				
Cd	0.0	0.47	0.6	100 X
Cu	1.4	41.2	3.4	29.4 X
Zn	4.9	101.	1.3	20.6 X
Mn	25.5	436.	2.3	17.1 X
Ni	0.4	6.3	1.4	15.8 X
Pb	2.2	31.8	0.9	14.4 X
P	87.7	1055.	1.7	12.0 X
Cr	1.4	15.5	1.0	11.1 X
V	3.4	29.4	1.7	8.6 X
Sn *	2.9	24.7	1.4	8.5 X
Co	0.9	5.8	1.3	6.4 X
As *	2.1	7.3	1.6	3.5 X
Ti	15.8	42.5	1.5	2.7 X
Mo	0.5	1.3	4.2	2.6 X
Hg	---	0.10	0.8	?

* analyses have poor reproducibility, hence somewhat low reliability.

Outer Neuse River Estuarine Zone

Outer Neuse River: East of Minnesott Beach

The outer Neuse River extends eastward from Minnesott Beach-Cherry Point areas to the mouth of the Neuse River at Pamlico Sound (Figs. 5 and 9). East of Minnesott Beach the estuary makes a right angle turn to a northeast-southwest orientation and becomes a much wider, somewhat deeper, and much more saline estuary. Both the north and south shorelines of the outer Neuse River are characterized by undeveloped, low-sediment bank shorelines backed by lowland pine forests.

Small tributaries extend north off the trunk estuary and include, Dawson Creek, the Oriental Creek complex, Broad and Brown Creeks, and Bay River on the eastern end (Fig. 5). Much larger estuarine tributaries extend southward off the southern side of the trunk estuary and include Clubfoot Creek, Adams Creek, South River, and Turnigan Bay (Fig. 5). The tributaries are generally bordered by fringing Juncus marsh in the outer estuarine regions, swamp forest in the upper reaches of the tributaries, and low-sediment bank shorelines along the interstream divides.

The largest urban development is in the Oriental area with an old commercial fishing harbor, a small waste water treatment plant, numerous boat yards, and extensive new marina development for recreational craft. Bayboro, Vandemere, and Stonewall are small towns located on the Bay River and Whortonville and Pamlico are very small towns located on Broad Creek. The remainder of the area is largely undeveloped forest land with minor and scattered areas of very low-density residential development. South River drains an extensive area of intensive agricultural land that is very low and extensively ditched.

Most existing industrial development along the outer portions of the Neuse River is associated with either forestry, agriculture, or seafood processing. There are about 16 NPDES permits within the outer Neuse River area that discharge up to 376,000 gallons of waste water per day into the Neuse River estuarine system (App. C). Most of these are in the Oriental, Bayboro, and Vandemere areas and include small municipal and school waste water treatment plants or seafood processing plants. Urban development pressures are extensive throughout this area and will probably continue to expand in the future, particularly for tourism, retirement, second homes, and recreation.

Figures 34 and 35 and Appendix A present the locations of all sediment samples collected within the Outer Neuse River Area and utilized for the following discussion. The sediments throughout the outer Neuse River are generally very uniform with low concentrations of 10 of the 15 trace elements considered. These 10 elements have concentrations that are below or just slightly above the trimmed mean for the Neuse River (Table 43). Table 44 lists 5 elements that are slightly to substantially enriched at multiple sample sites in the outer Neuse River and do not follow the distribution patterns of the other 10 trace elements (Table 45).

Table 45 shows the changing pattern of mean concentrations for each of 15 trace elements down the trunk of the Neuse River estuary from the transition zone at the western side of the estuary to the mouth at Pamlico Sound (Fig. 5). These data demonstrate that 10 elements have a general systematic decrease in mean concentration in a downstream direction and away

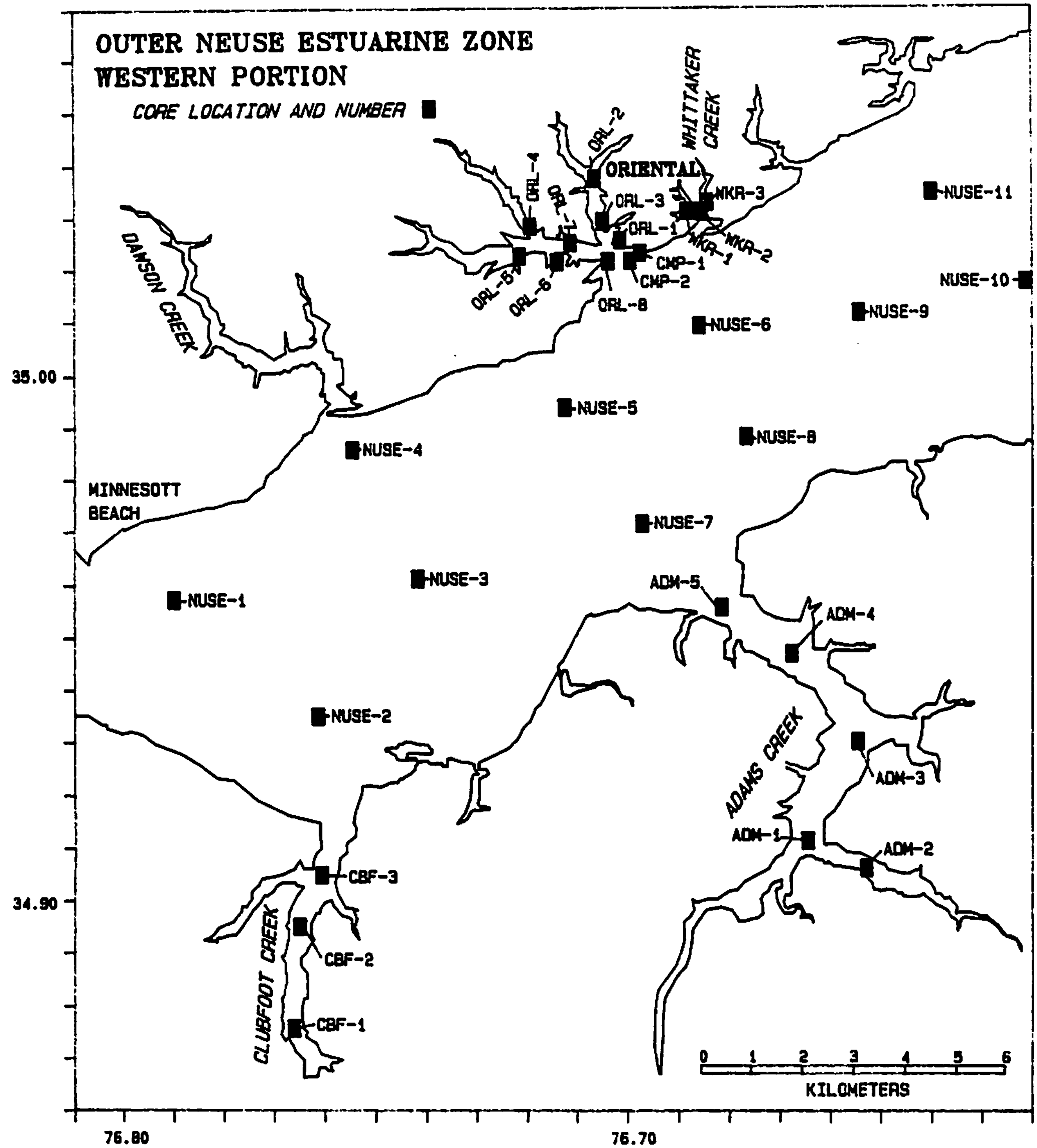

FIGURE 34. Sample location map of the Outer Neuse River Area: Western Portion.

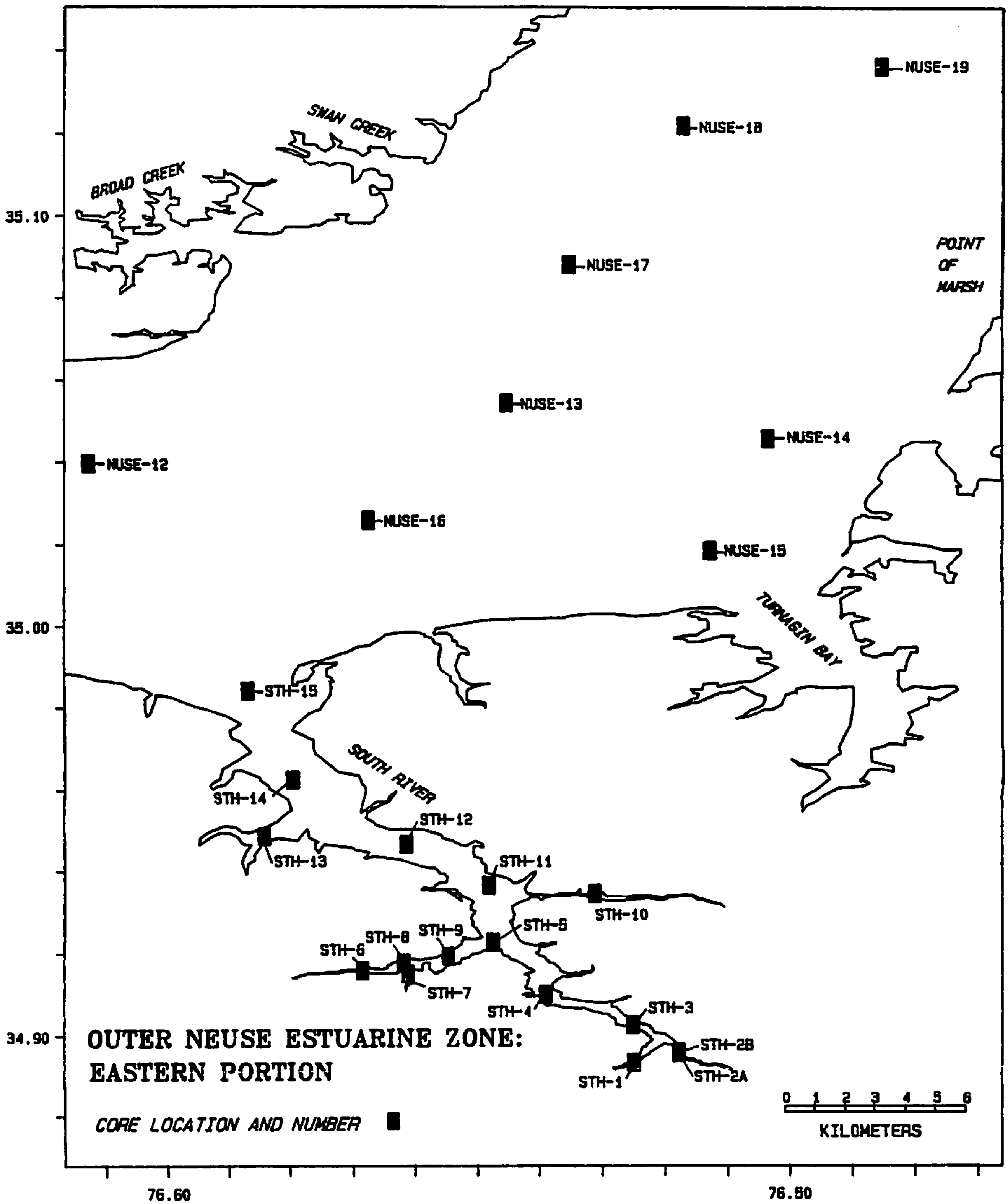

FIGURE 35. Sample location map of the Outer Neuse River Area: Eastern Portion.

TABLE 43. Concentrations and enrichment factors of 15 trace elements in surface sediments in the outer Neuse River estuarine area. Elements with underlined enrichment factors are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold type are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	N	CONCENTRATIONS (μg/g or ppm) MEAN	MINIMUM	MAXIMUM	ENRICHMENT FACTORS MEAN	MAXIMUM
OUTER NEUSE RIVER: EAST OF MINNESOTT BEACH						
Mn	19	442.	88.4	1029.	1.5	3.6
As *	19	8.3	1.1	16.7	1.4	2.8
Ti	19	47.8	22.8	74.3	1.5	2.3
Mo	19	0.47	0.1	1.2	0.9	2.2
V	19	27.2	6.3	38.8	1.2	1.7
Sn *	19	19.0	2.7	32.3	0.9	1.5
Co	19	3.6	1.3	6.0	0.8	1.3
Ni	19	2.9	0.6	6.1	0.6	1.3
Cr	19	12.2	2.9	19.7	0.7	1.2
Pb	19	20.8	5.2	38.9	0.6	1.1
Zn	19	51.4	10.6	98.2	0.5	1.0
Cd	19	0.28	0.0	0.7	0.4	0.9
Cu	19	7.8	2.0	16.6	0.4	0.9
Hg	12	0.09	0.05	0.13	0.6	0.9
P	19	320.	26.2	627.	0.4	0.7

* analyses have poor reproducibility, hence somewhat less reliability.

TABLE 44. Trace metals that are slightly to substantially enriched in multiple sample sites from a total of 19 sites in the outer Neuse River.

TRACE ELEMENT	SUBSTANTIALLY ENRICHED (EF = > 2 X NRTM) No. of Sites	SLIGHTLY ENRICHED (EF = > 1.5 X and > 2.0 X NRTM) No. of Sites	TOTAL ENRICHED SITES
OUTER NEUSE RIVER: EAST OF MINNESOTT BEACH			
Manganese	4	7	11
Titanium	3	6	9
Arsenic	6	1	7
Vanadium	0	6	6
Molybdenum	1	2	3

TABLE 45. Summary of mean concentrations of 15 trace elements as they change from the head of the Neuse River trunk estuary (Transition Zone: New Bern--Bridgeton Area West) systematically downstream to the River mouth (Outer Neuse River). The highest mean concentration of each element is underlined and the lowest mean concentration is in bold print.

TRACE ELEMENTS	MEAN CONCENTRATIONS (μg/g or ppm)			
	TRANSITION ZONE NEW BERN--BRIDGETON AREA		INNER NEUSE RIVER	OUTER NEUSE RIVER
	WEST n = 30	EAST n = 12	n = 40	n = 19
ELEMENTS THAT DECREASE IN CONCENTRATION DOWNSTREAM				
Hg	0.2	0.2	0.2	0.1
Co	6.9	6.8	5.1	3.6
Pb	43.2	43.4	31.7	20.8
Cd	1.8	0.7	0.5	0.3
Cr	28.8	20.0	16.0	12.2
Cu	38.2	20.8	13.6	7.8
Ni	37.0	6.1	4.4	2.9
P	1450.	1110.	601.	320.
Sn *	47.3	22.7	28.1	19.0
Zn	149.	121.	79.5	51.4
ELEMENTS THAT INCREASE IN CONCENTRATION DOWNSTREAM				
Mn	323.	331.	388.	442.
Ti	33.7	34.3	37.3	47.8
ELEMENTS WITH AN IRREGULAR DISTRIBUTION PATTERN				
As *	8.2	4.9	6.2	8.3
Mo	0.6	0.4	0.6	0.5
V	24.3	28.6	30.3	27.2

* analyses have poor reproducibility, hence somewhat less reliability.

from the main source areas. Two elements (manganese and titanium) display a systematic increase in mean concentration downstream, while 3 elements (arsenic, molybdenum, and vanadium) have an irregular distribution pattern. Arsenic is the only one of these metals that is included in the EPA list of priority pollutant metals. It should be pointed out that the relative trends in arsenic values are real but absolute values have poor reproducibility, hence somewhat less reliability due to limitations of the analytical technique.

The general downstream decrease in mean concentration of 10 trace elements, demonstrated in Table 45, primarily results from 3 important interacting factors.

1. Most of the trace element input into the estuarine system is coming from major point sources that occur within the very high-density and industrialized regions in the upstream portion of the drainage basin such as Kinston and Raleigh.
2. The largest number of permitted point source discharges directly into the estuarine system occur around New Bern--Bridgeton area at the western edge of the flooded Neuse River estuarine system.
3. These elements are being concentrated within the estuarine transition zone which is generally the location of the estuarine turbidity maxima. Fresh river water, containing its load of dissolved and diluted elements, enters the estuary with a rapidly changing salinity gradient and a major change in composition of bottom sediments. Rapid changes in water chemistry cause suspended clays and organic matter to flocculate and chemically sequester the dissolved trace elements from the water column, depositing and concentrating them within the zone of estuarine turbidity maxima.

Two lines of evidence support the location of the Neuse River turbidity maxima within this transition zone (Fig. 5). First, this zone represents a major shift from sand-dominated bottom sediments in the fluvial portion of the River to organic-rich mud bottom sediments which begins at the western edge of the transition zone. Second, the general downstream decrease in most trace elements as demonstrated in Table 45, also supports this interpretation.

Thus, the distribution patterns for the five elements (Mn, Ti, As, V, and Mo) do not appear to be directly related to known point source inputs. Rather, their distribution is probably due to specific chemical characteristics and solubilities of these elements; they are probably being transported in solution farther from their point sources into the saltier portions of the estuarine system.

<u>Adams Creek</u>

Adams Creek connects the outer Neuse River to the Atlantic Ocean via the Adams Creek Canal, Newport River estuary and Beaufort Inlet. Water flow between the Neuse and Newport Rivers is bidirectional and is a function of the interaction between astronomical tides in the Newport River and wind tides in the Neuse River. Adams Creek is part of the Intracoastal Waterway and contains a narrow, dredged navigation channel down the axis from the Neuse River to the mouth of Adams Creek Canal. Heavy commercial and recreational boat traffic and trawling in this estuary resuspends bottom sediments and generally keeps creek waters turbid. No NPDES permitted discharges are located in Adams Creek.

Five stations were sampled in Adams Creek and associated tributaries (Fig. 34). Table 46 demonstrates that concentrations of all trace elements average well below or around the Neuse River trimmed mean. For example, maximum enrichment factors for copper (0.5 X), lead (0.5 X), and zinc (0.5 X), major metals often enriched in sediments around marinas and boat yards, show concentrations well below the Neuse River trimmed mean. This suggests that movement of boats and ships alone does not lead to metal enrichment. Concentrations of all trace elements are fairly uniform throughout the Adams Creek area, both laterally and vertically suggesting that Adams Creek is fairly pristine with respect to trace metal contamination.

TABLE 46. Summary of mean and maximum enrichment factors for 15 trace elements in surface sediments from Adams and Clubfoot Creeks, two uncontaminated tributaries in the outer Neuse River area. Enrichment factors in bold print are slightly enriched (EF >1.5X to <2X NRTM) relative to the Neuse River trimmed mean.

	ADAMS CREEK		CLUBFOOT CREEK	
TRACE ELEMENTS	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR
As *	1.1	1.6	0.5	1.0
Cd	0.3	0.4	0.4	0.4
Co	0.7	0.9	0.7	0.7
Cr	0.7	0.8	0.8	0.9
Cu	0.4	0.5	0.6	0.7
Hg	0.3	0.3	0.6	0.7
Mn	0.7	1.1	0.6	0.8
Mo	1.0	1.5	0.6	0.7
Ni	0.7	0.9	0.6	0.7
P	0.4	0.5	0.6	0.8
Pb	0.4	0.5	0.7	0.7
Sn *	0.7	1.0	1.1	1.2
Ti	1.3	1.5	1.0	1.1
V	0.8	1.1	0.9	0.9
Zn	0.5	0.5	0.6	0.7

* analyses with poor reproducibility, hence somewhat less reliability.

Clubfoot Creek

Clubfoot Creek is a tributary with only low-density residential and agricultural development along the shores. No NPDES permitted discharges occur in the Clubfoot Creek drainage basin. Concentrations of all 15 trace elements in the surface sediments from 3 sample stations (Fig. 34) in Clubfoot Creek are at or below the Neuse River trimmed mean (Table 46). The sediments in Clubfoot Creek are the least contaminated with respect to the trace elements of the entire Neuse River estuarine system. This creek is believed to more closely approximate the pre-man conditions within the estuarine system than any other area.

Bay River

The Bay River and its tributaries drain the swamp and lowland forest areas in the vicinity of Bayboro, Vandemere and Stonewall, then the River joins the outer Neuse River estuary at the southwestern edge of Pamlico Sound. Development along the shores of the Bay River is sparse except in areas immediately surrounding the various towns. Low-sediment bank shorelines are fringed with Juncus marshes on the outer regions and swamp forests on the inner regions. Eight NPDES permits discharge up to 246,000 gallons of waste water per day from seafood processing plants and municipal waste water treatment plants located in the Bayboro and Vandemere areas.

Two stations were sampled near the mouth of the Bay River (Fig. 3). Concentrations of 11 trace elements at these locations are around the Neuse River trimmed mean (Table 47). Arsenic (1.8 X), manganese (1.5 X), molybdenum (1.7 X and 1.5 X), and titanium (1.8 X) are slightly enriched above the Neuse River trimmed mean. In only one sample, titanium (2.2 X) is substantially enriched over the Neuse River trimmed mean. All four of these metals show increased concentrations, or at least irregular distribution patterns, seaward down the Neuse River estuarine system (Table 45). No samples were collected in the upper reaches of the Bay River which has a fairly high level of anthropogenic influence. It is predicted that the concentrations of the trace elements will systematically increase in the surface sediments in the upstream direction to levels comparable to those in the Oriental harbor.

TABLE 47. Summary of mean and maximum enrichment factors for 15 trace elements in surface sediments from Bay and South Rivers, two tributaries in the outer Neuse River estuarine area. Enrichment factors that are underlined are substantially enriched relative to the Neuse River trimmed mean (EF = >2X NRTM), whereas those in bold print are slightly enriched (EF = >1.5X to <2X NRTM).

TRACE ELEMENTS	BAY RIVER (n=2)		SOUTH RIVER (n=4) NORTHERN PORTION		SOUTH RIVER (n=13) SOUTHERN PORTION	
	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR
As *	1.5	1.8	0.5	1.1	0.7	1.5
Cd	0.3	0.4	0.3	0.4	0.3	0.6
Co	1.0	1.2	0.5	0.6	0.5	1.4
Cr	0.8	0.9	0.5	0.6	0.5	0.6
Cu	0.5	0.5	0.4	0.6	0.5	0.8
Hg	0.3	0.3	0.8	0.9	0.7	1.1
Mn	1.5	1.5	0.5	0.7	0.5	0.7
Mo	1.6	1.7	0.9	1.7	1.0	2.2
Ni	0.9	0.9	0.4	0.6	0.6	0.9
P	0.2	0.3	0.3	0.4	0.7	1.1
Pb	0.7	0.7	0.4	0.6	0.5	2.0
Sn *	0.7	0.8	1.0	1.4	1.0	1.5
Ti	2.0	2.2	1.0	1.2	1.0	1.3
V	1.3	1.4	0.7	0.9	0.7	1.0
Zn	0.5	0.5	0.4	0.6	0.4	1.1

* analyses with poor reproducibility, hence somewhat less reliability.

South River

South River is near the mouth of the Neuse River and drains extensive areas of very low and flat swamp forest, pocosin and marsh terrains. Much of the shoreline consists of low-sediment banks that are fringed by Juncus marsh. Residential development is limited to several small villages located near the mouth of the river. No NPDES permitted discharges are located in the South River basin. However, most of the land around the inner or southern portions of South River has been cleared and drained for intensive agriculture with fringing zones of vegetation between the farmland and the estuary. Drainage from cultivated fields is directed through an extensive system of canals and discharged into South River and the associated tributaries such as Southwest Creek.

Prior to the 1974 agricultural development in the South River area, Berryhill et al. (1972) analyzed 25 surface samples from throughout South River for total concentration of 10 heavy metals. No anomalous concentrations of any heavy metals that might have environmental significance were found. At this time, the South River drained dominantly pine, open grassland, pocosin, and swamp forest. In 1974, large-scale land clearing and drainage ditching began for conversion into farmland around much of the southern portion of South River (Kirby-Smith and Barber, 1979). Whaling et al. (1977) came in after farming was just beginning and analyzed the upper 3 cm of surface sediment from 6 sites within the southern portion of South River. All prior analyses of total metals found concentrations around or below the trimmed mean values for the Neuse River of the present report, with the exception of mercury. The total mercury of Whaling et al. (1977) was only slightly higher than our values.

In the present study, 15 sites were sampled throughout South River (Fig. 35) in order to evaluate the potential impact of intensive agriculture upon heavy metal sediment contamination within the estuarine system. These samples have been divided into two categories in Table 47: the northern portion (containing samples STH-12 through STH-15 in Fig. 35) and the southern portion (containing samples STH-1 through STH-11 in Fig. 35). The southern portion contains the intensive agricultural areas, whereas the northern area is dominantly forest land.

Table 47 demonstrates that 11 of the trace elements in the surface sediments of South River occur in concentrations that are around or below the Neuse River trimmed mean. A few samples have slightly enriched concentrations of arsenic (1.5 X in STH-10), tin (1.5 X in STH-7), and molybdenum (1.8 X in STH-2A, 1.7 X in STH-14). Two samples have substantially enriched levels of molybdenum (2.2 X in STH-7 and 2.0 X in STH-10) and one sample has substantial concentrations of lead (2.0 X in STH-3) (Fig. 35). All enriched samples occur in sediments either in Southwest Creek or in the southern portion of South River dominated by large-scale agricultural development which is probably the source of this very low-level metal enrichment.

Oriental Area

Oriental is a small urban area (Figs. 9, 34, and 36) that is undergoing very rapid growth and development. It is characterized by increased rates of construction, road and parking lot pavement, small industries and growth pressure on a small waste water treatment plant. Consequently, the trace

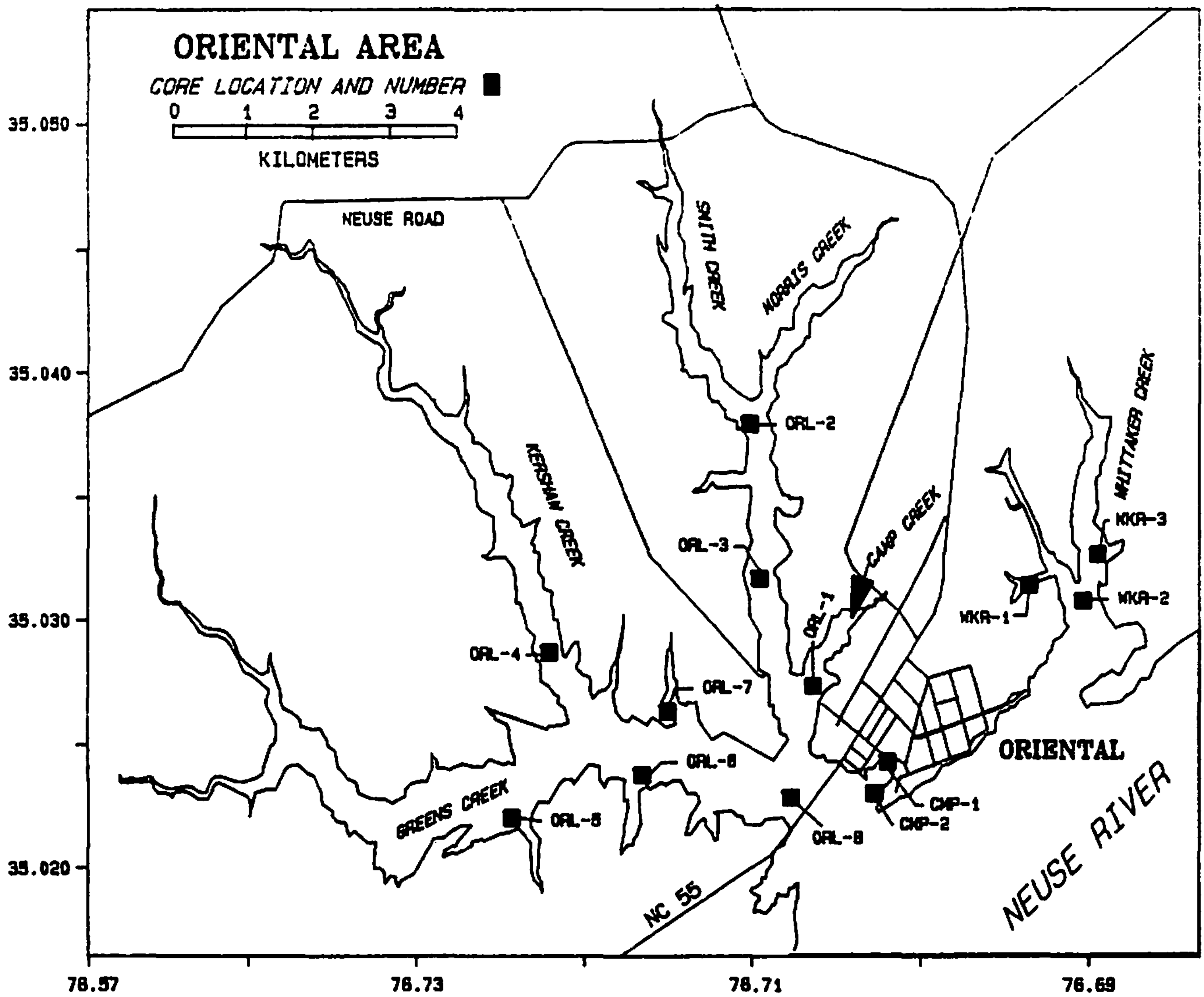

FIGURE 36. Sample location map for the Oriental Area.

element contamination within the estuarine sediments around Oriental reflects an intermediate level of anthropogenic influence. The analytical results and associated discussion for the Oriental area have been divided into 3 regions (Fig. 36) as follows:

1. Oriental harbor area (CMP-1, CMP-2, and ORL-1);
2. Adjacent tributary creeks to the west of Oriental including Smith, Kershaw, and Greens Creeks (ORL-2 through ORL-8); and
3. Whittaker Creek (WKR-1 through WKR-3) located along the eastern perimeter of Oriental.

Oriental Harbor. The Oriental harbor was dredged from an existing creek, bulkheaded and jettied to form a semi-enclosed basin. The small harbor contains two large seafood packing houses, several commercial and municipal boat docks, and small marinas. Many streets and parking lots in the surrounding town drain into the harbor. The Oriental waste water treatment plant is located on the northwest side of Oriental and discharges up to 100,000 gallons of waste water per day into Camp Creek (Fig. 36).

Oriental harbor sediments are substantially enriched in copper and zinc, with one sample being enriched in mercury (Table 48). Figure 37 indicates that all samples collected in the harbor area were substantially enriched in copper (EF from 3.9 X to 9.6 X NRTM), while zinc enrichment was slightly less (EF from 1.6 X to 2.9 X NRTM), and one sample was enriched in mercury (EF = 2.2 X NRTM). The highest level of enrichment occurs in the inner portion of the harbor (CMP-1 in Fig. 36) and decreases towards the harbor entrance (CMP-2). The sample off the waste water treatment plant (ORL-1 in Fig. 36) is only substantially enriched in copper (EF = 4.2 X NRTM).

Oriental Area Creeks. A network of tributaries drain the area immediately west and northwest of Oriental and includes Smith, Kershaw, and Green Creeks (Fig. 36). Low- to moderate-density residential development occurs adjacent to the creeks closest to Oriental while the creeks further west are relatively undeveloped with the exception of small-scale agriculture. This pattern is beginning to change as large real estate developments and marinas expand into this entire region.

Table 48 indicates that molybdenum and tin (EF = 2.4 X NRTM and 2.1 X NRTM, respectively in ORL-4) are the only trace elements that are substantially enriched with respect to the Neuse River trimmed mean. One sample each contains slightly enriched levels of copper (EF = 1.6 X NRTM in ORL-7) and arsenic (1.5 X NRTM in ORL-3). ORL-3 was sampled upstream from the Oriental WWTP (Fig. 36), ORL-7 was adjacent to an old, small marina in a tributary to Greens Creek (Fig. 36), and ORL-4 was adjacent to a marina in Kershaw Creek.

Whittaker Creek. Low density residential development and several very large, but relatively new marina complexes are located in the small tributaries on the east side of Oriental (Fig. 36). Two boat yards with extensive dock facilities occur along the perimeter and within Whittaker Creek and its branches. Much of the western shoreline has been dredged and partially bulkheaded.

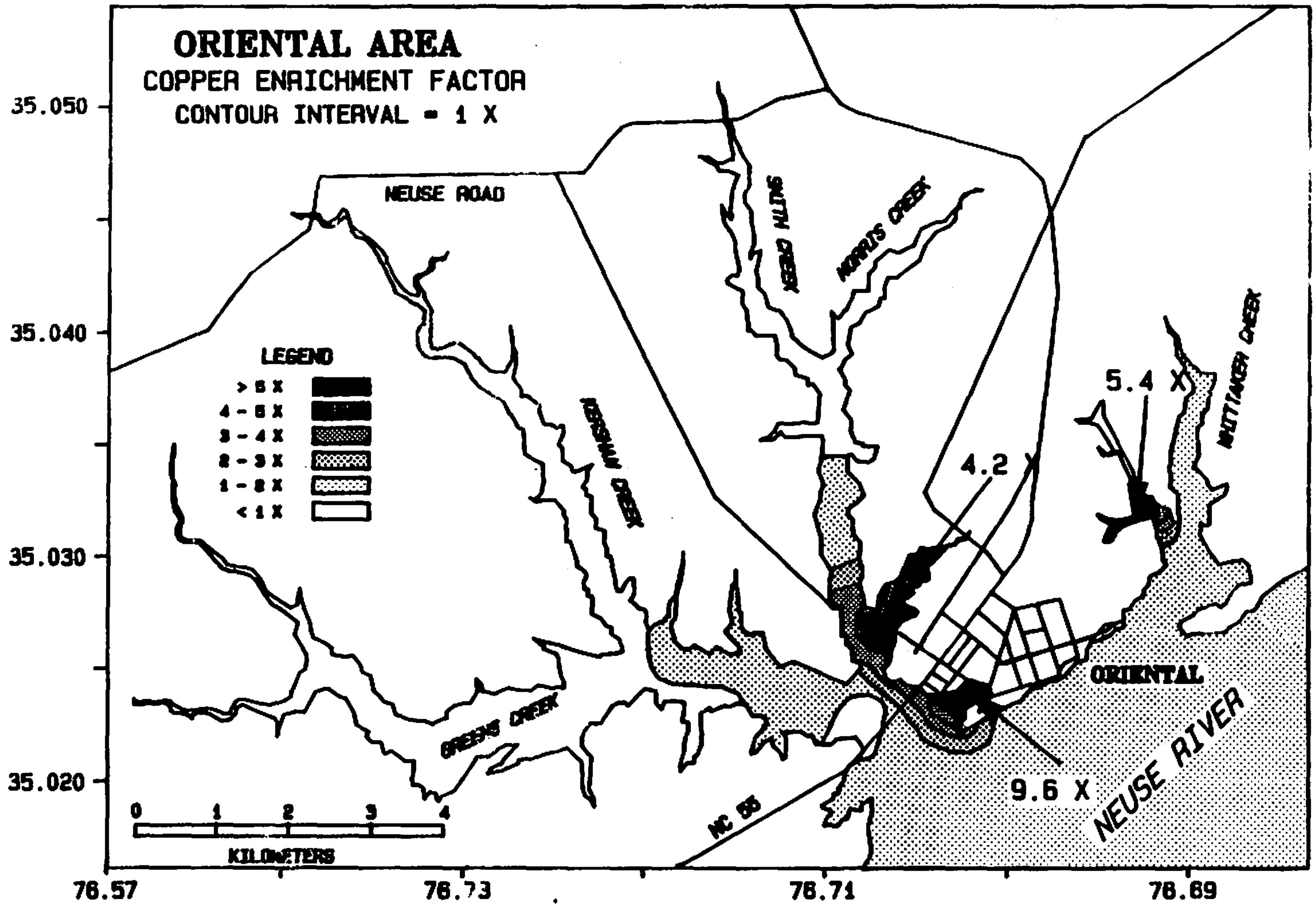

FIGURE 37. Schematic contour map of the copper enrichment factors in the Oriental Area. This map shows very general patterns of changing enrichment factors based upon computer contouring techniques.

TABLE 48. Summary of mean and maximum enrichment factors for 15 trace elements in surface sediments in the Oriental area. This area includes the Oriental harbor, Oriental creeks (Smith, Kershaw, and Greens Creeks) and Whittaker Creek, all tributaries to the outer Neuse River estuarine area. Enrichment factors that are underlined are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean, whereas those in bold print are slightly enriched (EF >1.5X to <2X NRTM).

TRACE ELEMENTS	ORIENTAL CREEKS (n = 7)		ORIENTAL HARBOR (n = 3)		WHITTAKER CREEKS (n = 3)	
	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR	MEAN ENRICH FACTOR	MAXIMUM ENRICH FACTOR
As *	0.8	1.5	1.1	1.2	1.1	1.9
Cd	0.2	0.4	0.4	0.5	0.1	0.3
Co	0.6	0.7	0.7	0.8	0.5	0.7
Cr	0.7	0.8	0.7	0.8	0.6	0.7
Cu	0.9	1.6	5.9	9.6	2.8	5.4
Hg	0.6	0.8	1.3	2.2	---	---
Mn	0.5	0.5	0.8	1.2	0.5	0.8
Mo	0.9	2.4	0.9	1.1	0.6	0.9
Ni	0.5	0.7	0.6	0.6	0.4	0.5
P	0.3	0.3	0.7	0.9	0.2	0.4
Pb	0.6	0.8	1.1	1.4	0.4	0.6
Sn *	0.9	2.1	0.7	0.9	0.7	0.9
Ti	1.0	1.1	1.3	1.4	1.0	1.4
V	0.8	1.0	0.8	1.0	0.8	1.2
Zn	0.6	0.8	1.8	2.9	0.5	0.7

* analyses with poor reproducibility, hence somewhat less reliability.

Figure 37 and Table 48 indicate that substantially enriched levels of copper (EF = 5.4 X NRTM in WKR-1) occur in sediments collected in the dredged canal off of the two boat yards. The sample site adjacent to the dock facilities (WKR-3) was slightly enriched in copper (EF = 1.8 X NRTM in WKR-3). The sample site adjacent to the fuel dock was also slightly enriched in arsenic (EF = 1.9 X NRTM in WKR-2).

Marina Summary

Many news articles have recently appeared in various North Carolina newspapers concerning a study released by the N.C. DEM (1990) entitled "North Carolina Coastal Marinas: Water Quality Assessment." This report represents a sound scientific study and the beginning of an important long-term assessment. However, due to the limited nature of this study, the conclusions pertaining to effects of marinas upon environmental quality are potentially misleading.

The DEM report clearly states that it analyzed only the water column for toxic metal contamination and not the sediments. However, at the concentration levels that toxic metals occur within the water column in and around marinas, they will generally NOT be detected by the most frequently applied analytical procedures. However, this does not mean that toxic metal contamination is absent or that it is an unimportant factor in determining water quality associated with the North Carolina marinas.

Due to their mineralogy and chemistry as previously discussed, organic-rich mud bottom sediments occurring within most marina sites, can sequester trace elements from very low concentrations within the water column. Most of these sequestered metals are loosely bound to the organic-rich mud sediment and therefore, potentiall available to shellfish and filter-feeding organisms living in these sediments.

For example, copper paint is used on the bottom of boats specifically to eliminate fouling by benthic organisms. This paint does not all stay on the boats as demonstrated by the never-ending need for hauling and repainting boat bottoms. Copper, whether it is on the boat bottoms or in the sediments below and around the marinas, is toxic to benthic organisms (Long and Morgan, 1990). The other two metals that are commonly enriched in marina sediments are lead and zinc; both are also used extensively in boats and around marinas. All 3 of these metals, when they occur at elevated levels, are potentially toxic to both marine organisms (Long and Morgan, 1990).

The present Neuse River study has evaluated sediments associated with marinas throughout the estuarine system. These data suggest that marinas can have substantial impacts upon sediment quality within the North Carolina estuarine system. Table 49 and Figure 38 summarize the results for 6 marinas within the Neuse River estuarine system. All 6 marinas have surface sediments containing substantially high concentrations of copper with maximum enrichment factors that range from 3.8 X to 14.3 X the Neuse River trimmed mean. Four marinas have substantially high concentrations of zinc with maximum enrichment factors up to 11.6 X the NRTM, while 3 marinas have enrichment factors of lead up to 6.9 X the NRTM. Also, preliminary evaluation of these data suggest that there are correlations between amount of metal enrichment and age, size, and type of marina.

It is our opinion that the presence of high concentrations of metals in bottom sediments in and around marinas can have substantial negative effects upon overall environmental quality, upon associated marine organisms, and the viability of the estuarine ecosystem. Consequently, a strong set of regulations should be established and maintained for citing and operating marinas within the North Carolina estuarine system, particularly within areas designated as Outstanding Resource Waters.

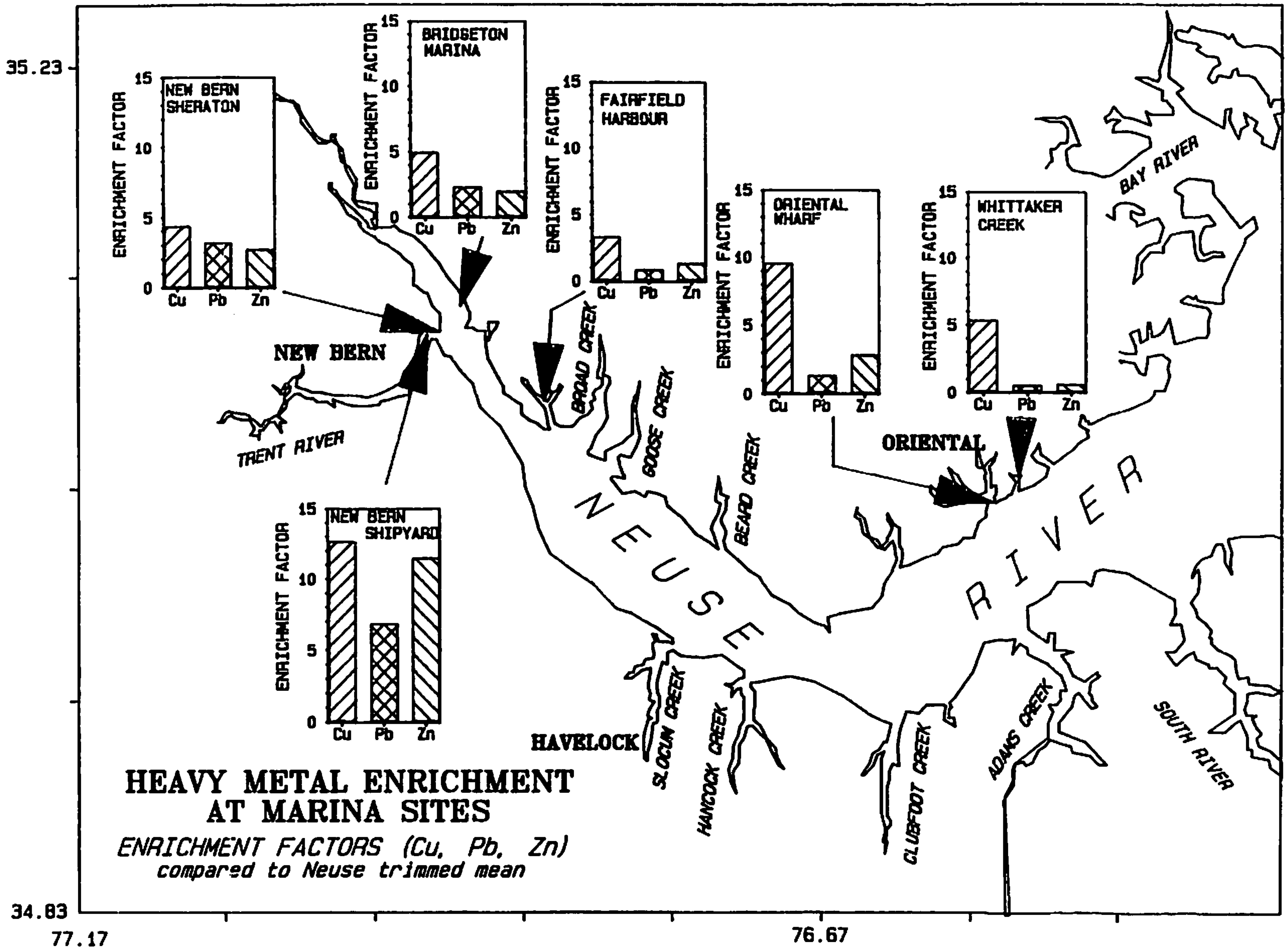

FIGURE 38. Comparison of maximum enrichment factors for copper, lead, and zinc in the surface sediments in and adjacent to six marinas within the Neuse River estuarine system.

TABLE 49. Summary of maximum and mean enrichment factors for three trace metals in surface sediments in and adjacent to six marinas within the Neuse River estuarine system. Enrichment factors that are underlined are substantially enriched (EF = or >2X NRTM) relative to the Neuse River trimmed mean.

NEUSE RIVER MARINAS	N	COPPER MEF	COPPER MEAN EF	LEAD MEF	LEAD MEAN EF	ZINC MEF	ZINC MEAN EF
Bridgeton Marina	1	5.0 X	5.8 X	2.3 X	2.3 X	2.0 X	2.0 X
Fairfield Harbor	1	3.4 X	3.4 X	0.9 X	0.9 X	1.3 X	1.3 X
New Bern Sheraton	3	4.4 X	4.3 X	3.4 X	2.8 X	2.8 X	2.6 X
New Bern Shipyard	2	12.8 X	11.4 X	6.9 X	5.6 X	11.6 X	7.8 X
Oriental Wharf	3	9.6 X	5.9 X	1.4 X	1.2 X	2.9 X	1.8 X
Whittaker Creek	3	5.4 X	2.8 X	0.6 X	0.6 X	0.7 X	0.5 X

PART V: REFERENCES CITED

REFERENCES CITED

Agemian, H., and Chau, A.S.Y., 1977, A study of different analytical extraction methods for nondetrital heavy metals in aquatic sediments: Archives of Environmental Contamination and Toxicology, v. 6, p. 69-82.

Allen, D.W., 1964, Clay minerals of Tar-Pamlico River sediment: M.S. Thesis, Univ. of North Carolina, Chapel Hill, 34 pp.

Aller, R.C., 1980, Tracking Particle-associated processes in nearshore environments by use of 234Th/238U disequlibrium: Earth Planet. Sci. Lett., v. 47, p. 161-175.

Aller, R.C., and Cochran, J.K., 1976, 234Th/238U disequilibrium in nearshore sediment: particle reworking and diagenetic time scales: Earth Planetary Science Letters, v. 29, p. 37-50.

Barker, R.G., Eddins, W.H., Garret, B.C., Ragland, B.C., and Rinehardt, J.F., 1986, Water resources data for North Carolina, water year 1986: U.S. Geol. Survey Water Data Rept. NC-86-1, 495 pp.

Bauer C.F. and C Kheboian, 1988, Response to comments: Analytical Chemistry, v. 60.

Bellis, V., O'Connor, M.P., and Riggs, S.R., 1975, Estuarine shoreline erosion in the Albemarle-Pamlico region of North Carolina: Univ. North Carolina Sea Grant Pub. No. UNC-SG-75-29, 67 p.

Benninger, L.K., 1976, The use of uranium-series radionuclides as tracers of geochemical processes in Long Island Sound: Ph.D. Thesis, Yale Univ., New Haven, Conn.

Benninger, L.K and Martens, C.S., 1983, Sources and fates of sedimentary organic matter in the White Oak and Neuse River Estuary, NC: Univ. North Carolina, Water Resources Research Inst. Rept. No. 194.

Berryhill, H.L., Swanson, V.E., and Love, A.H., 1972, Organic and trace-element content of Holocene sediments in two estuarine bays, Pamlico Sound area, North Carolina: U.S. Geological Survey Bull. No. 1314-E, p. E1-E32.

Brown, C.Q., and Ingram, R.L., 1954, The clay minerals of the Neuse River sediments: Jour. of Sedimentary Petrology, v. 24, p. 196-199.

Bruland, K.W., Bertine, K., Koide, M. and Goldberg, E.D., 1974, History of metal pollution in Southern California coastal zone: Envt. Sci. Technol., v. 8, p. 425-432.

Caulcutt, R. and Boddy, R., 1983, Statistics for analytical chemists: Chapman and Hall, New York, 253 pp.

Cantillo, A.Y., S.A. Sinex and G.R. Heltz, 1984, Element analysis of estuarine sediments by lithium metaborate fusion and direct current plasma emission spectrometry: Analytical Chemistry, v. 56, p. 33-37.

Carr, D.J., Aginopolos, A., and Zanoni, A.E., 1983, Characteristics and treatability of urban runoff residuals: U.S. Environmental Protection Agency, EPA-600/S2-82-094, 5 p.

Chester, R. and Hughes, M.J., 1966, A chemical technique for the separation of ferro-manganese minerals, carbonate minerals and adsorbed trace elements from pelagic sediments: Chemical Geology, v. 2, p. 249-262.

Clean Water Fund-NC, 1990, Trouble on the Neuse: a review of the 23 major dischargers in the Neuse River basin: Raleigh, N.C., 72 pp.

Copeland, B.J., R.G. Hodson, S.R. Riggs, and J.E. Easley, 1983, Ecology of Albemarle Sound, North Carolina: An Estuarine Profile: U.S. Dept. Interior, Fish & Wildlife Service, Washington D.C., FWS/OBS-83-1, 68 pp.

Copeland, B.J., R.G. Hodson, and S.R. Riggs, 1984, Ecology of the Pamlico River, North Carolina: An Estuarine Profile: U.S. Dept. Interior, Fish & Wildlife Service, Washington D.C., FWS/OBS-82-06, 83 pp.

Crites, R.W., Uiga, A., Seabrook, B.L., and Lim, L.K., 1979, An approach for comparing health risks of wastewater treatment alternatives: U.S. Environmental Protection Agency Tech. Rpt. EPA 430/9-79-009, 66 p.

Cross, F.A., T.W. Duke and J.N. Willis, 1970, Biogeochemistry of trace elements in a coastal plain estuary: distribution of manganese, iron and zinc in sediments, water and polychaetous worms: Chesapeake Science, v. 11, p. 221-224.

Cross, F.A., and Sunda, W.G., 1978, Relationship between bioavailability of trace metals and geochemical processes in estuaries: in, Estuarine Interactions, M.L. Wiley, ed.: Academic Press, New York, p. 429-442.

Crounse, R.G., W.J. Pories, J.B. Bray and R.L. Mauger, 1983a, Geochemistry and man: health and disease, 1. Essential elements: in, Applied Environmental Geochemistry, Thornton, I., ed.: Academic Press, London, p. 267-302.

Crounse, R.G., W.J. Pories, J.T. Bray and R.L. Mauger, 1983b, Geochemistry and man: health and disease, 2. Elements possibly essential, those toxic and others: in, Applied Environmental Geochemistry, Thornton, I., ed.: Academic Press, London, p. 309-330.

C.T. Main, Inc., 1989, Engineering report for sewage and industrial waste treatment: Contract No. N62470-88-R-5865 with the U.S. Marine Corps, Cherry Point, N.C.

Daniels, F., Williams, J.W., Bender, P., Alberty, R.A., and Cornwell, C.D., 1962, Experimental physical chemisty: McGraw-Hill Book Co., Inc., New York, 625 pp.

Davis, G.K., Jorden, R., Kubota, J., Laitinen, H.A., Matrone, G., Newberne, P.M., O'Dell, B.L., and Webb, J.S., 1974, Copper and molybdenum: in, Geochemistry and the environment: Nat. Acad. Sciences, p. 68-79.

De Groot, A.J. and K.H. Zschuppe, 1981, Contribution to the standardization of the methods of analysis for heavy metals in sediments: J. Cons. Perm. Int. Explor. Mer., v. 181, p. 111-122.

Duque, T.A., 1978, Geology of organic-rich mud in Slocum and Hancock Creeks, Craven County, North Carolina: Unpub. M.S. Thesis, Dept. of Geology, East Carolina Univ., Greenville, 54 pp.

Engel, D.W., and Noga, E.J., 1989, Shell disease in the blue crabs of the Pamlico River: Environs., v. 12, no. 1, p. 3-5.

Engler, R.M., J.M. Brannon, J. Rose and G. Bigham, 1977, A practical selective extraction procedure for sediment characterization, in Chemistry of Marine Sediments, Yen, T.F., ed.: Ann Arbor Science, Ann Arbor, Michigan, p. 163-171.

Evans, D.W., Di Giulio, R.T., and Ryan, E.A., 1984, Mercury in peat and its drainage waters in eastern North Carolina: Univ. of North Carolina Water Resources Research Inst. Rept. No. 218, 66 pp.

Filer, J.K., 1979, Modern sedimentation through the fluvial to estuarine transition of the Neuse River and estuary, North Carolina: M.S. Thesis, Univ. of North Carolina, Chapel Hill, 142 pp.

Forstner, U., and Wittmann, G.T.W., 1983, Metal Pollution in the Aquatic Environment: Springer-Verlag, Berlin, Second Ed., 486 pp.

Gale, J.A., and Adams, D.A., 1984, Cumulative impacts of peat mining final project report: N.C. Coastal Energy Impact Program, N.C. Dept. Natural Resources & Comm. Devel., CEIP Rept. No. 40, 418 p.

Gallagher, E.P., and Di Giulio, R.T., 1989, Effects of complex waste mixtures on Hepatic Monooxygenase activities in brown bullheads (Ictalurus nebulosus): Environmental Pollution, v. 62, p. 113-128.

Giese, G.L., Wilder, H.B., and Parker, G.G., 1979, Hydrology of major estuaries and sounds of North Carolina: U.S. Geological Survey, Water-Supply Paper No. 2221, 108 pp.

Gilford, J.H., and Zeller, R.W., 1987, Information needs related to toxic chemicals bound to sediments--a regulatory perspective: in Fate and Effects of Sediment-Bound Chemiclas in Aquatic Systems, K.L. Dickson, A.W. Maki, and W.A. Brungs, eds.: Pergamon Press, New York, p. 35-39.

Griffin, G.M., and Ingram, R.L., 1955, Clay minerals of the Neuse River estuary: Jour. of Sedimentary Petrology, v. 25, p. 194-200.

Gupta, S.K. and K.Y. Chen, 1975, Partitioning of trace metals in selective chemical fractions of nearshore sediments: Environmental Letters, v. 10, p. 129-158.

Hardaway, C.S., 1980, Shoreline erosion and its relationship to the geology of the Pamlico River Estuary: Unpub. M.S. Thesis, Dept. of Geology, East Carolina Univ., Greenville, 116 p.

Harding, S.C., 1974, Distribution of selected trace elements in the Pamlico River estuary, North Carolina: Unpub. M.S. Thesis, Dept. of Geoscience, North Carolina State University, Raleigh, 40 p.

Harned, D.A., 1980, Water quality of the Neuse River, North Carolina: variability, pollution loads, and long-term trends: U.S. Geol. Surv. Water-Resources Invest. 80-36, 84 p.

Hartness, T.S., 1977, Distribution and clay mineralogy of organic-rich mud sediments in the Pamlico River Estuary, North Carolina: Unpub. M.S. Thesis, Dept. of Geology, East Carolina Univ., Greenville, 45 p.

Hawkins, J.H., 1987, Fish disease assessments and current North Carolina Division of Marine Fisheries initiatives, in The Proceedings of the Workshop on Fishery Diseases for the Albemarle-Pamlico Estuarine Study: North Carolina Water Resources Research Inst. Rept., p. 5-10.

Hayes, M.O., 1978, Impact of hirricanes on sedimentation in estuaries, bays, and lagoons, in Estuarine Interactions, M.L. Wiley, ed.: Academic Press, New York, p. 323-346.

Hobbie, J.E., and Smith, N.W., 1975, Nutrients in the Neuse River estuary, North Carolina: Univ. of North Carolina Sea Grant Pub. No. UNC-SG-75-21, 183 pp.

Horvath, D.J., 1972, An overview of soil/plant/animal relationships with respect to utilization of trace elements: Ann. N.Y. Acad. Sci., v. 199, p. 82-94.

Huggett, R.J., M.E. Bender and H.D. Slone, 1973, Utilizing metal concentration relationships in the eastern oyster (Crassostrea virginica) to detect heavy metal pollution: Water Research, v. 7, p. 451-460.

Jenne, E.A., and Luoma, S.A., 1975, Forms of trace elements in soils, sediments, and associated waters: an overview of their determination and biological availability, in Biological implications of metals in the environment, 15th Life Sciences Symposium, Richland, WA.

Jenne, E.A. and Luoma, S.N., 1977, Forms of trace elements in soils, sediments and associated waters: an overview of their determination and biological availability: in, Biological Implications of Metals in the Environment, Wildung, R.E. and H. Drucker, eds.: CONF-750929, NTIS, Springfield Virginia, p. 110-143.

Kheboian C., and C.F. Bauer, 1987, Accuracy of selective extraction procedures for metal speciation in model aquatic sediments: Analytical Chemistry, v. 59, p. 1417-1423.
Kimerle, R.A., 1987, A chemical industry's perspective on issues related to chemicals bound to sediments: in Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems, K.L. Dickson, A.W. Maki, and W.A. Brungs, eds.: Pergamon Press, New York.
Kirby-Smith, W.W., and Barber, R.T., 1979, The water quality ramifications in estuaries of converting forest to intensive agriculture: Univ. of North Carolina Water Resources Research Inst. Rept. No. 148, 70 pp.
Knowles, C.E., 1975, Flow dynamics of the Neuse River estuary: Univ. of North Carolina Sea Grant Pub. No. UNC-SG-75-10, 18 pp.
Levine, J.F., 1988, Estuarine monitoring for ulcerative mycosis, in The Proceedings of the Workshop on Fishery Diseases for the Albemarle-Pamlico Estuarine Study: North Carolina Water Resources Research Inst. Rept., p. 25-30.
Levine, J.F., Dykstra, M.J., Camp, J.T., Cone, R.S., Clark, A., Sandukis, N., Markwardt, N.A., and Wenzel, T., 1989, Temporal distribution of ulcerative lesions in menhaden: N. C. Dept. of Environment, Health, and Natural Resources, Div. of Marine Fisheries, Morehead City, 26 pp.
Li, Y.H., Burkardt, L., and Teraoka, H., 1984, Desorption and coagulation of trace elements during esturaine mixing: Geochimica et Cosmochemica Acta, v. 48, p. 1879-1884.
Linebach, K.C., 1990, Hydrogeology and environmental quality of the water table aquifer in the Kennedy Creek area, Beaufort County, North Carolina: M.S. Thesis, East Carolina Univ., Greenville, N.C., 95 pp.
Long, E.R., and Morgan, L.G., 1990, The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program: National Oceanic and Atmospheric Administration, Seattle, Wash., NOAA Tech. Mem. NOS OMA 52, 175 p. plus appendices.
Loring, D.H., 1981, Potential bioavailability of metals in eastern Canadian estuarine and coastal sediments: Rapp. P. V. Reun. Cons. Int. Explor. Mer., v. 181, p. 93-101.
Loring, D.H. and Rantala, R.T.T., 1988, An intercalibration exercise for trace metals in marine sediments: Marine Chem., v. 24, p. 13-28.
Luoma, S.N. and E.A. Jenne, 1976a, Estimating bioavailability of sediment bound trace metals with chemical extractants: in, Trace Substances in Environmental Health - X, Hemphill, D.D., ed.: University of Missouri, Columbia Missouri.
Luoma, S.N. and E.A. Jenne, 1976b, Factors affecting the availability of sediment-bound cadmium to the estuarine, deposit-feeding clam, Macoma balthica: in, Radioecology and Energy Resources, Cushing, C.E., ed.: Dowden, Hutchinson and Ross, Inc., Stroudsberg, Pennslyvania.
Luoma, S.N. and E.A. Jenne, 1977, The availability of sediment-bound cobalt, silver, and zinc to a deposit-feeding clam: in, Biological Implications of Metals in the Environment, Wildung, R.E. and H. Drucker, eds.: CONF-750929, NITS, Springfield, Virginia, p. 213-230.
Luoma, S.N. and G.W. Bryan, 1979a, Factors controlling the availability of sediment-bound lead to an estuarine bivalve: J. Mar. Biol. Assn. U.K.

Luoma, S.N. and G.W. Byran, 1979b, Trace metal bioavailability: modeling chemical and biological interactions of sediment-bound zinc: in, Chemical Modeling in Aquatic Systems, ACS Symposium Series y3, Jenne, E.A., ed.: American Chemical Society, Washington, DC.

Mahan, K.I., T.A. Foderaro, T.L. Garza, R.M. Martinez, G.A. Maroney, M.R. Trivisonno and E.M. Willging, 1987, Microwave digestion techniques in the sequential extraction of calcium, iron, chromium, manganese, lead, and zinc in sediments: Analytical Chemistry, v. 59, p. 938-945.

Marsal, D., 1987, Statistics for geoscientists: Pergamon Press, Oxford, p. 58-68.

Matson, E.A., Brinson, M.M., Cahoon, D.D. and Davis, G.J., 1983, Biogeochemistry of the sediments of the Pamlico and Neuse River Estuaries, North Carolina: Univ. of North Carolina Water Resources Research Inst. Rept. No. 191.

McKenna, S., Jansen, M., and Pulley, M.G., 1990, Shell disease of blue crabs, Callinectes sapidus, in the Pamlico River, North Carolina: N.C. Dept. of Environment, Health, and Natural Resources, Div. of Marine Fisheries, Morehead City, 30 pp.

Mertz, W., Angino, E.E., Cannon, H.L., Hambridge, K.M., and Voors, A.W., 1974, Chromium: in Geochemistry and the environment: Nat. Acad. Sciences, p. 29-35.

Miller, K.H., Bland, R.W., Camp, J., Hawkins, J.H., Tyndall, C.R., and Adams, B.L., 1990, Pamlico environmental response team report for 1988: N.C. Dept. of Environment, Health, and Natural Resources, Div. of Environmental Management and Div. of Marine Fisheries, Washington, 35 pp. and appendices.

Miller, J.C., and Miller, J.N., 1984, Statistics for analytical chemistry: John Wiley & Sons, New York, 202 pp.

Moore, R.P., in prep., Partitioning of heavy minerals in sediments of the Pamlico River estuary, North Carolina: Unpub. M.S. Thesis, Dept. of Geology, East Carolina Univ., Greenville.

Murray, L.C., and Daniel, C.C., 1990, Hydrogeologic and water-quality data from well clusters near the wastewater-treatment plant, U.S. Marine Corps Air Station, Cherry Point, North Carolina: U.S. Geological Survey, Open-File Rept 89-615, 56 pp.

Murray, L.C., and Keoughan, K.M., 1990, Hydrogeologic, water-level, and water-quality data from monitoring wells at the U.S. Marine Corps Air Station, Cherry Point, North Carolina: U.S. Geological Survey, Water-Resources Invest. Rpts. 89-4200, 86 pp.

National Academy of Sciences, 1974, Geochemistry and the environment: U.S. Govt. Printing Office, 113 p.

National Status and Trends Program (NSTP), 1987, Progress Report and preliminary assessment of findings of the benthic surveillance Project-1984: NOAA, US Dept. Commerce., 81 p.

N.C. DEM, 1983a, An assessment of mercury in North Carolina: N.C. Dept. Natural Resources & Comm. Devel., Div. of Environmental Management, Raleigh, Rept. No. 83-02.

N.C. DEM, 1983b, Basic water monitoring program data review 1981-1982: N.C. Dept. Natural Resources & Comm. Devel., Div. of Environmental Management, Raleigh, Rept. No. 83-10, 209 pp.

N.C. DEM, 1990a, Interim review (June-November 1988) of baseline water quality data from the Pamlico and Neuse River estuaries: N.C. Dept. of Environment, Health, and Natural Resources, Div. of Environmental Management, Raleigh, Rept. No. 90-02, 47 pp.

N.C. DEM, 1990b, North Carolina coastal marinas: water quality assessment: N.C. Dept. of Environment, Health, and Natural Resources, Div. of Environmental Management, Raleigh, Rept. No. 90-01, 43 pp.

N.C. DPA, 1987, North Carolina: state of the environment report: N.C. Dept. Natural Resources & Comm. Devel., Div. of Planning and Assessment, Raleigh, 60 pp.

Noga, E.J., Dykstra, M.J., and Levine, J.F., 1989, Fish diseases of the Albemarle-Pamlico estuary: Univ. of North Carolina Water Resources Research Inst. Rept. No. 238.

NUS Corporation, 1984, Confirmation study to determine existence and possible migration of specific chemicals in situ at the Marine Corps Air Staion, Cherry Point, N.C., Step 1A--verification study work plan: Naval Facilities Engineering Command Contract Rpt. N62470-84-B-6886, Pittsburg, Pa.

Oldfield, J.E., Allaway, W.H., Laitinen, H.A., Lakin, H.W., and Muth, O.H., 1974, Selenium: in Geochemistry and the environment: Nat. Acad. Sciences, p. 57-63.

Park, B.K., 1971, Mineralogy of Recent sediments of North Carolina sounds and estuaries: Ph.D. thesis, Univ. of North Carolina, Chapel Hill, 157 pp.

Pesch, G., B. Reynolds and P. Rogerson, 1977, Trace metals in scallops from within and around two ocean disposal sites: Marine Pollution Bulletin, v. 8, p. 224-228.

Petree, D.H., 1974, The influence of grain size of clay mineral composition of sediments in the Neuse River estuary, North Carolina: M.S. Thesis, Univ. of North Carolina, Chapel Hill, 30 pp.

Pickering, W.F., 1986, Metal ion speciation - soils and sediments (a review): Ore Geology Reviews, v. 1, p. 83-146.

Pringle, B.H., D.E. Hissong, E.L. Katz and S.T. Mulawka, 1968, Trace metal accumulation by estuarine mollusks: Proceedings of the American Society of Civil Engineers, June, 1968, p. 455-475.

Putnam, H., Sullivan, J., Hein, M., Adams, W., and Fellows, C., 1982, Initial assessment study of Marine Corps Air Station, Cherry Point, N.C.: Naval Energy and Environmental Support Activity, Water and Air Research, Inc., Contract NEESA 13-009, Gainesville, Fla.

Rader, D.N., Loftin, L.K., McGee, B.A., Dorney, J.R., and Clements, J.T., 1987, Surface water quality concerns in the Tar-Pamlico River basin: N.C. Division of Environmental Management, Rept. No. 87-04, 114 p.

Renfro, W.C., 1973, Transfer of 65Zn from sediments by marine polychaete worms: Marine Biol., v. 21, p. 305-316.

Rhoads, D.C., Tenore, K., and Browne, M., 1975, The role of suspended bottom mud in nutrient cycles of shallow embayments: in Estuarine Research I. Chemistry, Biology and the Estuarine System, L.E. Cronin, ed.: Academic Press, New York, p. 563-579.

Rhoads, D.C., Yingst, J.Y., and Ullman, W.J., 1978, Seafloor stability in Central Long Island Sound: Part I. Temporal changes in erodibility of fine-grained sediment: in Estuarine Interactions, M.L. Wiley, ed.: Academic Press, New York, p. 221-244.

Riggs, S.R., 1985, Evolution of coupled fluvial/estuarine/barrier coastal systems through the late Quaternary of northeastern North Carolina: Geol. Soc. Amer., Abstr. with Progr., v. 17, n. 7, p. 700.

Riggs, S.R., Bray, J.T., and Powers, E.R., 1989a, Revised quality assurance project plan for "heavy metal and organic-rich mud pollutants: their concentration and distribution in the Albemarle, Pamlico, and Neuse estuarine systems: U.S. Environmental Protection Agency, Region IV Water Management Division, 35 pp.

Riggs, S.R., Powers, E.R., Bray, J.T., Stout, P.M., Hamilton, C., Ames, D., Moore, R., Watson, J., Lucas, S., and Williamson, M., 1989b, Heavy metal pollutants in organic-rich muds of the Pamlico River estuarine system: their concentration, distribution, and effects upon benthic environments and water quality: Albemarle-Pamlico Estuarine Study, Raleigh, N.C., U.S. Environmental Protection Agency and N.C. Department of Natural Resources and Community Development, Project No. 89-06, 108 pp.

Salomons, W. and U. Forstner, 1980, Trace metal analysis on polluted sediments, Part II: Evaluation of environmental impact: Environmental Technology Letters, v. 1, p. 506-517.

Sandstead, H.H., Allaway, W.H., Burau, R.G., Fulkerson, W., Laitinen, H.A., Newberne, P.M., Pierce, J.O., and Wixson, B.G., 1974, Cadmium, zinc, and lead: in Geochemistry and the environment: Nat. Acad Sciences, p. 43-56.

Schnabel Engineering Associates, Inc., 1981, Hydrogeologic and geotechnical engineering analysis, putrescible waste landfills, Marine Corps Air Station, Cherry Point, N.C.: Contract Rpt. NC 81399, Richmond, Va.

Schropp, S. J., Lewis, F.G., Windom, H.L., Ryan, J.D., Calder, F.D., and Burney, L.C., 1990, Interpretation of metal concentrations in estuarine sediments of Florida using aluminum as a reference element: Estuaries, v. 13, p. 227-235.

Shiller, A.M. and Boyle, E.A., 1987, Variability in dissolved trace metals in the Mississippi River: Geochim. Cosmochim. Acta, v. 51, p. 3273-3278.

Sholkovitz, E.R., 1978, The flocculation of dissolved Fe, Mn, Al, Cu, Ni, Co, and Cd during esturine mixing: Earth & Planetary Sci. Lett., v. 41, p. 77-86.

Sholkovitz, E.R., and Copland, D., 1981, The coagulation and solubility and adsorption properties of Fe, Mn, Cu, Ni, Co, and Cd and humic acids in river water: Geochim. et Cosmochim. Acta, v. 45, p. 181-187.

Sinex, S.A., A.Y. Cantillo and G.R. Heltz, 1980, Accuracy of acid extraction methods for trace metals in sediments: Analytical Chemistry, v. 52, p. 2342-2346.

Soils and Material Engineers, Inc., 1983, Sludge disposal area investigation report, Marine Corps Air Station, Cherry Point, N.C.: Contract Report 051-83-097-A.

Staples, C.A., Werner, A.F., and Hoogheem, T.H., 1985, Assessment of ambient priority pollutant concentrations using Storet-I, occurrence in United States waterways: Environ. Toxicol. Chem., v. 4, p. 131-142.

Staples, C.A., and Werner, A.F., in press, Priority pollutant assessment in the U.S.A.: scientific and regulatory implications: Toxic Substances Jour.

Tenore, K.R., 1977, Food chain pathways in detrital feeding benthic communities: a review, with new observations on sediment resuspension and detrital recycling: in Belle Baruch Symposium on the ecology of marine benthos, B.C. Coull, ed.: The Belle Baruch library in marine science no. 6, Univ. S. Carolina Press, Columbia, p. 37-53.

Tessier, A., P.G.C. Campbell and M. Bisson, 1979, Sequential extraction procedure for the speciation of particulate trace metals: Analytical Chemistry, v. 51, p. 844-851.
Tessier, A. and P.G.C. Campbell, 1988, Comments on the testing of the accuracy of an extraction procedure for determining the partitioning of trace metals in sediments: Analytical Chemistry, v. 60, p. 1475-1476.
Turekian, K.K., 1971, Rivers, tributaries and estuaries: in Impingement of man on the ocean, D.W. Hood, ed.: Wiley, New York, p. 9-73.
Turekian, K.K., 1977, Trace metals, in New Haven Harbor Ecological Studies-Summary Report: United Illuminating Report to Connecticut Dept. of Environmental Protection.
Turekian, K.K., Cochran, J.K., Benninger, L.K., and Aller, R.C., 1980, The sources and sinks of nuclides in Long Island Sound: in Estuarine physics and chemistry: studies in Long Island Sound, B. Saltzman, ed.: Advances in Geophysics, Acacemic Press, New York, v. 22, p. 129-164.
U.S. EPA, 1976, Quality criteria for water: U.S. Environmental Protection Agency, U.S. Government Printing Office, Washington, D.C., 256 pp.
U.S. EPA, 1979, Methods for Chemical Analysis of Water and Waste: U.S. Environmental Protection Agency, EMSL Cincinnati, Ohio, EPA-600/4-79-020.
U.S. EPA, 1980, Criteria for mercury: U.S. Environmental Protection Agency, EPA440/5-80-058.
U.S. EPA, 1986, Quality criteria for water: U.S. Environmental Protection Agency, EPA440/5-86-001, 310 pp.
U.S. FWS, 1985, Memo to B.D. Waddell, Colonel of the U.S. Marine Corps Air Station, Cherry Point, N.C.: U.S. Fish and Wildlife Service, Raleigh, N.C.
Valiela, I., M.D. Banus and J.M. Teal, 1974, Response of salt marsh bivalves to enrichment with metal-containing sewage sludge and retention of lead, zinc and cadmium by marsh sediments: Environmental Pollution, v. 7, p. 149-157.
Wells, J.T., 1989, A scoping study of the distribution, composition, and dynamics of water-column and bottom sediments: Albemarle-Pamlico estuarine system: Albemarle-Pamlico Estuarine Study, Raleigh, N.C., U.S. Environmental Protection Agency and N.C. Department of Natural Resources and Community Development, Project No. 89-05, 39 pp.
Wells, J.T., and Kim, S.Y., 1989, Sedimentation in the Albemarle-Pamlico lagoonal system: synthesis and hypotheses: Marine Geology, v. 88, p. 263-284.
Werme, C., 1985, Final report on guidance for preparation of combined work/quality assurance project plans for bays program studies for the U.S. Environmental Protection Agency, Region I: Battelle, Washington, D.C., Contract No. 68-01-6986, 18 p.
Whaling, P.J., Barber, R.T., and Paul, J.C., 1977, The distribution of toxic metals in marine ecosystems as a result of sewage disposal and natural processes: Univ. of North Carolina Water Resources Research Inst. Rept. No. 123, 132 pp.
Wharfe, J.R., W.L. Van Den Broek, 1977, Heavy Metals in Macroinvertebrates and fish from the Lower Medway Estuary, Kent: Marine Pollution Bulletin, v. 8, p. 31-34.
Wolfe, D.A. and T.R. Rice, 1972, Cycling of elements in estuaries: Fisheries Bulletin, v. 70, p. 959-972.
Zoller, W.H., Gladney, E.S., and Duce, R.A., 1974, Atmospheric concentrations and sources of trace metals at the South Pole: Science, v. 183, p. 198-200.

PART VI: APPENDICES

APPENDIX A

CORE SAMPLE LOCATION DATA FOR THE NEUSE RIVER ESTUARINE SYSTEM

Column 1: Core hole number as used for all analytical work, on maps, and within the text.
Column 2: Loran coordinate S1; no entry where shoreline interference was too great to obtain a meaningful number.
Column 3: Loran coordinate S2; no entry where shoreline interference was too great to obtain a meaningful number.
Columns 4, 5, and 6: Latitude in degrees with minutes and seconds converted to decimals.
Columns 7, 8, and 9: Longitude in degrees with minutes and seconds converted to decimals.
Column 10: Location description.

SAMPLE ABBREV.	ESTUARY OR STREAM	FIGURE NUMBERS FOR REGIONAL LOCATION MAPS
		Figure 9: Index of Regional Map Areas
ADM	Adams Creek	Figure 34
BRD	Beard Creek	Figure 21
BROD	Broad Creek	Figure 21
CBF	Clubfoot Creek	Figure 34
DUC	Duck Creek	Figure 10
FFD	Fairfield Harbour	Figure 21
GOS	Goose Creek	Figure 21
HCK	Hancock Creek	Figure 23
LSN	Lawson Creek	Figure 10
NBNW	Mill Branch	Figure 10
NUSE	Outer Neuse River East (east of Neuse River Ferry)	Figure 35
NUS	Outer Neuse River West (east of Black Beacon Point and west of Neuse River Ferry Route)	Figures 21 and 34
NBNE	New Bern East (Neuse River east of US Hwy 17 Bridge and west of Black Beacon Point)	Figure 10
NBNW	New Bern West (Neuse River west of US Hwy 17 Bridge)	Figure 10
ORL	Oriental Area Creeks	Figures 34 and 36
CMP	Oriental Harbour (Camp Creek)	Figures 34 and 36
RIV	Neuse River (west of the New Bern WWTP to Streets Ferry)	Figure 20
SCT	Scotts Creek	Figure 10
SLO	Slocum Creek	Figures 23 and 24
STH	South River	Figure 35
SWT	Swift Creek	Figure 20
TNT	Trent River (New Bern Area east of US Hwy 70 Bridge)	Figure 19
TNT	Trent River (west of US Hwy 70 Bridge)	Figure 10
WKR	Whittaker Creek	Figures 34 and 36

CORE	LATITUDE	LONGITUDE	LOCATION DESCRIPTION
ADAMS CREEEK			
ADM-1	34.91314	76.66304	Mid-channel off mouth of Back Crk
ADM-2	34.90768	76.65271	Mid-channel, Back Crk off 1st crk on S shore; 0.5 nmi SE of ICWW
ADM-3	34.93238	76.65253	100 ft N of ICWW MKR 9 in Adams Crk
ADM-4	34.94635	76.66652	300 ft S of ICWW MKR 6 in Adams Crk
ADM-5	34.95682	76.68008	50 ft SE of ICWW MKR 4 in mouth of Adams Crk
BAY RIVER			
BAY-1	35.16815	76.52967	300 ft N of MKR 1; mid mouth of Bay River
BAY-2	35.18298	76.55846	300 ft N of MKR 3
BEARD CREEK			
BRD-1	35.03595	76.86753	400-500 ft S of SR 1005 bridge; mid-channel
BRD-2	35.02502	76.86647	Mid-channel, upper Beard Crk where begins to narrow
BRD-3	35.00879	76.86778	Mid-channel, 0.5 nmi inside mouth of Beard Crk
BROAD CREEK			
BROD-1	35.06268	76.94892	200 ft NW of marina dock & WWTP in Upper Broad Crk
BROD-2	35.07331	76.93902	Mid-channel, 750 ft S of power cable crossing
BROD-3	35.05952	76.94356	SE side of Upper Broad Crk opposite marina
CLUBFOOT CREEK			
CBF-1	34.87563	76.76457	Mid-channel, 2.5 nmi S of Crk mouth, near big farmhouse
CBF-2	34.89606	76.76387	Mid-channel, 1.5 nmi S of Crk mouth
CBF-3	34.90582	76.76233	Mouth of Mitchell Crk, 300 ft S of marina
DUCK CREEK			
DUC-1	35.09950	77.00723	Mid-channel, 0.33 nmi inside mouth of Duck Crk
FAIRFIELD HARBOR			
FFD-1	35.07397	76.96460	NE fork of NW Crk, middle of dredged Fairfield Harbor
FFD-2	35.07271	76.97686	Mid-channel, 1.1 nmi NW of Fairfield Harbor marina, NW Crk
FFD-3	35.06520	76.96941	300 ft W of Fairfield Harbor marina dock, NW Crk
GOOSE CREEK			
GOS-1	35.05707	76.91595	Mid-channel off fish house, at dog-leg in Goose Crk
GOS-2	35.04651	76.93170	Mid-channel, 1.1 nmi NE of Goose Crk mouth

CORE	LATITUDE	LONGITUDE	LOCATION DESCRIPTION
HANCOCK CREEK			
HCK-1	34.88416	76.85761	300 ft N of runway lights across upper Hancock Crk
HCK-2	34.89149	76.86296	100 ft off mouth of Shop Branch
HCK-3	34.90944	76.86036	Mid-channel, off mouth of Jacks Branch
HCK-4	34.92847	76.85253	Mid-channel off airstrip, 1.1 nmi N mouth of Cahogue Crk
HCK-5	34.93521	76.86025	In Still Gut at mouth of Reeds Gut; near small marina
HCK-6	34.93606	76.85872	75 ft off boat ramp inside mouth of Still Gut
LAWSON CREEK			
LSN-1	35.10189	77.05130	Mid-channel, 75 ft W of Mkr 7 in Lawson Crk
LSN-2	35.10399	77.04597	150 ft off storm outfall at mouth of Lawson Crk
NEW BERN: NEUSE RIVER EAST			
NBNE-1	35.10492	77.03304	E edge of nav. channel off Union Pt; 150 ft S of MKR 34
NBNE-2	35.10486	77.03432	W side of nav. channel off Union Pt; 400 ft SW of MKR 34
NBNE-3	35.10614	77.02567	Mid-river between Sandy Pt and Union Pt
NBNE-4	35.10976	77.02013	750 ft W of E shore; midway between US 17 bridge & Sandy Pt
NBNE-5	35.09932	77.02559	Mid-river between James City & Sandy Pt
NBNE-6	35.09311	77.03080	300 ft offshore @ James City, S of MKR 29
NBNE-7	35.09682	77.03357	850 ft E of S end of HWY 17 bridge over Trent River
NBNE-8	35.10057	77.03346	Mid-nav channel, E of HWY 17 swing bridge over Trent River
NBNE-9	35.08955	77.02874	500 ft offshore @ James City, NE of fertilizer plant dock
NBNE-10	35.08483	77.02241	750 ft offshore @ James City, NW of Black Beacon Pt
NBNE-11	35.09110	77.01935	Mid-Neuse River; halfway between Black Beacon Pt & Sandy Pt
NBNE-12	35.09811	77.01544	0.3 nmi SSE of Sandy Pt; 0.4 nmi NW of Duck Crk mouth
NEW BERN: NEUSE RIVER WEST			
NBNW-1	35.11624	77.02033	25 ft off end of boat dock @ boat yard, Bridgeton
NBNW-2	35.11527	77.02075	300 ft SW of boat yard dock; 75 ft NW of HWY 17 bridge
NBNW-3	35.11284	77.02780	Mid-HWY 17 bridge over Neuse River; 150 ft NW of bridge
NBNW-4	35.10934	77.03379	150 ft SW of S bridge fender; W side HWY 17 bridge
NBNW-5	35.11011	77.03263	75 ft NW of middle fender of HWY 17 swing bridge
NBNW-6	35.11270	77.03462	Mid-channel, 150 ft SE of MKR 38
NBNW-6F	35.11270	77.03462	Mid-channel, 150 ft SE of MKR 38
NBNW-7	35.11412	77.03648	150 ft offshore, E of relic dock & 200 ft NW of MKR 38
NBNW-8	35.11701	77.03130	Mid-River, mid-way between HWY 17 & RR bridges
NBNW-9	35.11777	77.03994	Mid-way between lumber processing plant & nav channel
NBNW-10	35.11927	77.04164	300 ft SW of SW end of RR bridge

CORE	LATITUDE	LONGITUDE	LOCATION DESCRIPTION
NBNW-11	35.12312	77.03362	300 ft SE of mid-section of RR bridge; mid-River
NBNW-12	35.12634	77.03006	NE side of Neuse River; 75 ft SE of RR bridge
NBNW-13	35.12062	77.04217	350 ft NW of SW end of RR bridge; near fuel docks
NBNW-14	35.12454	77.04594	300 ft off residential waterfront NW of MKR 39
NBNW-15	35.13164	77.05032	300 ft off residential waterfront; SW of MKR 43
NBNW-16	35.13756	77.05700	40 ft off of New Bern WWTP discharge ditch
NBNW-17	35.13639	77.05628	Mid-crk, 600 ft upcreek S of New Bern WWTP; off cypress
NBNW-18	35.13813	77.05592	200 ft E of New Bern WWTP discharge ditch; in crk mouth
NBNW-18F	35.13813	77.05592	200 ft E of new Bern WWTP discharge ditch; in crk mouth
NBNW-19	35.11835	77.02412	600 ft offshore near Bridgeton condos
NBNW-20	35.12253	77.02725	750 ft offshore near Bridgeton school
NBNW-21	35.11904	77.03525	NW side of River between RR & HWY 17 bridges
NBNW-22	35.12778	77.03831	Mid-River; 600 ft NW of RR bridge
NBNW-23	35.12900	77.03003	600 ft W of NE end of RR bridge
NBNW-24	35.13320	77.02885	300 ft up canal; mid-way between RR bridge & Lewis Ferry
NBNW-25	35.13274	77.03170	150 ft off mouth of canal; mid-way between RR bridge & Lewis Ferry
NBNW-26	35.14233	77.03846	500 ft up Mill Branch; mid-crk
NBNW-27	35.14061	77.03985	300 ft off mouth of Mill Branch
NBNW-28	35.13952	77.04388	Mid-deep channel; 0.2 nmi WSW of Mill Branch mouth
NBNW-29	35.13337	77.04121	Mid-River; 0.25 nmi SW of Lewis Ferry
NEUSE PROFILE			
NP-1	34.94990	76.86922	South end; 0.15 nmi N of S shoreline
NP-2	34.95271	76.86903	0.3 nmi N of S shoreline
NP-3	34.95708	76.86880	0.6 nmi N of S shoreline
NP-4	34.96201	76.86808	0.9 nmi N of S shoreline
NP-5	34.96731	76.86792	1.2 nmi N of S shoreline
NP-6	34.97192	76.86695	1.5 nmi N of S shoreline
NP-7	34.97690	76.86691	1.2 nmi S of MKR 1 @ mouth of Beard Crk
NP-8	34.98146	76.86638	0.9 nmi S of MKR 1 @ mouth of Beard Crk
NP-9	34.98674	76.86610	0.6 nmi S of MKR 1 @ mouth of Beard Crk
NP-10	34.99203	76.86649	0.3 nmi S of MKR 1 @ mouth of Beard Crk
NP-11	34.99668	76.86486	At MKR 1 @ mouth of Beard Crk
NP-12	34.99823	76.86371	North end; 0.1 nmi NE of MKR 1 @ mouth of Beard Crk
OUTER NEUSE RIVER EAST			
NUSE-1	34.95764	76.78777	Mid-River; 0.9 nmi SE of Wilkinson Pt
NUSE-2	34.93560	76.75846	0.8 nmi N of MKR 1 @ mouth of Clubfoot Crk

CORE	LATITUDE	LONGITUDE	LOCATION DESCRIPTION
NUSE-3	34.96178	76.73929	Mid-River between Daniels Pt & Great Is
NUSE-4	34.98625	76.75158	0.3 nmi SE of MKR 2 @ mouth of Dawson Crk
NUSE-5	34.99406	76.70951	0.6 nmi S of Wiggins Pt
NUSE-6	35.01031	76.68274	0.6 nmi SE of MKR 1 @ entrance to Oriental
NUSE-7	34.97175	76.69428	0.8 nmi NW of MKR 3 in Adams Crk; 0.2 nmi S of MKR 1AC
NUSE-7A	34.97175	76.69428	0.8 nmi NW of MKR 3 in Adams Crk; 0.2 nmi S of MKR 1AC
NUSE-8	34.98896	76.67408	1.5 nmi NNE of MKR 3 @ Adams Crk; 1.4 nmi SW of Garbacon Shl MKR 7
NUSE-9	35.01309	76.65210	0.7 nmi ENE of Garbacon Shoals MKR 7
NUSE-10	35.01987	76.61926	1.8 nmi NNE of Sandy Pt
NUSE-11	35.03555	76.63846	1.5 nmi S of Orchard Crk; 0.85 nmi ESE MKR 2PA @ Pierce Crk
NUSE-12	35.04014	76.61342	1.6 nmi SE of Orchard Crk; 2 nmi SW of MKR 6P @ Gum Thicket Shl
NUSE-13	35.05450	76.54569	1.4 nmi SE of Gum Thicket Shl MKR 6P; 2 nmi SSW MKR 4 off Broad Crk
NUSE-14	35.04554	76.50423	0.4 nmi W prohibited area @ Rattan Bay; 2 nmi N MKR 1 @ Turnigan Bay
NUSE-15	35.01759	76.51351	0.8 nmi NW of MKR 1 @ Turnigan Bay
NUSE-16	35.02542	76.56813	2.5 nmi NE of MKR 1 @ South River
NUSE-17	35.08850	76.53587	0.2 nmi E of MKR 4 off Piney Pt Shl & Broad Crk
NUSE-18	35.12157	76.51904	0.8 nmi SSW of MKR 2PA @ Maw Pt Shl
NUSE-19	35.13710	76.48698	1.4 nmi E of MKR 2PA @ Maw Pt Shl; 0.9 nmi SE of MKR "NRJ"
OUTER NEUSE RIVER WEST			
NUS-1	35.08464	77.00766	0.3 nmi N MKR 22; mid-fish haven
NUS-2	35.07230	77.00172	Mid-River; 0.5 nmi SSE of MKR 22
NUS-3	35.05681	76.99495	0.2 nmi ENE of SW shore; 0.65 nmi SSW of Bay Pt on NE shore
NUS-4	35.05426	76.96193	0.25 nmi S of shore between Upper Broad Crk and Northwest Crk
NUS-5	35.05406	76.98384	Mid-River; 0.5 nmi WSW of McCotter Pt
NUS-6	35.03943	76.98055	0.3 nmi E of W Shore; 0.4 nmi SE of Johnson Pt
NUS-7	35.02237	76.97016	300 ft SSW of MKR 17
NUS-8	35.03066	76.95165	0.9 nmi SSW of Creek Pt; 1.0 nmi NNE of MKR 15
NUS-9	35.01262	76.93595	0.9 nmi NNE of MKR 11
NUS-9A	35.01262	76.93595	0.9 nmi NNE of MKR 11
NUS-10	34.98984	76.93021	0.9 nmi SE of MKR 11
NUS-11	35.00542	76.90612	0.9 nmi SSW of Myrtle Marsh Pt on NE shore
NUS-12	34.97792	76.90456	1 nmi N of S shore along axis of Slocum Crk
NUS-12A	34.97792	76.90456	1 nmi N of S shore along axis of Slocum Crk
NUS-13	34.95671	76.88776	0.35 nmi N of MKR 2 @ entrance to Slocum Crk
NUS-14	34.95710	76.86772	Neuse River Profile; 0.6 nmi N of S shoreline
NUS-15	34.97157	76.86570	Neuse River Profile; 1.5 nmi N of S shoreline
NUS-15F	34.97157	76.86570	Neuse River Profile; 1.5 nmi N of S shoreline

CORE	LATITUDE	LONGITUDE	LOCATION DESCRIPTION
NUS-16	34.99145	76.86564	Neuse River Profile; 0.3 nmi S of MKR 1 @ mouth of Beard Crk
NUS-17	34.96978	76.84513	0.8 nmi SW of NE shoreline; N of axis of Hancock Crk
NUS-18	34.94554	76.84601	0.35 nmi NNE of MKR 1 @ entrance to Hancock Crk
NUS-19	34.95727	76.82495	Mid-River; 1 nmi N of NFS Pine Cliff recreation area
NUS-20	34.96285	76.80938	300 ft S of MKR 2 @ entrance to Minnesott Beach
NUS-21	34.94839	76.81200	0.15 nmi W of MKR 9 @ entrance to Cherry Pt ferry landing
ORIENTAL AREA CREEKS			
CMP-1	35.02429	76.69565	NE end Oriental Harbor; mid-chan, 50 ft from town dock
CMP-2	35.02336	76.69691	100 ft off Oriental Yacht Club dock in Oriental Harbor
ORL-1	35.02746	76.70037	100 ft off SW-most docks on E side of Camp Crk
ORL-2	35.03887	76.70498	Mid-channel; confluence of Morris & Smith Crks
ORL-3	35.03105	76.70384	Mid-channel of Smith Crk; 0.2 nmi N of Blackwell Pt
ORL-4	35.02992	76.71789	Mid-channel of Kershaw Crk; off new marina & farm field
ORL-5	35.02258	76.72049	Greens Crk; 150 ft off mouth of E-most trib on S shore
ORL-6	35.02413	76.71161	Mid-channel, E of confluence of Kershaw and Greens Crks
ORL-7	35.02680	76.70979	100 ft off old marina; crk between Kershaw Crk & Dewey Pt
ORL-8	35.02376	76.70249	Mid-channel; 200 ft NW of main hwy bridge
NEUSE RIVER: FLUVIAL			
RIV-1	35.19917	77.11177	400 ft NW of Weyerhauser outfall crk @ MKR 74
RIV-2	35.19904	77.11322	River bank, 50 ft SE of Weyerhauser outfall crk
RIV-3	35.19299	77.10053	200 ft NW of MKR 68 @ mouth of Swift Crk
SCOTTS CREEK			
SCT-1	35.09220	77.03577	Mid-turning basin in Scotts Crk
SCT-2	35.09090	77.03938	Mid-channel; S side of HWY 70 and RR bridges
SLOCUM CREEK			
SLO-1	34.90535	76.91404	Upper Slocum Crk; opp mouth of Cedar Crk; 200 ft W of E shore
SLO-2	34.90752	76.91468	Upper Slocum Crk; mid-crk opp old discharge pipes on E shore
SLO-3	34.90924	76.91291	Upper Slocum Crk; 100 ft W of mouth of Turkey Gut
SLO-4	34.91008	76.91162	Upper Slocum Crk; mouth of Turkey Gut, upstream of delta bar
SLO-5	34.91177	76.91372	Upper Slocum Crk; mid-crk, between Turkey Gut & Cherry Pt WWTP
SLO-6	34.91168	76.91180	Upper Slocum Crk; 100 ft off Cherry Pt WWTP waterfall
SLO-7	34.91498	76.91024	Upper Slocum Crk; in Luke Rowes Gut at old shoreline & oilboom
SLO-8	34.91594	76.91297	Upper Slocum Crk; opp Luke Rowes Gut; 100 ft E of W shore
SLO-9	34.91739	76.91178	Upper Slocum Crk; 50 ft S of mid-bridge

CORE	LATITUDE	LONGITUDE	LOCATION DESCRIPTION
SLO-10	34.91864	76.90941	Upper Slocum Crk; 900 ft NE of bridge, 200 ft off S shore
SLO-11	34.91976	76.90686	Upper Slocum Crk; in meander, 200 ft E of recreation pt
SLO-12	34.92585	76.90732	Upper Slocum Crk; mid-crk opp mouth of Mill Crk
SLO-13	34.94395	76.90652	Lower Slocum Crk; 400 ft W of Cherry Pt marina dock near MKR 10
SLO-14	34.94394	76.91817	Lower Slocum Crk; 0.55 nmi W of MKR 10 in mid-Tucker Crk
SLO-15	34.95293	76.90224	Lower Slocum Crk; mouth of Slocum Crk @ MKR 8
SLO-16	34.88636	76.90646	E Prong Slocum Crk; 30 ft NE of Havelock WWTP outfall
SLO-17	34.88769	76.90719	E Prong Slocum Crk; mid-crk 800 ft N of Havelock WWTP
SLO-18	34.88955	76.90868	E Prong Slocum Crk; in meander 1400 ft N of Havelock WWTP
SLO-19	34.89067	76.90923	E Prong Slocum Crk; W side of crk opp Cherry Pt chem facility
SLO-20	34.89308	76.91096	E Prong Slocum Crk; mid-crk 1200 ft N of Cherry Pt chem facility
SLO-21	34.89721	76.91301	E Prong Slocum Crk; mid-crk 200 ft S of old foot bridge
SLO-22	34.90033	76.91449	Upper Slocum Crk; off mouth of E Prong, 100 ft W of E shore
SLO-23	34.89664	76.91942	SW Prong Slocum Crk; mid-crk 300 ft NE of Havelock water plant
SLO-24	34.89924	76.91699	SW Prong Slocum Crk; mid-crk 600 ft SW of crk mouth
SLO-25	34.90328	76.91443	Upper Slocum Crk; mid-crk 1000 ft N of pt between E & SW Prongs
SOUTH RIVER			
STH-1	34.88419	76.52522	West Fork Crk; mid-crk 2500 ft SW of South River
STH-2A	34.88710	76.51763	East Fork; mid-crk off mouth of ditch 1200 ft SSE of South River
STH-2B	34.88710	76.51763	East Fork; mid-crk off mouth of ditch 1200 ft SSE of South River
STH-3	34.89549	76.52495	South River; mid-river just SE of Miry Gut
STH-4	34.90199	76.53696	South River; mid-river opp Neal Crk
STH-5	34.91951	76.54713	South River; 400 ft NE of mouth of Southwest Crk
STH-6	34.91130	76.56806	Southwest Crk; mid-crk 2800 ft WSW of dam
STH-7	34.91046	76.56119	Southwest Crk; up crk on S side off Duke U. station
STH-8	34.91342	76.56128	Southwest Crk; opp crk on S side & 700 ft SW of break in dam
STH-9	34.91513	76.55406	Southwest Crk; mid-crk 2000 ft SW of South River
STH-10	34.93284	76.53064	Eastman Crk; mid-crk 4000 ft E of South River
STH-11	34.93530	76.54794	South River; mid-river opp mouth of Eastman Crk
STH-12	34.94768	76.56602	South River; mid-river opp Dixon Creek
STH-13	34.95030	76.58542	Big Crk; 500 ft off State shell loading facility
STH-14	34.96339	76.58056	South River; mid-river E of the town of South River
STH-15	34.98585	76.58837	South River; mid-river at mouth; midway between MKRs 1 & 2
SWIFT CREEK			
SWT-1	35.19927	77.09655	Mid-channel; at 1st turn beyond 1st meander in Swift Crk
SWT-2	35.19647	77.09794	Mid-channel; 1200 ft NE MKR 68 in Swift Crk

CORE	LATITUDE	LONGITUDE	LOCATION DESCRIPTION
TRENT	RIVER		
TNT-1	35.06961	77.13264	West; mid-river 300 ft NW of MKR 20
TNT-2	35.07057	77.13313	West; 3 ft off discharge pipe on N shore opp MKR 20
TNT-3	35.07663	77.11829	West; mid-channel midway between MKRs 16 & 14
TNT-4	35.06981	77.08834	West; mid-channel 50 ft E of MKR 8; opp country club marina
TNT-5	35.07233	77.08775	West; 10 ft off end of covered boat house @ country club
TNT-6	35.07317	77.09002	West; 1000 ft W of boat docks & off crk draining golf course
TNT-7	35.07947	77.05701	West; 100 ft off NW shore next to MKR 2
TNT-8	35.09186	77.04816	East; 100 ft off outer docks of marina; 900 ft SW of new HWY 70 bridge
TNT-9	35.09659	77.04374	East; 300 ft NE of bridge fender of new HWY 70 bridge
TNT-9A	35.09659	77.04374	East; 300 ft NE of bridge fender of new HWY 70 bridge
TNT-10	35.09833	77.04741	East; 300 ft NE of new HWY 70 bridge; 200 ft E of W shore
TNT-11	35.10268	77.04285	East; 200 ft off large railway slip at New Bern shipyard
TNT-12	35.10317	77.04402	East; 200 ft W of end of W-most dock at New Bern shipyard
TNT-13	35.10294	77.04529	East; in channel @ mouth of Lawson Crk
TNT-14	35.10132	77.04340	East; 500 ft off main railway & 75 ft E of barges @ shipyard
TNT-15	35.09898	77.04242	East; 75 ft W of southern side RR bridge fender
TNT-16	35.10245	77.04112	East; 100 ft S of fuel dock @ Sheraton Hotel marina
TNT-16A	35.10245	77.04112	East; 100 ft S of fuel dock @ Sheraton Hotel marina
TNT-17	35.10241	77.03769	East; 200 ft E of eastern-most Sheraton dock
TNT-18	35.09961	77.03859	East; 200 ft N of S shore & 200 ft W old HWY 70 bridge
TNT-19	35.10014	77.04071	East; 50 ft N of old dock next to RR bridge
WHITTAKER	CREEK		
WKR-1	35.03195	76.68578	W-most crk; mid-ditch off boat maintenance yards
WKR-2	35.03095	76.68237	100 ft off end of fuel dock & E MKR 5 in outer Whittaker Crk
WKR-3	35.03264	76.68200	East Branch Whittaker Crk; 150 ft off marina docks

APPENDIX B

SEDIMENT ANALYTICAL PROCEDURES

SEDIMENT PROCEDURES

Sediment Sub-Sampling

Sub-sampling of sediment cores (Fig. 7) were done according to the following routine. Each core was allowed to thaw around the core liner until the solid sample could be extruded from the core liner. Cores were extruded horizontally into individual trays and allowed to completely thaw; pore waters were kept with the sediment as thawing occurred. The lithologic characteristics of each core were described. Two sub-samples of 7 cm thickness were obtained, at the top and bottom of the core if the core was longer than 20 cm; cores less than 20 cm long had only a top sample. In some cases, a floc sample was taken at the core site and became the second or third sample from that site. Samples from each interval were homogenized using a plastic spatula and divided into two plastic containers for sedimentological and chemical analyses.

Textural and Compositional Analyses of Sediment

Water content of each subsample was determined by evaporation. Approximately 3 to 5 grams of thoroughly homogenized sediment was placed in a pre-weighed crucible and oven-dried at 95° to 105° C for at least 24 hours or until the final weight had stabilized. Water content was determined by subtracting the dry weight from the wet weight. Organic content was determined by placing the dried sediment in a muffle furnace at 385° C for at least 24 hours or until a constant final weight was achieved. The remaining ash was weighed and subtracted from the initial dry weight to yield the fraction of combustible organic matter in the sample.

Distribution of three major size fractions (sand, silt, and clay) in each subsample was determined using a modified pipet analysis procedure. Three to five grams of homogenized sediment were pre-weighed and transferred into a 120 ml plastic beaker with 20 ml of sodium oxalate and agitated to disperse the sediment. Following dispersion, the disaggregated sediment was rinsed with additional sodium oxalate solution through a 62.5 micron sieve into a 100 ml graduated cylinder separating sand-size material from the fines. Additional sodium oxalate was added until the volume in the graduated cylinder was brought to exactly 100 ml. The sieves were air dried in a warm oven (20° to 25° C) for at least 6 hours and the sand content calculated by subtracting the empty sieve weight from the dry sieve weight containing the sand fraction. The remaining 100 ml mixture of sediment and sodium oxalate was transferred into a 120 ml beaker and agitated until the sediment was suspended. Following a 15 second settling interval, 10 ml of suspension was withdrawn from the beaker with a pipet inserted 3/4 of the distance from the surface to the bottom of the cup. The suspension containing silt and clay-sized particles was transferred into a pre-weighed disposable polystyrene beaker and placed in a 95° to 105° C oven for 24 hours or until completely dry. The remaining sediment mixture was resuspended and allowed to settle for 22 minutes before a second 10 ml withdrawal was taken exactly 2 mm below the liquid surface. The suspension, now containing only clay-sized particles, was transferred into a pre-weighed 10 ml disposable beaker and dried under the same conditions as the previous withdrawal. Four additional pre-weighed beakers were filled with 10 ml of sodium oxalate solution and allowed to evaporate in the 95° to 105° C oven. The dry weight of the oxalate residue was used to correct for the weight contributed to the silt and clay samples by the oxalate residue. Silt and clay contents were calculated from the final dry weight of each beaker after correcting for oxalate residues.

The sand and mud (silt plus clay) fractions were then microscopically inspected for mineralogic descriptions. Percent organic content in the sand fraction was determined by placing the weighed dried sand in a muffle furnace at 385° C for at least 24 hours or until a constant final weight was achieved. The remaining ash was weighed and subtracted from the initial dry weight to yield the fraction of combustible organic matter in the sand fraction. The concentration of combustable organic matter in the mud fraction (silt plus clay) was calculated by subtracting the amount of organic matter in the sand fraction from the total amount of organic matter previously determined in the total sediment.

CHEMICAL PROCEDURES

Sample Pre-Treatment

Though freeze drying may have some effect on the natural particle size characteristics of the sediments, the weighing of dry samples is much more accurate and reproducible than weighing them wet. In addition, these sediments were frozen for storage as cores, therefore any disruption that might have taken place from the freezing process had already occured. Large particles such as shells, rocks, and twigs were removed from the core subsamples; the remainder of the sample was thoroughly homogenized and placed in plastic containers for freeze drying. Frozen subsamples were then placed in the lyophilizer till dry. The dried mass was broken up by mild stirring with a plastic spatula to thoroughly loosen all particles and to homogenize the dried material; no attempt was made to reduce the natural grain sizes. The intent was for extraction to proceed with as nearly the same particle size and surface area characteristics as occurs in the natural state.

Extraction Procedures

Samples for inductively coupled-argon plasma-emission spectrometry (ICAPES) and fluorine analyses were processed utilizing a mild extraction technique similar to that delineated by W.S. Boothman of the U.S. EPA ERLN facilities at Narragansett, R.I. (pers. comm., Jan. 1988). A 2N HNO_3 extraction procedure was utilized for chemical analysis of all estuarine samples.

A. Equipment

1. 120-mL urine specimen cups with lids (Fisher Brand, cat. no. 14-375-112A).
2. 50-mL graduated cylinder.
3. 50-mL syringes with Luer-Lok fitting (B-D).
4. 0.45-um disposable syringe filter assembly (Gelman Acrodisc-CR TFE filters #4219).
5. 50-mL plastic centrifuge tubes with caps.

B. Reagents

1. 2N HNO_3: 252-mL concentrated double distilled HNO_3 (GFS Chemicals, Columbus, OH) diluted to 2 L with high purity water.

C. Procedure

1. Weigh 2.500 g ± .005 g of freeze dried sediment into urine specimen cup.
2. At Hour 0 (Normally starting at 0830 in order to fit the schedule into regular working days) add 50-mL of 2 N HNO_3 to the sediment. CAUTION: Some sediments contain large amounts of shell material ($CaCO_3$) that react vigorously with the acid. First add a few mLs of acid to test for this situation. For those samples containing considerable $CaCO_3$, add the remaining acid slowly in 5 to 10-mL increments after the reaction has subsided.
3. After the acid has been added to all samples in a manageable batch (20 to 40 samples), swirl each sample five (5) times to thoroughly wet and suspend the sample in the acid.
4. Repeat the swirling step above at the following times
   a. Hour 4.5 (Same day 1300)
   b. Hour 8.0 (Same day 1630)
   c. Hour 24 (Next day 0830)
   d. Hour 28.5 (Next day 1300)
   e. Hour 32 (Next day 1630)

   CAUTION: It is important that the elapsed times at which these activities are begun be kept within ± 30 min. Repeatability of extractions is an important requirement that can only be achieved with close adherence to times and duration of these activities.
5. Promptly at Hour 48 (0830 of the third day) filter the samples.
   a. Using the 50-mL syringe, withdraw the plunger (in air) to about the 10 to 15-mL mark. This is to prevent contact between the solution and black rubber tip of the plunger (a source of metal contamination, especially Zn).
   b. While keeping the barrel vertical, carefully insert the syringe tip into solution and withdraw as much solution as possible.

   CAUTION: i. Be careful to minimize the amount of sediment disturbed and drawn into the syringe: too much sediment in the barrel will clog up the filter. ii. Be careful to minimize contact between solution and black rubber tip of the plunger.

   c. Remove the syringe from the cup, wipe off the excess material from the end of the syringe and clear the LuerLok tip by expelling a few drops of solution from the syringe.
   d. Affix an Acrodisc filter to the Leur-Lok tip and expel solution through the filter. Discard the first 2 to 3-mL and collect the rest in a 50-mL plastic, centrifuge tube appropriately labeled. In order to speed up the filtering process and minimize strain to operator's hands, it is recommended that some type of syringe filtering aide be used at this step (e.g. "Main Squeeze" from Scientific Technologies of Raleigh, N.C.).
   e. Cap the tube, mix by inversion 2 to 3 times, and save until analysis.
   f. Rinse out and air dry the 50-mL syringes for future use but discard the filter.
6. Note: Laboratory temperatures where the extraction are performed over the period of work varied from 19° to 24° C.

Comparison of Extraction Procedures

The study of trace metals in Neuse River estuarine sediments was based on a partial dissolution/extraction procedure utilizing 2N HNO_3. It is essential to evaluate and compare the results obtained by this extraction procedure with results of similar studies.

The International Council for the Exploration of the Sea (ICES) recently sponsored an intercalibration exercise between more than 40 laboratories world-wide (Loring and Rantala, 1988). Participants analyzed replicate digests of three samples for concentrations of Al, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Ti and Zn. ICES utilized a total metal analysis (HF + aqua regia), a mercury analysis (HNO_3 + H_2SO_4), and three partial dissolution-extraction procedures including 1) aqua regia (HNO_3 + HCl), 2) 1N HCl, and 3) 25% (v/v) acetic acid (HOAc).

Figure 39 compares the means of results obtained by the various partial extraction procedures obtained by ICES and the samples from the Pamlico study (Riggs et al., 1989b) which are similar in character to those of the Neuse; both sets of results are compared with analysis of the NIST Estuarine Sediment. These comparisons indicate that procedures used in both the Pamlico and Neuse studies are most similar to extraction procedure two with 1N HCl; aqua regia dissolves substantially more metals and 25% acetic acid is slightly weaker. Loring (1981) suggested that the 25% acetic acid approach was least likely to release metals bound in aluminosilicate mineral lattices; thus, this approach may be more likely to represent only material potentially available to biota. It is likely the 1N HCl and 2N HNO_3 extraction procedures release some metals from aluminosilicate minerals, especially considering the relatively high values of aluminum found in both the ICES and samples from the Pamlico and Neuse Rivers. Consequently, these results may overestimate, and almost certainly represent maximum amounts of metals potentially available to biota.

Figure 40 shows another comparison between the technique utilized in the Pamlico and Neuse studies and that used in a heavy metal pollution study in sediments one mile seaward of the Los Angeles wastewater-treatment outfall (LAWWTO) (Bruland et al., 1974). The latter study utilized a partial extraction procedure of 25% acetic acid in hydroxylamine hydrochloride (NH_2OH HCl) and 30% hydrogen peroxide (H_2O_2). Figure 40 also contains analytical results for metals in the National Institute of Standards and Technology estuarine sediment standard SRM-1646 (NIST SRM-1646). These data were produced by the Riggs et al. study (1989b) and utilized the same 2N HNO_3 partial extration procedure as the present Neuse River study.

Data in Figure 40 indicate a similarity in percent metals extracted between the LAWWTO (Bruland et al., 1974) and Pamlico-Neuse studies, as indicated by the NIST SRM-1646 plot. Partial extraction procedures utilized in the Los Angeles study undoubtedly recovered heavy metals in the sediments derived from a known point source, the wastewater-treatment outfall. Similarities in percent extracted between the Los Angeles and Pamlico studies, indicates that the approach utilized in the Pamlico-Neuse studies should be able to determine anthropogenic inputs of heavy metals to the sediments.

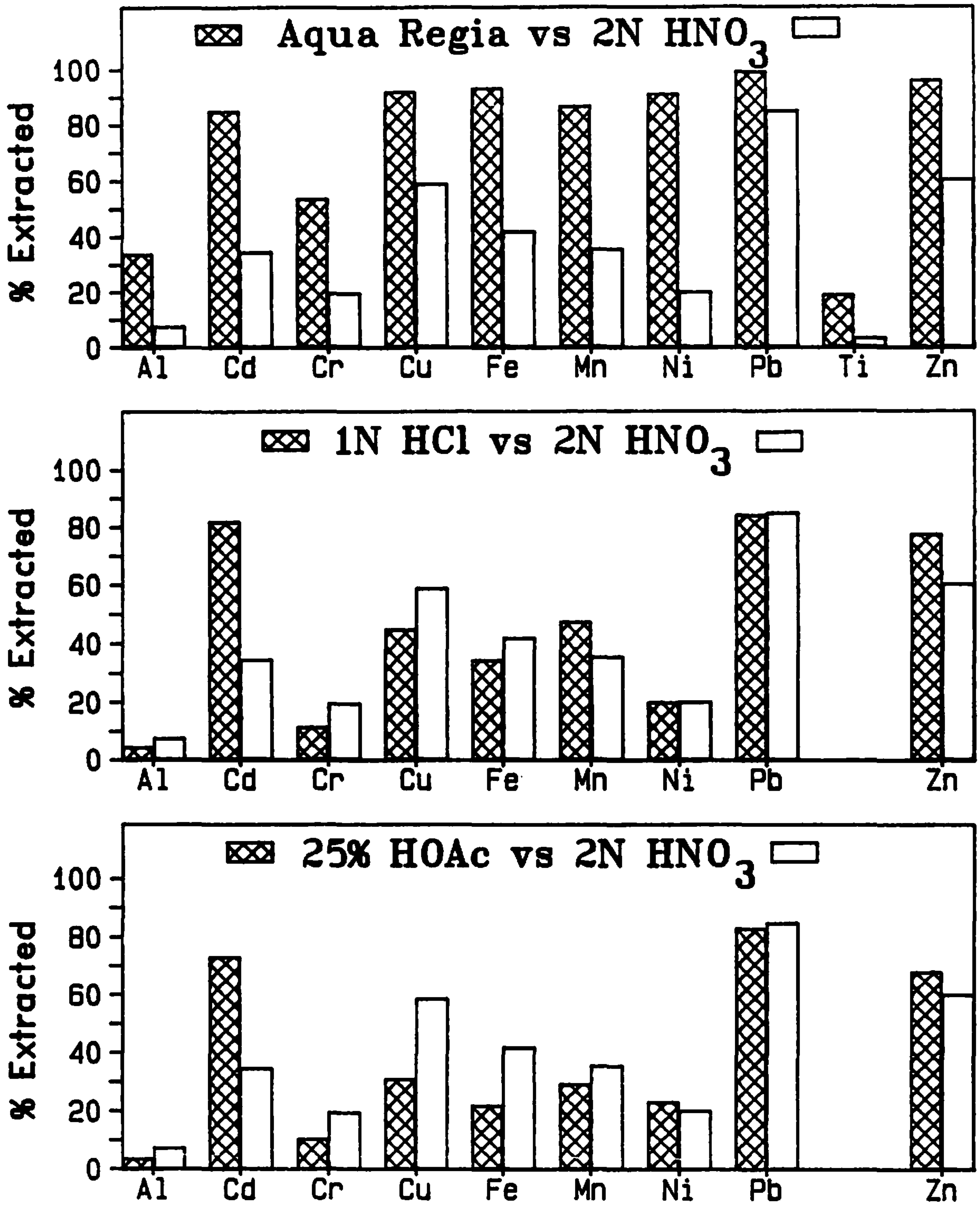

FIGURE 39. Comparison of mean percent of various metals obtained by three partial extraction procedures used by the International Council for Exploration of the Sea (Loring and Rantala, 1988) and those produced by the 2N HNO_3 partial extraction procedure used by Riggs et al. (1989b) in the Pamlico River study. The 2N HNO_3 procedure used in the Pamlico River is the same as that used in the present Neuse River study.

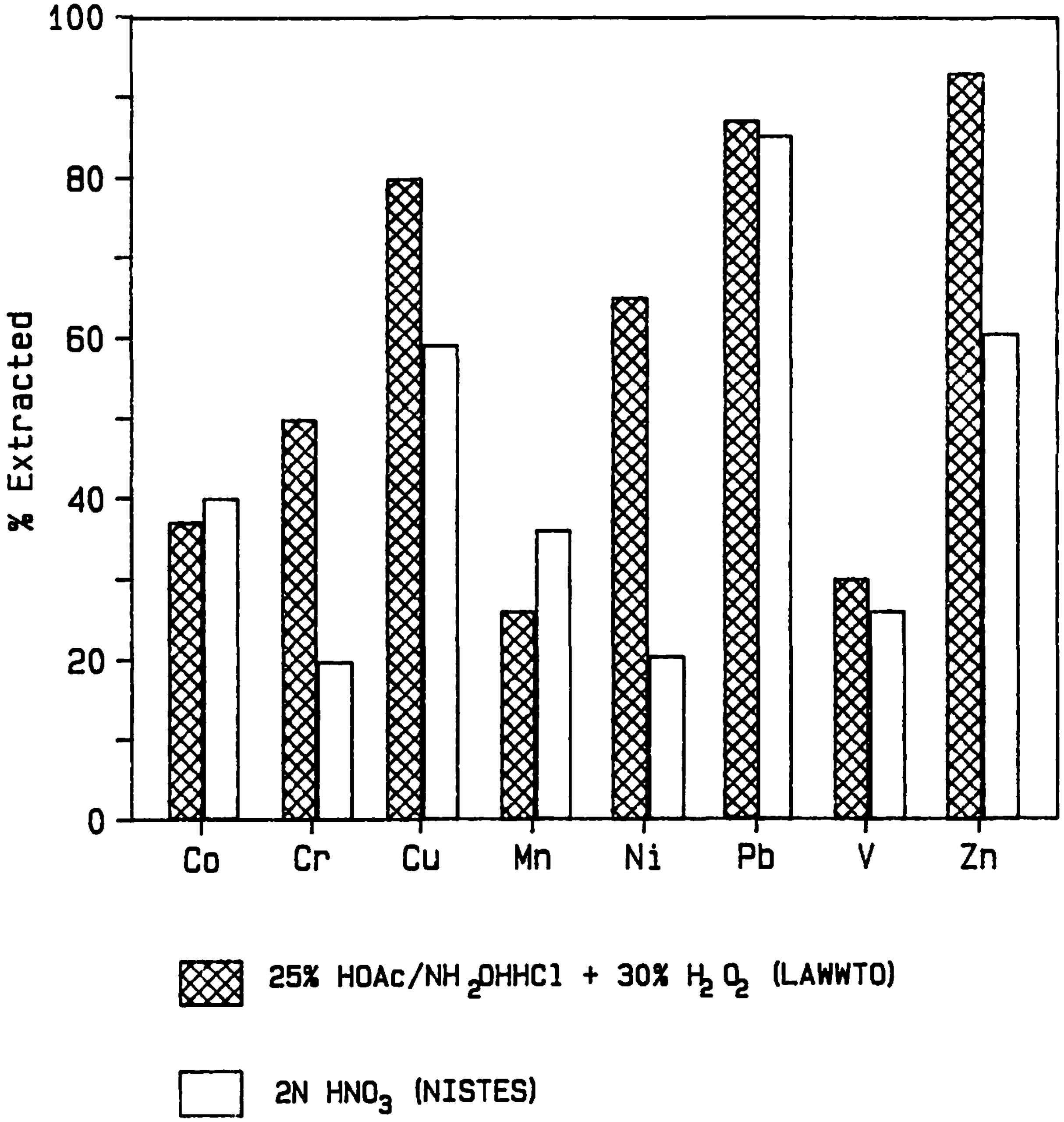

FIGURE 40. Comparison of mean percent of various metals obtained by two partial extraction procedures in metal pollutant studies. The Los Angeles waste water treatment outfall (LAWWTO) study utilized a 25% HOAc/NH_2OHHCl + 30% H_2O_2 procedure (Bruland et al., 1974), whereas the National Institute of Standards and Technology estuarine sediment standard (NISTES) was analyzed during the Pamlico River study (Riggs et al., 1989b) utilizing a 2N HNO_3 procedure.

APPENDIX C

NPDES WASTE WATER DISCHARGE PERMITS FOR THE NEUSE DRAINAGE BASIN AS OF MAY 1990

1. Table delineating the permittee, location, and design flow for industrial and municipal NPDES waste water discharge permits for the Neuse drainage basin

APPENDIX C

NPDES FACILITIES IN THE NEUSE RIVER BASIN ---- AS OF MAY 1990

Facility Name	Township	Latitude Decimal	Longitude Decimal	Design Flow MG/D	Monitoring Parameters
NEUSE RIVER FLUVIAL SYSTEM	(n=196)	Design Flow:	148.0497 million gallons per day		
Piedmont Minerals Co Inc	Hillsboro	36.070278	79.108333	0.0000	
Person Co Sch - Oaklane Elem	Hurdle Mills	36.275556	79.098056	0.0060	
Hillsborough WWTP, Town of	Hillsboro	36.115000	79.092222	3.0000	Cr
Economy Motel	Hillsboro	36.060278	79.085833	0.0050	
Cardens Mobile Park	Durham	36.053611	79.058333	0.0060	
Dixie Trailer Park	Durham	36.031389	78.993889	0.0100	
Aluminum Coil, Inc.	Roxboro	36.380556	78.991111	0.0500	Cr, Zn
Eaton Corp,-Air Controls Div.	Roxboro	36.359167	78.986944	0.0000	
Person Co Sch - Helena Elem.	Timberlake	36.287500	78.952778	0.0030	
Garrard Sausage	Durham	36.059167	78.950000	0.0050	
Sedgefield Dev. Corp-Grande Oak	Durham	35.104444	78.943889	0.0068	
Jimmie's Grill	Durham	36.081944	78.932222	0.0006	
Courtyard	Rougemont	36.218333	78.923333	0.0012	
Mt. Sylvan United Meth. Ch.	Durham	36.098056	78.909444	0.0020	
Durham Co Sch-Little River	Durham	36.144167	78.908333	0.0150	
Nello Teer-Durham	Durham	36.069444	78.894444	0.0000	
Durham (Eno WWTP)	Durham	36.076111	78.887500	2.5000	Cd, Cr, Cu, Pb, Ni, Ag, Zn
Unity Oil CO	Durham	35.985278	78.885556	0.0000	
Griffin Property (Rudy)	Durham	36.077778	78.882500	0.0010	
Durham Co Sch-Mangum Elem	Durham	36.171667	78.875833	0.0050	
Durham (Northside WWTP)	Durham	36.029722	78.863611	10.0000	Cd, Cr, Cu, Pb, Ni, Zn, Hg
Durham Products	Durham	36.059444	78.860278	0.0150	
Bible Baptist Church	Durham	36.022778	78.848611	0.0030	
Apex, Town of (Middle Crk.)	Apex	35.708611	78.834444	3.6000	
Durham Co Sch-Glenn Elem	Durham	36.028333	78.831944	0.0052	
Mobile Acres One	Durham	36.034444	78.827778	0.0121	
Morrisville WWTP, Town of	Morrisville	35.821944	78.821944	0.2000	
Durham Co Sch-Chewning	Durham	36.059722	78.818611	0.0250	
Morrisville (Perimeter Pk), Town	Morrisville	35.850833	78.818333	0.2000	
Colonial Pipeline - Apex	Apex	35.717500	78.817222	0.0000	
Gorman Baptist Church	Durham	36.045278	78.815833	0.0040	
Gorman Mobile Home Park	Bahama	36.046667	78.811667	0.0042	
Heater Util.-Briarwood Farm MH	Cary	35.693056	78.808333	0.0400	
Durham (Little Lick Crk WWTP)	Durham	35.970278	78.805278	1.5000	
Redwood Academy	Durham	36.021667	78.803889	0.0020	
Lawrence Transfer and Storage	Durham	35.888056	78.798611	0.0023	
Days Inn of America	Durham	36.058056	78.795833	0.0250	
Durham Co Sch-Neal Jr HS	Durham	35.980556	78.785278	0.0150	
Ward Transformer Co.	Raleigh	35.900000	78.781944	0.0100	
Northern Telecom-Raleigh	Raleigh	35.899167	78.781111	0.0100	
Cary-North WWTP, Town of	Cary	35.838056	78.780833	4.0000	Cr, Cu, Ag, Zn, Hg

Facility Name	Township	Latitude Decimal	Longitude Decimal	Design Flow MG/D	Monitoring Parameters
Lake Ridge Aero Park	Durham	32.053611	78.779167	0.0160	
Estes Express Lines	Morrisville	35.901389	78.774722	0.0010	
Coley Mobile Home Park	Butner	36.095556	78.774167	0.0250	
DHR-John Umstead Hospital WWTP	Butner	36.127500	78.772222	3.5000	
Carolina Sunrock Corporation	Butner	36.115556	78.770833	0.0000	
Triangle Coatings, Inc.	Morrisville	35.902222	78.770833	0.0050	Cd, Cr, Cu, Pb, Ni, Ag, Zn
DHR-John Umstead Hospital WTP	Butner	36.151944	78.767500	0.1000	
Quality Fast Foods	Morrisville	35.901389	78.767222	0.0010	
Wake Stone Corp-Triangle Quar.	Cary	35.841389	78.762500	0.5000	
Cary-South WWTP, Town of	Cary	35.645278	78.761944	16.0000	
Wake-Durham Limited Part	Raleigh	35.926389	78.755000	0.6000	
Athol Manufacturing Co	Butner	36.138056	78.750278	0.0000	Zn
Martin Marietta-Raleigh/Durham	Raleigh	35.900556	78.750000	0.0000	
S. E. Douglass Warehouse	Raleigh	35.895556	78.747222	0.0010	
U.S. Floor Systems, Inc.	Raliegh	35.881111	78.737500	0.0000	
Wake Co. Sch.-Swift Creek Ele.	Raleigh	35.743333	78.734722	0.0075	
Nero Utility, Inc.	Apex	35.643611	78.733056	0.0533	
The Forty Niners Club, Inc.	Fuquay Varina	35.630556	78.731111	0.0065	
Wake Co. Sch.-Willow Springs E	Willow Springs	35.593056	78.730833	0.0034	
Canterbury Utility Corp.	Raleigh	35.931389	78.728056	0.2500	
Nello Teer-Crabtree	Raleigh	35.845556	78.714167	0.0000	
Mobile Village MHP	Creedmore	36.132778	78.713611	0.0200	
Countryside Mobile Estates	Raleigh	35.651389	78.710833	0.0125	
Creedmore WTP, Town of	Creedmore	36.128056	78.705556	0.0180	
Heater Utilities-Wildwood	Raleigh	35.912222	78.681667	0.1000	
Kayser-Roth Hosiery, Inc.	Creedmore	36.119722	78.670000	0.0000	
Pope Indust. Park, II Ltd.	Raleigh	35.706389	78.664722	0.0000	
Edward Valves, Inc.	Raleigh	35.754444	78.651667	0.0000	Cr
Raleigh Transit/Traffic Comple	Raleigh	35.758333	78.640278	0.0000	
Dumas Oil Company	Raleigh	35.759722	78.631944	0.0000	
Mill Run Assc./Uniprop	Raleigh	35.650833	78.624444	0.0450	
Indian Creek Overlook Dev.	Garner	35.646389	78.603333	0.1120	
Bobby L. Murray/Plantation Inn	Raleigh	35.873611	78.581944	0.0250	
The Falls Utility Co	Raleigh	35.939167	78.579167	0.0060	
Martin Marietta-Garner	Garner	35.705000	78.578333	0.0000	
River Mill Homeown. Assoc., Inc.	Raleigh	35.940278	78.578056	0.0200	
Crosby Water & Sewer	Wake Forest	35.873333	78.576111	0.3200	
Wake Co. Sch.-Vena Wilburn E.	Raleigh	35.822222	78.575556	0.0083	
Wall's Antiques	Raleigh	35.878333	78.575000	0.0005	
Durant Trails Subdivision	Raleigh	35.891111	78.574167	0.3500	
Goodmark Foods-Garner	Garner	35.744167	78.573611	0.1500	
Rowland Industrial Park	Raleigh	35.879167	78.573611	0.0100	
Gresham Lake Utilitiy Co.	Raleigh	35.891667	78.573056	0.0400	
The Durant Group	Raleigh	35.891389	78.568333	0.0500	
Camp Kanata-Durham YMCA	Wake Forest	35.998056	78.566667	0.0025	
Barclay American Mortgage Corp	Raleigh	35.875556	78.564167	0.2000	
Homestead Village MHP	Raleigh	35.875000	78.556944	0.0450	

Facility Name	Township	Latitude Decimal	Longitude Decimal	Design Flow MG/D	Monitoring Parameters
Burlington Ind., Wake Plant	Wake Forest	35.908889	78.555556	5.0000	Cr
Strawns Crossing	Raleigh	35.871111	78.552222	0.1800	
Paragon Development Company	Raleigh	35.877500	78.551389	0.1800	
Foxhall Village MHP	Raleigh	35.840278	78.545000	0.0800	
Wake Cty Comm. Devel. Services	Raleigh	35.691667	78.543889	0.0024	
Hidden Cove, Inc. (MHP)	Raleigh	35.816944	78.539444	0.0350	
Wake Forest-Smith Creek WWTP	Wake Forest	35.909167	78.538889	1.2000	
Heater Utilities-Beachwood	Raleigh	35.800833	78.538333	0.1000	
Riverbend at Lakeside	Raleigh	35.830556	78.537500	0.0260	
Utility Sys. Ltd.-Barclay Down	Raleigh	35.781667	78.537222	0.0350	
Wake High Meadows Homeowners	Raleigh	35.890000	78.531944	0.0350	
River Landings	Raleigh	35.843056	78.531389	0.0500	
Uniprop, Inc./River Walk MHP	Raleigh	35.848333	78.530000	0.0510	
Riverview Mobile Home Park	Raleigh	35.756111	78.530000	0.0350	
Carolina Water Service, Inc.	Clayton	35.647222	78.522778	0.0000	
Ira D Lee Assoc., Inc. Deercha	Wake Forest	35.913333	78.515556	0.1100	
Benson WWTP, Town of	Benson	35.389167	78.509167	1.0000	Cr, Cu, Pb, Zn
Knightdale Estates M H P	Knightdale	35.757500	78.508611	0.0250	
Cross Creek Mobile Estates	Raleigh	35.750000	78.507222	0.0700	
Lovick Property - Tradewinds	Raleigh	35.871667	78.506389	0.0500	
Johnston Co Sch-S. Johnston HS	Smithfield	35.412778	78.501111	0.0200	
Wake Stone Corp-Knightdale	Knightdale	35.809167	78.500556	0.0000	
CWS-Pine Hollow (Willow Brook)	Clayton	35.680833	78.500278	0.0600	
Martin Marietta-Benson	Benson	35.420833	78.498333	0.0000	
Heater Utilities-Mallard Xing.	Raleigh	35.848611	78.495556	0.1000	
Wake Forest WTP, Town of	Wake Forest	35.969167	78.489167	0.0000	
Raleigh Neuse River WWTP	Raleigh	35.716667	78.481944	40.0000	Cr, Cu
Jones Dairy Farm Corp.	Zebulon	35.959722	78.473889	0.1600	
Cottonwood Homeowners Asso	Knightdale	35.762500	78.472778	0.0260	
Carolina Water Service, Inc.	Knightdale	35.748889	78.466111	0.1500	
Clayton WWTP, Town of	Clayton	35.640833	78.464167	0.6000	
Creekside Mobile Village	Knightdale	35.807222	78.464167	0.0200	
Wake Co. Sch.-Rolesville Elem.	Rolesville	35.916667	78.461111	0.0075	
Carolina Water Service , Inc.	Zebulon	35.730556	78.460556	0.2100	
Wake Co. Sch.-E. Wake High Sch	Knightdale	35.813056	78.423611	0.0375	
Wake Co. Sch.-N. Wake Optional	Wendell	35.857500	78.420833	0.0012	
Data General Corp.	Clayton	35.645833	78.406944	0.4500	Cd, Cr, Cu, Pb, Ni, Ag, Zn
Pace Mobile Home Park	Clayton	35.708889	78.381944	0.0000	
Wendell WWTP, Town of	Wendell	35.770000	78.377778	0.7000	Cd, Cr, Cu, Pb, Ni, Ag, Zn
Central Johnston County WWTP	Smithfield	35.501111	78.375556	4.0000	
Wake Co. Sch.-Carver Elem.	Wendell	35.780278	78.353611	0.0037	
Zebulon WTP, Town of	Zebulon	35.822222	78.352222	0.0000	
Burlington Ind., Smithfield	Smithfield	35.511944	78.331944	0.0000	
DOC - Johnston Co Youth CTR	Smithfield	35.554722	78.327222	0.0090	
Fina Oil and Chemical Company	Selma	35.551111	78.313056	0.0000	
Exxon Company USA-Selma	Selma	35.550556	78.312222	0.0000	
Shell Oil Company	Selma	35.548889	78.308611	0.0000	

Facility Name	Township	Latitude Decimal	Longitude Decimal	Design Flow MG/D	Monitoring Parameters
BP Oil - Selma	Selma	35.550000	78.308333	0.0000	
Colonial Pipeline - Selma	Selma	35.551389	78.307222	0.0000	
Triad Terminal Co of Selma	Selma	35.551667	78.306944	0.0000	
Citgo Petroleum - Selma	Selma	35.553056	78.304444	0.0000	
Johnston Co Sch-Corinth Holder	Smithfield	35.731667	78.301111	0.0090	
Phillips Pipe Line Company-Sel	Selma	35.549444	78.297222	0.0000	Pb
Zebulon WWTP, Town of	Zebulon	35.824722	78.296944	0.5280	Cu, Pb, Ni, Zn
Conoco Inc-Selma	Selma	35.555000	78.295833	0.0000	
Middlesex WWTP, Town of	Middlesex	35.782500	78.206111	0.0800	
Bunn Manufacturing Company	Zebulon	35.581389	78.166111	0.0030	
Kenly New WWTP, Town of	Kenly	35.582778	78.158889	0.5200	
E R Squibb & Sons Inc.	Kenly	35.587778	78.145278	0.0040	
Princeton, Town of WWTP	Princeton	35.481667	78.143889	0.2750	
CP&L Lee S.E. (PWR PLT)	Goldsboro	35.377500	78.101944	1.4000	As, Cd, Cr, Cu, Fe, Pb, Ni, V Zn, Se, Hg
Nash Co Sch-Southern Nash HS	Bailey	35.851944	78.092222	0.0150	
Burlington Ind., Mt. Olive	Mount Olive	35.209167	78.085000	0.0000	
Wilson Co. Sch.-Rock Ridge Sch.	Wilson	35.700556	78.070556	0.0110	
Wilson Co.-Springfd. Middle	Wilson	35.663611	78.065278	0.0075	
Celotex Corp.	Goldsboro	35.332500	78.029722	0.0000	
Wayne County (Genda INd. WWTP)	Goldsboro	35.339444	78.024444	0.4000	
Cherry Hospital	Goldsboro	35.383333	78.020556	1.0000	
Goldsboro WWTP, City of	Goldsboro	35.333889	77.985556	6.7350	Cr, Cu, Pb
Worsley Copanies-Scotchman#76	Goldsboro	35.395556	77.984722	0.0060	Pb
Wayne Co Sch-C. B. Aycock H.S.	Pikeville	35.511944	77.975000	0.0100	
Seymour Johnson Air Force Base	Goldsboro	35.336111	77.962222	0.0000	
Wayne Co Sch-Norwayne Jr High	Fremont	35.511667	77.956389	0.0120	
Canshell, Inc.	Wilson	35.686111	77.945556	0.0100	
Standard Commercial Tobacco, Co.	Wilson	35.700278	77.920833	0.0000	Cr, Zn
Wilson WWTP, Town of	Wilson	35.676944	77.914167	12.0000	Cd, Cr, Pb, Ni, Hg
Eureka WWTP, Town of	Eureka	35.515833	77.884444	0.0400	
Wayne Co Sch-Eastern Wayne HS	Goldsboro	35.378611	77.876944	0.0180	
Walnut Creek, Village of	Goldsboro	35.302778	77.863333	0.0250	
Howell's Child Care Center Inc.	La Grange	35.320000	77.814167	0.0187	
Stantonsburg WWTP, Town of	Stantonsburg	35.582778	77.800278	0.3750	
Wilson Co. Sch.-Speight	Wilson	35.655000	77.797778	0.0110	
Wilson Co. Sch.-Gardners	Wilson	35.743056	77.784444	0.0038	
La Grange WWTP, Town of	La Grange	35.310556	77.774167	0.6000	
Joy Manufacturing Co	La Grange	35.293333	77.757778	0.0000	
Lenoir Co Sch-Moss Hill Elem.	Kinston	35.196111	77.752778	0.0110	
Pink Hill WWTP, Town of	Pink Hill	35.055833	77.733611	0.1000	
Lenoir Co Sch-S. Lenoir High	Kinston	35.146944	77.703889	0.0120	
Walstonburg WWTP, Town of	Walstonburg	35.614167	77.680833	0.1380	
Lenoir Co Sch-N. Lenoir High	Kinston	35.343056	77.677778	0.0180	
Snow Hill WWTP, Town of	Snow Hill	35.456389	77.661389	0.2500	
Lenoir Co Sch-Woodington Mid	Deep Run	35.156111	77.622500	0.0120	
A.C. Monk & Company, Inc.	Farmville	35.593333	77.609722	0.0000	

Facility Name	Township	Latitude Decimal	Longitude Decimal	Design Flow MG/D	Monitoring Parameters
Hookerton WWTP, Town of	Hookerton	35.428889	77.596944	0.0600	
Doc - East'n Corp. Ctr.-Greene	Maury	35.480833	77.593056	0.1000	
Lenoir Co Sch - Southwood Elem	Kinston	35.207500	77.563611	0.0090	
Kinston, City-Peachtree Plant	Kinston	35.243611	77.558611	6.7000	Cr, Cu, Pb, Zn
Farmville WWTP, Town of	Farmville	35.585556	77.540833	3.5000	Cr, Cu, Zn
Texasgulf Chemical	Kinston	35.308611	77.527778	0.0000	
Lenoir Co Sch - Contentnea Ele	Kinston	35.314167	77.511667	0.0100	
Lenoir Co Sch- Savannah Middl	Kinston	35.345000	77.506389	0.0075	
Kinston-Northside WWTP	Kinston	35.288056	77.501944	4.5000	Cu, Zn
E. I. Dupont, Kinston	Kinston	35.326944	77.465278	3.6000	
Contentnea Sewage Dist. WWTP	Grifton TWP	35.351667	77.417778	2.0000	Pb
Pitt Co. Sch.-Chicod Elem.	Greenville	35.462778	77.353611	0.0060	
Trenton WWTP, Town of	Trenton	35.065000	77.350556	0.0700	
Pitt Co Sch-D H Conley HS	Greenville	35.529167	77.323056	0.0160	
Vanceboro WWTP, Town of	Vanceboro	35.294722	77.146667	0.1000	
NEUSE RIVER ESTUARINE SYSTEM	(n=46)	Design Flow:	57.7045 million gallons per day		
Weyerhauser, New Bern	Streets Ferry	35.198889	77.112500	35.0000	
Weyerhauser Car Wash	Streets Ferry	35.220556	77.109444	0.0000	
Craven Co. Sch-W. Craven Midd.	New Bern	35.219444	77.150278	0.0170	
Martin-Marietta-Clarks Quarry	New Bern	35.150833	77.136111	12.0000	
Craven Co Sch-W. Craven High	New Bern	35.238889	77.135833	0.0150	
Carolina Water Ser-River Bend	New Bern	35.070000	77.133611	0.1700	
Craven Eval/Training Center	New Bern	35.154722	77.127778	0.0030	
Pepsi Cola New Bern	New Bern	35.098056	77.105556	0.0400	
Martin-Marietta New Bern	New Bern	35.141389	77.085833	0.0000	
Renny Creek Mine	New Bern	35.128611	77.070556	0.0000	
Glenburnie Mine	New Bern	35.139167	77.066389	0.0000	
New Bern, WWTP, City of	New Bern	35.138889	77.059167	4.0000	Cd, Cr, Cu, Pb, Ni, Ag, Zn
Barbour Boat Works, Inc.	New Bern	35.104167	77.043611	0.0005	
Bridgepointe Harbor	New Bern	35.093333	77.042500	0.1000	
D.B. Arant, Inc.	New Bern	35.118056	77.041667	0.0000	
Shipyard Property	New Bern	35.099444	77.039722	0.0750	
Craven Co. Sch-Bridgeton Elem.	New Bern	35.123333	77.026389	0.0070	
Sunbelco, Inc.	New Bern	35.091667	76.991667	0.0000	
Northeast Craven Utilities	New Bern	35.062778	76.950833	0.1000	
Horse Creek Utilities Corp.	New Bern	34.972222	76.936111	0.1000	
Phillips Plating Co.	Bridgeton	35.148889	77.029444	0.1000	Cr, Cd, Cu, Pb, Ni, Ag, Zn
Bridgeton WWTP, Town of	Bridgeton	35.128056	77.028611	0.0750	
Georgia Pacific	Bridgeton	35.125833	77.028333	0.0000	
D&M Enterprises	Bridgeton	35.125833	77.028333	0.0010	
Encee Chemical Sales, Inc.	Bridgeton	35.130556	77.026667	0.0000	
Eastern Shore Partners	Bridgeton	35.120278	77.023333	0.0250	
First Craven Sanitary District	Bridgeton	35.119167	77.000556	0.0000	
Carolina Pines Utility Co.	Havelock	34.972222	76.930000	0.5000	
USMC-Cherry Point MCAS WWTP	Havelock	34.914167	76.911389	3.5000	Cd, Cr, Cu, Pb, Ni, Ag, Zn, Hg

Facility Name	Township	Latitude Decimal	Longitude Decimal	Design Flow MG/D	Monitoring Parameters
Havelock WWTP, City of	Havelock	34.883611	76.908333	1.5000	
Minnesott Beach WTP	Minnesott Beach	35.968333	76.812222	0.0030	
Buccaneer Bay, Inc.	Oriental	37.083333	76.705556	0.0264	
Oriental WWTP	Oriental	35.025556	76.702222	0.1000	
Tom Thumb Seafood	Oriental	35.030833	76.698611	0.0000	
Fulcher Point Pride Seafood	Oriental	35.023611	76.696667	0.0006	
Garland F. Fulcher Seafood	Oriental	35.025000	76.696111	0.0000	
C.M. Muse Seafood, Inc.	Oriental	35.084444	76.634722	0.0000	
Sound Packing Co.	Broad Creek	35.095000	76.605556	0.0000	
McCotter Seafood Co.	Vandemere	35.184722	76.662500	0.0000	
Pamlico Packing Company	Vandemere	35.183333	76.661111	0.0010	
Gaskill Seafood Co.	Bayboro	35.144167	76.900000	0.0000	
Pamlico Co. Sch.-Pamlico H.S.	Bayboro	35.136111	76.780833	0.0300	
Pamlico Co Courthouse-B of Com.	Bayboro	35.146667	76.771389	0.0030	
Potter Seafood Co.	Bayboro	35.144167	76.765000	0.0000	
Pamlico Co. Sch-Pamlico Jr. High	Bayboro	35.136111	76.762500	0.0120	
Bay River Metro Sewarage District	Bayboro	35.145278	76.702222	0.2000	