# Contaminants in Chesapeake Bay Sediments 1984 - 1991
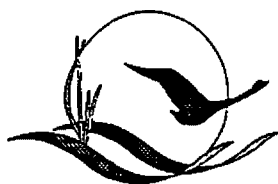
## Chesapeake Bay Program

# Contaminants in Chesapeake Bay Sediments 1984 - 1991

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# ACKNOWLEDGMENTS

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# Introduction

The 1987 Chesapeake Bay Agreement committed the signatories to the development and adoption of a strategy to reduce chemical contaminants in the Bay to levels that will ensure the "protection of human health and living resources" (Chesapeake Executive Council, 1987). The Chesapeake Basinwide Toxics Reduction Strategy, signed in January 1989, included a long-term commitment to "design and implement a long-term sediment monitoring program to identify the location and extent of contaminated sediments within the Bay and its tidal tributaries and to track multiple-year trends in sediment concentrations of toxics" (Chesapeake Executive Council, 1989).

This report presents data on sediment chemical contaminant concentrations in the Chesapeake Bay and its tidal tributaries collected between 1984 and 1991. The majority of this data collection was coordinated by Maryland and Virginia with support from the Chesapeake Bay Program. Data collected by the U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, and the Interstate Commission on the Potomac River Basin are also presented for purposes of comparison and to provide supplementary data to that collected by Maryland and Virginia.

The primary objectives of this report are to describe the spatial patterns in the distribution of sediment chemical contaminants in Chesapeake Bay and to compare sediment chemical contaminant concentrations in Chesapeake Bay to sediment quality guidelines in order to identify areas where sediment chemical contaminants may adversely impact aquatic biota. Trends and year-to-year differences in concentrations of sediment chemical contaminants evident from the monitoring program are discussed to the extent possible with limited data. Where possible, the recently collected data are compared with data available from the 1970s and early 1980s to determine whether there is any evidence that sediment chemical contaminant concentrations in Chesapeake Bay sediments are changing.

Following this introductory chapter, Chapter 2 provides information on the methods used in gathering the data discussed throughout the remainder of the report. Discussion of the sediment chemical contaminant concentration data is organized into several chapters which deal separately with distinct geographic regions of the Bay, namely the mainstem Bay (Chapter 3), the tidal tributaries (Chapter 4), Baltimore Harbor and the Back River (Chapter 5), the Elizabeth River (Chapter 6), and the Anacostia and upper Potomac rivers (Chapter 7). Each of these chapters begins with a description of the sampling program and the sediment characteristics in that area, followed by a brief summary of the data with respect to each class of chemical contaminants. This summary is followed by discussion of the data with respect to individual chemical contaminants. Following the presentation of data for each of these geographic areas, Chapter 8 provides a preliminary analysis of sediment trace metal concentrations in Chesapeake Bay sediments and identifies stations at which sediment concentrations of one or more trace metals are probably elevated due to anthropogenic activities. Chapter 9 discusses baywide patterns in sediment chemical contaminant concentrations and ranks areas of the Bay according to the potential risk to aquatic biota posed by exposure to the measured sediment concentrations of chemical contaminants.

## Sediments as a Habitat

Many aquatic organisms live in or on bottom sediments. Animals and other lesser organisms that live in or on the sediment are called benthic organisms or just "benthos." Examples include clams, oysters, clamworms, and bloodworms used for fish bait, crabs, small shrimp-like organisms called amphipods, and bottom fish such as flounder.

Benthic organisms modify the characteristics of the sediment they live in by building tubes and burrows, by binding sediment particles together with mucus, and by ingesting the sediment itself and egesting it after its nutrients have been removed (Jones and Jago, 1993). Tubes and burrows, along with the filtering activities of benthic organisms during feeding, can enhance the exchange of materials between

the sediment and the overlying water, and can create zones of oxygenated sediment in layers that would otherwise be anoxic i.e., completely without oxygen. Burrowing and feeding activities also mix the sediment, causing "bioturbation" which may bury or release contaminants bound to sediment. Bioturbation may also homogenize the top 20 cm of bottom sediments. Because bioturbation has the effect of mixing recently deposited sediments with older, previously deposited sediments, bioturbation makes it difficult to determine when a given layer of sediment was deposited.

The particle size of sediments plays an important role in determining which benthos can exist in a particular benthic habitat. For instance, benthic organisms which feed on organic deposits in the sediment tend to be found in areas with siltier sediments, while organisms which feed by filtering suspended particles from the water column are typically predominant in sandier sediments (Day et al., 1989). Thus the percentage of the finest particles in the sediment, the silt and clay particles, is an important sediment characteristic. Depending on the percentage of each size class of particles, a sediment may be categorized as sand, muddy sand, sandy mud, or mud (Table 1.1).

Other environmental characteristics are typically associated with specific types of sediment. For example, muddy sediments are generally found in areas where the overlying water currents are minimal, since fast currents will not allow fine particles to settle. The large surface area of sediments composed predominantly of fine particles can support large bacterial populations, and fine sediments consequently often have high rates of decomposition of organic material and high respiration rates. This rapid sediment metabolism combined with slow water movement often results in fine, muddy or silty sediments being low in oxygen or "reduced".

| Table 1.1 Categorization of sediments by grain size composition | | |
|---|---|---|
| Category | Percentage Sand (Particles 62-1000 μm) | Percentage Mud (Particles ,62 μm) |
| Sand | ≥ 90 | < 10 |
| Muddy Sand | > 50 | < 50 |
| Sandy Mud | ≤ 50 | > 50 |
| Mud < 15 | ≥ 85 | |

Source: Scott et al, 1988

## Types of Sediment Associated Chemical Contaminants

Sediment chemical contaminants include trace metals, polycyclic aromatic hydrocarbons, and chlorinated organic compounds and pesticides. Each of these categories is discussed briefly below. The Chesapeake Bay Program has designated several toxic substances from these categories as Chesapeake Bay Toxics of Concern (Chesapeake Bay Program, 1991a) due to their significant potential to be deleterious to the Chesapeake Bay. The Chesapeake Bay Program has also identified a list of chemicals which are being considered for designation as Chesapeake Bay Program Toxics of Concern, but for which more information on toxicity and abundance in the Chesapeake Bay basin is needed (Chesapeake Bay Program, 1991a).

## Trace Metals

Trace metals are naturally present in sediments[. Trace metals are also] released to the environment through municipal and industrial wastewater, the burning of fossil fuels, [the weathering and corrosion] oxidation of metals, and leaching from landfills (MacDonald, 1993). Some trace metals are used in wood preservatives, paints, and pesticides, and may be released into the environment from these sources as well (Macdonald, 1993). Eight trace metals have been routinely monitored in Chesapeake Bay sediments: arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc.

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Cadmium, chromium, copper, lead, mercury, and tributyl tin are Chesapeake Bay Toxics of Concern (Chesapeake Bay Program, 1991a). Arsenic and zinc are on the list of chemicals under consideration for inclusion on the Toxics of Concern list, but for which more information is being sought (Chesapeake Bay Program, 1991a).

## Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds composed of two or more fused aromatic rings (Macdonald, 1993). PAHs are produced by the high temperature combustion of organic matter such as fossil fuel combustion occurring in automobile engines, coal-fired electric power plants, and wood fires (MacDonald, 1993). PAHs may also enter the aquatic environment via oil refinery effluents and spills of petroleum or petroleum-based products (Macdonald, 1993). The anthropogenic inputs of PAHs have greatly increased environmental PAH concentrations and PAHs are now ubiquitous in the environment (Menzie et al., 1992). Many individual PAHs have been monitored in Chesapeake Bay sediments, including anthracene, benzo[a]pyrene and fluoranthene.

Polycyclic aromatic hydrocarbons which have been designated as Chesapeake Bay Toxics of Concern are benzo[a]anthracene, benzo[a]pyrene, chrysene, fluoranthene and naphthalene (Chesapeake Bay Program, 1991a). No PAHs are on the list of compounds for which more information is being sought.

## Chlorinated Organic Compounds and Pesticides

Chlorinated organic compounds include many pesticides, polychlorinated biphenyls (PCBs), dioxins and furans. Several organochlorine pesticides were previously widely used, but are either no longer registered for use in the U.S., or their uses have been narrowly restricted, e.g., DDT and chlordane, (MacDonald, 1993). These compounds are still of concern, however, because they are extremely persistent in the environment (MacDonald, 1993). Other less persistent organic compounds containing chlorine or other halogens are still used as pesticides in the Chesapeake Bay area, e.g., alachlor, while other commonly-used pesticides, such as carbofuran, do not contain chlorine or other halogens (Chesapeake Bay Program, 1994).

PCBs are extremely persistent man-made compounds that have been widely used in electrical transformers and various industrial applications (Chesapeake Bay Program, 1991b). The U.S. banned production of PCBs in the late 1970s, but poor operating and disposal practices involving products and equipment containing PCBs can lead to environmental contamination (MacDonald, 1993). PCBs can exert chronic, sublethal effects on aquatic organisms (Kennish et al., 1992). PCBs are also of concern because they have considerable potential to accumulate in the tissues of aquatic organisms (Kennish et al., 1992).

Chlorinated dioxins and furans are two families of compounds with a basic structure consisting of two benzene rings linked by one or two oxygen atoms (MacDonald, 1993). These compounds are generally produced unintentionally, either during chemical manufacturing, the incomplete combustion of materials containing chlorine atoms and organic compounds, or during the bleaching process at pulp and paper manufacturing plants (MacDonald, 1993).

The PCBs and the pesticides alachlor, atrazine and chlordane have been designated Chesapeake Bay Toxics of Concern (Chesapeake Bay Program, 1991a) while aldrin, dieldrin, fenvalerate, metolachlor and permethrin are nominees for inclusion. (Chesapeake Bay Program, 1991b).

## Sediments as a Source or Sink for Chemical Contaminants

The fate of chemical contaminants in the aquatic ecosystem is determined by a complex combination of biological, geochemical, and physical processes associated with the sediment environment. Chemical contaminants initially associated with sediments may be taken up by aquatic organisms, released to the overlying water, or permanently buried within the sediments. Chemical contaminant adsorption to sediment particles, precipitation of insoluble metal compounds, colloidal flocculation and

biological uptake all play a role in depositing chemical contaminants in the sediments. Thus, sediments can act as a "sink" for many chemical contaminants and concentrations of metals and organic contaminants are typically much higher in sediments than in the overlying water column (Helz et al., 1975).

Chemical contaminants associated with sediment particles may become buried as they are covered by additional sediment. The burial of contaminated sediments may be slowed by disturbance of the sediments caused by bioturbation or storms or dredging operations which move or remove more recently deposited sediments. Sediment-associated chemical contaminants may also be transported from one area to another by tide and wind-driven currents.

The adherence of chemical contaminants to sediment particles is dependent upon the chemistry of the surface sediments and that of the overlying water. While chemical conditions usually favor the removal of chemical contaminants from the water column through binding to sediment particles, changes in physical or chemical characteristics of the sediment environment or the overlying water column can convert the sediment from a "sink" to a "source" of toxic substances to the water column, or vice versa, often on a seasonal basis. For example, changes in oxygen availability, physical disturbance such as dredging, or bacterial or geochemical decomposition of organic matter may effect the release of sediment-associated chemical contaminants.

Both metals and organic contaminants can be removed from the water through adherence to iron and manganese oxides or organic material which frequently coat the surfaces of sediment particles (Luoma, 1990). Since finer sediments have a greater surface area for a given mass than coarser sediments, fine sediments generally have a greater capacity to adsorb chemical contaminants. Thus, the concentrations of chemical contaminants are often higher in fine sediments than in coarser sediments.

## Bioavailability of Chemical Contaminants in the Sediment

Exposure of organisms to sediment-associated chemical contaminants can occur through the ingestion of sediment or interstitial water, direct physical exposure of the gills or body wall to sediment or interstitial water, and the partitioning of the chemical contaminant between sediment, water, and organism. Biological availability from each of these exposure pathways will vary with the chemical and physical characteristics of the chemical contaminant as well as with the characteristics of the organism and sediment. Significant uptake of chemical contaminants from sediments has been found, for example, for cadmium by polychaete worms and amphipods (Kratzenburg and Boyd, 1992; Ankley et al., 1991; Mac et al., 1990; Tay, 1989) and for polycyclic aromatic hydrocarbons (PAHs) by chironomids (Clements, et. al, 1994).

The bioavailability of metals is often affected by oxygen availability (Luoma, 1990). When the concentration of oxygen is low, sulfur becomes reduced and divalent metals may precipitate as sulfides and be less bioavailable. In oxygenated sediments, trace metals may bind to iron and manganese hydroxides and organic matter (Luoma, 1990). The properties of the trace metal and the availability of various potential binding sites in the sediment will determine the bioavailability of a given trace metal. The concentration of total organic carbon in sediments has significant effects on the bioavailability of non-ionic organic contaminants in sediments (DiToro et al., 1991).

## Sediment Accumulation Rates

Knowledge of sedimentation rates helps to determine potential areas of accumulation of potentially toxic substances and the period over which sediment-associated chemical contaminants may have been deposited (Brush et al., 1982). Officer et al. (1984) used Pb-210 to date sediments from cores and estimated average sedimentation rates of 0.76 cm/year and 0.35 cm/year for the Maryland and Virginia portions of the mainstem Bay, respectively. However, because sedimentation rates vary widely

in space and in time, average sediment accumulation rates for large areas are of limited value. Since sediment accumulation rates were not determined as part of the various sediment contaminant monitoring programs conducted in Chesapeake Bay, sedimentation rates from the scientific literature are reported in Appendix A. Average sediment accumulation rates are used for regions when site-specific data are not available.

Sediment accumulation rates estimated using pollen dating techniques (Brush, 1990) reveal a pattern similar to that found by Officer et al. (1984). The highest sedimentation rates were in the upper mainstem Bay (probably as a result of high sediment loads from the Susquehanna River), with the lowest rates in the middle mainstem Bay. Sedimentation rates in the lower mainstem Bay were midway between sedimentation rates estimated for the upper and middle mainstem Bay. Brush (1984a) found that within the tidal tributaries the highest sediment accumulation rates occurred in upper and middle tributary reaches, with the lowest accumulation rates observed in tributary lower reaches.

The two methods which have been used to measure sediment accumulation rates (Pb-210 and pollen) in Chesapeake Bay reveal similar spatial patterns and result in estimates of sedimentation rates in reasonable agreement. However, pollen dating produces sediment accumulation rates that are consistently lower than rates determined by Pb-210. Part of the error may result from difficulties in determining the exact dates corresponding to sedimentary horizons (Brush et al., 1982).

### Management Applications of Sediment Chemical Contaminant Data

Knowledge of the concentrations and spatial distributions of sediment-associated chemical contaminants is helpful in focusing management actions. However, assessing the environmental risks of contaminated sediments is a very complicated matter, especially since some chemical contaminants (notably trace metals) are naturally present in sediments. Extremely elevated concentrations of chemical contaminants in sediment are usually worthy of increased attention, and concentrations at natural background levels almost certainly pose an insignificant risk. Determining the environmental significance of sediment contaminant concentrations between these extremes is more problematic.

No final federal sediment quality criteria have been published, and draft criteria exist for only five substances (U.S. Environmental Protection Agency, 1991a, 1991b, 1991c, 1991d). However, regulatory sediment quality criteria developed and adopted for use in the Puget Sound area of Washington state (Washington State Department of Ecology, 1991), and various informal sediment quality guidelines, e.g., Long and Morgan, 1990; MacDonald, 1993, are available to suggest what sediment concentrations may result in adverse effects to aquatic biota. The U.S. Environmental Protection Agency is currently developing a contaminated sediment management strategy which will has wider applicability (U.S. Environmental Protection Agency, 1992a).

Upon finding elevated concentrations of chemical contaminants in sediments, field investigations may be conducted to assess the toxicity of the sediments to resident organisms, as well as the potential for bioaccumulation of the sediment contaminants. Managers can determine the historic and current potential sources of these chemical contaminants and methods to reduce current sources. The costs and benefits of various action (or of taking no action) can be evaluated to develop a sound management strategy.

The presence of elevated concentrations of chemical contaminants in sediments does not necessarily imply that the sediments pose significant environmental or human health risks. Goldberg (1992) draws a helpful distinction between contamination and pollution of the environment. By Goldberg's definition, pollution is "an alteration in the composition of the marine environment with a consequential loss of resources such as seafoods, healthy ecosystems..." etc. To establish a pollution event, a cause and effect relationship between the pollutant and the affected resource must be established. Contamination, in contrast, is defined as an alteration in the composition of the environment without the consequent losses of resources associated with pollution.

Evaluation of data presented at the Chesapeake Bay Contaminated Sediment Critical Issues Forum suggested that sediment pollution by trace metals and anthropogenic organic compounds in Chesapeake Bay is minimal and localized, although contamination is widespread (Chesapeake Bay Program, 1993). This localization of pollution to restricted areas has important implications for management strategies.

**Approaches to the Development of Sediment Quality Criteria and Guidelines**

Evaluation of the toxicity of various concentrations of chemical contaminants in sediments is complicated because different organisms, and even different life stages of the same organism, may react differently to the same concentration of a chemical contaminant in the sediment. While substantial information is available regarding the sediment concentrations of chemical contaminants which cause harmful effects to resident organisms during acute (short-term) exposures, information regarding the sediment concentrations of chemical contaminants which would be harmful in chronic (long-term), exposures is limited to relatively few substances. Synergistic or antagonistic interactions between individual chemical contaminants are even less well understood.

The binding of chemical contaminants to various sediment components, such as organic carbon or sulfides, may render them unavailable to biota. As the amount of these sediment components may differ among different sediments, two sediment samples with the same concentration of a given chemical contaminant may have differing portions of the chemical in a biologically available form, and thus exhibit different levels of toxicity.

Ideally, sediment quality criteria or guidelines will provide benchmarks useful in evaluating the potential for toxic effects, and thus be useful in the assessment of sediment quality, identification of problem areas for remedial action, evaluation of dredge spoil for disposal, and the design and evaluation of monitoring programs (Chapman, 1989). Several methods have been developed to determine whether contaminated sediment is likely to be toxic and whether or not some type of action, e.g., regulation or remediation, may be required. Chapman (1989) divides the approaches into two categories: those that provide sediment quality guidelines or criteria on a chemical-by-chemical basis only and those that can also address mixtures of chemicals by directly measuring site-specific biological effects.

*Chemical-by-Chemical Sediment Criteria and Guidelines*

These criteria or guidelines are typically numeric, relatively easy to apply and interpret, and can be modeled effectively. They also have lower data requirements than the other category of criteria since they do not require the collection of information on site-specific biological effects. However, these approaches do not explicitly take into account the potential for interactions in mixtures of chemical contaminants or the presence of unmeasured chemical contaminants, and cannot predict biological availability or biological effects.

The *background sediment chemistry* approach compares sediment contaminant concentrations in the area of interest to reference sediments that are assumed to be uncontaminated. It has minimal data requirements, but assumes that biological effects are not influenced by grain size, organic carbon, or other sediment characteristics. It does not specifically address biological effects or bioavailability, but can be combined with bioassay results to address those issues. Chapman (1989) considers this approach inappropriate for criteria development because it does not make allowance for biological effects and bioavailability.

The *water quality criteria* approach compares chemical contaminant concentrations in interstitial water with EPA water quality criteria intended for application to water column measurements. Its major advantage is that it uses a well-established toxicological data base. Its disadvantages are the lack of water quality criteria for many chemical compounds and the lack of a standardized method for measuring [the concentration of] chemical concentrations in the interstitial water of sediments

(Chapman, 1989). This method also implicitly assumes that interstitial water is the route of exposure of aquatic organisms to sediment contaminants.

In the *sediment/water equilibrium partitioning* approach, which is currently favored by EPA for development of sediment criteria for nonpolar organic compounds, contaminant concentrations are normalized for organic carbon content and equations are used to predict the resulting concentrations in the interstitial water (Shea, 1988). These predicted concentrations are then compared to applicable water quality criteria. This method assumes that organic contaminants are in equilibrium with sediment organic carbon and interstitial water. Under these conditions, the activity of the contaminant will be equal in both the water and sediment phase, and thus this method does not assume that interstitial water is the only route of exposure. The only field measurements that are required are sediment concentrations of chemical contaminants and organic carbon. A disadvantage of this approach is the limited number of chemicals for which water quality criteria are available and, for some chemicals, uncertainty in the estimates of the partition coefficients which are used to predict contaminant concentrations in interstitial water (MacDonald, 1993).

## Sediment Criteria and Guidelines Applicable to Mixtures of Chemical Contaminants

These approaches address the issue of adverse biological effects due to chemical mixtures and the presence of unmeasured chemical contaminants. They can be used with any toxic substance and require no assumptions about interactions between the chemical contaminants and organisms. However, these criteria are more difficult to interpret and it can be difficult to demonstrate that a particular contaminant has caused a biological effect. They also are much more data intensive, since they require measurements of biological effects in addition to chemical measurements.

The *bulk sediment bioassay* approach generally follows that used to develop water quality criteria. Chemical analyses and bioassays can be conducted on field-collected sediments from contaminated and reference areas and quantitatively compared to determine the extent of contamination and what potential effects it may have on benthic organisms. This approach has the advantage of providing a direct, integrated measurement of toxicity resulting from one or several chemicals present at a particular site, and uses relatively simple and inexpensive procedures. This approach is routinely used for assessing the suitability of ocean or freshwater disposal of dredge spoil. A disadvantage of this approach is that bioassays of field sediment do not provide chemical-specific results. Thus, attempts to determine what sediment concentrations of a specific chemical will likely result in biological effects could be confounded by the presence of unmeasured or covarying chemical contaminants. Changes in physical and/or chemical characteristics in the sediments may also reduce the relevance of the laboratory results to field conditions (Chapman, 1989).

In the *spiked sediment toxicity test* method a dose-response relationship for a particular toxic substance can be determined by spiking sediments with that substance. The major advantage of this approach is that it can be used to develop chemical-specific criteria (Chapman, 1989). The major disadvantage of this test is that it assumes that the experimental conditions created in the laboratory adequately simulate conditions in the field, an assumption that has not been confirmed for an array of chemicals (Adams *et al.*, 1992). In addition, criteria developed using one sediment type may not be applicable to another sediment with differing chemical or physical properties.

The *screening level concentration* approach estimates the highest level of a sediment associated contaminant that can be tolerated by 95 percent of the species of benthic organisms living in the sediment in an area. It requires matching data on sediment chemical concentrations and benthic invertebrate distributions. Disadvantages of this method include the sensitivity of the derived criteria to the range and distribution of contaminant concentrations and the suite of species used in developing the criteria (Chapman, 1989).

The *sediment quality triad* approach uses three measurements: (1) sediment chemistry to determine

the degree of contamination, (2) sediment bioassays to determine toxicity, and (3) changes in benthic community structure or presence of fish pathology to determine the biological effects of sediment contamination and toxicity (Chapman, 1989). This approach may be the most comprehensive and realistic, but it is difficult to apply because of the extensive data requirements (Alden, 1992).

The *apparent effects threshold* (AET) utilizes matching field data on sediment chemical concentrations and at least one indicator of bioeffects from a number of sites (Chapman, 1989). The AET for a given chemical is the sediment concentration of the contaminant above which statistically significant biological effects are always found in the data set. This approach was used by the state of Washington in developing its sediment management standards for use in the Puget Sound area (MacDonald, 1993). The criteria for a particular chemical developed from data on sites within one area may be invalid if chemical contaminant concentrations among these sites covary strongly. Thus, AET criteria should be based on toxicological information collected from a set of sites within the area in which the criteria are to applied (Alden and Rule, 1992). There is a risk of under-protection of biological resources in adopting AETs as sediment guidelines, since by definition they are based on the concentration at which toxic effects will always be expected to occur, although effects may sometimes be observed at lower concentrations (Chapman, 1989).

## Numeric Sediment Criteria and Guidelines

Numeric sediment quality standards and guidelines have been developed for many chemical contaminants, but they remain controversial (Lee and Jones-Lee, 1993). Despite this controversy, the need for an evaluative tool for sediment quality has led various governmental agencies in North America to develop and use such criteria (Table 1.2).

Long and Morgan (1990) collected the results of eighty-five studies using equilibrium partitioning calculations, spiked sediment bioassays, and various types of bioeffects/sediment contaminant concentration co-occurrence analyses such as the screening level approach and apparent effects threshold. The only observations included in the analysis for a given chemical contaminant were those for which adverse biological effects were found and believed to be related to the presence of the chemical contaminant in the sediment. The data are all from marine and estuarine studies. For each chemical contaminant, these observations were ordered by the bulk sediment concentration of the chemical contaminant. The lower 10th percentile of ordered observations in which biological effects were found was used to define the Effects Range-Low (ER-L) concentration for the chemical contaminant. This ER-L is considered to be an estimate of the low end of the sediment contaminant concentration range at which adverse effects may begin or are predicted to occur among sensitive life stages or species. The Effects Range-Median (ER-M) concentration was defined as the 50th percentile of ordered concentrations for which toxicity was observed. The ER-M is considered an estimate of the sediment concentration above which toxic effects would be "frequently or always observed or predicted among most species" (Long and Morgan, 1990). These ER-L and ER-M values were intended to serve only as informal sediment quality guidelines, and were originally developed to aid the National Oceanographic and Atmospheric Administration (NOAA) in identifying sites at which chemical contaminants in the sediment had the greatest potential for causing adverse biological effects (Long and Morgan, 1990).

The data set used to generate the ER-L and ER-M values has subsequently been expanded, and the estimates of values comparable to the ER-L and ER-M values have been revised (MacDonald, 1993). In this effort, initiated by the state of Florida, the data base used by Long and Morgan (1990) was updated, with a special emphasis on adding more studies from the southeastern U.S., which was poorly represented in the original data set. In addition, the methods used to develop the lower limit of toxic concentrations (termed the No Observable Effect Level or NOEL) and the concentration at which toxic effects occur frequently (termed the Probable Effects Level or PEL) were revised. Unlike the method used to determine ER-L and ER-M values, the methodology for determining the NOEL and PEL utilized both observations in which toxicity was found and observations in which toxicity was not found.

The NOEL concentration was developed by applying a safety factor of two to the upper range of concentrations at which the majority (approximately 75 percent) of observations found no adverse biological effects of the chemical contaminant. The safety factor of two was applied because the data base was biased towards acute (short-term exposure) toxicity data. The PEL concentration was similarly defined as the concentration above which most observations (approximately 75 percent) found adverse biological effects. In MacDonald's (1993) terminology, sediment contaminant concentrations below the NOEL concentration are expected to only rarely be associated with toxic effects to aquatic biota. At sediment contaminant concentrations above the NOEL value but below the PEL value, MacDonald (1993) considered toxic effects to aquatic biota "possible". At sediment contaminant concentrations above the PEL, toxic effects to aquatic biota are considered "probable" (Figure 1.1). These NOEL and PEL guidelines are intended to apply to marine and estuarine waters only (MacDonald, 1993).

For both the Long and Morgan (1990) ER-L and ER-M values and the NOEL and PEL values of MacDonald (1993), the level of confidence the authors place in the validity of the sediment quality guidelines varies among different chemical contaminants, depending on the amount and consistency of toxicity data available for each chemical contaminant. For several contaminants for which ER-L and ER-M guidelines are available, MacDonald (1993) did not develop NOEL and PEL guidelines because he believed insufficient data were available to adequately determine the concentration ranges likely to be associated with adverse biological effects. Neither the ER-L and ER-M guidelines nor the NOEL and PEL guidelines address the potential for bioaccumulation of persistent chemical contaminants and resultant potential adverse effects on higher levels of the food chain.

The state of Washington has developed regulatory sediment quality criteria based on the apparent effects threshold approach applied to matching biological effects and sediment chemistry data from the Puget Sound area (MacDonald, 1993). The criteria were designed to meet a goal of no adverse acute or chronic effects on biological resources and no significant health risk to humans. The numeric criteria are used initially to identify sediments which meet or fail to meet the goal of no adverse effects. Biological testing may be used to confirm or reverse the initial designation based on chemical criteria (Washington State Department of Ecology, 1991).

The EPA has published draft criteria for five nonpolar organic compounds based on the equilibrium partitioning approach (Environmental Protection Agency, 1991a, 1991b, 1991c, 1991d, 1994). Several other jurisdictions have also published sediment guidelines or criteria. The province of Ontario has developed sediment quality guidelines for ten metals, total PCBs, and nine organochlorine pesticides utilizing a combination of the background chemistry approach (metals only), the equilibrium partitioning approach (non-polar organic compounds only), and a modification of the traditional screening level concentration approach (Persaud et al., 1990; Jaagumagi 1990a, 1990b).

**Application of Sediment Quality Guidelines to Chesapeake Bay Sediment Contaminant Data**

There are no generally accepted methods for the difficult task of assessing the biological significance of the concentrations of chemical contaminants in sediments. This report compares sediment contaminant concentrations from various monitoring programs conducted in the Chesapeake Bay to the No Observable Effect Level (NOEL) and the Probable Effects Level (PEL) concentrations developed by MacDonald (1993). The MacDonald (1993) NOEL and PEL values provide sediment quality guidelines for evaluating the potential for biological impacts of the measured concentrations of most of the chemical contaminants monitored in the Chesapeake Bay. In addition, these guidelines are based on a large data base consisting of data from throughout the U.S., rather than one focusing on a limited geographic area.

Throughout this report, toxic effects are considered likely only at stations where average sediment chemical contaminant concentrations are in excess of MacDonald's (1993) PEL values. The NOEL

values (MacDonald, 1993) are listed, but interpretation of the biological significance of sediment chemical contaminant concentrations between the NOEL and PEL values is left to the reader. Where NOEL and PEL values (MacDonald, 1993) are not available, sediment contaminant concentrations may be compared to other sediment quality guidelines or standards. Table 1.2 lists the values provided in several sets of sediment quality guidelines or criteria to assist the reader in making more detailed comparisons between data on sediment chemical contaminants and various sediment quality guidelines and criteria.

MacDonald (1993) notes that toxicity from sediment chemical contaminant concentrations between the NOEL and PEL values may be dependent on site-specific conditions, and that it is difficult to reliably predict the occurrence of toxic effects associated with sediment contaminant concentrations in this range based solely on data on sediment chemistry. Because of the greater level of uncertainty associated with these intermediate concentrations of sediment-associated chemical contaminants, the authors believe that interpreting their potential for exerting toxic effects requires more information than can be provided in this survey.

In comparing the data on sediment contaminant concentrations with NOEL and PEL concentrations, the intended applications of these sediment quality guidelines should be kept in mind. The NOEL and PEL concentrations were developed to use in determining the potential for sediment contaminants to induce toxic effects; the values cannot be used by themselves to identify sediments that are exerting toxic effects on local biota. We recommend that these guidelines be used in conjunction with other tools and protocols to provide comprehensive evaluation of sediment quality (MacDonald, 1993).

The NOEL and PEL concentrations are derived from a wide variety of studies using diverse measures of adverse biological impacts and involving contaminated sediments from many different geographic areas contaminated from a wide variety of sources. Because of differences in sediment characteristics, the sensitivities of resident species, and the mix of contaminants which may be present at a given site, the guidelines cannot be expected to always accurately predict the range of concentrations at which a given chemical contaminant may exert toxic effects in the sediments of Chesapeake Bay and its tidal tributaries.

In some cases, the NOEL and PEL concentrations are strongly influenced by the results of chemical-biological co-occurrence analyses such as the apparent effects threshold and screening level concentration approaches. As discussed previously, a weakness of this type of study is that covariance of measured or unmeasured sediment associated chemical contaminants may affect the validity of their findings.

Finally, the sediment quality guidelines are not expressed in terms of factors that are thought to control the bioavailability of sediment associated chemical contaminants, such as acid volatile sulfide for divalent metals and total organic carbon for non-ionic organic compounds and some trace metals. Since the toxicity of a sediment with a given concentration of a chemical contaminant will vary [strongly]*significantly* depending on a variety of chemical and physical characteristics of the sediment, the presence of other chemical contaminants, and the sensitivity of the suite of organisms which are exposed to the sediment, it is difficult to determine how well the NOEL and PEL concentrations may apply at a given site.

In Table 1.2 the sediment quality criteria published by various jurisdictions in North America is presented. The Effects Range - Low(ER-L) and Effects Range - Median(ER-M) values are from Long and Morgan, 1990. The sediment management standards for the state of Washington are from the Washington Department o Ecology, 1991. Criteria for protection of benthic organisms in freshwater (EPA-F) and saltwater (EPA-S) habitats is from that agency's publication, 1993. No-effect level(O-NE), Low-effects level(O-LE), and Severe-effects level(O-SE) come from Province of Ontario sediment criteria(Persaud *et al*, 1990).

The superscripts, L, M, and H denote low, medium, and high confidence in ER-L,ER-M, NOEL, and PEL values as assigned by Long and Morgan (1990) for ER-L and ER-M, and by MacDonald (1993) for NOEL, and PEL

Table 1.2. Sediment quality criteria or guidelines published by various jurisdictions in North America. Units are parts per million dry weight for metals and in parts per billion dry weight for polycyclic aromatic hydrocarbons (PAHs), pesticides and polychlorinated biphenyls (PCBs) unless otherwise indicated. ID indicates insufficient data were available to develop sediment quality guidelines.

| Chemical Contaminant | ER-L | ER-M | WASH | NOEL | PEL | EPA-F. | EPA-S | O-NE | O-LE | O-SE |
|---|---|---|---|---|---|---|---|---|---|---|
| **Trace Metals** | | | | | | | | | | |
| Arsenic | 33[L] | 85[M] | 57 | 8[H] | 64[M] | | | ID | 6 | 33 |
| Cadmium | 5[H] | 9[H] | 5.1 | 1[H] | 7.5[H] | | | ID | 0.6 | 10 |
| Chromium | 80[M] | 145[M] | 260 | 33[H] | 240[M] | | | ID | 26 | 110 |
| Copper | 70[H] | 390[H] | 390 | 28[H] | 270[H] | | | ID | 16 | 110 |
| Lead | 35[M] | 110[H] | 450 | 21[H] | 160[H] | | | ID | 31 | 250 |
| Mercury | .15[M] | 1.3[H] | 0.41 | 0.1[H] | 1.4[L] | | | ID | 0.2 | 2 |
| Nickel | 30[M] | 50[M] | | ID | ID | | | ID | 16 | 75 |
| Silver | 1.0[M] | 2.2[M] | | 0.5[H] | 2.5[H] | | | | | |
| Zinc | 120[H] | 270[H] | 410 | 68[H] | 300[H] | | | ID | 120 | 820 |
| **Polycyclic Aromatic Hydrocarbons (PAHs)** | | | | | | | | | | |
| Acenaphthene | 150[L] | 650[L] | | 22[L] | 450[H] | 130[I] | 230[I] | | | |
| Anthracene | 85[L] | 960[M] | | 85[M] | 740[H] | | | | | |
| Benzo(a)anthtracene | 230[M] | 1600[M] | 130[I] | 160[L] | 1300[H] | | | | | |
| Benzo(a)pyrene | 400[M] | 2500[M] | 99[I] | 230[H] | 1700[H] | | | | | |
| Chrysene | 400[M] | 2800[M] | 110[I] | 220[M] | 1700[H] | | | | | |
| Dibenzo(a,h)-anthracene | 600[M] | 2600[M] | | 310[H] | 3200[M] | | | | | |
| Fluoranthene | 600[H] | 3600[H] | 160[I] | 380[L] | 3200[H] | 1020[I] | 1340[I] | | | |

[1] Carbon in the sediment.Criteria are in ppm carbon, i.e., normalized for organic carbon. The dry weight concentration for each chemical has been divided by the fraction of total organic carbon in the sediment.

| | ER-L | ER-M | WASH | NOEL | PEL | EPA-F | EPA-S | O-NE | O-LE | O-SE |
|---|---|---|---|---|---|---|---|---|---|---|
| Naphthalene | 340[M] | 2100[H] | 99[I] | 130[M] | 1100[H] | 180[I] | | | | |
| Phenanthrene | 225[M] | 1380[M] | | 140[M] | 1200[H] | | 240[I] | | | |
| Pyrene | 350[M] | 2200[M] | | 290[H] | 1900[M] | | | | | |
| Total PAHs | 4000[L] | 35000[M] | | 2900[H] | 28000[H] | | | | 0.002 | 11000[I] |
| Pesticides and Polychlorinated Biphenyls(PCBs) | | | | | | | | | | |
| Chlordane | 0.5[L] | 6.0[L] | | ID | ID | | | 5.0 | 7.0 | 600 |
| Dieldrin | 0.02[L] | 8.0[L] | | ID | ID | 11[I] | 20[I] | 0.6 | 2.0 | 91000 |
| p,p'-DDE | 2.0[M] | 15[L] | | 1.7[H] | 130[H] | | | | 5 | 19 |
| p,p'-DDD | 2.0[M] | 20.0[L] | | ID | ID | | | | .008 | 6 |
| p,p'-DDT | 1.0[L] | 7.0[L] | | ID | ID | | | | .008 | 71 |
| Total DDT | 3.0[L] | 350[L] | | 4.5[L] | 270[M] | | | | .007 | 10 |
| Endrin | | | | | | 4.2[I] | 0.76[I] | | | |
| Lindane | ID | ID | | ID | ID | | | .0002 | 0.16[I] | |
| Total PCBs | 50[M] | 400[M] | | 24[M] | 260[M] | | | .01 | .07 | 530[I] |

[I] Carbon in the sediment.Criteria are in ppm carbon, i.e., normalized for organic carbon. The dry weight concentration for each chemical has been divided by the fraction of total organic carbon in the sediment

| Table 1.2a Revised ER-Ls and ER-Ms. In th final editing stages of this report an update to these guidelines was published. | | |
|---|---|---|
| CHEMICAL CONTAMINANT | ER-L | ER-M |
| Trace Metals | | |
| Arsenic | 8.2 | 70 |
| Cadmium | 1.2 | 9.6 |
| Chromium | 81 | 370 |
| Copper | 34 | 270 |
| Lead | 46.7 | 218 |
| Mercury | 0.15 | 0.71 |
| Nickel | 20.9 | 51.6 |
| Zinc | 150 | 410 |
| PAHs | | |
| Acenaphthene | 16 | 500 |
| Anthracene | 85.3 | 1,100 |
| Benzo(a)anthracene | 261 | 1,600 |
| Benzo(a)pyrene | 430 | 1,600 |
| Chrysene | 384 | 2,800 |
| Dibenzo(a,h)-anthracene | 63.4 | 260 |
| Fluoranthene | 600 | 5,100 |
| Naphthalene | 600 | 2,100 |
| Phenanthrene | 240 | 1,500 |
| Pyrene | 665 | 2,600 |
| Total PAHs | 4,022 | 44,792 |
| Pesticides and PCBs | | |
| p,p'-DDE | 2.2 | 27 |
| Total DDT | 1.58 | 2.2 |
| Total PCBs | 22.7 | 1.58 |

Long, E.R., D.D. MacDonald, Sherri L. Smith, and Fred D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19(1): 81-97.

# Methods

Data from several monitoring programs have been included or compared in this report. As one would expect, different methods have often been used for the different programs, thus comparisons between programs must be made with care. Quality assurance data are included in the appendix.

**Design of Sediment Contaminant Monitoring Programs**

Sediment contaminant monitoring in the Chesapeake Bay and its tidal tributaries has been conducted by several jurisdictions (Maryland, Virginia, National Oceanic and Atmospheric Administrations (NOAA), Environmental Protection Agency (EPA)), each addressing a separate Bay region or concern. Thus, the frequency and timing of sample collection, the collection methods and the analytical protocols often differ among the monitoring programs. Details of the monitoring program design (i.e., location of stations, frequency of sample collection) in each region of the Bay are presented at the beginning of the chapter presenting data for that region. The following section describes the methods used for sample collection and sample analysis in the monitoring programs which provided the data discussed in the following chapters.

Data from sediment contaminant monitoring programs conducted by Maryland, Virginia, the EPA Chesapeake Bay Program, and the Interstate Commission on the Potomac River Basin (ICPRB) are the primary focus of this report and the following discussion of methods focuses on these programs. The sediment contaminant monitoring programs conducted by the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) and the National Oceanic and Atmospheric Administrations's (NOAA) National Status and Trends Program used methods similar to those employed by the ICPRB and are described below. See Environmental Protection Agency (1993) for further information on the methods used in the EMAP sediment contaminant monitoring program. MacLeod *et al.* (1985) and National Oceanic and Atmospheric Administration, (1991) provide complete information on the methods employed in the NOAA National Status and Trends monitoring program.

**Sample Collection**

Sediment samples collected from the Maryland tidal tributaries by the Maryland Department of the Environment (MDE) and from the Bay mainstem as part of the joint EPA Chesapeake Bay Program-MDE- Virginia Department of Environmental Quality (VADEQ) mainstem monitoring program were surface samples (top 2 cm) of sediments collected using acid and methanol-rinsed stainless steel Van Veen (Maryland) or Smith-MacIntyre (Virginia) dredges. The upper 2 cm were removed from three grabs at each station location and mixed in a solvent-rinsed stainless steel bucket to produce a composite sample. Each grab sample was taken while the boat was anchored at the same location.

This composite sample was homogenized and then dispensed into three pre-cleaned jars with teflon lids. In the Virginia sampling program, all jars were of glass and one sample was used for the analysis of organic contaminants; the second jar for the analysis of metals, sediment grain size composition, and acid- volatile sulfide (AVS) and total organic carbon (TOC); and the third jar for duplication in case of sample loss (Unger *et al.*, 1991). In the Maryland sampling program, two glass jars were used, the first for metals analysis and the second for grain size composition, AVS, and TOC measurements. A third Teflon jar was used for analysis of organic contaminants. In both sampling programs, samples were stored on ice in the field and immediately frozen when returned to the laboratory.

Sediment samples from the upper Potomac and Anacostia rivers were collected with an acetone-rinsed, stainless steel petite-Ponar grab sampler. The top 2-3 cm of sediment not in contact with the sides of the sampler were removed and placed into a pre-cleaned pyrex bowl. This process was repeated until sufficient sediment had been collected. The grab samples were mixed until

homogeneous and then aliquots were placed into separate containers. Samples for organic analysis were placed in pre-baked glass mason jars capped with pre-baked aluminum foil-lined caps and stored on ice while in the field. Samples for grain size and trace metals analysis were placed into pre-cleaned glass jars and sealed with Teflon-lined caps and stored on ice in the field. Sediment samples for AVS were placed in a 50 ml plastic centrifuge tube which was then quick frozen in the field using dry ice. Once on shore, sediment samples for organic and metal analyses were placed in a freezer at -20°C, while samples for grain size analysis were kept at 4°C (Velinsky et al., 1992).

**Metals**

All metal extractions from sediments collected from the Maryland tidal tributaries by MDE and the Bay mainstem as part of the joint Chesapeake Bay Program-Maryland-Virginia mainstem monitoring program were done by a "total recoverable" method using hydrochloric and nitric acids to extract metals from the sediment. Metal analyses of sediment samples from the James River collected by the VADEQ were also analyzed by the "total recoverable" method. This method generally yields the majority of metals from the sediment but does not recover metals tightly bound within the mineral lattice (Horowitz, 1985).

Trace metal analyses of mainstem sediments were conducted by the EPA Region III laboratory in Annapolis, Maryland in 1984 and 1985, and by the Virginia Institute of Marine Science (VIMS) laboratory in 1991. Maryland tributary sediments in all years were analyzed for trace metal content by the Maryland DHMH laboratory. Quality assurance/quality control (QA/QC)data for the VIMS and DHMHs lab are shown in Appendices B and C respectively. Analyses of the James River sediment samples collected by VADEQ were conducted by the Division of Consolidated Laboratories Services in Richmond, Virginia.

The NOAA National Status and Trends Program, the EPA's Environmental Monitoring and Assessment Program (EMAP), and the study by the Interstate Commission on the Potomac River Basin (ICPRB) of the Anacostia and upper Potomac rivers used the "total" method of trace metal analysis of sediments. In this method, hydrofluoric acid is used to completely dissolve the silica matrix in sediment. This method of metal extraction is more rigorous than the "total recoverable" method described above.

Analyses of sediment metals in samples collected by MDE and VADEQ used atomic absorption spectrophotometry using atomic absorption spectrophotometry with a graphite furnace for arsenic, cold vapor for mercury and inductively coupled plasma (ICP) for all other trace metals. The ICPRB utilized atomic absorption spectrophotometry with cold vapor for mercury, and graphite furnace for all other trace metals (Velinsky et al., 1992).

**Acid-Volatile Sulfides**

Acid-volatile sulfide (AVS) concentrations were measured in the 1991 mainstem sediment samples and in samples from the upper Potomac and Anacostia rivers. The analyses of AVS in mainstem sediments was performed by the Virginia Institute of Marine Science (QA/QC data are in Appendix BII) and the Maryland Department of Health and Mental Hygiene according to the EPA draft Method 376.3. In this method, sulfide in the sample is converted to hydrogen sulfide by acidification with hydrochloric acid at room temperature. The hydrogen sulfide is purged from the sample and trapped in a solution of silver nitrate. The silver sulfide precipitate is filtered and weighed. Analysis of AVS in sediment samples collected in the upper Potomac and Anacostia rivers by the ICPRB was performed using the method of Cutter and Oatts (1987).

**Total Organic Carbon**

Sediment total organic carbon (TOC) for the Maryland tributary samples collected by MDE were analyzed by the Chesapeake Biological Laboratory using a Leeman CHN analyzer and the

II-2

Environmental Protection Agency's Method 440 (Environmental Protection Agency, 1992). Detection limit development is shown in Appendix D. The mainstem Bay and Virginia tributary samples collected in 1991 were analyzed for TOC by VIMS using a Carlo Erban Analyzer, following acidification of those samples for which effervescence was noted following treatment of a subsample with 10% hydrochloric acid (Unger et al., 1992). Total organic carbon concentrations in sediment samples from the Anacostia River and upper Potomac River collected by the ICPRB were determined by infra-red absorption after combustion in an $O_2$ stream using a LECO WR-12 Total Carbon system. The sediments were acidified prior to analysis (Velinsky et al., 1992).

The acidification step in sediment total organic carbon measurements has the effect of removing carbonates. This step was not used in Maryland tributary sediments, but since the majority of carbon in Chesapeake Bay sediments is organic (Hennessee et al., 1986), the differences in estimates of total organic carbon obtained by the two methods are probably minor.

**Grain size**

Grain size analysis methods for samples from the Maryland and Virginia tributaries and the mainstem Bay collected by the Maryland and Virginia monitoring programs followed Plumb (1981) and are described in Appendix E. The silt fraction was distinguished from the clay fraction only in Virginia. For consistency, silt and clay (the fraction less than 63 μm) were combined for all presentations of grain size data in this report. Grain size analyses in the ICPRB study of the Anacostia and upper Potomac Rivers followed the method of Folk (1980).

Ranges for general categories of grain size distribution that have proven useful in differentiating benthic community habitats are listed in Table 1.1. These categories are used throughout the report to describe the grain size distribution typical of sediments from various areas of Chesapeake Bay and its tidal tributaries.

**Organic Compounds**

Organic contaminants in all mainstem Bay and Virginia tributary sediment samples were analyzed by the Virginia Institute of Marine Science (VIMS). Maryland tributary sediment samples from 1986 and 1987 were analyzed for organic contaminants by the Maryland Department of Health and Mental Hygiene following VIMS' methods (VIMS Division of Chemistry and Toxicology, 1991). Maryland tributary sediment samples from 1991 were analyzed for organic contaminants by the State Chemist Laboratory in the Maryland Department of Agriculture (MDA).

The VIMS' methodology for analysis of organic compounds included a 48 hour soxhlet extraction with dichloromethane, followed by the use of gel permeation chromatography and silica gel chromatography to remove large biogenic molecules and isolate an aromatic fraction containing most of the anthropogenic compounds of interest. Polycyclic aromatic hydrocarbons and related compounds were analyzed by gas chromatography with flame ionization. Chlorinated organic compounds were analyzed by gas chromatography with electrolytic conductivity detection, a detector highly selective for chlorinated compounds and less likely to be affected by interfering compounds than the typically used electron capture detector (Unger et al., 1991). QA/QC data are presented in Appendix B.

The method followed by the MDA in the analysis of organic compounds in Maryland tributary sediments was somewhat different than the VIMS' method. Samples were extracted by mixing with methylene chloride in a blender, removal of the methylene chloride fraction, and then re-mixing of the aqueous and solid portions, with the mixing procedure repeated a total of three times. A sulfur cleanup (EPA method 366A) was applied to the extract prior to subsequent analysis. Pesticides and polychlorinated biphenyls (PCBs) were analyzed with a gas chromatograph with an electron capture detector while

polycyclic aromatic compounds (PAHs) were analyzed by reverse phase chromatography with fluorescence detection. QA /QC data is presented in Appendix F.

Organic contaminants in sediment samples from the Anacostia and Upper Potomac rivers were analyzed following a method adapted from MacLeod et al. (1985). Samples were soxhlet extracted and the extracts fractionated by alumina:silica open column chromatography. Aliphatic hydrocarbons were analyzed by gas chromatography using a flame ionization detector. Aromatic hydrocarbons were separated and quantified by gas chromatography-mass spectrometry. Pesticides and PCBs were quantified by gas chromatography and an electron capture detector (Velinsky et al., 1992).

The VIMS laboratory uses a "fingerprint method" of analysis of organic contaminants in sediment samples which is designed to provide a reasonable level of confidence in identifying and quantifying those anthropogenic PAHs and chlorinated organic compounds which are of greatest interest and are most likely to be found in environmental samples. The "fingerprint method" analytical technique utilized by VIMS has evolved during over twenty years of experience analyzing environmental samples for hazardous organic chemicals at VIMS. Because of this use of the "fingerprint method", a list of organic chemical analytes is not available for sediment samples from the mainstem and Virginia tributaries. Because VIMS' methods were followed in the analysis of Maryland tributary samples from 1986 and 1987, a list of organic chemical analytes is also not available for these samples. A list of organic chemical analytes for the analysis of Maryland tributary samples in 1991 by the Maryland State Chemist Laboratory is provided in Appendix F.

The method detection limits for organic contaminants typically vary among sediment samples due to differences in the volume of solvent used in extracting the contaminants of interest and differences in the concentrations of potentially interfering chemicals in the sediment samples. The nominal detection limit for organic contaminants at the VIMS' laboratory was 0.01 ppb (Unger et al., 1991).

### Quality Assurance and Quality Control

Quality assurance and quality control procedures in each laboratory consisted of internal standards, laboratory duplicates and spike analyses and/or analyses of standard reference materials. Quality assurance/quality control (QA/QC) data for each of the three laboratories performing analyses for the Virginia and Maryland monitoring programs are provided in Appendices as listed above. Quality assurance/quality control information for the ICPRB study can be found in Velinsky et al., 1992.

### Normalization of Sediment Concentration Data

The data contained in this report are reported both as "measured" concentrations (bulk concentration by dry weight), and as "normalized" concentrations, in which the bulk concentration is normalized with reference to grain size composition for trace metals and to sediment organic carbon for organic contaminants.

### Trace Metals

The percentage of fine material in sediments, in particular the proportion of sediment passing through a 63 μm sieve, usually correlates well with concentrations of trace metals in the sediment (Horowitz, 1985). This is believed to occur because fine particles have a greater surface area per unit mass than do large particles and consequently adsorb more metals than the same mass of larger particles (Horowitz, 1985). In addition, larger particles adsorb only small quantities of metals and thus act to dilute the metal concentration of sediments (Horowitz, 1985). Thus, data tables for sediment trace metal concentrations include data normalized by dividing the bulk metal concentration of the sediment by the fraction of the sediment consisting of particles less than 63 μm. (Horowitz, 1985). Grain size normalization is often used to reduce natural variation in sediment trace metal concentrations that are

The normalized sediment concentrations of organic compounds presented in this report were determined by dividing the sediment concentration by the fraction of organic carbon in the sediment. Nonpolar organic contaminants have an affinity for organic carbon, and thus organic contaminants in sediments tend to be located in organic coatings which surround sediment particles (Long and Morgan, 1990). Thus, a sediment with a high concentration of organic carbon will generally have a greater concentration of a particular organic contaminant than will a sediment with a low organic carbon concentration receiving a similar loading of the contaminant (Long and Morgan, 1990).

Sediments may have different concentrations of organic carbon due to both natural factors or differences in anthropogenic loadings of organic carbon or nutrients which stimulate primary production (Long and Morgan, 1990). In some sediment contaminant monitoring programs, total organic carbon is considered a sediment contaminant (National Oceanographic and Atmospheric Administration, 1991). Thus, in some cases, normalizing sediment concentrations of organic contaminants eliminates variation in contaminant concentrations due to differences in sediment organic carbon content. However, since elevated sediment total organic concentrations may be the result of anthropogenic inputs, carbon normalization does not strictly control for only natural variations in organic contaminant concentrations.

It has frequently been observed that the correlation between the sediment concentration of non-ionic organic compounds and the toxicity of sediments is relatively low (DiToro et al., 1991). The relationship between observed toxic effects and sediment organic contaminant concentrations in different sediments is much improved by normalizing sediment concentrations based on organic carbon content (DiToro et al. 1991). These results are due to the fact that for sediments with greater than 0.2% organic carbon by weight, organic carbon is the predominant phase for chemical sorption of non-ionic organic compounds (Di Toro et al., 1991).

# Mainstem Data Collection and Analysis

Data on concentrations of chemical contaminants in mainstem sediments have been obtained from monitoring programs of the Virginia Department of Environmental Quality, the Maryland Department of the Environment, and the U.S. EPA Chesapeake Bay Program Office. Data on mainstem sediment trace metal concentrations are available for 1984, 1985, (Maryland stations only) and 1991. Data on mainstem sediment concentrations of polycyclic aromatic hydrocarbons, PAHs, are available [from] *for the years* 1984, 1985, 1986, and 1991. The only available data on chlorinated organic compounds are from 1991.

Data on sediment concentrations of potentially toxic chemicals in the Chesapeake Bay mainstem are presented for aggregations of stations representing various segments of the Bay mainstem (Table 3.1). The aggregations of stations for the mainstem segments (Figure 3.1 and Figure 3.2) generally follow the Chesapeake Bay segmentation scheme described in Heasly, *et al.* (1989). Data from four river mouth stations (at the Potomac, Rappahannock, York, and James Rivers), and from the station in Mobjack Bay (north of the York River mouth) are presented individually to indicate sediment-associated contaminant concentrations at the interface between the major tidal tributaries and the Bay mainstem.

For trace metals, data are available for four linear arrays of stations which transect the Bay across the deep trough (segments three and four). The data for these stations are included in the summary statistics for these segments, but are also presented as longitudinal aggregates to compare middle mainstem Bay sediments from west to east. This longitudinal aggregation is supported by the observations of Helz and Valette-Silver (1992) which suggest that western flank sediments may be derived from the Susquehanna River, while eastern flank sediments may have been transported from the south.

All available data were combined for the analyses. Medians, quartiles, and the minimum and maximum values of bulk concentrations of each chemical contaminant are presented in tables and displayed graphically. This presentation provides measures of central tendency (median and mean), dispersion (quartiles), and range. Statistics are also provided for trace metal concentrations normalized by the fraction of silt and clay particles in the sediment and for PAH concentrations normalized by the fraction of total organic carbon in the sediment. However, grain size distribution and/or total organic carbon data were not available for all samples. Note that the scale may differ for graphs of measured (bulk) concentrations and normalized concentrations of the same contaminant.

Analysis of variance (ANOVA) was used to test for statistically significant differences in mean sediment contaminant concentrations among the different years during which sediment contaminant data were collected. If the ANOVA was significant, a Duncan multiple-range test was used to determine which years had significantly different mean sediment contaminant concentrations.

**Table 3.1** Segment location, grain size, and sedimentation rates for mainstem stations. The asterisk (*) indicates stations sampled for organic compounds and metals; other stations sampled for metals only. (M=mud; MS=muddy sand; SM=sandy mud. See Table 1.1 for details.)

| Segment No. or Region | Stations | Grain Size | Approx. Sed. Rate cm/yr |
|---|---|---|---|
| 1 | MCB1.1* | MS | |
| 2 | MCB2.1, MCB2.2* | SM | 0.6-0.38 |
| 3 | MCB3.1,MCB3.2*,MCB3.3W,MCB3.3C*,MCB3.3E | M | 0.12-1.0 |
| 4 | MCB4.1W,MCB4.1C*,MCB4.1E,MCB4.2W,MCB4.2C, MCB4.2E,MCB4.3W,MCB4.3C*,MCB4.3E,MCB4.4 | SM | 0.09-0.54 |
| 5 | MCB5.1*,MCB5.2,MCB5.3,CB5.2(1984),CB5.4(1991) | SM | 0.007-0.07 |
| 7 | CB7.5E (1984), CB7.1S* (1984, 91), CB7.3E* (1991) | SM | |
| 8 | CB8.1E* | MS | |
| West | MCB3.3W, MCB4.1W, MCB4.2W, MCB4.3W | SM | 0.13-0.28 |
| Center | MCB3.3C, MCB4.1C, MCB4.2C, MCB4.3C* | M | 0.12-0.26 |
| East | MCB3.3E, MCB4.1E, MCB4.2E, MCB4.3E | SM | 0.08-0.12 |
| Potomac | MLE2.3* | | |
| Rappahanock | LE3.6* | M | 0.08 |
| Mobjack Bay | WE4.1* | M | |
| York | WE4.2* | M | 0.14 |
| James | LE5.5* | MS | |

Sources: Goldberg, et al. 1973; Schubel and Hirschberg, 1977; Brush, 1989; Brush 1990.

Figure 3.1  Chesapeake Bay mainstem segments.
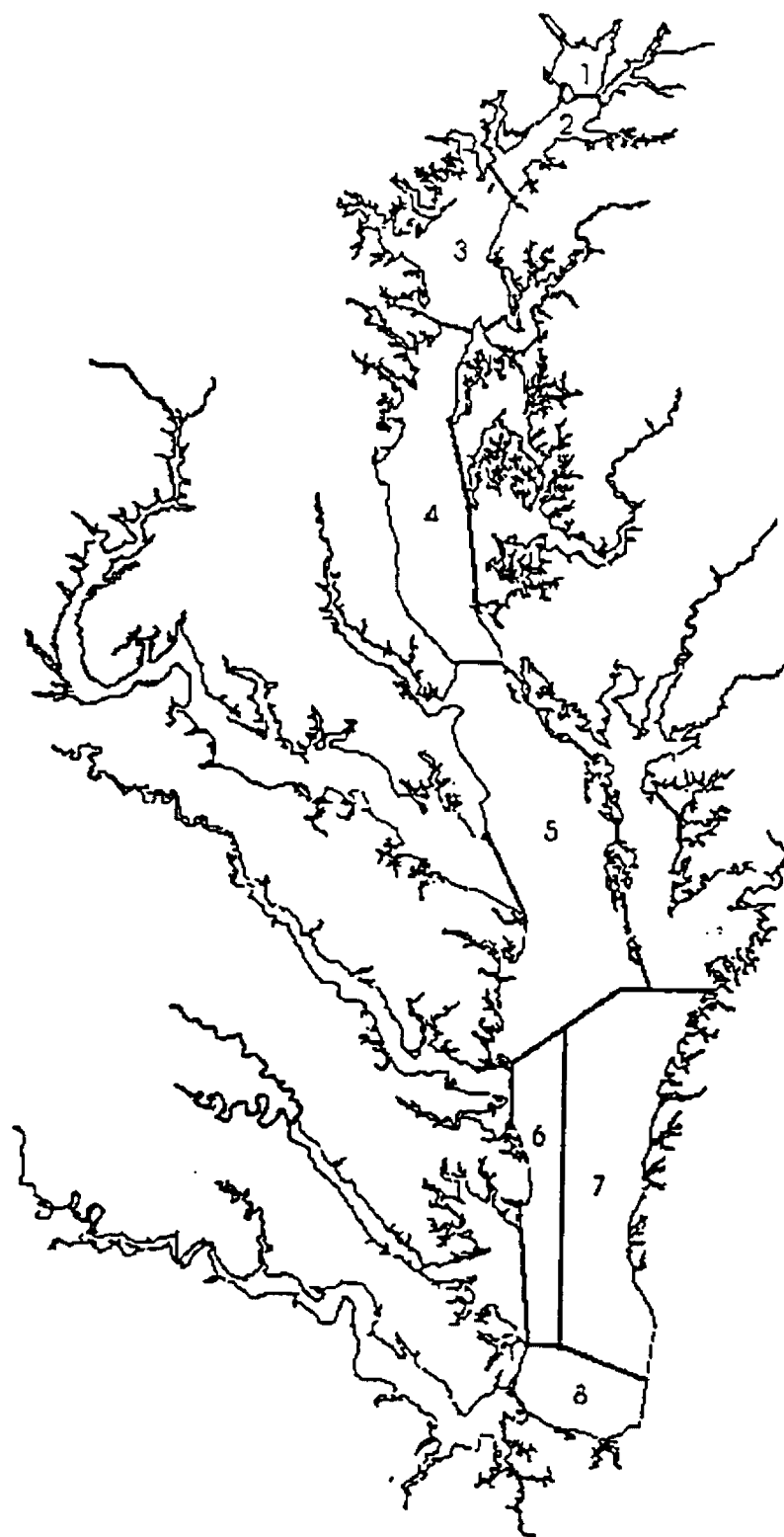
# Figure 3.2 Sediment Contaminant Monitoring Stations in Chesapeake Bay Mainstem

MCB1.1

MCB2.1

MCB2.2

MCB3.1

MCB3.2

MCB3.3 W,C,E

MCB4.1 W,C,E

MCB4.2 W,C,E

MCB4.3 W,C,E

MCB4.4

MCB5.1

MCB5.2

MCB5.3

CB5.4

LE3.6

CB7.1S

WE4.1

WE4.2

CB7.3E

LE5.5

CB8.1

● Trace metals only

🔲 Trace metals and organic contaminants
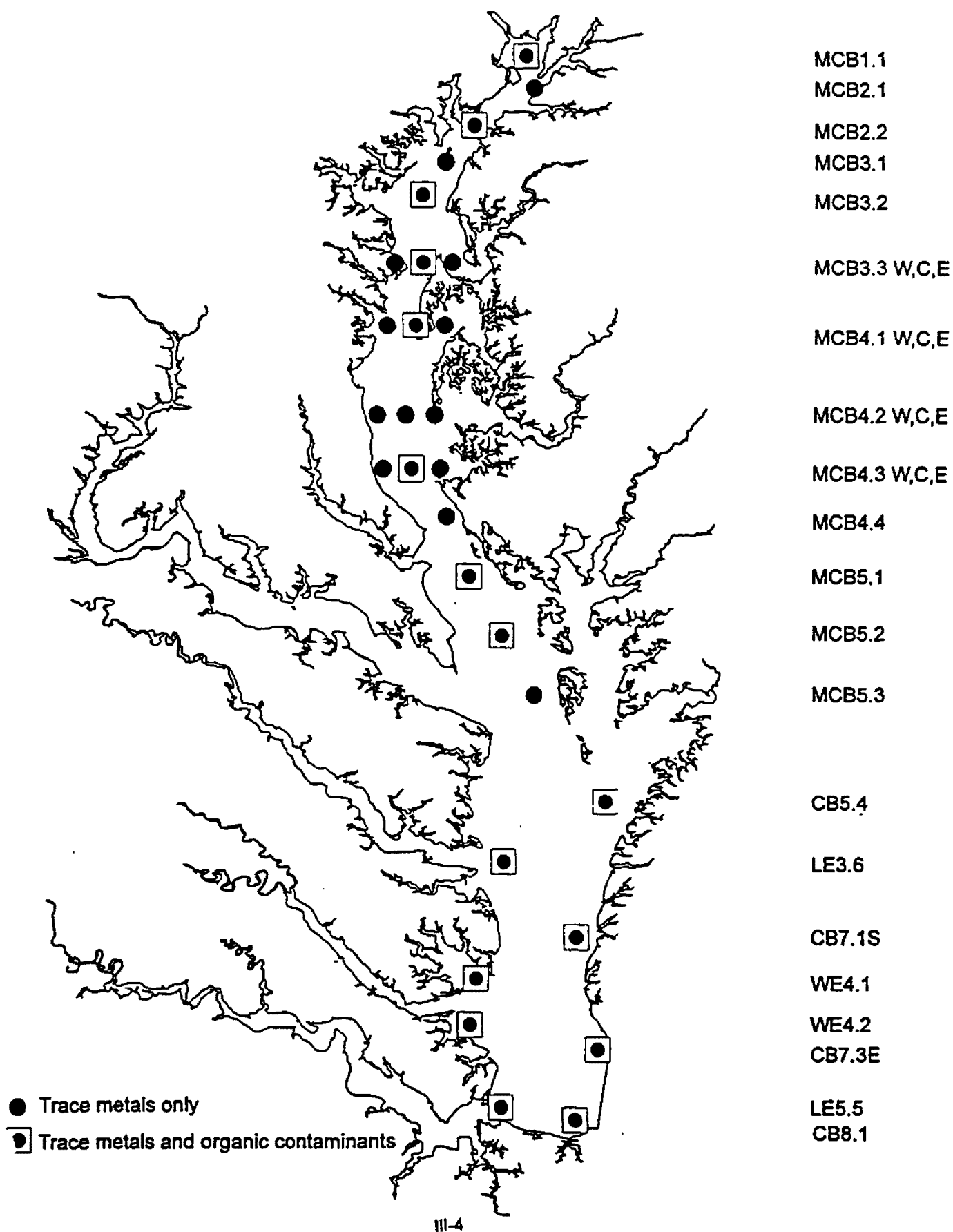
Data from the recent sampling program were also compared with data from a 1970s study of the sediment concentrations of trace metals in Bay sediments (Helz, et al., 1983). This study used a "total recoverable" type of metals analysis, as was the case in the recent sampling program. In the study of Helz, et al. (1983) metals were extracted from the sediment in a 9:1 mixture of hot concentrated nitric and hydrochloric acids. The extracts were analyzed by atomic absorption flame spectrophotometry, with background correction used for cadmium (Helz, et al., 1983).

Differences in sediment trace metal concentrations between sampling events at a given location could be attributable partly to differences in the proportion of silt and clay between the two samples; therefore, both comparisons between bulk ("measured") trace metal concentrations from the two studies and comparisons of grain-size normalized trace metal concentrations from 1991 and analyses of the silt-clay fraction made in the late 1970s are presented. In interpreting these data, it is important to keep in mind that the upper approximately 20 cm of sediment can be well-mixed and can represent deposition from the last 2.5 to more than 40 years (Goldberg, et al., 1978). Thus, the 1991 data may not always be derived from the most recently deposited sediments.

**Loadings of Trace Meals and Organic Contaminants to the Chesapeake Bay**

Several studies have estimated the loadings of trace metals and organic contaminants to Chesapeake Bay from various sources, including fall line loadings from the major tributaries, point sources and urban stormwater runoff below the fall line, and direct atmospheric deposition to Bay waters (Table 3.2).

Estimated fall line loadings of trace metals are much higher than loadings from below fall line point sources, urban stormwater, and direct atmospheric deposition to tidal waters (Table 3.2). However, fall line loads are reduced during transit to Bay tidal waters, whereas below fall line loads are delivered directly to the mainstem Bay (Chesapeake Bay Program, 1994a). Groundwater loadings of metals and organic contaminants to the Bay are unknown, but are probably of most significance at local scales close to sources of contamination (Chesapeake Bay Program, 1994a).

In contrast, estimated fall line loadings of most organic contaminants were similar to below fall line urban stormwater loads and below fall line point source loads (Table 3.2). The estimates for direct atmospheric deposition of trace metals and organic contaminants to Chesapeake Bay waters were based on measurements made at stations which probably were not influenced by the air plume from the highly industrialized and urbanized area around Baltimore, Maryland (Baker, et al., 1992). Thus, the figures for atmospheric loadings in Table 3.2 probably underestimate the actual loadings to the Bay from atmospheric deposition. Atmospheric deposition is a significant source of many pollutants to major water bodies (Table 3.2 and Table 3.3). Note, however, that the relative importance of atmospheric loadings varies among different water bodies (Table 3.2 and Table 3.3).

The magnitude of below fall line loadings from point sources and urban stormwater varies considerably among different portions of the Bay watershed (Table 3.4). The highest loadings are found in the West Chesapeake and Potomac regions of the Bay watershed, with intermediate loadings in the James and Patuxent regions and the lowest loadings from the Rappahannock, York, and Eastern Shore regions.

Table 3.2 Estimated mean annual loadings of selected trace metals and polycyclic aromatic hydrocarbon (PAHs) to Chesapeake Bay from various sources. Loads are in pounds per year.

| Chemical | Fall line loadings[1] | Below fall line loadings | | Atmospheric Deposition[3] |
|---|---|---|---|---|
| | | Urban Stormwater[2] | Point Sources[2] | |
| **Trace Metals** | | | | |
| Arsenic | 54,000 | 25,000 | 1,400 | 3,800 |
| Cadmium | 51,000 | 6,200 | 1,300 | 2,700 |
| Chromium | 270,000 | 36,000 | 44,000 | 7,500 |
| Copper | 450,000 | 100,000 | 83,000 | 24,000 |
| Lead | 540,000 | 22,000 | 13,000 | 32,000 |
| Mercury | 7,600 | 1,100 | 510 | NE |
| Zinc | 1,900,000 | 570,000 | 360,000 | 91,000 |
| **PAHs** | | | | |
| Benzo[a]anthracene | 320 | 210 | NE | 300 |
| Benzo[a]pyrene | 370 | 190 | 100 | 280 |
| Chrysene | NE | 520 | 20 | 710 |
| Fluoranthene | 650 | 780 | 50 | 1,400 |
| Naphthalene | 970 | 990 | 1,400 | NE |
| **PCBs** | | | | |
| Alachlor | 410 | NE | NE | 5,600 |
| Aldrin | 58 | NE | NE | NE |
| Atrazine | 6000 | NE | NE | 1,700 |
| Chlordane | 320 | NE | NE | 170 |
| Dieldrin | 65 | NE | NE | NE |
| Metalochlor | 3,100 | NE | NE | 2,700 |

NE = no estimate

Sources:

[1] Chesapeake Bay Program, 1994a. Loadings are based on the sum of estimated loadings from the Susquehanna River and James River. These two tributaries together contribute approximately 64% of the total river flow into the Bay

[2] Chesapeake Bay Program, 1994b. Loadings are based on the sum of estimated loadings from the Susquehanna River, Potomac River, and James River. These three tributaries together contribute approximately 84% of the total river flow into the Bay

[3] Chesapeake Bay Program, 1994b. Estimates are for direct loadings to tidal surface waters.

Table 3.3 Estimates of atmospheric deposition as percent of the total load for select trace metals and organic contaminants in various water bodies.

| Pollutant | Jamaica Bay[1] | Lake Erie[2] | Mediter.Sea[3] | North Sea[4] | Chesapeake Bay[5] |
|---|---|---|---|---|---|
| Arsenic | — | 8 | — | — | 4.7 |
| Cadmium | 28 | 59 | 80 | 0-10 | 4.6 |
| Chromium | — | 17 | — | — | 2.1 |
| Copper | 6 | — | 12 | 0-10 | 3.8 |
| Lead | 30 | 23 | 16 | 20-50 | 5.6 |
| Mercury | — | 22 | — | 10-20 | — |
| Nickel | — | — | 9 | 10-20 | — |
| Zinc | 17 | — | — | 0-10 | 3.2 |
| Total PAHs | — | 21 | — | 20-50 | — |
| Total PCBs | — | 26 | — | >50 | — |
| Benzo[a]pyrene | — | 66 | — | — | 42 |
| Fluoranthene | — | — | — | — | 95 |

Sources:

[1] Seidemann, D.E., 1991.
[2] Kelly, et al., 1991.
[3] Guieu and Martin, et al., 1991. (note that variances from flux measurements were approximately equal to the mean).
[4] Warmenhoven, et al., 1989.
[5] Estimated from data in preceding table.

— — — — — — — — — — — — — — — — — — — — — — — —

Table 3.4 Estimated below fall line loadings of trace metals and organic contaminants to Chesapeake Bay from various portions of the Bay watershed. Loads are in pounds per year.

Urban stormwater loads

| | West Chesapeake | Patuxent | Potomac | Rapp. | York | James | Eastern Shore |
|---|---|---|---|---|---|---|---|
| Trace metals[1] | 280,000 | 100,000 | 170,000 | 17,000 | 17,000 | 120,000 | 69,000 |
| PAHs[2] | 1,400 | 100 | 620 | 0 | 160 | 260 | 160 |

Point source loads

| | West Chesapeake | Patuxent | Potomac | Rapp. | York | James | Eastern Shore |
|---|---|---|---|---|---|---|---|
| Trace metals[1] | 290,000 | NE | 134,650[3] | NE | NE | 70,000 | 6,300 |
| PAHs[2] | 1,400[4] | NE | NE | NE | NE | 150[5] | NE |

[1] Trace metals include arsenic, cadmium, chromium, copper, lead, mercury, and zinc.
[2] PAHs include benzo[a]pyrene, chrysene, fluoranthene and naphthalene.
[3] Does not include arsenic, for which no estimate was available.
[4] Estimate does not include chrysene and fluoranthene, for which data were not available.
[5] Estimate does not include naphthalene, for which data were not available.
Sources: Chesapeake Bay Program, 1994a and Chesapeake Bay Program, 1994b

## Sediment Characteristics

Average deposition rates of sediment vary among regions of the mainstem Bay (Table 3.1). The highest deposition rates are observed in segments three and four in the middle mainstem Bay. Relatively high sedimentation rates are also observed at most of the river mouth stations, with the exception of the Rappahannock River, a relatively fast flowing river.

Most sampled areas in the mainstem Bay had sediments classified as sandy mud, with the percentage of silt and clay between 50 and 85 percent (Table 3.5). River mouth stations (except for the mouth of the James River) and stations in the deep channel in the middle mainstem Bay had sediments of mud, with silt and clay greater than 85 percent. Sediments in segments one and eight at the extreme upper and lower end of the mainstem Bay, respectively, had coarser sediments (silt and clay between 10 and 50 percent). Grain size composition of sediments within the different segments varied substantially (Table 3.5 and Figure 3.3). Median percent silt and clay were similar on the western, central, and eastern portions of the transects across the deep trough of the midbay. However, the range of percentage silt and clay was greater among samples from the eastern flank of the midbay.

Median sediment total organic carbon (TOC) concentrations increased from about 2.5 percent at the extreme upper end of the mainstem Bay in segment one to a peak of approximately 4 percent in segment two, and then gradually declined towards the mouth of the Bay, with markedly lower concentrations in segments seven and eight, where TOC concentrations were about 0.5 percent (Table 3.6 and Figure 3.4). Total organic carbon concentrations are somewhat lower in the eastern portion of the midbay than in the central and western portions. The Potomac River mouth station had average TOC concentrations of about 3.5 percent, while the other river mouth stations had lower TOC concentrations, ranging from 1 to 2.5 percent. The mainstem Bay average TOC concentration was 2.55 percent. The maximum TOC concentration, 7.74 percent, was found in segment two.

In 1986, Hennessee, *et al.* reported an average sediment total organic carbon concentration of total organic carbon of 2.1 percent for the Maryland portion of the mainstem Bay. Total organic carbon was significantly correlated with the mud content of the sediment. In the northern portion of the mainstem Bay (above the Bay bridge) the average sediment TOC concentration was 3.3 percent and in the middle portion of the Bay (from the Bay bridge to the Maryland border), sediment TOC averaged 1.7 percent.

Most of the carbon in the upper Bay is terrestrial in origin and largely carried by the Susquehanna River. Some of this carbon is refractory, originating from coal, plant detritus, and anthropogenic sources. In the middle mainstem Bay, (below the Bay Bridge) algal production contributes the largest portion of organic carbon (Hennessee, *et al.*, 1986).

Table 3.5 Summary statistics for percent silt and clay in Chesapeake Bay mainstem sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River.

| Area | Mean | Median | N | SD | Min | Max |
|------|------|--------|---|-----|-----|-----|
| Mainstem | 75 | 67 | 28 | 3 | 87 | 100 |
| Segment 1 | 14 | 3 | 14 | 3 | 10 | 30 |
| Segment 2 | 79 | 5 | 13 | 60 | 87 | 90 |
| Segment 3 | 86 | 12 | 24 | 10 | 93 | 100 |
| Segment 4 | 83 | 21 | 13 | 49 | 86 | 98 |
| Segment 5 | 72 | 9 | 27 | 19 | 81 | 99 |
| Segment 7 | 51 | 4 | 35 | 5 | 61 | 79 |
| Segment 8 | 19 | 2 | 8 | 13 | 19 | 25 |
| Midbay | | | | | | |
| Center | 94 | 10 | 3 | 89 | 93 | 99 |
| East | 71 | 8 | 28 | 10 | 80 | 96 |
| West | 84 | 8 | 6 | 75 | 85 | 91 |
| River mouths | | | | | | |
| Potomac R. | 94 | 3 | 5 | 89 | 95 | 98 |
| Rapp. River | 94 | 2 | 0.2 | 94 | 94 | 94 |
| Mobjack Bay | 95 | 2 | 0.6 | 95 | 95 | 96 |
| York River | 89 | 2 | 10 | 82 | 89 | 96 |
| James River | 37 | 2 | 40 | 9 | 37 | 66 |

Table 3.6 Summary statistics for total organic carbon in mainstem Chesapeake Bay sediments. Concentrations are in per cent dry weight.

| Area | Mean - μ | Median | N | SD - σ | Min | Max |
|---|---|---|---|---|---|---|
| Mainstem | 2.55 | 2.55 | 88 | 1.37 | 0.10 | 7.74 |
| Segment 1 | 2.49 | 2.24 | 4 | 2.22 | 0.10 | 5.40 |
| Segment 2 | 4.03 | 4.20 | 7 | 2.16 | 1.20 | 7.74 |
| Segment 3 | 3.20 | 3.47 | 17 | 1.34 | 0.30 | 4.70 |
| Segment 4 | 2.46 | 2.50 | 31 | 0.86 | 0.50 | 3.91 |
| Segment 5 | 2.33 | 2.60 | 11 | 0.87 | 0.23 | 3.15 |
| Segment 7 | 0.56 | 0.48 | 4 | 0.31 | 0.30 | 1.00 |
| Segment 8 | 0.43 | 0.43 | 2 | 0.38 | 0.16 | 0.70 |
| Midbay | | | | | | |
| Center | 2.84 | 3.05 | 14 | 0.88 | 1.40 | 4.40 |
| East | 1.93 | 2.11 | 12 | 1.03 | 0.30 | 3.24 |
| West | 3.00 | 3.28 | 12 | 0.76 | 1.60 | 4.00 |
| River Mouths | | | | | | |
| Potomac | 3.41 | 3.47 | 4 | 0.29 | 3.00 | 3.68 |
| Rappahannock | 2.37 | 2.37 | 2 | 0.33 | 2.13 | 2.60 |
| Mobjack Bay | 1.45 | 1.45 | 2 | 0.06 | 1.40 | 1.49 |
| York | 1.59 | 1.59 | 2 | 0.01 | 1.58 | 1.60 |
| James | 1.11 | 1.11 | 2 | 1.26 | 0.22 | 2.00 |

## General Patterns in the Spatial Distribution of Trace Metals

Trace metals such as arsenic, cadmium, and lead are naturally present in the earth's crust, and their presence in the sediment does not necessarily indicate contamination from human activities. Some trace metals are essential to organisms in minute quantities, but may become toxic if present in high concentrations.

In addition to natural sources such as shoreline erosion and sediments from the watershed, trace metals reach Chesapeake Bay from anthropogenic sources. Trace metals from wood preservatives, the combustion of fossil fuels, pesticides, automobile tires and batteries, building materials such as pipes, roofing material and galvanized gutters all may become components of stormwater runoff. Trace metals are involved in numerous industrial processes, including electroplating and the manufacture of metal alloys, and thus are frequently found in industrial effluents. Trace metals also may reach Chesapeake Bay through municipal effluents and atmospheric deposition.

# Figure 3.3 Percentage silt and clay
## in mainstem sediments



Figure 3.3 Summary statistics for percent silt-clay in Chesapeake Bay mainstem sediments. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay.

# Figure 3.4 Percentage total organic carbon in mainstem sediments



## I. Mainstem Segments

## II. Transects
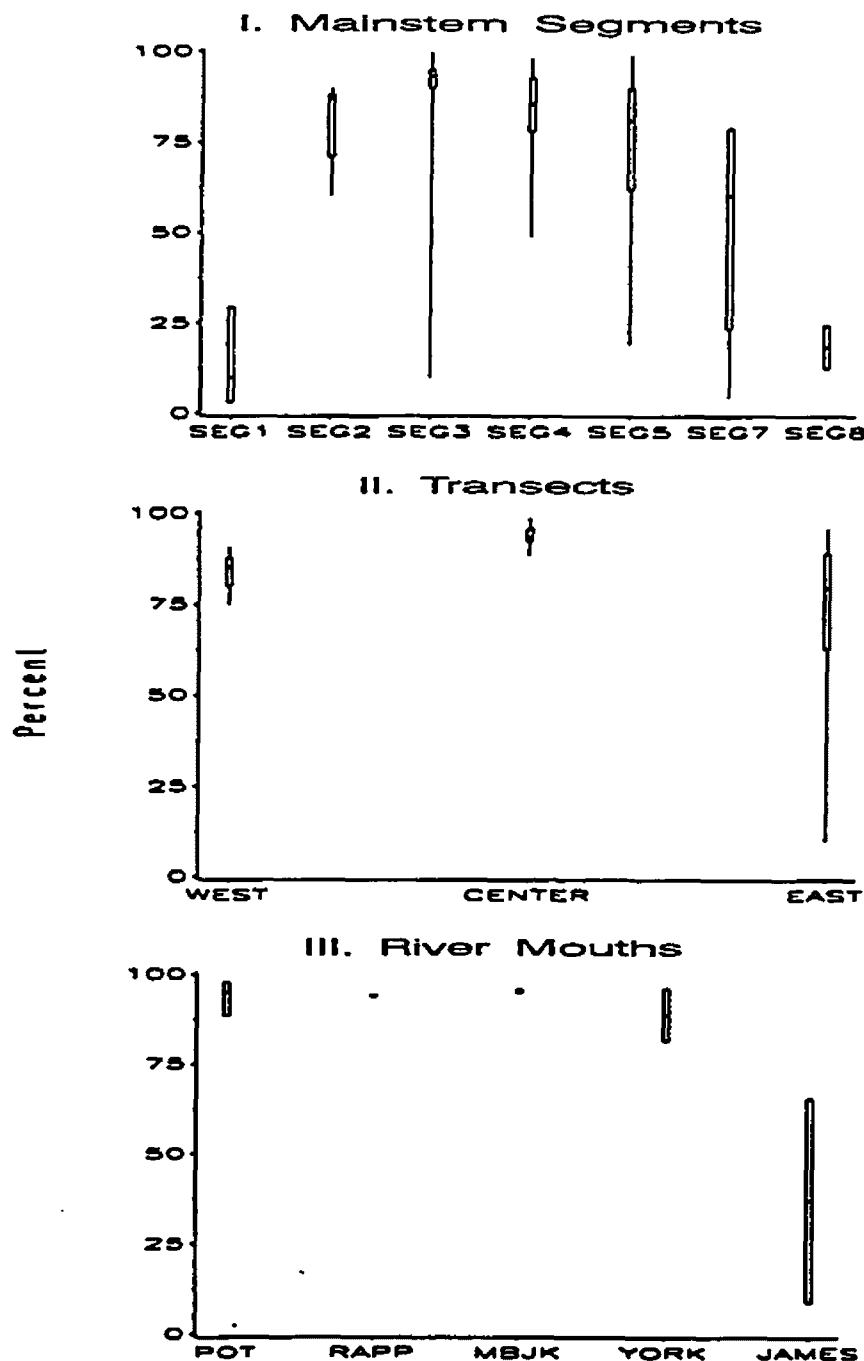
## III. River Mouths
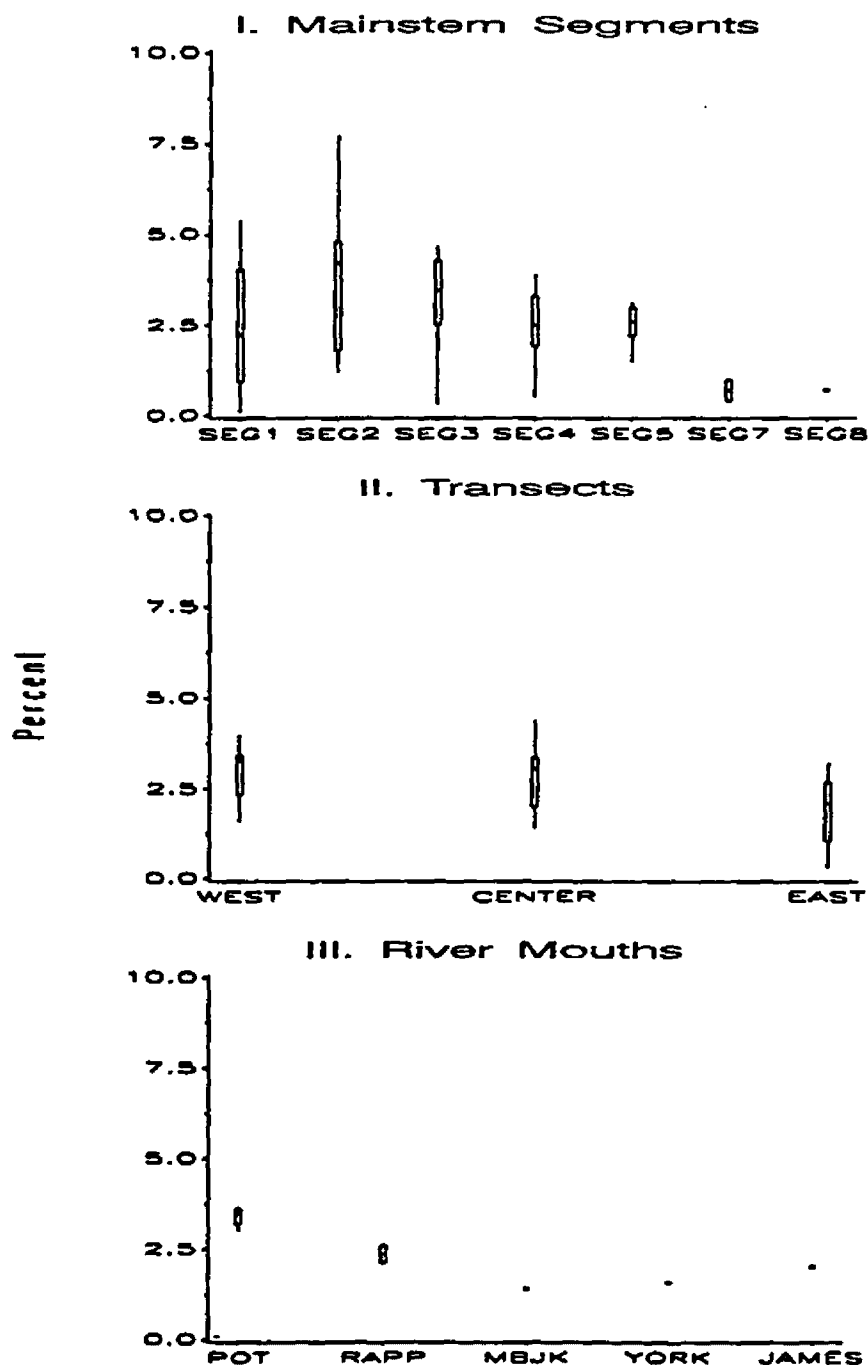
Figure 3.4 Summary statistics for percent total organic carbon in Chesapeake Bay mainstem sediments. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay.

In the mainstem Bay sediment contaminant monitoring program, sediments were analyzed for eight trace metals: arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Of these, cadmium, chromium, copper, lead and mercury are Chesapeake Bay Toxics of Concern, while arsenic and zinc are on the list of compounds for which additional information is being sought (Chesapeake Bay Program, 1991a).

The spatial distribution of trace metal concentrations in mainstem Bay sediments displayed a consistent pattern of low concentrations in segment one at the mouth of the Susquehanna River, markedly higher average concentrations in segments two through five in the region from Turkey Point to just below the Potomac River mouth, and then markedly lower average concentrations in segments seven and eight in the lower portion of the Bay southeast of the mouth of the Rappahannock River (Figures 3.5 through 3.12). The highest concentrations and the greatest variability in trace metal concentrations were observed in segment three.

This spatial pattern changed when trace metal concentrations were normalized by the fraction of fine particles in the sediment, indicating that the pattern in measured sediment concentrations of some trace metals may reflect differences in grain size composition among stations (Tables 3.1 and 3.5) more than differences in metal loadings. Normalized sediment trace metal concentrations were fairly uniform throughout the length of the mainstem Bay for arsenic, cadmium, chromium, and mercury, while for copper, lead, nickel and zinc, the highest values occurred in the extreme upper Bay with concentrations generally declining towards the mouth of the Bay (Figures 3.5-3.12). This down-Bay decrease in the concentration of these trace metals suggests that the Susquehanna River may represent the major source of these metals to the Bay. Helz, et al. (1983) found a down-Bay decrease in the concentration of several trace metals in the silt and clay fraction of sediment samples consistent with this finding. The large differences between bulk and normalized trace metal concentrations in the extreme upper and lower Bay (segments one and eight) are due to the high percentage of sand in the sediments in these segments.

In the middle mainstem Bay (segments three and four), the average measured concentrations of most trace metals decreased from west to east, with the exception of mercury, which reaches its highest concentration in the center of the mid-Bay (Figures 3.5-3.12). This gradient in trace metal concentrations is reduced somewhat when sediment concentrations are normalized for grain size, but the western middle mainstem Bay stations still have higher normalized sediment concentrations of most trace metals than do those in the east. This finding suggests that the east-west pattern in sediment trace metal concentrations may be partly due to differences in the magnitude of inputs from the two shores and/or to differences in sediment origin. This decreasing gradient in trace metal concentrations from west to east was also evident in the analyses of the silt and clay fraction of sediments conducted by Helz, et al. (1983). At the river mouths and in Mobjack Bay, both measured and normalized concentrations of most trace metals are fairly similar among stations and comparable to the concentrations in the lower portion of the Bay. However, the average cadmium and mercury concentrations are markedly higher at the mouth of the Potomac River than at the other river mouth stations (Figures 3.5-3.12).

The pattern of trace metal loadings, as estimated by the Chesapeake Bay Program (1994a), seems to correspond more closely to the pattern of normalized sediment metals concentrations than to that of the measured sediment metal concentrations. Fall line loads to the Susquehanna River are often the highest loadings of the various basins of the Chesapeake Bay (Chesapeake Bay Program (1994b). Below fall line loads to the West Chesapeake and Potomac regions are relatively high, with relatively small loads to the Rappahannock, York and Eastern Shore regions, and moderately increased loads to the James region (Table 3.4).

Median sediment concentrations of arsenic, chromium, copper, lead and zinc exceeded the No Observable Effects Level (NOEL) concentrations in the more metal-rich regions of the mainstem (the western and central portions of segments three and four, as well as segments two and five for some metals) (Tables 3.7a-3.14a). The median concentrations of cadmium did not exceed the NOEL concentration in any region of the mainstem, and median concentrations of mercury exceeded the NOEL only in segment two. Only zinc was found at concentrations above the Probable Effects Level (PEL), the concentrations above which toxic effects to aquatic biota are considered probable (MacDonald, 1993 and Table 3.14a). Current sediment quality guidelines are

inadequate for assessing the likelihood of toxicity due to sediment concentrations of nickel. Toxic effects to aquatic biota due to the measured sediment trace metal concentrations are unlikely in most sampled locations in the mainstem Bay. Toxic effects due to sediment zinc concentrations are probable in some areas within segments two through five. However, the potential for toxic effects due to sediment trace metal concentrations may be reduced by the presence of significant quantities of acid-volatile sulfide in much of the middle portion of the mainstem (Table 3.15). The quantity of acid volatile sulfide in the sediment is not considered in the PEL guidelines (MacDonald, 1993).

## Temporal Trends in Trace Metal Concentrations

There were few instances in which the mean measured concentrations of trace metals in 1991 were consistently significantly higher or lower than both the 1984 and 1985 concentrations. For most trace metals, mean concentrations in mainstem regions in 1991 tended to be lower than those observed in earlier years. This trend was particularly evident for cadmium. Arsenic was the only trace metal to show consistently higher mean sediment concentrations within mainstem regions in 1991 than in 1984 and 1985, but no potential source or cause for the apparent increase has been identified.

A review of the latitude and longitude of the mainstem Bay stations sampled in 1977-79 (Helz, et al., 1983), identified eleven stations which were near a station sampled as part of the recent monitoring program. Comparison of the 1977 data from these eleven stations with the 1991 data shows that sediment concentrations of most trace metals in the mainstem were generally lower in 1991 than in the late 1970s. Sediment cadmium concentrations have shown a rather large reduction, while other metals show more modest decreases. Sediments were not analyzed for arsenic and mercury concentrations in the 1977-79 study.

## General Patterns in the Spatial Distribution of Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are composed of two or more fused aromatic rings. PAHs are naturally produced by volcanos and forest fires, and some PAHs may also be formed from other natural sources such as plant pigments (Bouloubassi and Saliot, 1993). Anthropogenic sources of PAHs include spills of petroleum products, which typically release lower molecular weight PAHs, and the incomplete combustion of fossil fuels, generally resulting in the formation of higher molecular weight PAHs (National Oceanic and Atmospheric Administration, 1991). Polycyclic aromatic hydrocarbons are also released into the aquatic environment via oil refinery effluents (MacDonald, 1993). Anthropogenic fossil fuel combustion has greatly increased environmental PAH concentrations (Menzie, et al., 1992).

Although complete data have not been assembled, at least eight PAHs are considered possible or probable carcinogens: benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenzo[a,h]anthracene, and benzo[g,h,i]perylene (Menzie, et al., 1992). Other PAHs display no carcinogenic, teratogenic, or mutagenic activity. PAHs can be highly toxic to aquatic organisms, although the bioavailability of PAHs, as with many nonpolar organic compounds, is known to depend on the concentration of total organic carbon in the sediment (MacDonald, 1993).

The suspected carcinogens listed above are commonly found in PAH mixtures, as are many compounds which may be present in smaller amounts, or which are not consistently detected or identified. Total PAHs is an unspecified mixture of compounds which can vary widely in toxicity, depending on its specific composition. Several individual PAHs were measured and are discussed below, but some mixtures of PAHs resulting from combustion or petroleum products have been shown to be carcinogenic, and thus total PAHs was also measured. Benzo[a]pyrene, chrysene, fluoranthene, and naphthalene are PAHs that are Chesapeake Bay Program Toxics of Concern (Chesapeake Bay Program, 1991a).

Fewer stations were sampled for organic contaminants than for trace metals (Table 3.1). The three river mouth stations and Mobjack Bay and one or two stations in each of the mainstem segments (except segment six) were

sampled for organic contaminants (Table 3.1 and Figure 3.1). The sediment concentrations of many individual polycyclic aromatic hydrocarbons (PAHs) were measured , e.g., anthracene, benzo[a]anthracene, benzo[a]pyrene, etc., as well as total PAHs.

The concentrations of polycyclic aromatic hydrocarbons in mainstem Bay sediments show a somewhat different spatial pattern than that observed for trace metals. Instead of a broad peak in the middle mainstem Bay, concentrations of PAHs peak in a more narrow region within segments two and three, with the highest concentrations in segment two, between Turkey Point and the mouth of the Middle River (Tables 3.17-3.29). Median sediment concentrations of polycyclic aromatic hydrocarbons are similar among the river mouth stations, and generally comparable to the lower concentrations observed in the mainstem outside of segments two and three (Table 3.17-3.29). No sediment concentrations of any of the PAHs were in excess of the relevant PEL concentration (Macdonald, 1993 and Tables 3.17-3.29). Toxic effects to aquatic biota due to the measured sediment concentrations of PAHs are not likely at the monitored locations in the mainstem Bay.

This spatial distribution of sediment concentrations of PAHs is similar to that displayed by sediment total organic carbon (TOC) (see Table 3.6 and Figure 3.4). However, the pattern in the distribution of PAHs cannot be entirely attributed to patterns in TOC, concentrations, since for most PAHs a similar pattern is evident when the sediment PAH concentrations are carbon-normalized , i.e., divided by the fraction of TOC in the sediment (Tables 3.17-3.29).

Due to the small number of samples and high variability, no statistically significant differences in sediment concentrations were found among the different years of the monitoring program for any of the measured or normalized concentrations of PAHs analyzed.

General Patterns in the Spatial Distribution of Chlorinated Organic Compounds

The chlorinated organic compounds identified in mainstem Bay sediment samples included polychlorinated biphenyl (PCB) congeners, chlorinated hydrocarbons such as organochlorine pesticides, and one dioxin compound. Information on a suite of individual PCB congeners was also used to estimate the concentration of total PCBs in sediment samples.

Many of the organochlorine pesticides detected were previously widely used, but are either not currently registered for use in the U.S., or their uses have been narrowly restricted (MacDonald, 1993). Similarly, the uses of PCBs were curtailed in the U.S. in 1971. However, most of these compounds tend to accumulate in sediments and some may persist there for long periods (MacDonald, 1993). In addition, many of these chemicals can become concentrated in wildlife tissue (MacDonald, 1993).

Sediment samples were analyzed for a suite of chlorinated pesticides and other chlorinated organic compounds in 1984 and 1985. However, the detection limits for all compounds were too high to provide meaningful information on the distribution and concentration of these compounds in mainstem Bay sediments. The analysis of sediment samples conducted by the Virginia Institute of Marine Science in 1991 was sufficiently sensitive to provide a realistic picture of the levels of these compounds in mainstem Bay sediments. Only data from 1991 are discussed below (Tables 3.30 and 3.31).

Although several chlorinated organic compounds were found at many of the stations, concentrations in all cases were very low (Table 3.30). Measured concentrations were all below ER-M or PEL values for compounds for which these sediment guidelines are available. Toxic effects to aquatic biota due to the measured sediment concentrations of chlorinated organic compounds are not likely at the sampled locations in the mainstem Bay.

## Spatial and Temporal Distributions of Individual Trace Metals

### Arsenic

Arsenic is not listed as a Chesapeake Bay Toxic of Concern, but is a substance for which more information is being sought (Chesapeake Bay Program 1991a, 1991b). It may be released into the environment naturally through volcanic activity or the weathering of arsenic-rich rocks. Anthropogenic sources include fossil fuel combustion, the production of metal alloys, pesticides, fertilizers made from phosphate rock rich in arsenic, and wood preservatives (Long and Morgan, 1990; MacDonald, 1993; Chesapeake Bay Program 1991b).

The median sediment arsenic concentration in the mainstem was 8.5 ppm. The maximum value of 28.2 ppm (Table 3.7a and Figures 3.5) was found at station MCB4.1W in the lower mid-Bay in 1991. The No Observable Effect Level for arsenic (8.0 ppm) was equalled or exceeded by median concentrations in segments two, three, four, five, and at the stations located at the mouth of Mobjack Bay (Table 3.7a). The maximum measured arsenic concentration of 28.2 ppm was well below the Probable Effect Level value of 64 ppm (MacDonald, 1993 and Table 3.7a). Toxic effects to aquatic life due to the measured concentrations of arsenic in mainstem sediments are not likely at any of the monitored areas of the mainstem Bay.

When significant differences in sediment concentrations of arsenic were found among different years of sampling, sediment arsenic concentrations in 1991 were generally higher than those found in earlier years. However, with so few samples, no conclusion as to a trend can be drawn. Historical data on sediment arsenic concentrations were not available for comparison with the more recently collected data.

# As

Table 3.7a Summary statistics for arsenic in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppm dry weight. Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 10.3 | 8.5 | 81 | 7.1 | 0.6 | 28.2 | 14.7 | 10.1 | 66 | 9.4 | 4.3 | 48.0 |
| Segment 1 | 2.1 | 0.7 | 3 | 2.4 | 0.6 | 4.9 | 15.4 | 16.6 | 3 | 8.5 | 4.3 | 23.3 |
| Segment 2 | 11.6 | 9.2 | 6 | 6.6 | 6.2 | 24.1 | 15.3 | 10.2 | 5 | 8.7 | 7.1 | 26.8 |
| Segment 3 | 13.7 | 10.0 | 15 | 8.9 | 1.9 | 27.5 | 17.4 | 15.6 | 12 | 9.4 | 5.5 | 30.2 |
| Segment 4 | 11.8 | 9.6 | 29 | 6.9 | 1.3 | 28.2 | 15.3 | 10.2 | 21 | 9.7 | 4.3 | 36.3 |
| Segment 5 | 8.4 | 8.5 | 11 | 4.0 | 3.8 | 17.7 | 12.9 | 12.2 | 9 | 6.4 | 5.4 | 20.1 |
| Segment 7 | 3.3 | 3.1 | 4 | 1.7 | 1.4 | 5.4 | 5.9 | 6.6 | 3 | 1.4 | 4.3 | 6.9 |
| Segment 8 | 5.7 | 5.7 | 2 | 0.6 | 5.3 | 6.1 | 34.7 | 34.7 | 2 | 18.8 | 21.5 | 48.0 |
| Center | 12.9 | 9.6 | 11 | 8.1 | 4.1 | 26.2 | 14.2 | 10.1 | 10 | 9.2 | 4.3 | 27.6 |
| East | 9.9 | 7.7 | 12 | 7.9 | 1.3 | 23.8 | 17.4 | 17.7 | 8 | 11.3 | 4.9 | 36.3 |
| West | 14.4 | 13.0 | 12 | 7.4 | 6.4 | 28.2 | 17.7 | 15.8 | 8 | 10.1 | 7.8 | 32.5 |
| Potomac | 12.1 | 7.3 | 3 | 11.1 | 4.2 | 24.7 | 13.2 | 7.4 | 3 | 12.8 | 4.4 | 27.9 |
| Rappahannock | 7.7 | 7.7 | 2 | 1.2 | 6.8 | 8.5 | 8.1 | 8.1 | 2 | 1.3 | 7.2 | 9.1 |
| Mobjack Bay | 8.0 | 8.0 | 2 | 2.8 | 6.0 | 10.0 | 8.4 | 8.4 | 2 | 3.0 | 6.3 | 10.5 |
| York | 7.7 | 8.0 | 2 | 0.1 | 7.6 | 7.7 | 8.7 | 8.4 | 2 | 1.1 | 7.9 | 9.4 |
| James | 4.4 | 4.4 | 2 | 4.9 | 0.9 | 7.8 | 10.9 | 10.9 | 2 | 1.3 | 10.0 | 11.9 |

Table 3.7b Temporal variability in arsenic concentrations in Chesapeake Bay mainstem sediments. Means for years not connected by the underline are significantly different (p=0.05) as determined by ANOVA followed by a Duncan's multiple range test. The means indicated by the year are ordered from high to low. NS = no significant differences. There were insufficient data to perform the test in segments one and eight and the river mouth stations and Mobjack Bay.

| Area | Measured | Normalized |
|------|----------|------------|
| Segment 2 | NS | 91 84 85 |
| Segment 3 | 91 84 85 | 91 85 84 |
| Segment 4 | 91 84 85 | 91 84 85 |
| Segment 5 | 91 84 85 | 91 84 85 |
| Segment 7 | NS | NS |
| Center | 91 84 85 | 91 84 85 |
| East | 91 84 85 | 91 85 |
| West | 91 84 85 | 91 85 |

# Figure 3.5 Arsenic concentrations (ppm) in mainstem sediments
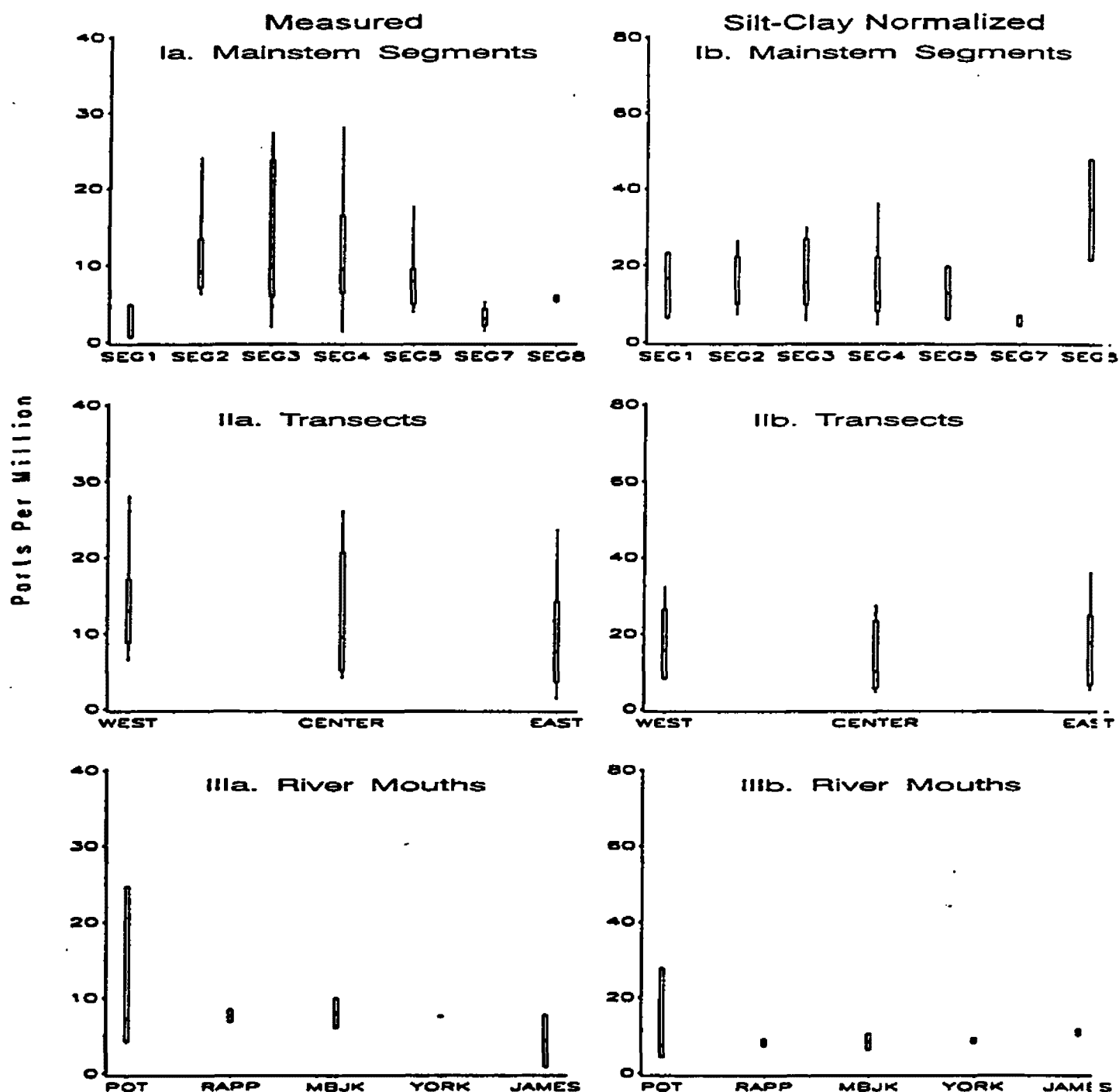


Figure 3.5 Summary statistics for measured and silt-clay normalized sediment concentrations of arsenic in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment arsenic concentrations are 8 ppm and 64 ppm, respectively (MacDonald, 1993).

## Cadmium

Cadmium, a Chesapeake Bay Toxic of Concern, (Chesapeake Bay Program 1991a and b), has numerous industrial uses and is found in tires and gasoline. Primary cadmium sources to the Bay are industrial and municipal effluents, landfills, and nonpoint sources (Chesapeake Bay Program, 1991b). In addition, cadmium is a natural element found in soils and rocks.

The median measured sediment cadmium concentration in the mainstem Bay was 0.40 ppm (Table 3.8a). The maximum value of 2.9 ppm (Table 3.8a) was found six times in 1984 at stations MCB3.1, MCB3.2, MCB3.3W, MCB3.3C, MCB4.2W and MCB4.3W in segments three and four (Table 3.8b and MacDonald, 1993). The NOEL for cadmium (1.0 ppm) was not exceeded by median concentrations except at the mouth of the Potomac River (Table 3.8a). All measurements were well below the PEL concentration of 7.5 ppm (Table 3.8a and MacDonald, 1993). Toxic effects to aquatic life due to the measured concentrations of cadmium in mainstem sediments are not likely at any of the mainstem Bay stations sampled.

The mean sediment measured and normalized concentrations of cadmium in 1991 were consistently lower than mean concentrations observed in 1984 and 1985. (Table 3.8b). Concentrations from 1991 were also much lower than those observed at nearby locations in 1977 by Helz, et al. (1983) (Figures 3.6b-c).

# Cd

Table 3.8a  Summary statistics for Cadmium in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppm dry weight. Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 0.66 | 0.40 | 79 | 0.79 | 0.01 | 2.90 | 0.77 | 0.47 | 64 | 1.02 | 0.01 | 6.67 |
| Segment 1 | 0.17 | 0.18 | 3 | 0.03 | 0.14 | 0.20 | 2.89 | 1.40 | 3 | 3.29 | 0.61 | 6.67 |
| Segment 2 | 0.62 | 0.65 | 6 | 0.43 | 0.13 | 1.16 | 0.68 | 0.68 | 5 | 0.50 | 0.17 | 1.33 |
| Segment 3 | 1.07 | 0.50 | 15 | 1.18 | 0.01 | 2.90 | 1.01 | 0.71 | 12 | 1.05 | 0.01 | 2.94 |
| Segment 4 | 0.65 | 0.50 | 29 | 0.73 | 0.01 | 2.90 | 0.55 | 0.42 | 21 | 0.51 | 0.01 | 1.60 |
| Segment 5 | 0.52 | 0.60 | 11 | 0.44 | 0.01 | 0.60 | 0.59 | 0.74 | 9 | 0.51 | 0.01 | 1.31 |
| Segment 7 | 0.15 | 0.16 | 4 | 0.06 | 0.09 | 0.20 | 0.22 | 0.25 | 3 | 0.09 | 0.09 | 0.28 |
| Segment 8 | 0.20 | 0.20 | 1 | | 0.20 | 0.20 | 0.81 | 0.01 | 1 | | 0.20 | 0.81 |
| Center | 0.60 | 0.40 | 11 | 0.83 | 0.01 | 2.90 | 0.62 | 0.37 | 10 | 0.89 | 0.01 | 2.94 |
| East | 0.38 | 0.20 | 12 | 0.33 | 0.01 | 1.0 | 0.67 | 0.54 | 8 | 0.69 | 0.01 | 2.0 |
| West | 1.19 | 0.95 | 12 | 1.11 | 0.03 | 2.90 | 0.73 | 0.73 | 8 | 0.64 | 0.03 | 1.60 |
| Potomac | 1.47 | 2.00 | 3 | 1.28 | 0.01 | 2.40 | 1.53 | 2.04 | 3 | 1.33 | 0.01 | 2.53 |
| Rappahannock | 0.36 | 0.36 | 2 | 0.08 | 0.30 | 0.41 | 0.38 | 0.32 | 2 | 0.08 | 0.32 | 0.44 |
| Mobjack Bay | 0.23 | 0.36 | 2 | 0.11 | 0.15 | 0.30 | 0.24 | 0.38 | 2 | 0.11 | 0.16 | 0.31 |
| York | 0.30 | 0.30 | 2 | 0.01 | 0.29 | 0.30 | 0.33 | 0.33 | 2 | 0.03 | 0.31 | 0.35 |
| James | 0.30 | 0.30 | 1 | | 0.30 | 0.30 | 0.46 | 0.46 | 1 | | 0.46 | 0.46 |

Table 3.8b Temporal variability in cadmium concentrations in Chesapeake Bay mainstem sediments. Means for years not connected by the underline are significantly different ($p=0.05$) as determined by ANOVA followed by a Duncan multiple range test. The means are ordered from high to low. NS = no significant differences. There were insufficient data to perform the test in segments one and eight, at the river mouth stations, and Mobjack Bay.

| Area | Measured | Normalized |
|---|---|---|
| Segment 2 | NS | NS |
| Segment 3 | <u>84</u> <u>85 91</u> | <u>84</u> <u>85</u> <u>91</u> |
| Segment 4 | <u>84 85</u> <u>91</u> | <u>85</u> <u>84 91</u> |
| Segment 5 | <u>84 85</u> <u>91</u> | NS |
| Segment 7 | <u>84</u> <u>91</u> | NS |
| | | |
| Center | NS | NS |
| East | <u>85 84</u> 91 | <u>85</u> <u>91</u> |
| West | <u>84 85</u> <u>91</u> | <u>85</u> <u>91</u> |

## Figure 3.6b Measured Cadmium Concentrations in Mainstem Sediments
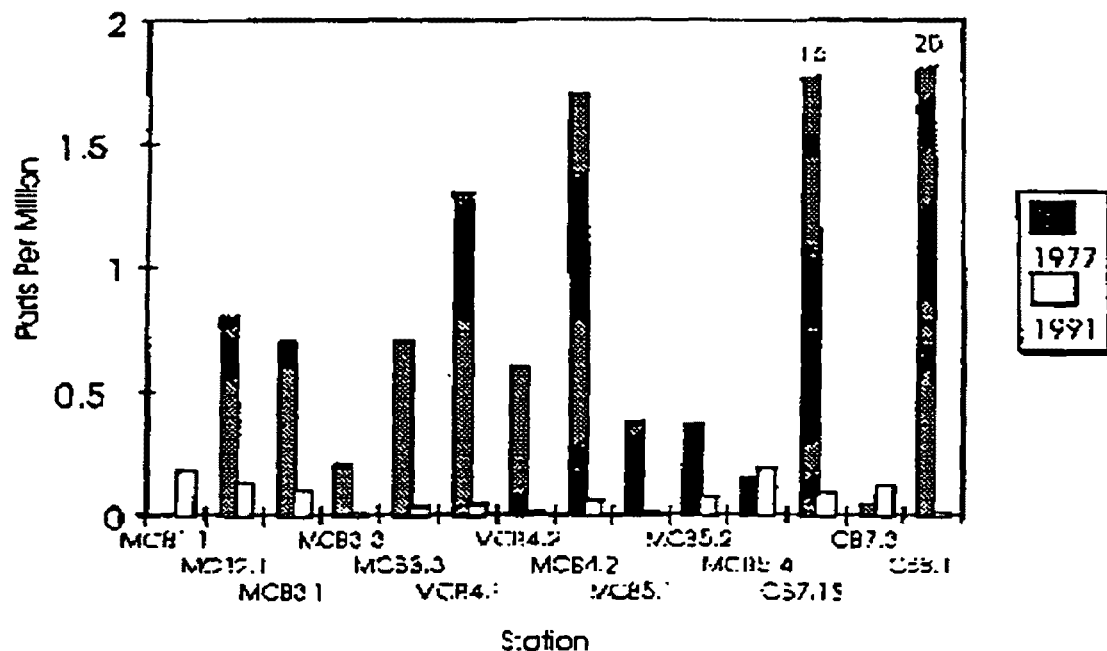### 1977 v. 1991



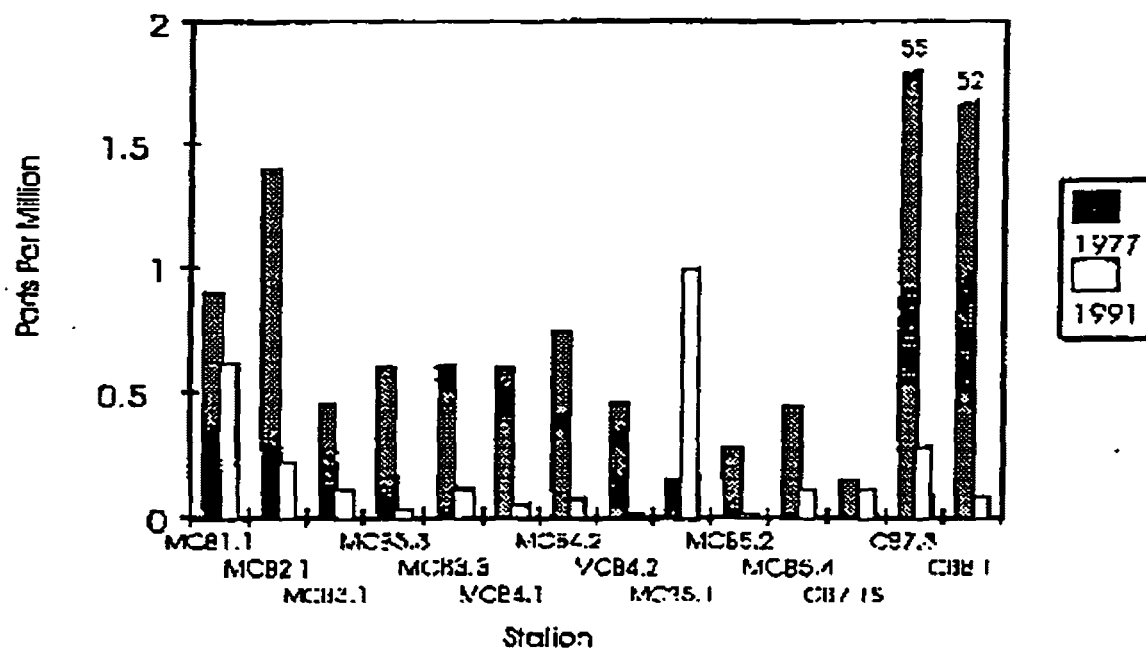## Figure 3.6c Normalized Cadmium Concentrations In Mainstem Sediments
### 1977 v. 1991



Comparison of Cadmium concentrations in mainstem sediments in 1977 and 1991. Station designation refer to the Chesapeake Bay Program monitoring stations. Data in 3.6b are measured sediment cadmium concentrations while the data in 3.6c are normalized, that is deivided, by the silt-clay fraction of the sediment samples.

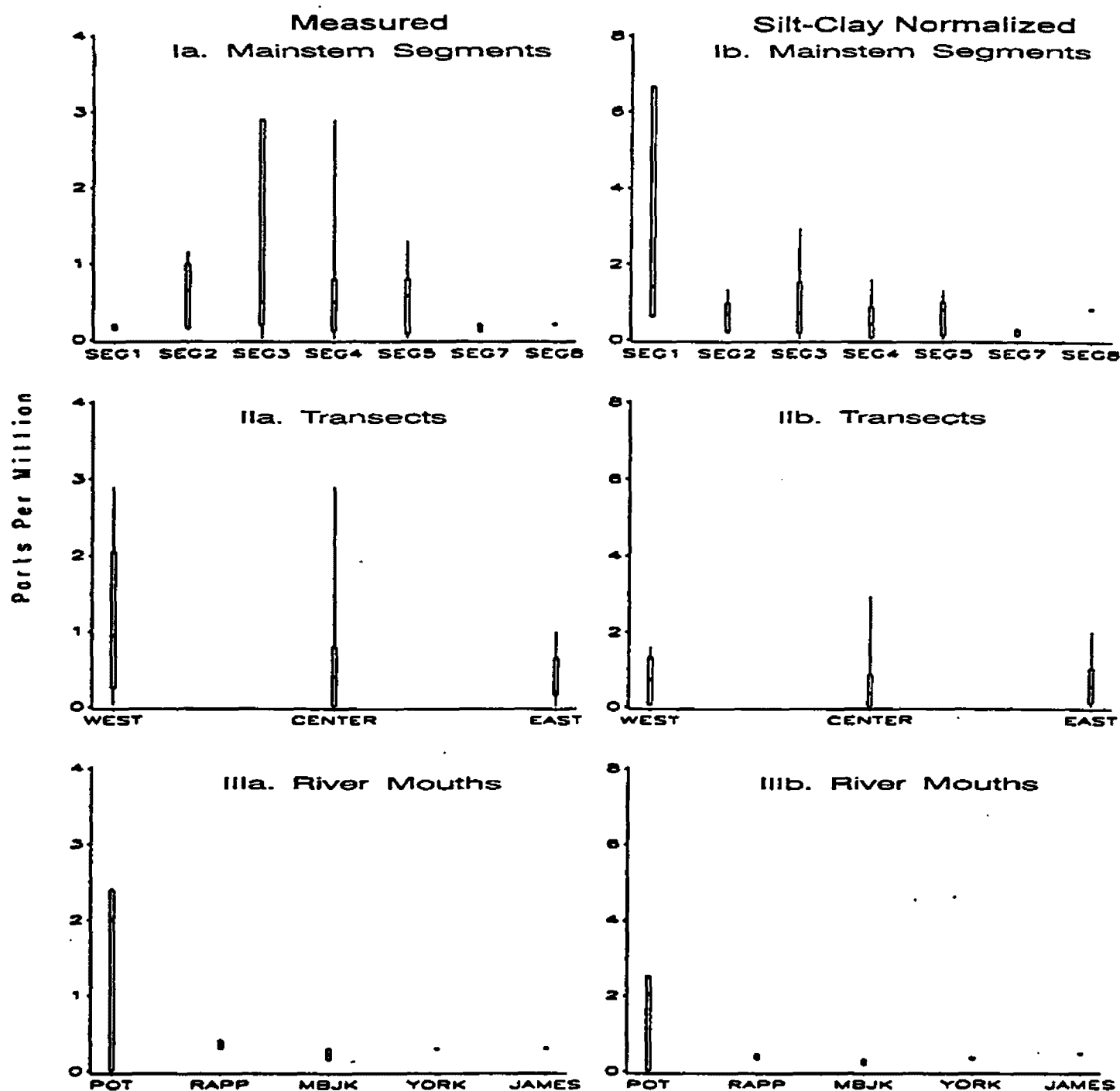# Figure 3.6a Cadmium concentrations (ppm) in mainstem sediments



Figure 3.6a  Summary statistics for measured and silt-clay normalized sediment concentrations of cadmium in the Chesapeake Bay mainstem.  The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data.  If there are less than four values, the rectangle's bottom and top show the range.  A dash indicates only a single value is available.  The stations are aggregated by:  I. Chesapeake Bay Program mainstem segments;  II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay.  The NOEL and PEL values for measured sediment cadmium concentrations are 1.0 ppm and 7.5 ppm, respectively (MacDonald, 1993).

## Chromium

Chromium, a Chesapeake Bay Toxic of Concern, is used in the manufacture of paint pigments, stainless steel and other electroplated metals, and enters the environment primarily through industrial sources, although it is also present naturally in rocks and soils (Chesapeake Bay Program 1991a and 1991b).

The mainstem median sediment chromium concentration was 35.6 ppm (Table 3.9a). The maximum value of 62.8 ppm (Table 3.9a) was found in 1991 at station MCB3.3W in segment three (Table 3.9a and Figure 7a). The median concentration of chromium exceeds the NOEL (33 ppm) in segments three, four, and five at the river mouth stations and Mobjack Bay, except for the James (Table 3.9a and MacDonald, 1993). However, all measured mainstem Bay chromium concentrations were well below the PEL of 240 ppm (Table 3.9a and MacDonald, 1993). Toxic effects to aquatic biota due to the measured sediment chromium concentrations are not likely at the monitored mainstem Bay stations.

There were few significant differences between annual mean sediment concentrations of chromium from 1984-1991 (Table 3.9b). At most stations where data were available, the measured and/or normalized chromium concentrations were somewhat lower in 1991 than in 1977 (Helz, et al. 1983), but differences in concentrations were generally not large (Figures 3.7b-c).

# Cr

Table 3.9a Summary statistics forChromium in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppm dry weight. Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 34.5 | 35.6 | 81 | 13.1 | 1.6 | 62.8 | 56.7 | 42.7 | 66 | 89.9 | 17.8 | 766.7 |
| Segment 1 | 16.6 | 23.0 | 3 | 11.3 | 3.5 | 23.2 | 293.4 | 78.6 | 3 | 410.4 | 35.0 | 766.7 |
| Segment 2 | 27.7 | 27.0 | 6 | 5.2 | 27.0 | 36.1 | 35.5 | 29.6 | 5 | 9.2 | 29.0 | 49.7 |
| Segment 3 | 38.8 | 38.4 | 15 | 15.1 | 8.9 | 62.8 | 49.2 | 45.0 | 12 | 16.0 | 30.6 | 89.0 |
| Segment 4 | 37.3 | 36.0 | 29 | 11.0. | 9.5 | 62.0 | 43.4 | 43.7 | 21 | 8.2 | 29.4 | 59.7 |
| Segment 5 | 36.0 | 53.0 | 11 | 10.1 | 16.0 | 53.0 | 52.1 | 43.0 | 9 | 16.5 | 36.6 | 83.3 |
| Segment 7 | 22.4 | 19.3 | 4 | 12.4 | 12.0 | 39.0 | 37.7 | 32.6 | 3 | 10.0 | 31.5 | 49.1 |
| Segment 8 | 14.2 | 14.2 | 2 | 12.5 | 5.3 | 23.0 | 67.4 | 67.4 | 2 | 36.3 | 41.7 | 93.1 |
| Center | 40.5 | 40.1 | 11 | 6.2 | 32.6 | 53.0 | 42.5 | 37.2 | 10 | 5.8 | 34.0 | 53.6 |
| East | 26.1 | 27.4 | 12 | 10.8 | 8.9 | 41.3 | 44.2 | 37.2 | 8 | 19.1 | 29.4 | 89.0 |
| West | 50.0 | 49.5 | 12 | 9.2 | 32.8 | 62.8 | 55.0 | 55.1 | 8 | 7.6 | 43.7 | 69.0 |
| Potomac | 34.7 | 35.2 | 3 | 4.6 | 29.9 | 39.0 | 37.0 | 39.7 | 3 | 4.8 | 31.5 | 39.8 |
| Rappahannock | 40.6 | 40.6 | 2 | 7.6 | 35.2 | 43.2 | 43.2 | 43.2 | 2 | 8.0 | 37.5 | 48.8 |
| Mobjack Bay | 40.2 | 40.2 | 2 | 4.0 | 37.3 | 43.0 | 42.1 | 42.1 | 2 | 3.9 | 39.3 | 44.8 |
| York | 44.5 | 44.5 | 2 | 16.3 | 32.9 | 56.0 | 49.2 | 49.2 | 2 | 12.7 | 40.3 | 58.2 |
| James | 22.3 | 22.3 | 2 | 29.3 | 1.6 | 43.0 | 41.7 | 41.7 | 2 | 33.8 | 17.8 | 65.5 |

7

Table 3.9b Temporal variability in chromium concentrations in Chesapeake Bay mainstem sediments. Means for years not connected by the underline are significantly different (p=0.05) as determined by ANOVA followed by a Duncan multiple range test. The means indicated by the year are ordered from high to low. NS = no significant differences. There were insufficient data to perform the test in segments one and eight and the river mouth stations and Mobjack Bay.

| Area | Measured | Normalized |
|------|----------|------------|
| Segment 2 | NS | NS |
| Segment 3 | NS | NS |
| Segment 4 | NS | NS |
| Segment 5 | 84 85 91 | NS |
| Segment 7 | NS | 84 91 |
| | | |
| Center | 84 91 85 | 84 91 85 |
| East | NS | NS |
| West | 84 91 85 | 91 85 |

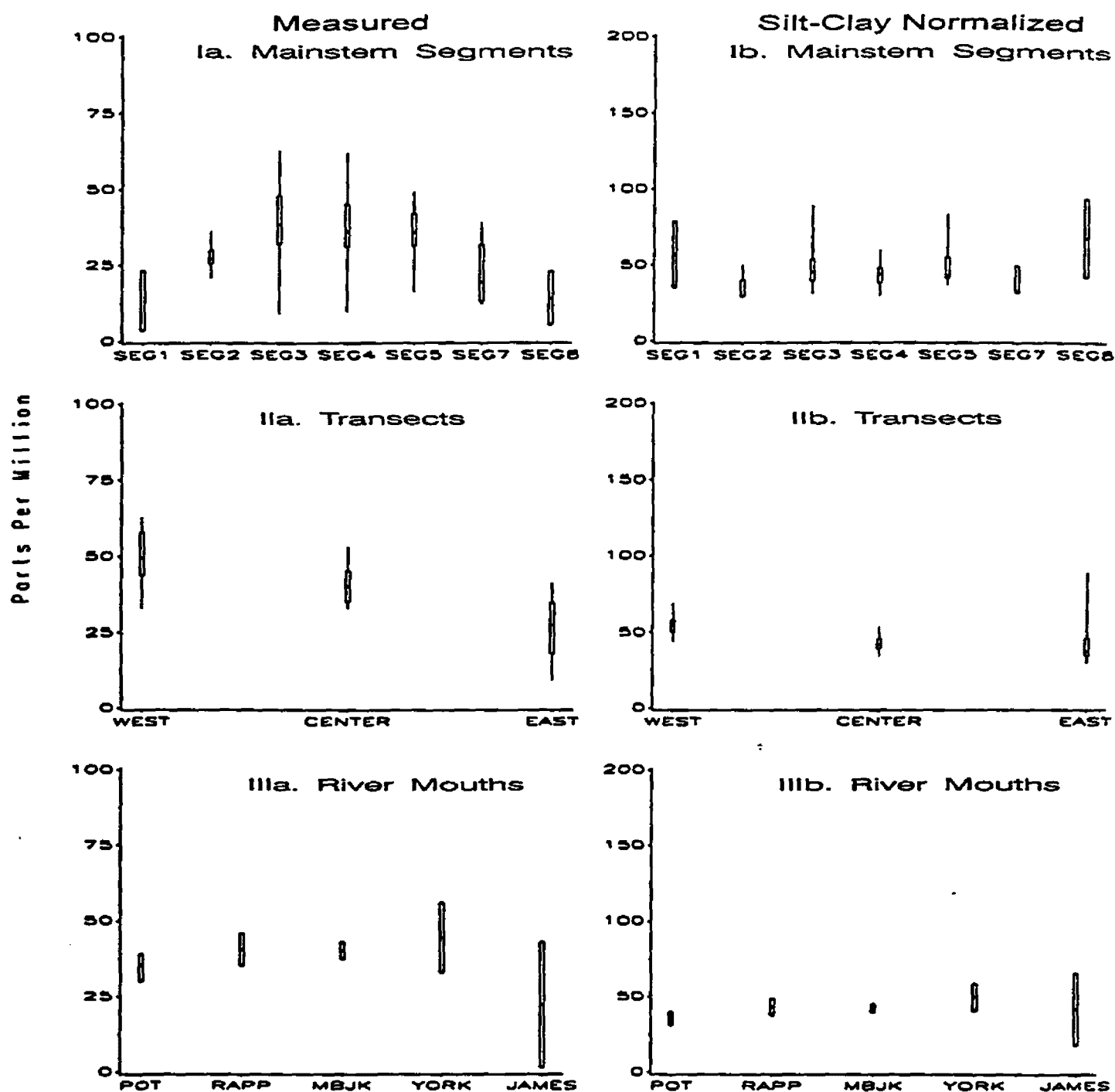# Figure 3.7a Chromium concentrations (ppm) in mainstem sediments



Figure 3.7a Summary statistics for measured and silt-clay normalized sediment concentrations of chromium in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment chromium concentrations are 33 ppm and 240 ppm, respectively (MacDonald, 1993).

## Figure 3.7b Measured Chromium Concentrations in Mainstem Sediments
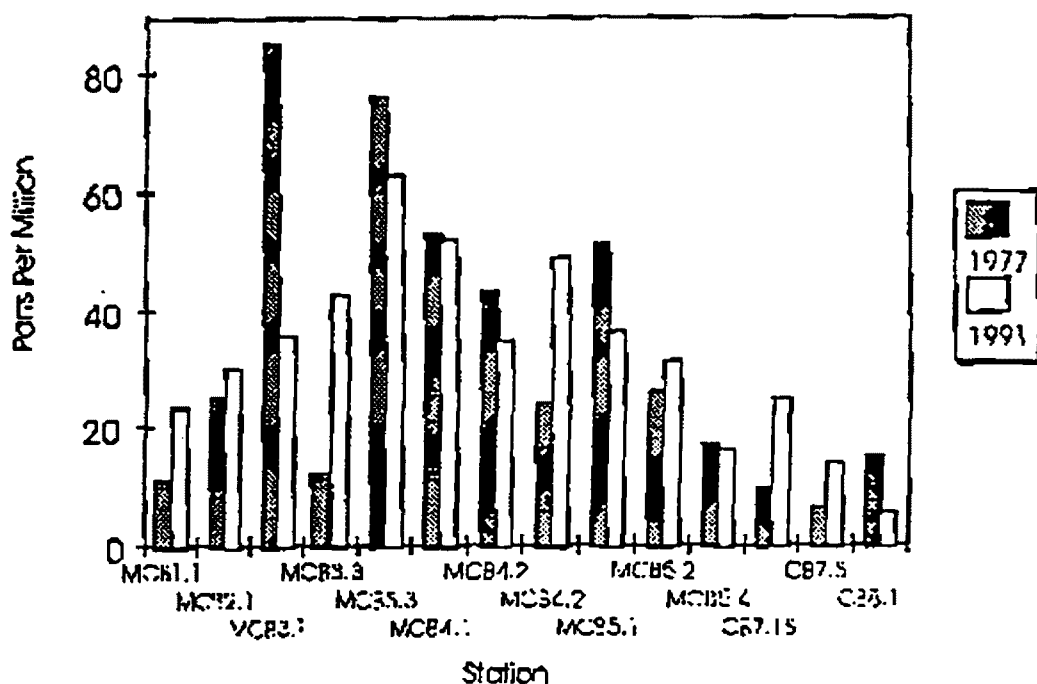## 1977 v. 1991



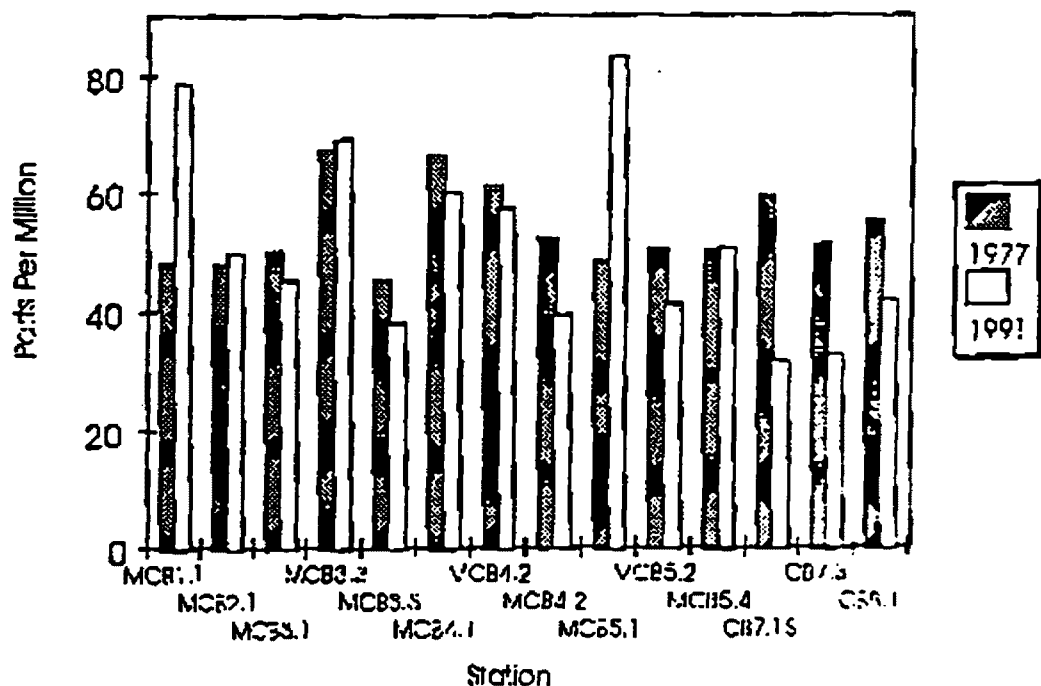## Figure 3.7c Normalized Chromium Concentrations in Mainstem Sediments
## 1977 v. 1991



Comparison of Chromium concentrations in mainstem sediments in 1977 and 1991. Station designation refer to the Chesapeake Bay Program monitoring stations. Data in 3.7b are measured sediment cadmium concentrations while the data in 3.7c are normalized, that is deivided, by the silt-clay fraction of the sediment samples.

## Copper

Marine and estuarine organisms are very sensitive to copper, a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program 1991a, 1991b). Natural sources of copper include the weathering or solution of copper-bearing minerals, copper sulfides, and native copper. Copper is frequently used in anti-fouling paint, wood preservatives, algicides, and fungicides (MacDonald, 1993). Copper is also widely used in the electrical industry and plumbing, roofing and building construction, and is present in effluents from smelting, refining, and metal plating industries (Chesapeake Bay Program, 1991b). Leaching from power plant pipes has caused locally high concentrations of copper in shellfish in the Chesapeake Bay in the past (Roosenburg, 1969).

The median copper concentration in mainstem sediments was 23.6 ppm, with a maximum concentration of 56 ppm (Table 3.10a) measured in 1984 at station MCB3.2 in segment three (Table 3.10a and Figure 3.8a). Median copper concentrations in segments two, three, and four were above the NOEL concentration (28 ppm), with the NOEL also exceeded several times in segment five (Table 3.10a and MacDonald, 1993). Among the river mouth stations, only one observation was above the NOEL, and this observation at the Potomac River mouth only exceeded the NOEL by a very small margin (Table 3.10a and MacDonald, 1993). All observations were below the PEL concentration of 170 ppm (Table 3.10a and MacDonald, 1993). Toxic effects to aquatic life due to the measured sediment copper concentrations are not likely at the mainstem Bay stations sampled.

There were few significant differences between annual mean sediment concentrations of copper. Where differences were found, concentrations in 1991 were lower than in preceding years (Table 3.10b). Sediment copper concentrations in 1977 (Helz, et al. 1983) were generally higher than those observed at nearby areas in 1991 (Figures 3.8b-c).

# Cu

Table 3.10a  Summary statistics for Copper in mainstem Chesapeake Bay sediments.  Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River.  Concentrations are in ppm dry weight.  Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 24.6 | 23.6 | 81 | 13.2 | 2.1 | 56.0 | 33.0 | 28.7 | 66 | 20.0 | 10.7 | 153.0 |
| Segment 1 | 9.6 | 4.6 | 3 | 9.5 | 3.7 | 20.5 | 86.6 | 69.5 | 3 | 60.0 | 37.0 | 153.0 |
| Segment 2 | 35.6 | 35.2 | 6 | 4.1 | 30.4 | 41.0 | 44.1 | 45.3 | 5 | 4.6 | 39.3 | 50.5 |
| Segment 3 | 4.3 | 33.6 | 15 | 15.5 | 4.6 | 56.0 | 42.5 | 42.1 | 12 | 15.6 | 25.4 | 79.0 |
| Segment 4 | 26.6 | 29.0 | 29 | 11.0 | 2.5 | 48.0 | 29.8 | 29.0 | 21 | 9.6 | 13.3 | 44.7 |
| Segment 5 | 19.5 | 19.2 | 11 | 8.6 | 6.0 | 32.0 | 24.5 | 24.1 | 9 | 5.0 | 17.6 | 31.3 |
| Segment 7 | 7.1 | 8.0 | 4 | 2.5 | 3.4 | 9.0 | 13.2 | 11.5 | 3 | 3.8 | 10.7 | 17.6 |
| Segment 8 | 4.6 | 4.6 | 2 | 3.6 | 2.1 | 7.2 | 25.4 | 25.4 | 2 | 8.9 | 16.5 | 29.1 |
| Center | 26.8 | 26.2 | 11 | 10.3 | 12.7 | 47.0 | 28.2 | 26.5 | 10 | 10.7 | 13.3 | 47.6 |
| East | 18.5 | 21.0 | 12 | 9.5 | 2.5 | 33.0 | 32.7 | 28.1 | 8 | 19.0 | 20.8 | 79.0 |
| West | 39.1 | 37.1 | 12 | 7.4 | 30.7 | 53.0 | 41.6 | 42.2 | 8 | 4.7 | 35.8 | 49.1 |
| Potomac | 25.4 | 25.5 | 3 | 3.7 | 21.6 | 29.0 | 26.9 | 26.8 | 3 | 2.6 | 24.4 | 29.6 |
| Rappahannock | 20.2 | 20.2 | 2 | 1.6 | 19.0 | 21.4 | 21.4 | 21.4 | 2 | 1.8 | 20.2 | 22.7 |
| Mobjack Bay | 15.9 | 15.9 | 2 | 1.6 | 14.8 | 17.0 | 16.7 | 16.7 | 2 | 1.5 | 15.6 | 17.7 |
| York | 21.6 | 21.6 | 2 | 2.2 | 20.0 | 23.1 | 24.5 | 24.5 | 2 | 5.3 | 20.8 | 28.3 |
| James | 9.1 | 9.1 | 2 | 9.8 | 2.2 | 16.0 | 24.4 | 24.4 | 2 | 0.04 | 24.4 | 24.4 |

Table 3.10b Temporal variability in copper concentrations in Chesapeake Bay mainstem sediments. Means for years not connected by the underline are significantly different (p=0.05) as determined by ANOVA followed by a Duncan multiple range test. The means indicated by the year are ordered from high to low. NS = no significant differences. There were insufficient data to perform the test for segments one and eight and the river mouth stations and Mobjack Bay.

| Region | Measured | Normalized |
|---|---|---|
| Segment 2 | NS | NS |
| Segment 3 | NS | NS |
| Segment 4 | NS | NS |
| Segment 5 | 84 85 91 | NS |
| Segment 7 | NS | NS |
| | | |
| Center | 84 85 91 | 84 85 91 |
| East | NS | NS |
| West | 84 85 91 | 85 91 |

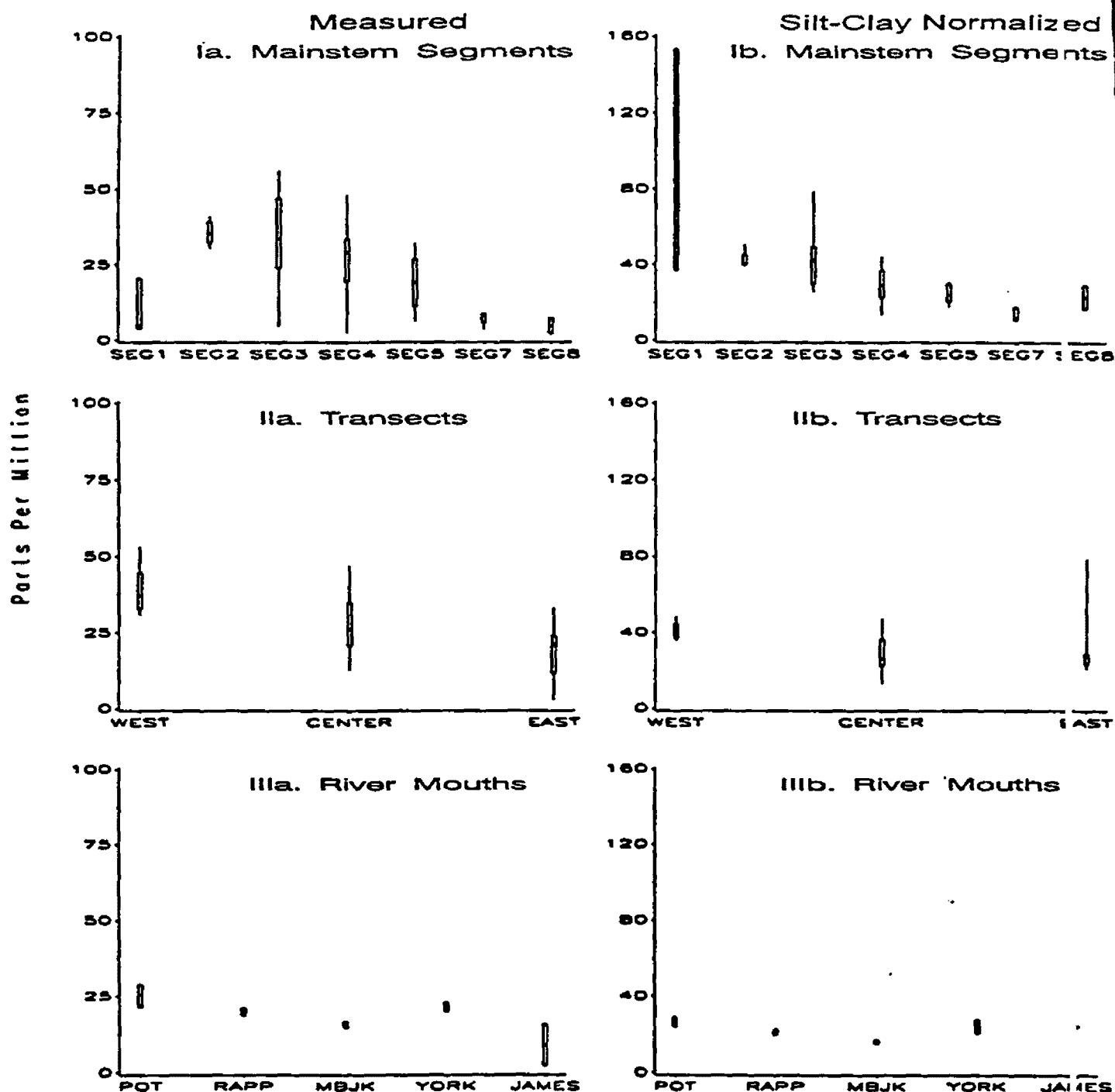# Figure 3.8a Copper concentrations (ppm) in mainstem sediments



Figure 3.8a Summary statistics for measured and silt-clay normalized sediment concentratio is of copper in the Chesapeake Bay mainstem. The box and whisker plots illustrate the medic n (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertic il lines) of the data. If there are less than four values, the rectangle's bottom and top show tl e range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep troug i; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and n Mobjack Bay. The NOEL and PEL values for measured sediment copper concentrations are 2 8 ppm and 170 ppm, respectively (MacDonald, 1993).

# Figure 3.8b Measured Copper Concentrations in Mainstem Sediments
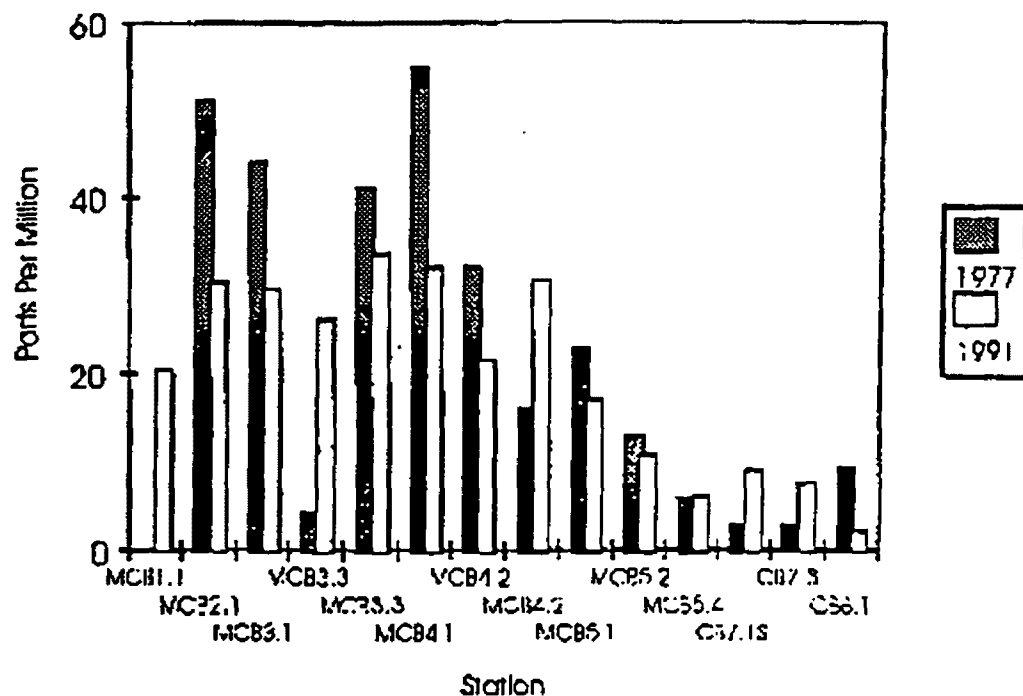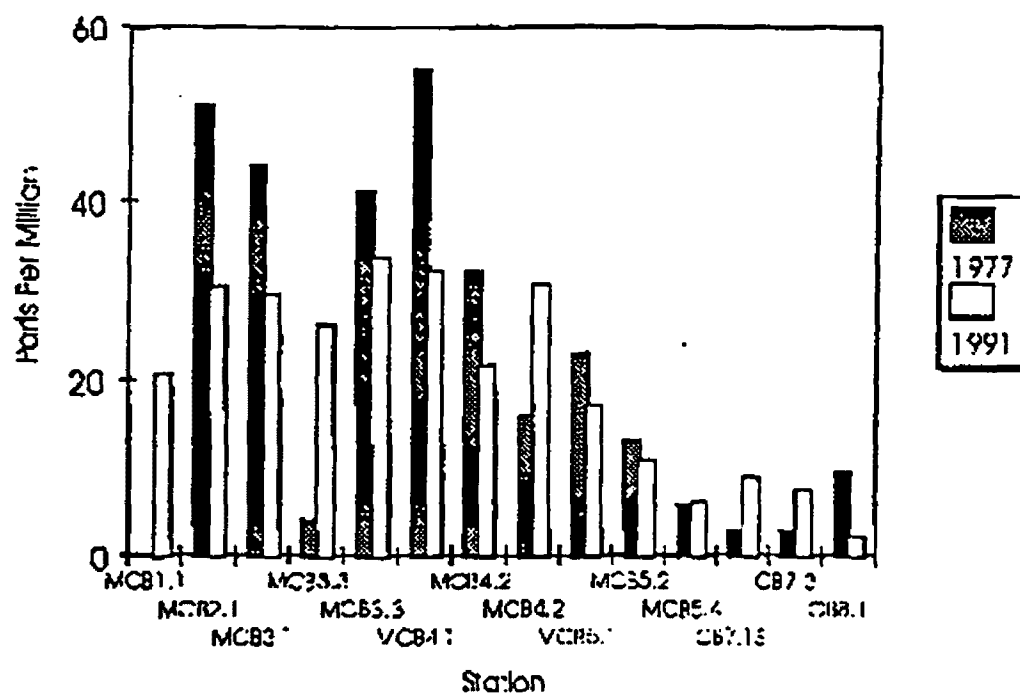## 1977 v. 1991



# Figure 3.8c Normalized Copper Concentrations In Mainstem Sediments
## 1977 v. 1991



Comparison of Copper concentrations in mainstem sediments in 1977 and 1991.  Station designation refer to the Chesapeake Bay Program monitoring stations.  Data in 3.8b are measured sediment cadmium concentrations while the data in 3.8c are normalized, that is deivided, by the silt-clay fraction of the sediment samples.

*Lead*

Lead, a Chesapeake Bay Toxic of Concern, has many industrial applications, including use in tank linings and piping, petroleum refining, paint pigments, batteries, ceramics, plastics, electronic devices, and the manufacture of steel and other metals (Chesapeake Bay Program, 1991a, 1991b). It was previously added to gasoline, but this use has been discontinued with a few exceptions (Chesapeake Bay Program, 1991b). Lead is generally more toxic in the form of organolead compounds (Long and Morgan, 1990) than in the elemental forms.

The median sediment lead concentration in the mainstem Bay was 35 ppm, with the maximum value of 86 ppm (Table 3.11a and Figure 3.9a) measured in 1984 at stations MCB3.2 and MCB3.3W in segments two and three, respectively. The NOEL concentration for lead (21 ppm) is equalled or exceeded by the median measured sediment concentrations in segments two, three, four, and five and at all the river mouth stations and Mobjack Bay except for James River (Table 3.11a and MacDonald, 1993). However, the PEL concentration of 160 ppm is well above all measured concentrations (Table 3.11a and MacDonald, 1993). Toxic effects to aquatic life due to the measured sediment lead concentrations are not likely at the sampled mainstem Bay stations.

There were some significant differences between annual mean sediment concentrations of lead. Where differences were found, sediment lead concentrations in 1991 were lower than in preceding years (Table 3.11b). Comparison of 1977 data (Helz, *et al.* 1983) with 1991 data shows that sediment lead concentrations were higher in 1977 than in 1991 in most of the upper and middle Bay, but lower than 1991 concentrations in the extreme upper Bay and the lower portion of the mainstem Bay (Figures 3.9b-c).

# Pb

Table 3.11a  Summary statistics for lead in mainstem Chesapeake Bay sediments.  Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River.  Concentrations are in ppm dry weight.  Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 35.7 | 35.0 | 81 | 18.9 | 1.6 | 86.0 | 54.8 | 42.4 | 66 | 65.5 | 10.8 | 500.0 |
| Segment 1 | 23.3 | 15.0 | 3 | 16.4 | 12.7 | 42.1 | 256.6 | 142.7 | 3 | 211.0 | 127.0 | 500.0 |
| Segment 2 | 49.4 | 48.3 | 6 | 15.1 | 32.0 | 66.0 | 57.4 | 53.2 | 5 | 10.6 | 46.6 | 72.8 |
| Segment 3 | 50.8 | 51.2 | 15 | 20.0 | 15.0 | 86.0 | 39 | 58.4 | 5 | 10.6 | 46.6 | 72.8 |
| Segment 4 | 36.8 | 35.0 | 29 | 17.8 | 11.5 | 76.0 | 39.0 | 37.4 | 21 | 17.1 | 13.2 | 72.8 |
| Segment 5 | 29.5 | 29.3 | 11 | 12.5 | 6.2 | 46.0 | 37.4 | 32.3 | 9 | 9.9 | 23.2 | 49.7 |
| Segment 7 | 13.9 | 11.8 | 4 | 8.2 | 6.9 | 25.0 | 19.5 | 16.2 | 3 | 10.7 | 10.8 | 31.5 |
| Segment 8 | 15.2 | 15.2 | 2 | 13.9 | 5.3 | 25.0 | 71.5 | 71.5 | 2 | 42.1 | 41.7 | 101.2 |
| Center | 38.2 | 39.9 | 11 | 17.7 | 11.7 | 66.0 | 39.5 | 39.7 | 10 | 19.0 | 13.2 | 66.8 |
| East | 29.1 | 26.3 | 12 | 11.6 | 15.0 | 46.0 | 64.3 | 40.1 | 8 | 75.2 | 21.6 | 246.0 |
| West | 54.8 | 48.0 | 12 | 16.8 | 34.1 | 48.0 | 52.8 | 54.8 | 8 | 7.5 | 39.2 | 60.5 |
| Potomac | 32.5 | 35.0 | 3 | 5.0 | 26.8 | 35.8 | 34.8 | 35.7 | 3 | 6.1 | 28.2 | 40.4 |
| Rappahannock | 23.5 | 23.5 | 2 | 2.1 | 22.0 | 25.0 | 25.0 | 25.0 | 2 | 2.2 | 23.4 | 26.5 |
| Mobjack Bay | 26.2 | 26.2 | 2 | 12.5 | 17.3 | 27.4 | 27.4 | 27.4 | 2 | 12.0 | 18.2 | 36.5 |
| York | 26.5 | 26.5 | 2 | 12.0 | 18.0 | 29.2 | 29.2 | 29.2 | 2 | 10.1 | 22.0 | 36.4 |
| James | 20.8 | 20.8 | 2 | 27.2 | 1.6 | 39.4 | 39.4 | 39.4 | 2 | 30.5 | 17.8 | 61.0 |

Table 3.11b Temporal variability in lead concentrations in Chesapeake Bay mainstem sediments. Means for years not connec ed by the underline are significantly different ($p<0.05$) as determined by ANOVA followed by a Duncan multiple range test. The m ans indicated by the year are ordered from high to low. · NS = no significant differences. There were insufficient data to perform t e test for segments one and eight, the river mouth stations, and Mobjack Bay.

| Area | Measured | Normalized |
|------|----------|------------|
| Segment 2 | NS | NS |
| Segment 3 | NS | NS |
| Segment 4 | <u>84 91 85</u> | NS |
| Segment 5 | NS | NS |
| Segment 7 | NS | NS |
| | | |
| Center | NS | NS |
| East | NS | NS |
| West | <u>84</u> <u>85 91</u> | NS |

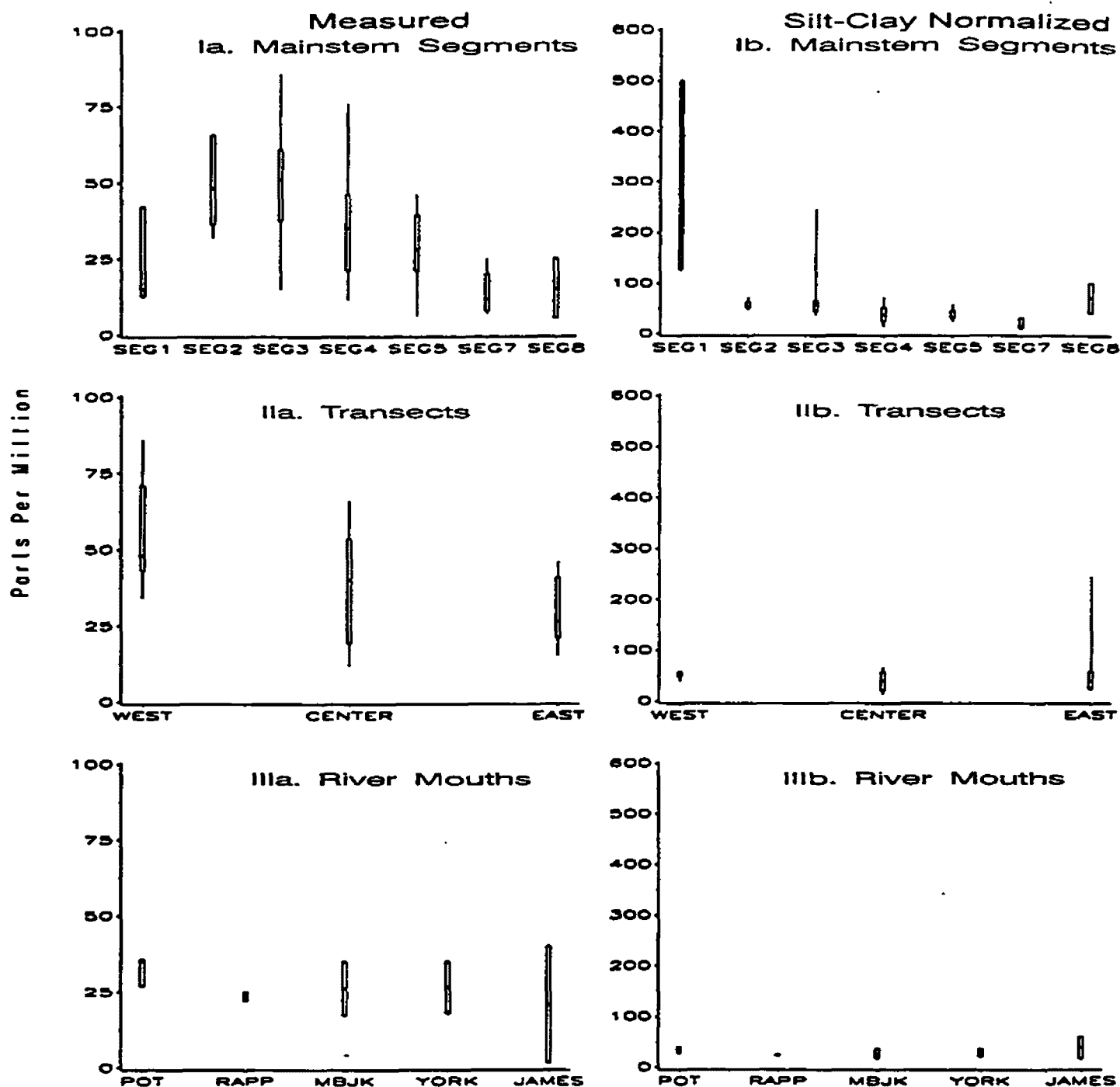# Figure 3.9a Lead concentrations (ppm) in mainstem sediments



Figure 3.9a Summary statistics for measured and silt-clay normalized sediment concentrations of lead in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment lead concentrations are 21 ppm and 160 ppm, respectively (MacDonald, 1993).

# Figure 3.9b Measured Lead Concentrations in Mainstem Sediments 1977 v. 1991
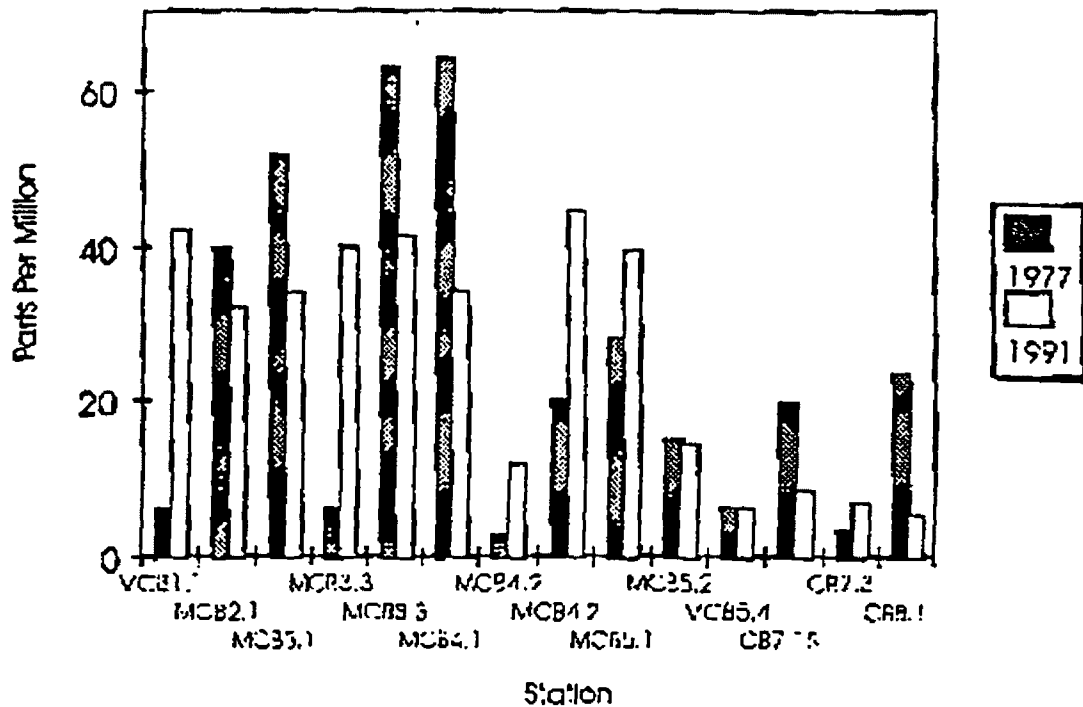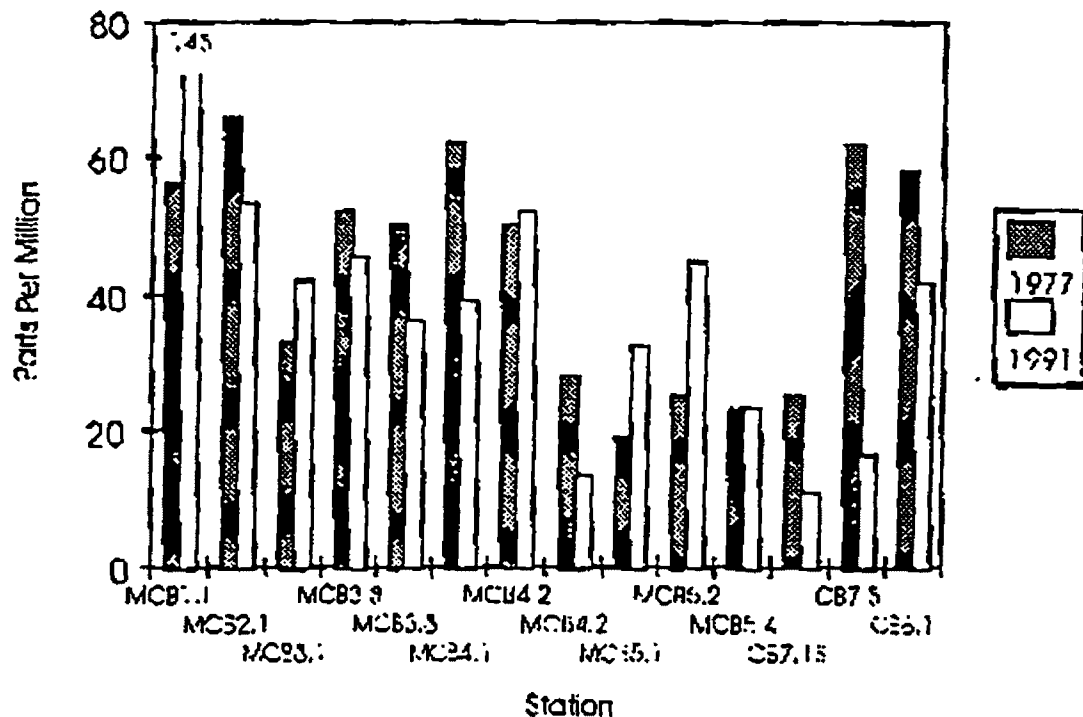


# Figure 3.9c Normalized Lead Concentrations in Mainstem Sediments 1977 v. 1991



Comparison of Lead concentrations in mainstem sediments in 1977 and 1991. Station designation refer to the Chesapeake Bay Program monitoring stations. Data in 3.9b are measured sediment cadmium concentrations while the data in 3.9c are normalized, that is deivided, by the silt-clay fraction of the sediment samples.

## Mercury

Mercury, a Chesapeake Bay Program Toxic of Concern, can exist as inorganic mercury (mercury II) or as organic mercury (Chesapeake Bay Program, 1991a and 1991b). Organic mercury, especially methylmercury, is generally more toxic than inorganic mercury. Mercury is a natural component of sediment, and is used in the chemical, paint, and pul· and paper industries. Mercury-based pesticides were once used in agriculture, but the use of such pesticides has beε restricted (MacDonald, 1993).

The median concentration in the mainstem Bay was 0.08 ppm (Table 3.12a). The maximum mercury concentration of 0.80 ppm (Table 3.12a and Figure 3.10) was found at station MCB3.3C in segment three in 1984. Median sediment mercury concentrations in segments two and three and the Rappahannock River mouth stations equalled or exceeded the NOEL concentrations of 0.10 ppm, and the maximum concentration at the Potomac River mouth station was also well above this concentration (Table 3.12a and MacDonald, 1993). All measurements of sediment mercury concentrations were well below the PEL of 1.4 ppm (Table 3.12a and MacDonald, 1993). Toxic effects to aquatic life due to the measured mercury concentrations in the sediment are not likely at the mainstem Bay stations sampled.

There were few significant differences between annual mean measured or normalized sediment concentrations of mercury. Where differences were found, sediment mercury concentrations in 1991 were lower than in preceding years (Table 3.12b). Historical data on mercury concentrations were not available for comparison with the recently collected data.

# Hg

Table 3.12a  Summary statistics for Mercury in mainstem Chesapeake Bay sediments.  Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River.  Concentrations are in ppm dry weight.  Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 0.15 | 0.08 | 81 | 0.17 | 0.01 | 0.80 | 0.20 | 0.10 | 66 | 0.42 | 0.01 | 3.33 |
| Segment 1 | 0.05 | 0.05 | 3 | 0.05 | 0.01 | 0.10 | 1.19 | 0.17 | 3 | 1.86 | 0.06 | 3.33 |
| Segment 2 | 0.23 | 0.14 | 6 | 0.22 | 0.05 | 0.60 | 0.19 | 0.15 | 5 | 0.16 | 0.06 | 0.46 |
| Segment 3 | 0.20 | 0.10 | 15 | 0.23 | 0.02 | 0.80 | 0.19 | 0.11 | 5 | 0.16 | 0.06 | 0.81 |
| Segment 4 | 0.15 | 0.08 | 29 | 0.16 | 0.01 | 0.60 | 0.10 | 0.08 | 21 | 0.12 | 0.01 | 0.61 |
| Segment 5 | 0.14 | 0.05 | 11 | 0.15 | 0.03 | 0.40 | 0.12 | 0.08 | 9 | 0.11 | 0.04 | 0.40 |
| Segment 7 | 0.07 | 0.07 | 4 | 0.04 | 0.03 | 0.10 | 0.09 | 0.11 | 3 | 0.05 | 0.03 | 0.13 |
| Segment 8 | 0.09 | 0.09 | 2 | 0.01 | 0.09 | 0.10 | 0.54 | 0.54 | 2 | 0.19 | 0.40 | 0.68 |
| Center | 0.23 | 0.08 | 11 | 0.27 | 0.02 | 0.80 | 0.21 | 0.08 | 10 | 0.27 | 0.02 | 0.81 |
| East | 0.10 | 0.05 | 12 | 0.11 | 0.02 | 0.40 | 0.08 | 0.07 | 8 | 0.05 | 0.04 | 0.20 |
| West | 0.16 | 0.10 | 12 | 0.12 | 0.05 | 0.40 | 0.10 | 0.10 | 8 | 0.03 | 0.05 | 0.15 |
| Potomac | 0.16 | 0.05 | 3 | 0.21 | 0.04 | 0.40 | 0.17 | 0.06 | 3 | 0.21 | 0.04 | 0.41 |
| Rappahannock | 0.10 | 0.10 | 2 | 0.00 | 0.10 | 0.10 | 0.11 | 0.11 | 2 | 0.00 | 0.11 | 0.11 |
| Mobjack Bay | 0.09 | 0.09 | 2 | 0.02 | 0.07 | 0.10 | 0.09 | 0.09 | 2 | 0.02 | 0.08 | 0.10 |
| York | 0.09 | 0.09 | 2 | 0.01 | 0.08 | 0.10 | 0.10 | 0.10 | 2 | 0.00 | 0.10 | 0.10 |
| James | 0.07 | 0.07 | 2 | 0.04 | 0.05 | 0.10 | 0.33 | 0.33 | 2 | 0.25 | 0.15 | 0.51 |

Table 3.12b Temporal variability in mercury concentrations in Chesapeake Bay mainstem sediments. Means for years not connected by the underline are significantly different (p<0.05) as determined by ANOVA followed by a Duncan multiple range test. The means indicated by the year are ordered from high to low. NS = no significant differences. There were insufficient data to perform the test for segments one and eight, the river mouth stations and Mobjack Bay.

| Area | Measured | Normalized |
|------|----------|------------|
| Segment 2 | <u>84</u> <u>85 91</u> | <u>84</u> <u>85 91</u> |
| Segment 3 | <u>84</u> <u>85 91</u> | <u>84</u> <u>85 91</u> |
| Segment 4 | <u>84 91</u> <u>85</u> | <u>84 91 85</u> |
| Segment 5 | <u>84 91</u> <u>85</u> | NS |
| Segment 7 | <u>84 91</u> | NS |
| | | |
| Center | <u>84 91</u> <u>85</u> | <u>84</u> <u>91 85</u> |
| East | <u>84 91</u> <u>85</u> | NS |
| West | <u>84</u> <u>85 91</u> | NS |

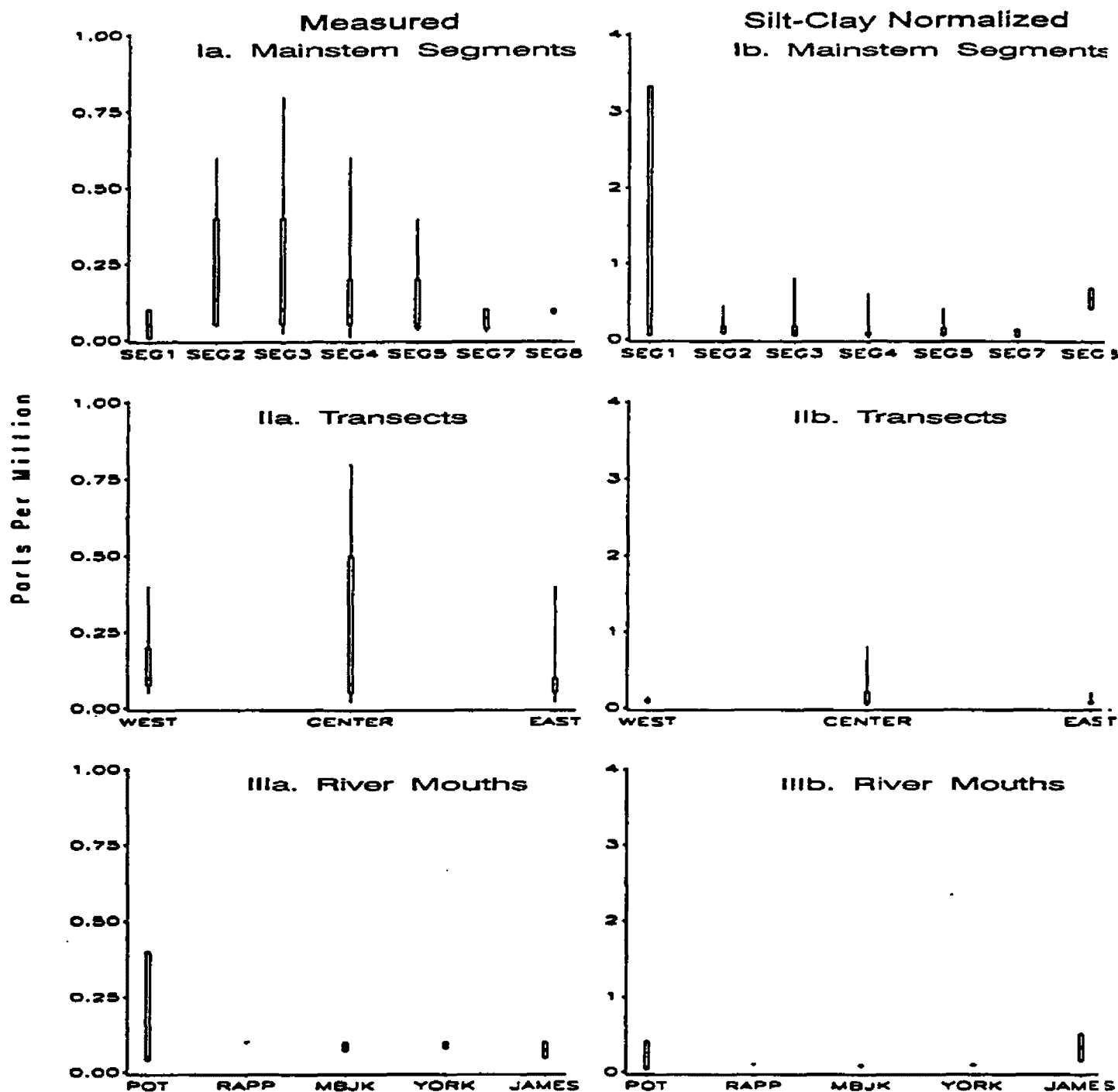# Figure 3.10 Mercury concentrations (ppm) in mainstem sediments



Figure 3.10 Summary statistics for measured and silt-clay normalized sediment concentrations of mercury in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment mercury concentrations are 0.1 ppm and 1.4 ppm, respectively (MacDonald, 1993).

## Nickel

Nickel is not listed as a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a). Nickel is used primarily in the manufacture of stainless steel, nickel plating, and other nickel alloys. It is also used as a catalyst in industrial processes and in oil refining (MacDonald, 1993). Nickel, like other trace metals, is naturally present in soils, rocks, and sediments. The principal anthropogenic sources of nickel are fossil fuel combustion, nickel ore mining, and the smelting, refining, and electroplating industries.

The median mainstem sediment nickel concentration was 26.9 ppm (Table 3.13a). The maximum value of 80 ppm (Table 3.13a and Figure 3.11a) was found at MCB3.2 in segment three in 1984.

The biological significance of nickel concentrations in sediment are difficult to evaluate due to the low level of confidence that can be placed in existing sediment quality guidelines. Long and Morgan (1990) placed only a moderate level of confidence in their ER-L and ER-M guidelines for nickel, since the only data available to develop the guidelines were from matching chemical and biological analyses performed on field samples from areas on the West Coast. MacDonald (1993) believed there were insufficient data available to develop NOEL and PEL concentrations. Subsequent analyses of the data set used by MacDonald (1993) showed no evidence of increasing incidence of toxicity with increasing sediment concentrations of nickel (Long, et al., 1995). Thus, current sediment guidelines do not provide an adequate basis for evaluating the likelihood of toxic effects to aquatic organisms due to sediment nickel concentrations.

There were some significant differences between annual mean measured and normalized sediment concentrations of nickel. Where differences were found, concentrations in 1991 were lower than in preceding years (Table 3.13b). Comparisons of 1991 sediment nickel concentrations with 1977 data (Helz, et al., 1983) show only moderate declines compared to those exhibited by some of the other trace metals (Figures 3.11b-c).

# Ni

Table 3.13a  Summary statistics for Nickel in mainstem Chesapeake Bay sediments.  Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River.  Concentrations are in ppm dry weight.  Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 30.0 | 26.9 | 81 | 16.9 | 0.90 | 80.0 | 44.2 | 3.6 | 66 | 49.0 | 10.0 | 400.0 |
| Segment 1 | 18.2 | 12.0 | 3 | 12.4 | 10.2 | 32.5 | 204.1 | 110.2 | 3 | 169.7 | 102.0 | 400.0 |
| Segment 2 | 53.7 | 52.8 | 6 | 5.4 | 45.9 | 61.2 | 67.7 | 64.6 | 5 | 10.4 | 59.2 | 85.4 |
| Segment 3 | 44.4 | 46.1 | 15 | 21.1 | 8.7 | 80.0 | 52.9 | 51.4 | 12 | 18.2 | 28.4 | 87.0 |
| Segment 4 | 29.1 | 26.9 | 29 | 10.9 | 2.5 | 53.0 | 32.1 | 33.2 | 21 | 7.7 | 15.4 | 46.3 |
| Segment 5 | 23.8 | 25.3 | 11 | 9.7 | 7.2 | 36.0 | 30.4 | 31.2 | 9 | 6.1 | 19.5 | 37.5 |
| Segment 7 | 10.2 | 9.2 | 4 | 7.5 | 2.5 | 20.0 | 18.5 | 15.5 | 3 | 5.8 | 14.9 | 25.2 |
| Segment 8 | 7.5 | 7.5 | 2 | 6.4 | 3.0 | 12.0 | 36.1 | 36.1 | 2 | 17.7 | 23.6 | 48.6 |
| Center | 32.5 | 31.0 | 11 | 10.2 | 21.1 | 55.0 | 33.6 | 32.1 | 10 | 10.1 | 2.9 | 55.7 |
| East | 21.0 | 24.2 | 12 | 11.0 | 2.5 | 36.0 | 35.9 | 30.8 | 8 | 21.6 | 15.4 | 87.0 |
| West | 39.7 | 37.4 | 12 | 10.3 | 26.0 | 61.0 | 40.2 | 40.1 | 8 | 5.0 | 33.5 | 46.9 |
| Potomac | 25.5 | 23.7 | 3 | 7.8 | 18.8 | 34.0 | 26.9 | 24.9 | 3 | 6.9 | 21.2 | 34.7 |
| Rappahannock | 22.1 | 22.1 | 2 | 4.1 | 19.2 | 25.0 | 23.5 | 23.5 | 2 | 4.3 | 20.4 | 26.5 |
| Mobjack Bay | 19.5 | 19.5 | 2 | 5.0 | 15.9 | 23.0 | 20.4 | 20.4 | 2 | 5.1 | 16.7 | 24.0 |
| York | 21.1 | 21.1 | 2 | 9.8 | 14.2 | 28.0 | 23.2 | 23.2 | 2 | 8.3 | 17.4 | 29.1 |
| James | 10.5 | 10.5 | 2 | 13.5 | 0.9 | 20.0 | 20.2 | 20.2 | 2 | 14.5 | 10.0 | 30.5 |

Table 3.13b Temporal variability in nickel concentrations in mainstem Chesapeake Bay sediments. Means for years not connected by the underline are significantly different (p<0.05) as determined by ANOVA followed by a Duncan multiple range test. The means indicated by the year are ordered from high to low. NS = no significant differences. There were insufficient data to perform the test for segments one and eight and the river mouth stations and Mobjack Bay.

| Region | Measured | Normalized |
|---|---|---|
| Segment 2 | NS | NS |
| Segment 3 | NS | NS |
| Segment 4 | <u>84 85</u> 91 | NS |
| Segment 5 | <u>84 85 91</u> | <u>84 85</u> 91 |
| Segment 7 | NS | <u>84 91</u> |
| Center | <u>84 85</u> 91 | NS |
| East | NS | NS |
| West | <u>84 85 91</u> | NS |

# Figure 3.11a Nickel concentrations (ppm)
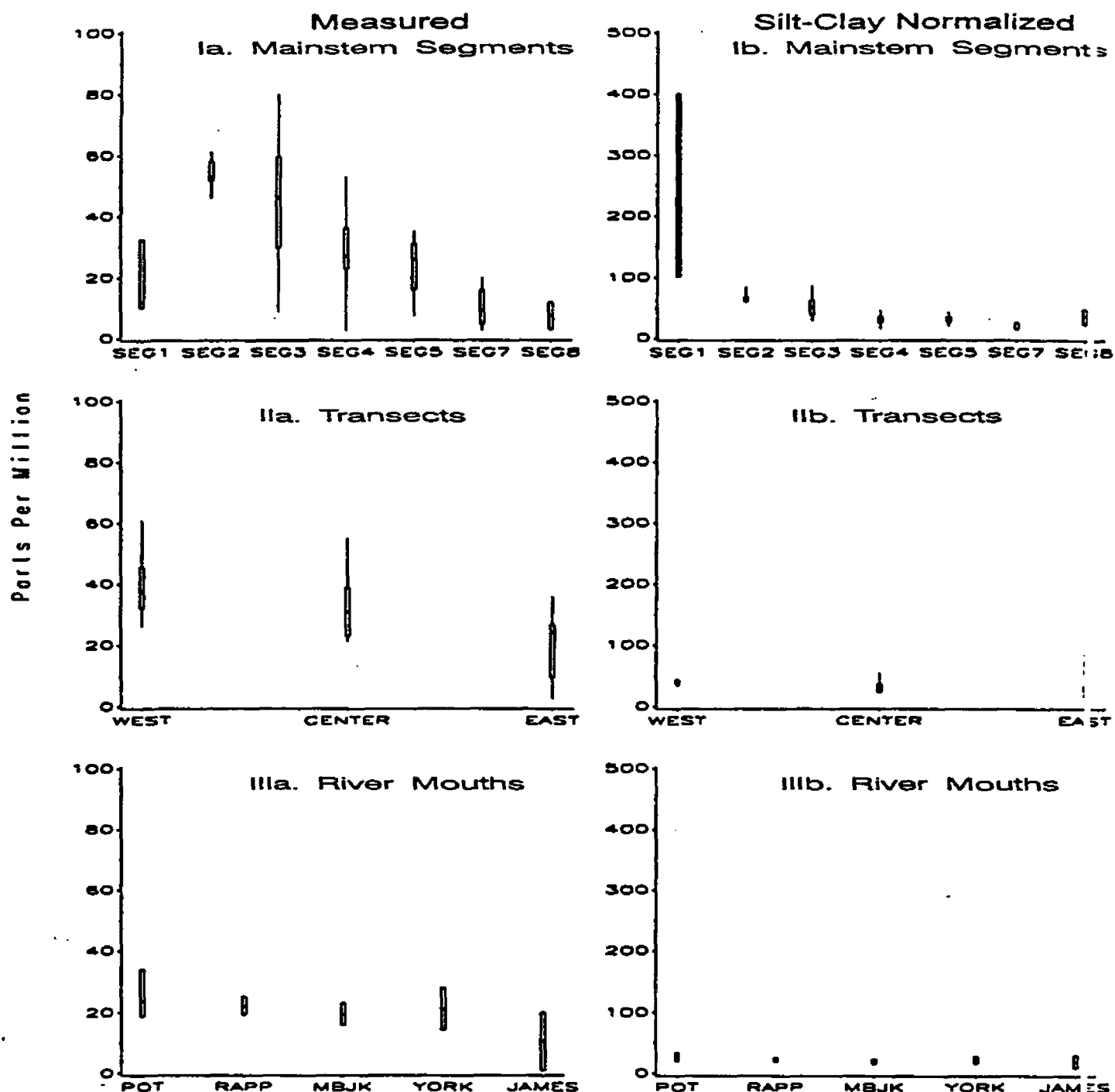## in mainstem sediments



Figure 3.11a    Summary statistics for measured and silt-clay normalized sediment concentrations of nickel in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment nickel concentrations are not available due to insufficient data (MacDonald, 1993).

## Figure 3.11b Measured Nickel Concentrations in Mainstem Sediments 1977 v. 1991
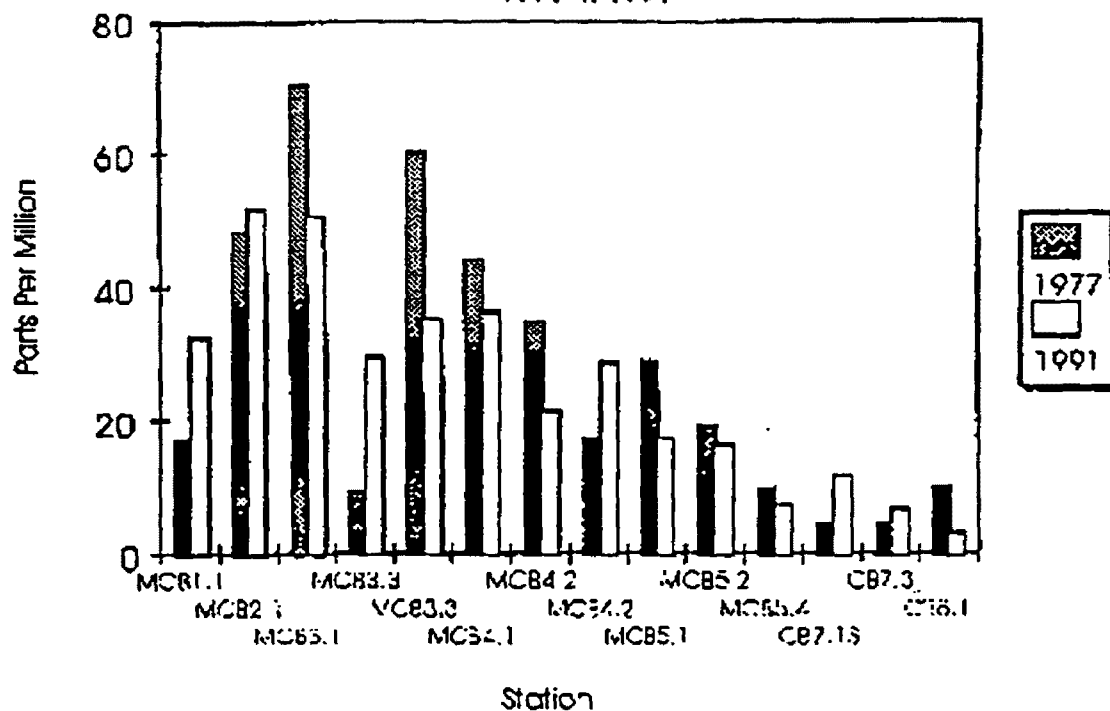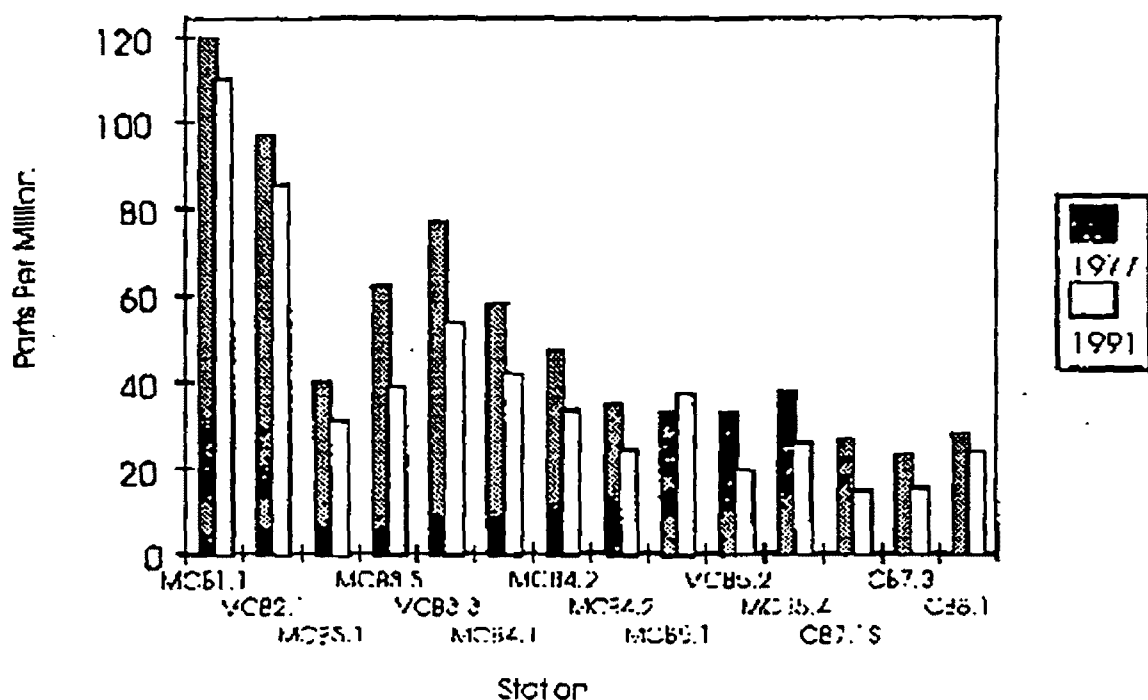


## Figure 3.7c Normalized Nickel Concentrations in Mainstem Sediments 1977 v. 1991



Comparison of Nickel concentrations in mainstem sediments in 1977 and 1991. Station designation refer to the Chesapeake Bay Program monitoring stations. Data in 3.11b are measured sediment cadmium concentrations while the data in 3.11c are normalized, that is deivided, by the silt-clay fraction of the sediment samples.
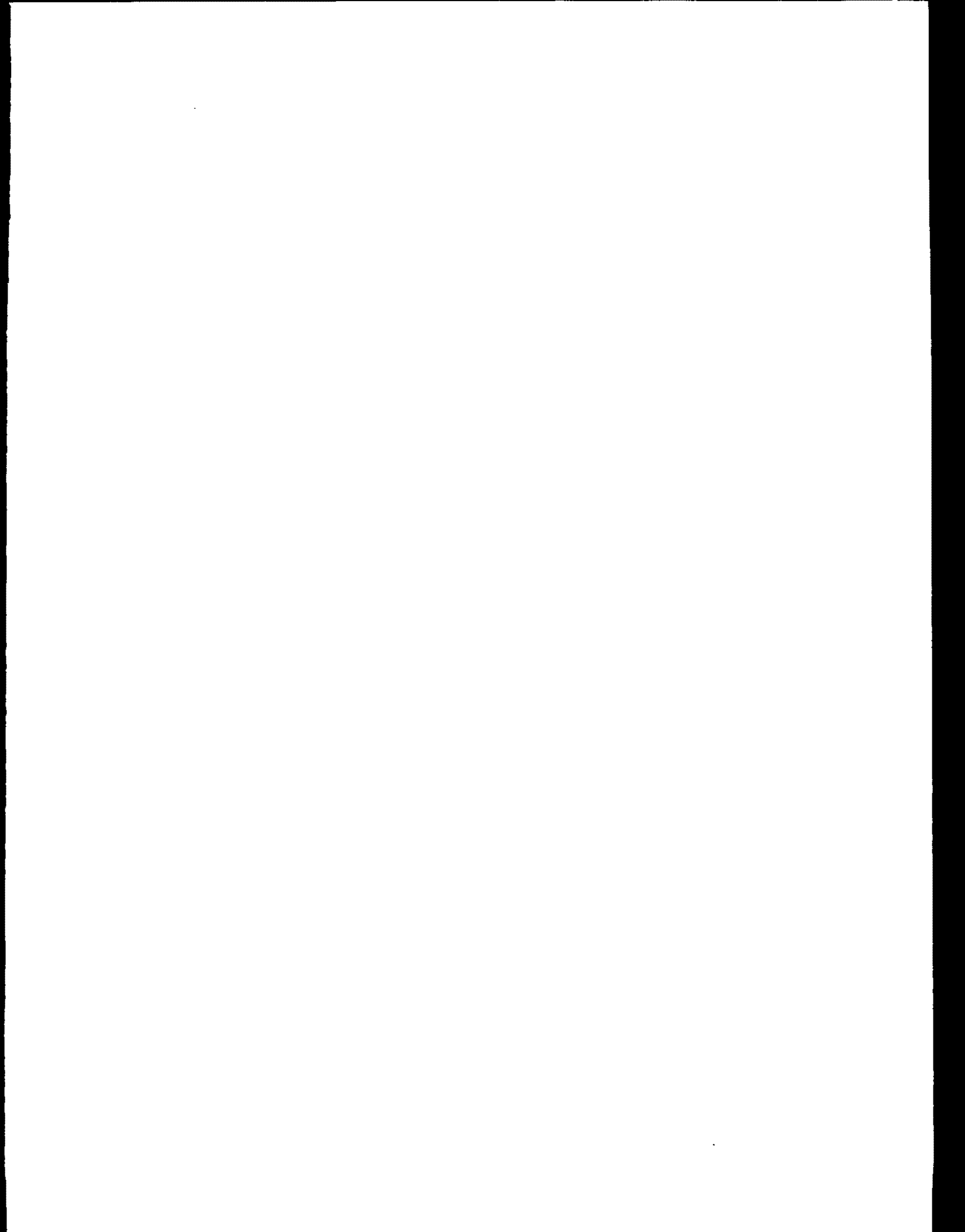
### Zinc

Zinc is not on the Chesapeake Bay Toxics of Concern list but is a substance for which more information is being soug (Chesapeake Bay Program, 1991a). Zinc is used in coatings to protect iron and steel, in brass, batteries, roofing and exterior fittings for buildings, and in some printing processes. Zinc is a natural element found in soils and sediments. Anthropogenic sources of zinc to aquatic ecosystems include industrial and municipal wastewater effluents, urban stormwater, waste incineration, iron and steel production, and atmospheric emissions (MacDonald, 1993). Zinc is ofte found at relatively high concentrations in urban stormwater (Olsenholler, 1991).

The median sediment zinc concentration in the mainstem Bay was 136 ppm (Table 3.14a). The maximum zinc concentration of 495 ppm was found at MCB3.2 in segment three in 1985 (Table 3.14a and Figure 3.12a). The NOEL concentration for zinc (68 ppm) was exceeded by the median sediment concentrations in segments 2 through 5, at Mobjack Bay, and at all river mouth stations except the James River mouth (Table 3.14a and MacDonald, 1993). Maximum sediment zinc concentrations above the NOEL concentration were found in all areas except segments 7 and 8 (Table 3.14a and MacDonald, 1993). The PEL concentration (300 ppm) was exceeded by individual measurement. only in segments two, three, four and five (Table 3.14a and MacDonald, 1993a). Toxic effects to aquatic organisms d to measured sediment zinc concentrations may occur in portions of the middle mainstem Bay.

There were some significant differences between annual mean sediment concentrations of zinc. Where differences were found, sediment zinc concentrations in 1991 were lower than in preceding years (Table 3.14b). The concentrations of zinc observed in sediment samples collected from the mainstem in 1977 (Helz, et al., 1983) are generally higher than those found in nearby locations in 1991, especially in the middle region of the mainstem Bay (Figures 3.12b-c).

# Zn

Table 3.14a  Summary statistics for Zinc in mainstem Chesapeake Bay sediments.  Statistics are presented for all mainstem stations; Chesapeake Bay Program segments; groups of stations within and adjacent to the deep trough of the midbay; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River.  Concentrations are in ppm dry weight.  Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 167 | 136 | 81 | 106 | 8 | 495 | 237 | 213 | 66 | 158 | 57 | 990 |
| Segment 1 | 62 | 43 | 3 | 55 | 19 | 123 | 494 | 430 | 3 | 121 | 418 | 633 |
| Segment 2 | 240 | 230 | 6 | 54 | 179 | 337 | 307 | 297 | 5 | 65 | 238 | 387 |
| Segment 3 | 255 | 242 | 15 | 123 | 68 | 495 | 360 | 288 | 5 | 65 | 238 | 387 |
| Segment 4 | 179 | 172 | 29 | 90 | 25 | 353 | 217 | 210 | 21 | 111 | 69 | 417 |
| Segment 5 | 137 | 123 | 11 | 83 | 48 | 312 | 190 | 149 | 9 | 85 | 96 | 328 |
| Segment 7 | 36 | 42 | 4 | 19 | 8 | 52 | 71 | 65 | 3 | 16 | 57 | 89 |
| Segment 8 | 39 | 39 | 2 | 16 | 27 | 50 | 208 | 208 | 2 | 7 | 202 | 213 |
| Center | 168 | 155 | 11 | 88 | 64 | 371 | 179 | 144 | 10 | 98 | 69 | 399 |
| East | 139 | 118 | 12 | 79 | 25 | 284 | 304 | 201 | 8 | 290 | 108 | 990 |
| West | 281 | 279 | 12 | 77 | 193 | 450 | 338 | 338 | 8 | 112 | 213 | 506 |
| Potomac | 151 | 128 | 3 | 60 | 105 | 219 | 160 | 130 | 3 | 62 | 118 | 231 |
| Rappahannock | 102 | 102 | 2 | 3 | 100 | 104 | 108 | 108 | 2 | 3 | 106 | 110 |
| Mobjack Bay | 93 | 93 | 2 | 18 | 80 | 106 | 97 | 97 | 2 | 19 | 84 | 111 |
| York | 101 | 101 | 2 | 17 | 89 | 113 | 113 | 113 | 2 | 6 | 109 | 117 |
| James | 55 | 55 | 2 | 62 | 11 | 99 | 137 | 137 | 2 | 20 | 122 | 151 |

Table 3.14b  Temporal variability in zinc concentrations in Chesapeake Bay mainstem sediments. Means for years not connected by the underline are significantly different (p=0.05) as determined by ANOVA followed by a Duncan multiple range test.  The means indicated by the year are ordered from high to low.  NS = no significant differences.  There were insufficient data to perform the test for segments one and eight, the river mouth stations, and Mobjack Bay.

| Area | Measured | Normalized |
|---|---|---|
| Segment 2 | NS | NS |
| Segment 3 | NS | <u>85 84</u> 91 |
| Segment 4 | <u>85</u> <u>84 91</u> | <u>85 91 84</u> |
| Segment 5 | <u>85 84 91</u> | <u>85 84 91</u> |
| Segment 7 | NS | NS |
| Center | NS | NS |
| East | NS | NS |
| West | <u>84 85 91</u> | <u>85 91</u> |

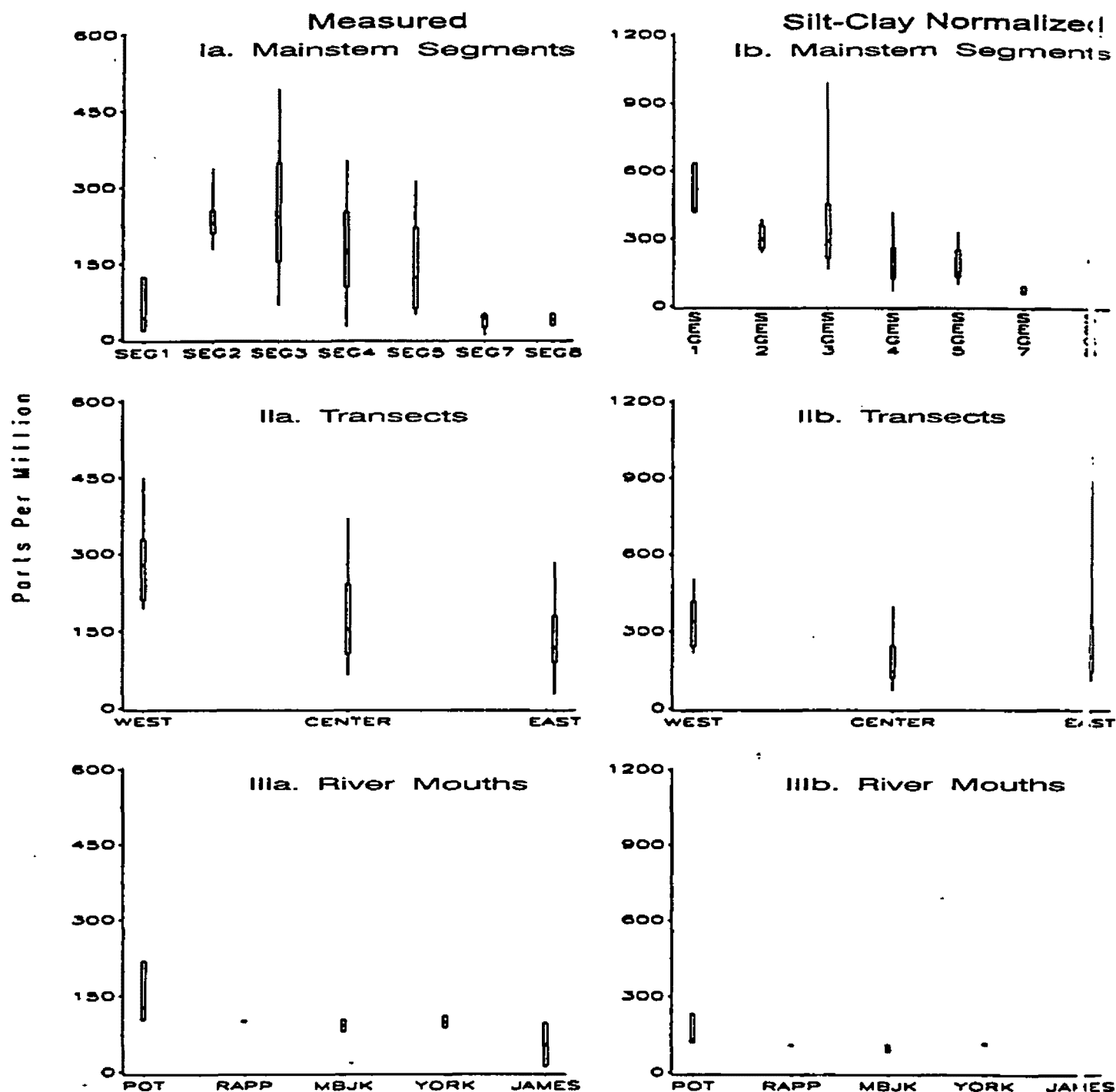# Figure 3.12a Zinc concentrations (ppm) in mainstem sediments



Figure 3.12a    Summary statistics for measured and silt-clay normalized sediment concentrations of zinc in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The stations are aggregated by: I. Chesapeake Bay Program mainstem segments; II. transects across the midbay deep trough; and III. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment zinc concentrations are 68 ppm and 300 ppm, respectively (MacDonald, 1993).

# Figure 3.12b Measured Zinc Concentrations in Mainstem Sediments
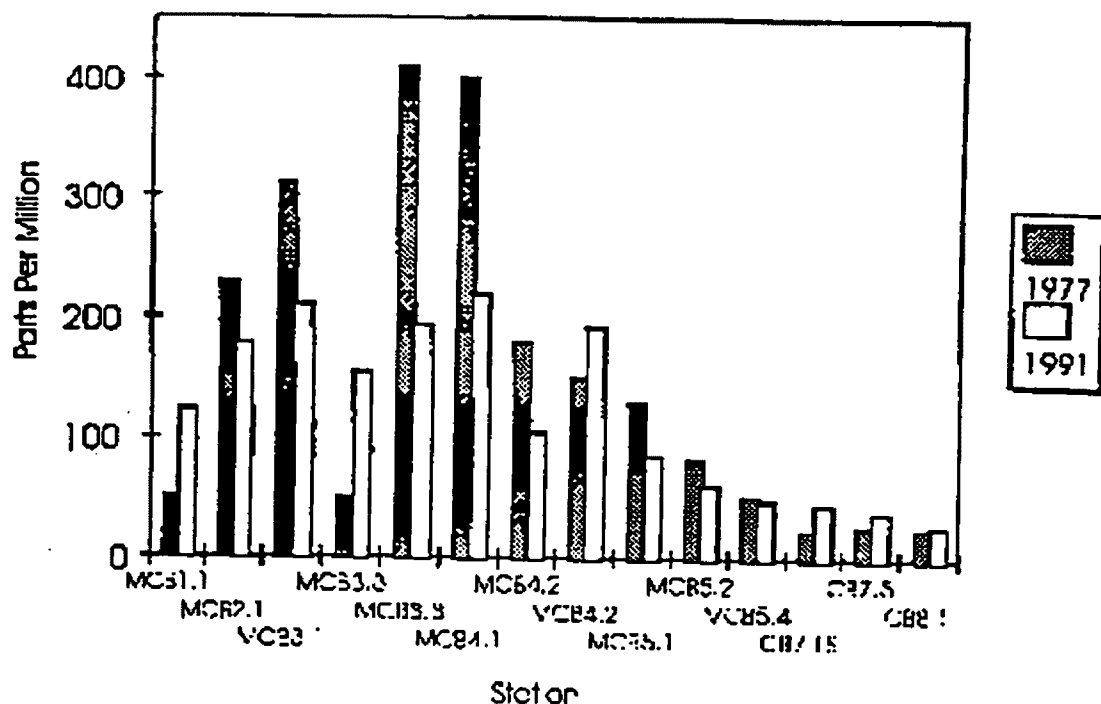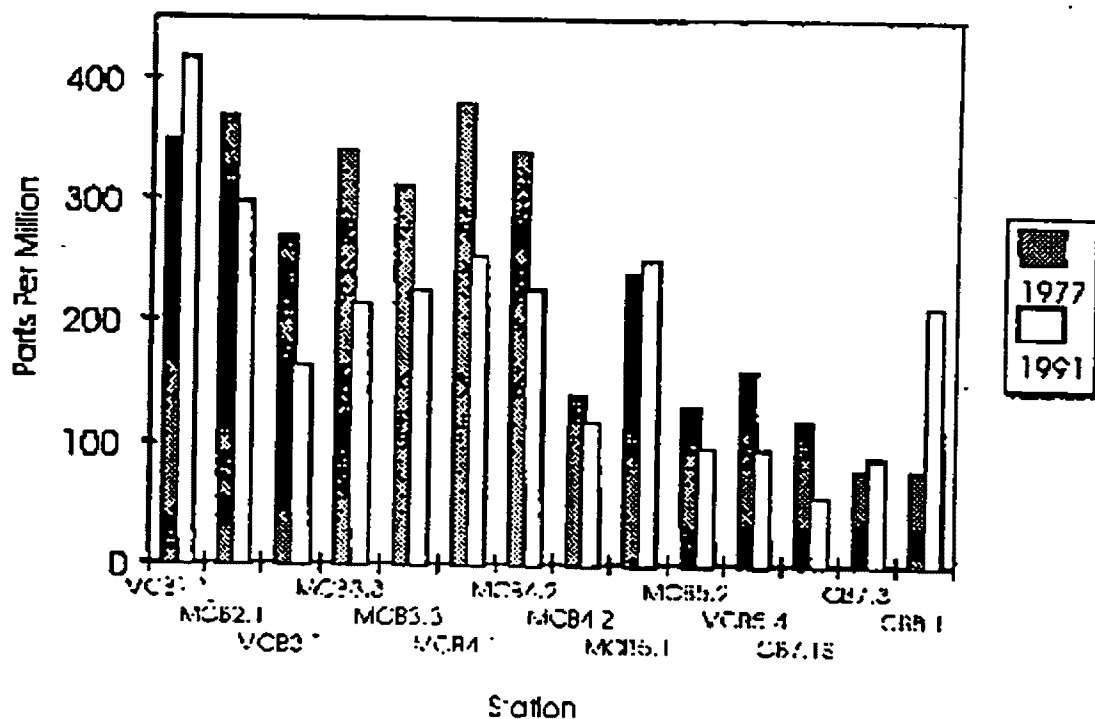## 1977 v. 1991



# Figure 3.12c Normalized Zinc Concentrations in Mainstem Sediments
## 1977 v. 1991



Comparison of Zinc concentrations in mainstem sediments in 1977 and 1991. Station designation refer to the Chesapeake Bay Program monitoring stations. Data in 3.12b are measured sediment cadmium concentrations while the data in 3.12c are normalized, that is deivided, by the silt-clay fraction of the sediment samples.

## Ratio of Trace Metals to Acid-Volatile Sulfides

Under anaerobic (oxygen deficient) conditions in sediments, bacterial oxidation of organic carbon reduces dissolved sulfate ($SO_4^{2-}$) to sulfide ($HS^-$) (Hennessee, et al., 1986). The sulfide typically reacts with iron and precipitates (Urban and Brezonik, 1993). The portion of this solid phase sulfide which can be extracted from the sediment with cold hydrochloric acid is operationally defined as "acid-volatile" sulfide or AVS (Leonard, et al., 1993). The divalent metals cadmium, copper, lead, mercury, nickel, and zinc are thought to be able to displace iron and react with the sulfide, forming a sulfide precipitate which is believed to be unavailable to biota (DiToro, et al., 1992).

In order to evaluate the amount of divalent metal present in a potentially bioavailable form (i.e., not bound to AVS), the sum of the molar concentrations of the divalent trace metals cadmium, copper, lead, mercury, nickel and zinc is compared to the molar concentration of AVS. The amount of divalent metal present in excess of the amount of AVS is thought to be bioavailable. The remaining portion of divalent metal is presumed to be bound to the sulfide and unavailable to the biota. The concentration of AVS in the sediment has been shown to influence the toxicity and/or bioavailability of cadmium, nickel, lead and copper (Di Toro, et al., 1990; Ankley, et al., 1991; Bourgoin, et al., 1991; Carlson, et al., 1991; Di Toro, et al., 1992; Ankley, et. al. 1993; and Casas and Crecelius, 1994).

The metal-AVS relationship is properly examined as the ratio of the sum of the molar concentrations of the simultaneously extracted divalent trace metals (SEM) to the molar concentration of AVS. Simultaneously extracted metals (SEM) is the concentration of metals measured when the sediment sample is treated with a weak hydrochloric acid solution i.e., 1 molar, in order to volatilize sulfide during the measurement of sediment AVS. Analysis for SEM had not been performed as part of the mainstem monitoring program during the period covered by this report. As a first approximation to the results of such analyses, the results of the strong acid digestion used by the monitoring program in measuring metals, i.e., " total recoverable" metals, were substituted for SEM. Since metals may be more thoroughly extracted by the "total recoverable" procedure, this procedure may overestimate SEM, and thus overestimate the bioavailability of divalent trace metals in these samples.

There is another reason why the metal-AVS data presented below may overestimate bioavailability of the divalent trace metals in mainstem sediments. In oxic sediments where AVS concentrations are very low (i.e., less than 0.1 µM) other constituents of the sediment may act as the principal partitioning phase for divalent metals and prevent their uptake by biota (Di Toro, et al., 1990; Ankley, et al., 1993). In addition, for at least one divalent metal (copper), the sediment concentration of AVS has not been found to account for the full binding capacity of the sediment for metal, and organic carbon may act as an important additional source of sediment binding capacity even in the presence of significant quantities of AVS (Ankley, et al., 1993 and Casas and Crecelius, 1994). Thus, the sediment divalent trace metal:AVS ratios presented below will indicate only when divalent trace metals are not bioavailable due to binding with AVS. If the data shows sediment divalent trace metal:AVS ratio is greater than one, indicating that there is divalent metal present in excess of the quantity of AVS available to bind with it, then one can conclude that a portion of the divalent metals in the sediment is potentially bioavailable, but a definitive determination of divalent trace metal bioavailability cannot be made in these instances.

The determination of trace metal and AVS concentrations in mainstem samples from the Maryland and Virginia portion of the mainstem were conducted by two different laboratories. However, the two laboratories used the same analytical methods to measure both trace metal and acid volatile sulfide concentrations in the sediment samples (see Chapter 2 for details on analytical methods). However, the detection limit for sediment AVS concentrations was higher in the Maryland samples than in the Virginia samples (Table 3.15).

Sediment concentrations of AVS were less than 3.13 µM in segment one, two, and the upper portion of segment three (Table 3.15). Much higher sediment AVS concentrations were observed in the middle

mainstem Bay in the lower portion of segment three and segment four (Table 3.15 and Table 3.16). Sediment AVS concentrations decreased towards the mouth of the Bay below the middle mainstem, and the sediment AVS concentration in segment eight at the mouth of the Bay was less than 0.06 µM (Table 3.15 and Table 3.16). In the region of the middle mainstem Bay encompassing the central deep trough, sediment samples from stations to the west of the central deep trough had lower sediment AVS concentrations on average than those stations located within the trough and those east of the trough (Table 3.16). Sediment AVS concentrations ranged from 1.38 µM to 13.0 µM among the river mouth stations and the station at Mobjack Bay (Table 3.15 and Table 3.16).

With the exception of the station at CB8.1 at the mouth of the Bay, divalent trace metal:AVS ratios were less than one (the ratio above which divalent metals are presumed to be bioavailable) at all of the stations located below station MCB3.2 in the upper portion of the middle mainstem Bay. This indicates divalent trace metals in the sediment are bound to sulfide in this region of the mainstem, and thus are not bioavailable. In the upper portion of the Bay from the mouth of the Susquehanna River through the upper portion of segment three in the middle mainstem Bay, only minimum divalent trace metal:AVS ratios could be determined, as sediment AVS concentrations in the sediment samples from this region were below detection limits. However, these minimum divalent trace metal:AVS ratios approached or exceeded one, indicating that divalent trace metals in the sediments in this portion of the mainstem are potentially bioavailable.

Trace metal concentrations in the sediment are most likely to cause toxic effects to aquatic organisms when the sediment divalent trace metal:AVS ratio is greater than one and the sediment concentration of divalent trace metals is high. Sediment trace metal concentrations at sampling stations in segment two and the upper portion of segment three are high relative to those located elsewhere in the Chesapeake Bay mainstem. In addition, sediment trace metal:AVS ratios in this region are greater than one, indicating that a portion of the trace metals in these sediments are not bound to sulfide. Thus, the potential bioavailability of sediment trace metals are of concern in this region of the mainstem. The western portion of the middle mainstem Bay (segments three and four) also have relatively high divalent trace metal concentrations in the sediment. However, there is sufficient AVS present in the sediments in this region to bind the metal and render it unavailable to biota, and thus sediment trace metal concentrations in this region are not of concern. The sediment AVS concentration was less than the very low detection limit in segment eight, indicating that the divalent trace metals in these areas are not bound by sulfide, and thus potentially bioavailable. However, as concentrations of divalent trace metals in the sediment in this area are low, the bioavailability of divalent trace metals is not of concern in this area, despite the low concentrations of sediment AVS.

The measurements of AVS presented here provide a "snapshot" of sediment AVS concentrations. However, AVS concentrations in both freshwater and estuarine sediments can vary substantially between seasons (Di Toro, et al., 1990; Zarba, 1991; Leonard, et al., 1993 and Urban and Brezonik, 1993). Sediment sulfide concentrations are typically highest in midsummer when temperature and sediment concentrations of organic carbon are high, creating optimal conditions for the microbial activity which produces sulfide (Leonard, et al., 1993). A recent study in the middle mainstem Bay showed that sediment AVS concentrations reached their highest levels in June with intermediate concentrations found in April and August, and the lowest concentrations occurring in November and December (Zarba, 1991).

All of the data presented here are from samples collected in late April or early May, typically before temperatures in the mainstem Bay reach the range optimal for sulfate reduction (Leonard et al, 1993; Magnien et al, 1993). Thus, the concentrations of AVS presented here are probably lower than the concentrations which might be expected to be present later in the spring and summer, and thus may overestimate metal bioavailability for that time period. Conversely, the values of AVS reported here for these areas are probably greater than what would likely be found during the winter months, and thus may underestimate trace metal bioavailability at that time. However, since the samples were taken during a period when benthic larvae, which may be sensitive to toxic metals, frequently settle, the data

provide measurements of sediment AVS concentrations for a time period when metal contaminants could potentially have a large adverse impact on benthic communities. It is possible that ongoing and planned reductions in nutrient inputs to the Bay will decrease the supply of organic carbon to the sediments in the mainstem Bay, and this, in turn, may reduce the concentration of AVS in the sediments in the middle and lower portions of the Bay, since AVS formation in this region is thought to be limited by the availability of organic carbon (Hennessee, *et al.*, 1986).

Table 3.15 Molar concentrations of the sum of divalent metals, acid volatile sulfide (AVS) and, the divalent trace metal:AVS ratio in Chesapeake Bay mainstem sediments. Molar concentrations are in micromoles per gram sediment. Divalent trace metals include cadmium, copper, mercury, nickel, lead, and zinc. Data are from 1991 only. Metal concentrations were determined by EPA's total recoverable method, rather than as simultaneously extracted metals (SEM). Therefore, the SEM:AVS ratio and the sum of divalent metals are probably overestimated, but should provide a relative indicator of potential metal bioavailability. SUM = sum of molar concentrations of the six divalent metals; AVS=molar concentration of AVS; RATIO=ratio of SUM to AVS.

| Station | Region | SUM | AVS | RATIO |
|---------|--------|-----|-----|-------|
| MCB1.1 | Segment 1 | 2.97 | <3.13[1] | >0.95[1] |
| MCB2.1 | Segment 2 | 4.25 | <3.13[1] | >1.36[1] |
| MCB2.2 | Segment 2 | 5.42 | <3.13[1] | >1.73[1] |
| MCB3.1 | Segment 3 | 4.71 | <3.13[1] | >1.51[1] |
| MCB3.2 | Segment 3 | 4.60 | <3.13[1] | >1.47[1] |
| MCB3.3C | Segment 3 | 3.47 | 30.42 | 0.11 |
| MCB3.3E | Segment 3 | 3.21 | 15.42 | 0.21 |
| MCB3.3W | Segment 3 | 4.30 | 6.81 | 0.63 |
| MCB4.1C | Segment 4 | 2.43 | 20.72 | 0.12 |
| MCB4.1E | Segment 4 | 1.77 | 41.56 | 0.04 |
| MCB4.1W | Segment 4 | 4.66 | 9.89 | 0.47 |
| MCB4.2C | Segment 4 | 2.37 | 24.9 | 0.10 |
| MCB4.2E | Segment 4 | 2.33 | 12.06 | 0.19 |
| MCB4.2W | Segment 4 | 4.15 | 23.20 | 0.18 |
| MCB4.3C | Segment 4 | 1.79 | 9.19 | 0.19 |
| MCB4.3E | Segment 4 | 2.35 | 31.96 | 0.07 |
| MCB4.3W | Segment 4 | 4.23 | 19.32 | 0.22 |
| MCB4.4 | Segment 4 | 2.22 | 43.70 | 0.05 |
| MCB5.1 | Segment 5 | 2.07 | 28.14 | 0.07 |
| MCB5.2 | Segment 5 | 1.43 | 11.31 | 0.13 |
| MCB5.3 | Segment 5 | 1.30 | 6.45 | 0.20 |
| CB5.4 | Segment 5 | 0.98 | 3.56 | 0.28 |
| CB7.1S | Segment 7 | 1.07 | 1.49 | 0.72 |
| CB7.3E | Segment 7 | 0.85 | 1.63 | 0.52 |
| CB8.1E | Segment 8 | 0.52[2] | <0.06[3] | * |
| MLE2.3 | Potomac River Mouth | 2.43 | 13.00 | 0.19 |
| LE3.6 | Rappahannock R. mouth | 2.30 | 11.97 | 0.84 |
| WE4.2 | Mobjack Bay | 1.81 | 2.49 | 0.73 |
| WE4.1 | York River mouth | 2.06 | 10.56 | 0.19 |
| LE5.5 | James River mouth | 0.23[2] | 1.38 | 0.16 |

[1] Sediment AVS concentrations were below the detection limit of 100 ppm for samples from the Upper portion of the Maryland mainstem. Values for AVS and RATIO listed are those obtained with AVS set to equal the detection limit.

[2] Sediment cadmium concentrations below the detection limit were set to equal the detection limit to calculate the sum of divalent metals.

[3] Sediment AVS concentration below the lowest detection limit (2 ppm) for samples from the Virginia portion of the mainstem. Values for AVS listed is that obtained with AVS set to equal the detection limit.

* METAL/AVS ratio not calculated, as the AVS concentration was below the lower limit of applicability of AVS normalization, approximately 1 µM/g (DiToro, et al., 1990)

[3] Sediment AVS concentration below the lowest detection limit (2 ppm) for samples from the Virginia portion of the mainstem. Values for AVS listed is that obtained with AVS set to equal the detection limit.

* METAL/AVS ratio not calculated, as the AVS concentration was below the lower limit of applicability of AVS normalization, approximately 1 µM/g (DiToro, et al., 1990)

Table 3.16 Average molar concentrations of divalent metals, AVS, and the divalent metal:AVS ratio in Chesapeake Bay mainstem segments. Concentrations are in micromoles per gram sediment. Divalent metals include cadmium, copper, mercury, nickel, lead, and zinc. Metal concentrations were determined by the total recoverable method, rather than as simultaneously extracted metals (SEM). Therefore, the metal:AVS ratio and the sum of divalent metals are probably overestimated, but should provide a relative indicator of potential metal bioavailability. All data are from 1991.

| | Number of observations | Sum of divalent metals | AVS | Average metal:Segment AVS ratio |
|---|---|---|---|---|
| Segment 1 | 1 | 2.97 | $<3.13^2$ | $>0.95^2$ |
| Segment 2 | 2 | 4.83 | $<3.13^2$ | $>1.55^2$ |
| Segment 3 | 5 | 4.06 | $11.78^2$ | $0.79^2$ |
| Segment 4 | 10 | 2.83 | 23.62 | 0.16 |
| Segment 5 | 3 | 1.44 | 12.37 | 0.17 |
| Segment 7 | 2 | 0.96 | 1.56 | 0.62 |
| Segment 8 | 1 | $0.52^2$ | $<0.06^3$ | * |
| Center Midbay | 4 | 2.52 | 21.31 | 0.13 |
| East Midbay | 4 | 2.42 | 25.25 | 0.13 |
| West Midbay | 4 | 4.33 | 14.81 | 0.38 |
| Potomac River Mouth | 1 | 2.43 | 13.00 | 0.19 |
| Rapp. R. mouth | 1 | 2.30 | 11.97 | 0.19 |
| Mobjack Bay | 1 | 1.81 | 2.49 | 0.73 |
| York River mouth | 1 | 2.06 | 2.42 | 0.85 |
| James River mouth | 1 | $0.23^2$ | 1.38 | 0.16 |

[1] Sediment AVS concentrations were below the detection limit of 100 ppm for some samples from the Maryland portion of the mainstem. Values for AVS and RATIO listed are those obtained with AVS set to equal the detection limit.

[2] Sediment cadmium concentrations below the detection limit were set to equal the detection limit to calculate the sum of divalent metals.

[3] Sediment AVS concentration was below the lowest detection limit (2 ppm) for samples from the Virginia portion of the mainstem. Value for AVS listed is that obtained with AVS set to equal the detection limit.

* METAL/AVS ratio not calculated, as the AVS concentration was below the lower limit of applicability of AVS normalization, approximately 1 µM/g (DiToro, et al., 1990)

**Spatial Distribution of Individual Polycyclic Aromatic Hydrocarbons**

*Total Polycyclic Aromatic Hydrocarbons (TOTAL PAHs)*

Total PAHs is not listed as a Chesapeake Bay Toxic of Concern. Total PAHs data are available from the monitoring program for 1991 only (Table 3.17 and Figure 3.13). The median sediment concentration of total PAHs in the mainstem Bay was 1,524 ppm. The maximum value of 14,854 ppb was found at station MCB2.2 in segment two in 1991. The NOEL and PEL guidelines for total PAHs are based on the sum of thirteen specific compounds (MacDonald, 1993), while the monitoring program data includes all PAHs detected (Unger, personal communication).

Median concentrations in segments two and three and at the mouth of the Potomac exceed the NOEL for total PAHs of 2,900 ppb, but all measurements are significantly less than the PEL of 28,000 ppb (Table 3.17 and MacDonald, 1993). Toxic effects to aquatic biota due to the measured concentrations of total PAHs in the sediments are not likely at the mainstem Bay stations sampled.

Table 3.17  Summary statistics for total PAHs in mainstem Chesapeake Bay sediments.  Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River.  Concentrations are in ppb dry weight.  Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| All | 2548 | 1524 | 16 | 3612 | 130 | 14854 | 101726 | 86426 | 16 | 61893 | 59746 | 316716 |
| Segment 1 | 1578 | 14853 | 1 | | 1578 | 1578 | 88652 | 88652 | 1 | | 88652 | 88652 |
| Segment 2 | 14854 | 14854 | 1 | | 14854 | 14854 | 316716 | 316716 | 1 | | 316716 | 316716 |
| Segment 3 | 4766 | 4766 | 2 | 328 | 4534 | 4998 | 121854 | 121855 | 2 | 30782 | 100088 | 143621 |
| Segment 4 | 2021 | 2021 | 2 | 1167 | 1196 | 2846 | 72456 | 72456 | 2 | 16610 | 60711 | 84201 |
| Segment 5 | 1070 | 1070 | 2 | 1148 | 258 | 1882 | 86953 | 86953 | 2 | 38476 | 59746 | 114159 |
| Segment 7 | 332 | 332 | 2 | 16 | 321 | 343 | 84429 | 84429 | 2 | 32935 | 61141 | 107718 |
| Segment 8 | 130 | 130 | 1 | | 130 | 130 | 79268 | 79268 | 1 | | 79268 | 79268 |
| Potomac | 3301 | 3301 | 1 | | 3301 | 3301 | 89701 | 89701 | 1 | | 89701 | 89701 |
| Rappahannock | 1469 | 1469 | 1 | | 1469 | 1469 | 68967 | 68967 | 1 | | 68967 | 68697 |
| Mobjack Bay | 1180 | 1180 | 1 | | 1180 | 1180 | 79195 | 79195 | 1 | | 79195 | 79195 |
| York | 1735 | 1735 | 1 | | 1735 | 1735 | 109810 | 109810 | 1 | | 109810 | 109810 |
| James | 140 | 140 | 1 | | 140 | 140 | 63927 | 63927 | 1 | | 63927 | 63927 |

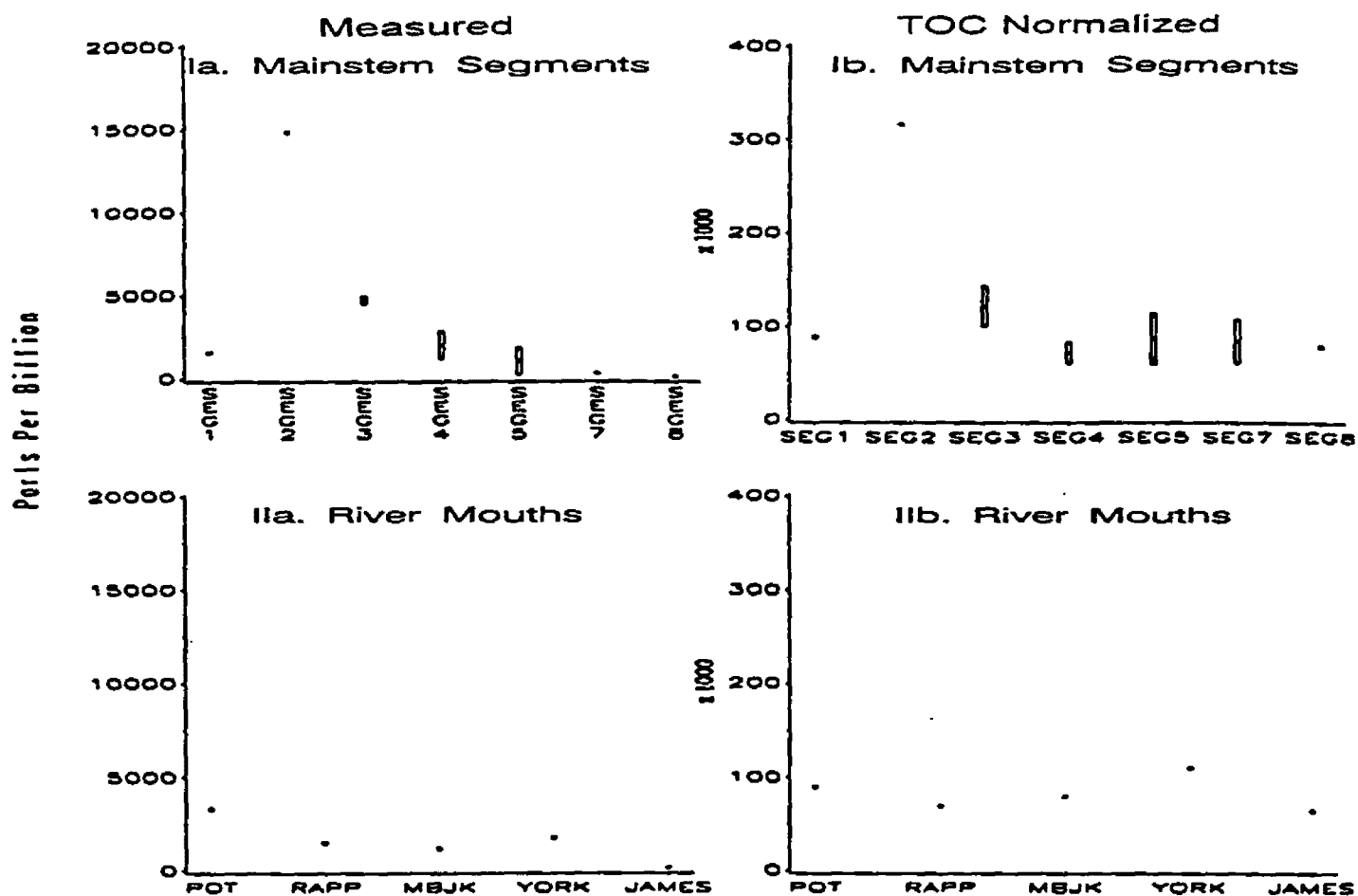# Figure 3.13 Total PAHs concentrations (ppb) in mainstem sediments



Figure 3.13 Summary statistics for measured and total organic carbon normalized sediment concentrations of total PAHs in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment total PAHs concentrations are 2900 ppb and 28000 ppb, respectively (MacDonald, 1993).

**Anthracene**

is a low molecular weight PAH, is not listed as a Chesapeake Bay Toxic of Concern. Data for this compound are only available for the mainstem Bay for 1991 (Table 3.18 and Figure 3.14). The median sediment anthracene concentration Baywide was 6.4 ppb (Table 3.18). The maximum value of 149 ppb was found at station CB2.2 in segment two in 1991 (Table 3.18). The measured sediment anthracene concentration in segment two exceeded the NOEL concentration of 85 ppb (Table 3.18 and MacDonald, 1993). All measured concentrations were well below the PEL concentration of 740 ppb. Toxic effects to aquatic biota due to the measured concentrations of anthracene in sediments are not likely at the mainstem Bay stations sampled.

Table 3.18 Summary statistics for anthracene in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 22 | 6.4 | 13 | 41 | 0.8 | 149 | 690 | 393 | 13 | 847 | 138 | 3179 |
| Segment 1 | 11 | 11 | 1 | | 11 | 11 | 590 | 590 | 1 | | 590 | 590 |
| Segment 2 | 149 | 149 | 1 | | 149 | 149 | 3179 | 3179 | 1 | | 3179 | 3179 |
| Segment 3 | 57 | 57 | 1 | | 57 | 57 | 1630 | 1630 | 1 | | 1630 | 1630 |
| Segment 4 | 15 | 26 | 2 | 17 | 3 | 26 | 458 | 458 | 2 | 45 | 458 | 778 |
| Segment 5 | 7 | 7 | 1 | | 7 | 7 | 213 | 213 | 1 | | 213 | 213 |
| Segment 7 | 1 | 1 | 1 | | 1 | 1 | 198 | 198 | 1 | | 198 | 198 |
| Segment 8 | 1 | 0.8 | 1 | | 0.8 | 0.8 | 506 | 506 | 1 | | 506 | 506 |
| Potomac | 1 | 14 | 1 | | 14 | 14 | 393 | 393 | 1 | | 393 | 393 |
| Rappahannock | 1 | 6 | 1 | | 6 | 6 | 302 | 302 | 1 | | 302 | 302 |
| Mobjack Bay | 1 | 2 | 1 | | 2 | 2 | 145 | 145 | 1 | | 145 | 145 |
| York | 1 | 4 | 1 | | 4 | 4 | 277 | 277 | 1 | | 277 | 277 |
| James | 1 | 1 | 1 | | 1 | 1 | 616 | 616 | 1 | | 616 | 616 |

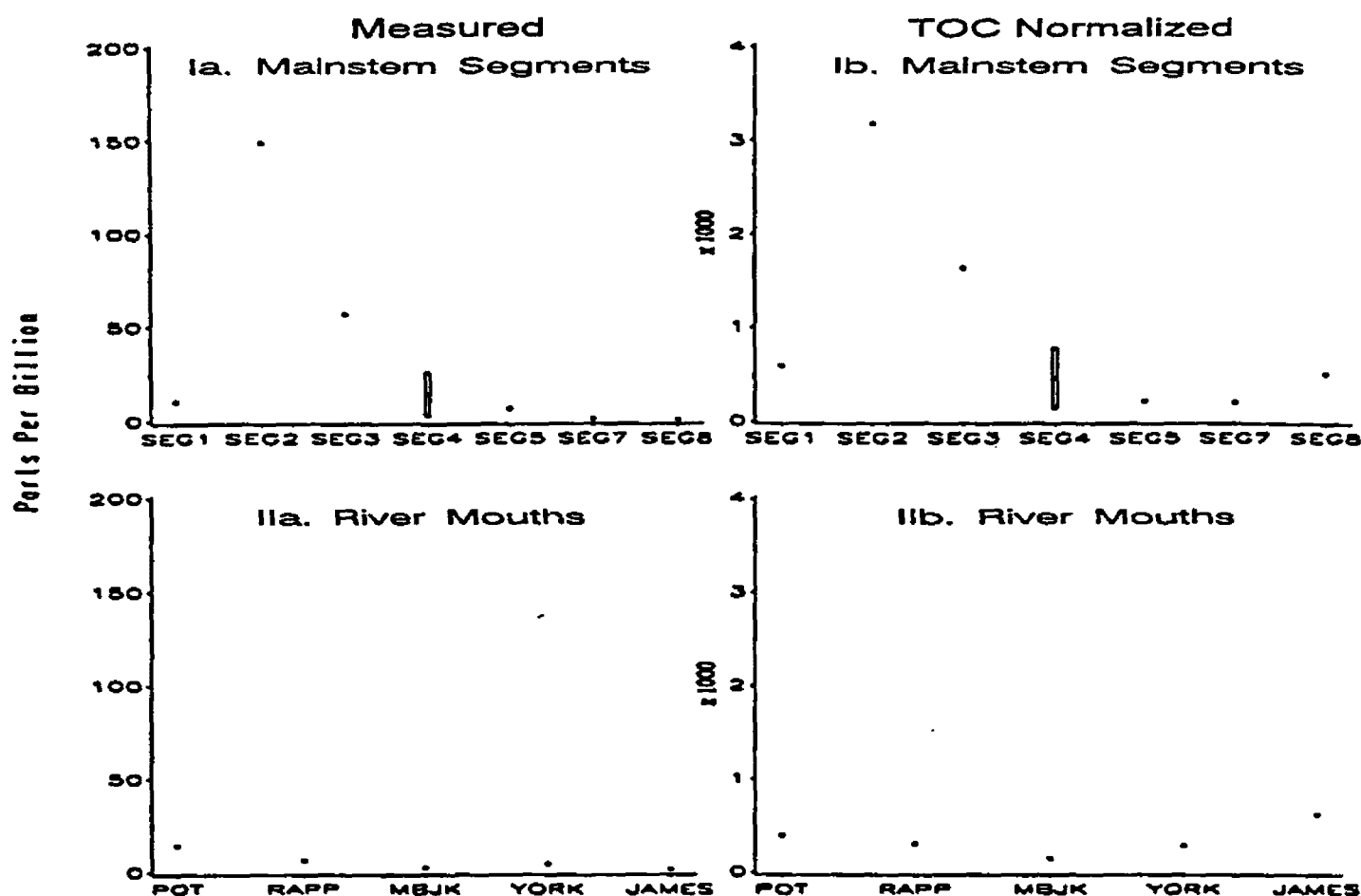# Figure 3.14 Anthracene concentrations (ppb) in mainstem sediments



Figure 3.14 Summary statistics for measured and total organic carbon normalized sediment concentrations of anthracene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment anthracene concentrations are 85 ppb and 740 ppb, respectively (MacDonald, 1993).

Benzo[a]anthracene is a high molecular weight polycyclic aromatic hydrocarbon, is listed as a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a). Although benzo[a]anthracene has not been shown to be carcinogenic to humans, the EPA does consider it a probable carcinogen (Chesapeake Bay Program, 1991b).

The median sediment concentration of benzo[a]anthracene in the mainstem was 20 ppb; the maximum value of 309 ppb was found at station MCB2.2 in segment two in 1991 (Table 3.19 and Figure 3.15). Measured concentrations in segments two and three exceeded the NOEL concentration of 160 ppb (Table 3.19 and MacDonald, 1993). All sediment concentrations of benzo[a]anthracene were well below the PEL concentration of 1300 ppb (Table 3.19 and MacDonald, 1993). Toxic effects to aquatic biota due to the measured concentrations of benzo(a)anthracene in sediments are not likely at the sampled locations in the mainstem Bay.

Table 3.19 Summary statistics for benzo[a]anthracene in Chesapeake Bay mainstem sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 38 | 20 | 53 | 56 | 0.4 | 309 | 1871 | 1279 | 37 | 1756 | 25 | 7417 |
| Segment 1 | 17 | 12 | 3 | 15 | 6 | 34 | 2879 | 1910 | 3 | 2879 | 446 | 6000 |
| Segment 2 | 208 | 210 | 2 | 143 | 107 | 309 | 2647 | 4717 | 2 | 2647 | 2846 | 6588 |
| Segment 3 | 122 | 113 | 6 | 37 | 80 | 178 | 2033 | 2913 | 6 | 2033 | 2136 | 7417 |
| Segment 4 | 35 | 50 | 5 | 25 | 0.5 | 57 | 1516 | 1279 | 5 | 1516 | 25 | 4071 |
| Segment 5 | 14 | 12 | 7 | 8 | 1.6 | 26 | 201 | 619 | 6 | 201 | 400 | 1000 |
| Segment 7 | 3 | 2 | 7 | 3 | 0.4 | 8 | 969 | 1060 | 2 | 969 | 374 | 1745 |
| Segment 8 | 4 | 3 | 4 | 2 | 2 | 7 | 198 | 1140 | 2 | 198 | 1000 | 1280 |
| Potomac | 27 | 28 | 3 | 2 | 25 | 28 | 119 | 761 | 3 | 119 | 706 | 933 |
| Rappahannock | 22 | 21 | 4 | 5 | 16 | 29 | 58 | 1.074 | 2 | 58 | 1033 | 1115 |
| Mobjack Bay | 23 | 21 | 4 | 7 | 16 | 33 | 718 | 1850 | 2 | 718 | 1342 | 2357 |
| York | 22 | 22 | 4 | 5 | 17 | 28 | 275 | 1555 | 2 | 275 | 1361 | 1750 |
| James | 46 | 20 | 4 | 64 | 2 | 142 | 0.16 | 1050 | 2 | 0.16 | 1050 | 1050 |

# Figure 3.15 Benzo(a)anthracene concentrations (ppb) in mainstem sediments
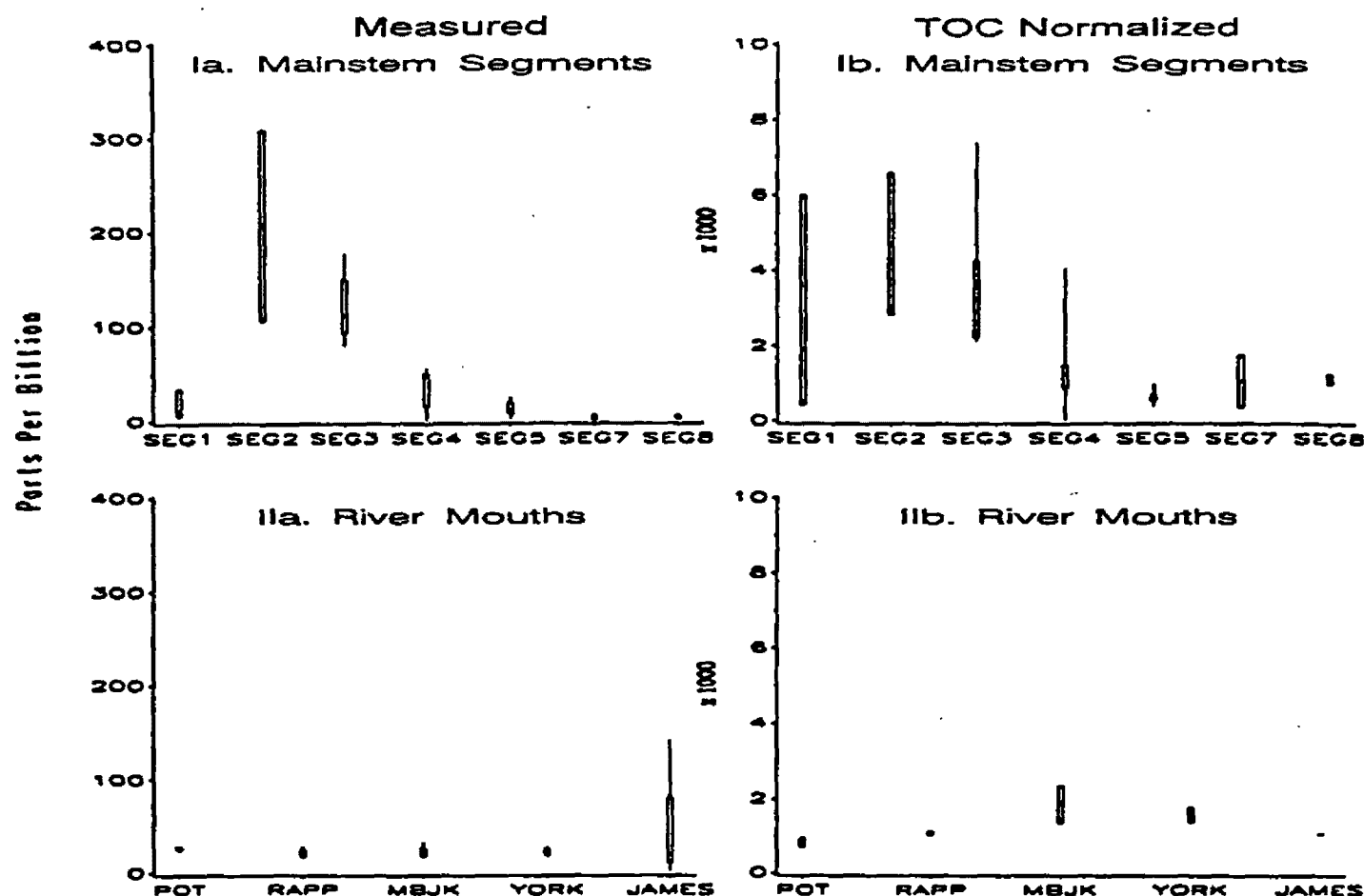


Figure 3.15 Summary statistics for measured and total organic carbon normalized sediment concentrations of benzo(a)anthracene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment benzo(a)anthracene concentrations are 160 ppb and 1300 ppb, respectively (MacDonald, 1993).

Benzo(g,h,i)perylene is a polycyclic aromatic hydrocarbon not on the Chesapeake Bay of Toxics of Concern list. Sediment quality guidelines pertaining to this compound were not found in the literature. The median and maximum concentrations of benzo[g,h,i]perylene in mainstem sediments were 21 and 204 ppb, respectively (Table 3.20). The maximum sediment concentration of benzo(g,h,i)perylene was found at station MCB2.2 in segment two in 1991 (Table 3.20 and Figure 3.16).

Table 3.20 Summary statistics for benzo[g,h,i]perylene in Chesapeake Bay mainstem sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 30 | 21 | 52 | 36 | 1 | 204 | 1548 | 1162 | 36 | 1327 | 112 | 5792 |
| Segment 1 | 12 | 3 | 3 | 15 | 3 | 29 | 1579 | 1624 | 3 | 1445 | 112 | 3000 |
| Segment 2 | 132 | 132 | 2 | 103 | 59 | 204 | 2964 | 2924 | 2 | 1972 | 1569 | 4359 |
| Segment 3 | 88 | 79 | 5 | 32 | 55 | 140 | 2827 | 1795 | 5 | 1804 | 1577 | 5792 |
| Segment 4 | 32 | 28 | 6 | 25 | 10 | 76 | 1624 | 1018 | 6 | 1888 | 493 | 5429 |
| Segment 5 | 21 | 19 | 6 | 7 | 14 | 35 | 758 | 603 | 5 | 363 | 467 | 1346 |
| Segment 7 | 3 | 2 | 7 | 3 | 1 | 9 | 615 | 615 | 2 | 445 | 300 | 930 |
| Segment 8 | 4 | 3 | 4 | 3 | 2 | 9 | 1140 | 1140 | 2 | 206 | 994 | 1286 |
| Potomac | 28 | 27 | 3 | 7 | 21 | 35 | 820 | 900 | 3 | 198 | 593 | 963 |
| Rappahannock | 23 | 25 | 4 | 7 | 12 | 28 | 1118 | 1118 | 2 | 60 | 1077 | 1158 |
| Mobjack Bay | 26 | 27 | 4 | 5 | 20 | 31 | 1999 | 1999 | 2 | 304 | 1784 | 2214 |
| York | 26 | 27 | 4 | 6 | 20 | 31 | 1943 | 1943 | 2 | 8 | 1938 | 1949 |
| James | 18 | 14 | 4 | 20 | 1 | 46 | 651 | 651 | 2 | 352 | 402 | 900 |

# Figure 3.16 Benzo(g,h,i)perylene concentrations (ppb) in mainstem sediments
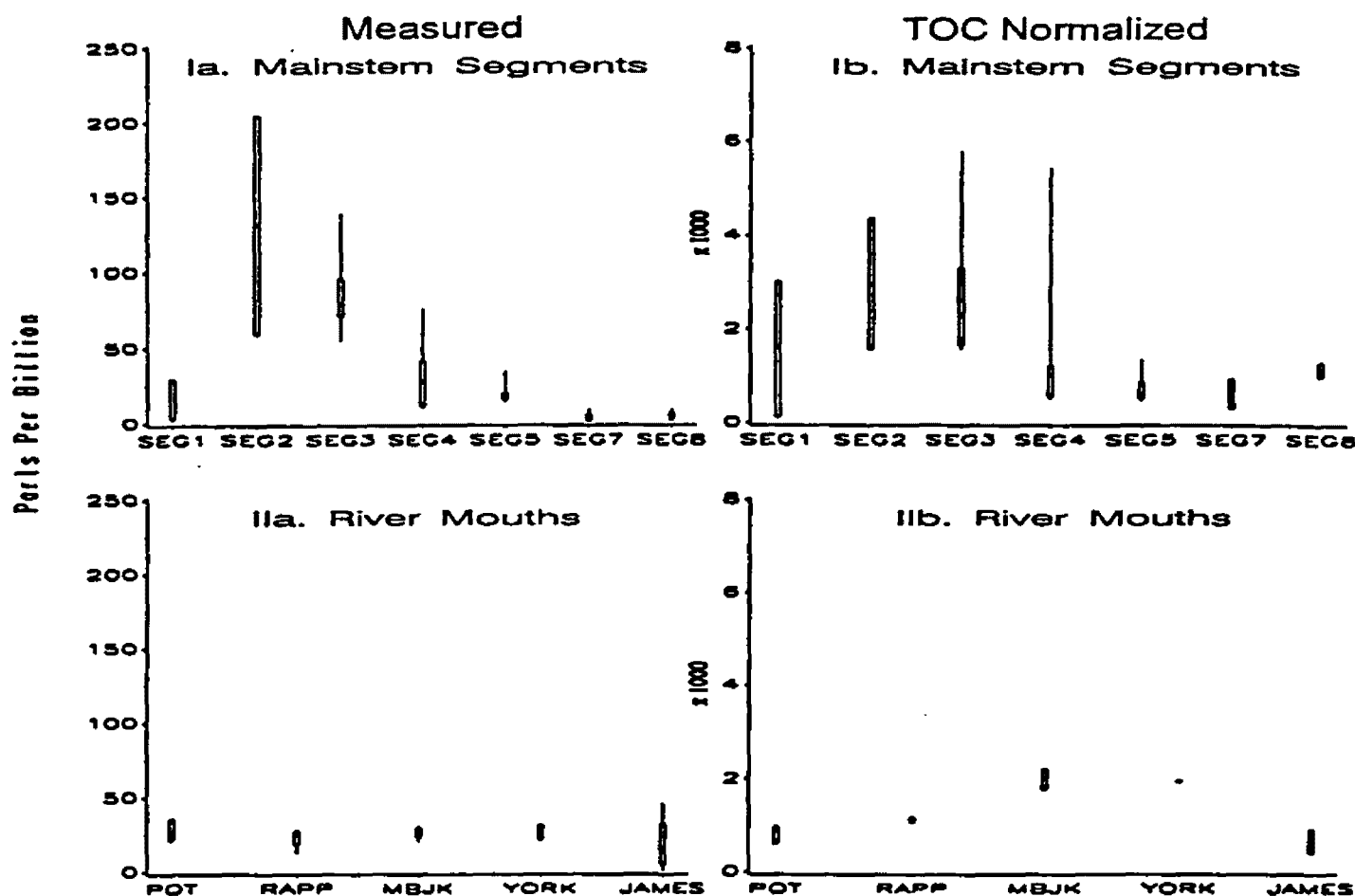


Figure 3.16 Summary statistics for measured and total organic carbon normalized sediment concentrations of benzo(g,h,i)perylene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment benzo(g,h,i)perylene concentrations are not available due to insufficient data (MacDonald 1993).

Benzo[a]pyrene

is a high molecular weight PAH found in coal tar, is listed as a Chesapeake Bay Toxic of Concern and is considered a probable human carcinogen by the EPA (Chesapeake Bay Program, 1991a, 1991b). The median concentration of benzo[a]pyrene in mainstem Bay sediments was 25 ppb (Table 3.21). The maximum value of 270 ppb was found at station CB2.2 in segment two in 1991 (Table 3.21 and Figure 3.17).

MacDonald (1993) lists the NOEL and PEL for benzo[a]pyrene at 230 and 1700 ppb, respectively. Only the maximum measured sediment concentration of benzo[a]pyrene was above the NOEL. Toxic effects to aquatic biota due to the measured sediment concentrations of benzo[a]pyrene are not likely at the mainstem stations sampled.

Table 3.21 Summary statistics for benzo[a]pyrene in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 39 | 25 | 54 | 51 | 1 | 270 | 1899 | 1350 | 38 | 1596 | 100 | 7208 |
| Segment 1 | 15 | 9 | 3 | 16 | 2 | 33 | 1396 | 1854 | 3 | 922 | 335 | 2000 |
| Segment 2 | 270 | 270 | 1 | | 270 | 270 | 5756 | 5757 | 1 | | 5757 | 5760 |
| Segment 3 | 123 | 130 | 6 | 40 | 71 | 173 | 3711 | 2989 | 6 | 2104 | 1832 | 7208 |
| Segment 4 | 34 | 32 | 6 | 28 | 3 | 66 | 1540 | 1192 | 6 | 1654 | 148 | 4714 |
| Segment 5 | 26 | 21 | 7 | 17 | 5 | 57 | 1054 | 840 | 6 | 611 | 467 | 2124 |
| Segment 7 | 5 | 3 | 8 | 4 | 1 | 12 | 1566 | 570 | 3 | 2144 | 100 | 4027 |
| Segment 8 | 4 | 3 | 4 | 3 | 2 | 9 | 1436 | 1436 | 2 | 212 | 1286 | 1585 |
| Potomac | 37 | 37 | 3 | 2 | 35 | 39 | 1099 | 1045 | 3 | 181 | 951 | 1300 |
| Rappahannock | 28 | 30 | 4 | 6 | 19 | 33 | 1291 | 1292 | 2 | 32 | 1269 | 1315 |
| Mobjack Bay | 32 | 32 | 4 | 10 | 21 | 43 | 2225 | 2225 | 2 | 489 | 1879 | 2571 |
| York | 29 | 30 | 4 | 8 | 19 | 39 | 2031 | 2031 | 2 | 573 | 1625 | 2437 |
| James | 43 | 21 | 4 | 57 | 3 | 127 | 1214 | 1214 | 2 | 91 | 1150 | 1279 |

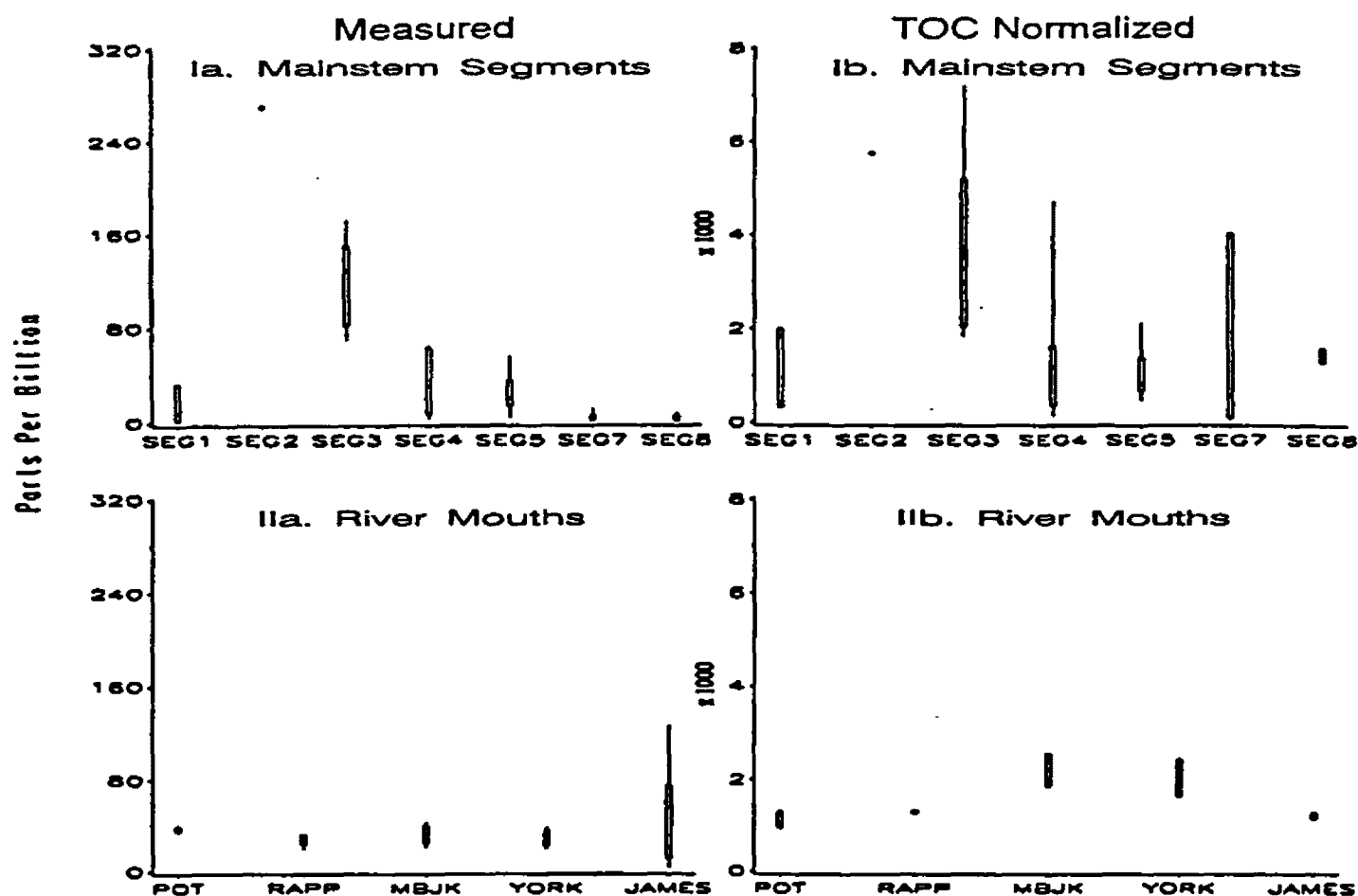# Figure 3.17 Benzo(a)pyrene concentrations (ppb) in mainstem sediments



Figure 3.17 Summary statistics for measured and total organic carbon normalized sediment concentrations of benzo(a)pyrene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment benzo(a)pyrene concentrations are 230 ppb and 1700 ppb, respectively (MacDonald, 1993).

**Chrysene**

is a high molecular weight PAH, is listed as a Chesapeake Bay Toxic of Concern, but it has not been shown to be carcinogenic (Chesapeake Bay Program 1991a). Chrysene is formed during the distillation of coal (Chesapeake Bay Program, 1991b). The median sediment chrysene concentration in the mainstem Bay was 34 ppb; the maximum value of 361 ppb was found at station MCB2.2 in 1991 (Table 3.22 and Figure 3.18). The median sediment concentrations exceeded the NOEL concentration of 220 ppb in segment two, but the PEL concentration of 1700 ppb was never exceeded (Table 3.22 and MacDonald, 1993). Toxic effects to aquatic biota due to the measured concentrations of chrysene in the sediments are not likely at the mainstem Bay stations sampled.

Table 3.22 Summary statistics for chrysene in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 61 | 34 | 55 | 78 | 1 | 361 | 3233 | 2152 | 39 | 3129 | 300 | 15000 |
| Segment 1 | 33 | 19 | 3 | 28 | 15 | 66 | 6471 | 3708 | 3 | 7537 | 706 | 15000 |
| Segment 2 | 279 | 279 | 2 | 116 | 197 | 361 | 6468 | 6468 | 2 | 1738 | 5239 | 7697 |
| Segment 3 | 196 | 182 | 6 | 71 | 112 | 298 | 5933 | 4671 | 6 | 3587 | 3218 | 12417 |
| Segment 4 | 78 | 93 | 6 | 33 | 13 | 96 | 3679 | 3626 | 6 | 2255 | 640 | 6571 |
| Segment 5 | 27 | 26 | 7 | 15 | 3 | 51 | 1134 | 986 | 6 | 442 | 773 | 1962 |
| Segment 7 | 7 | 4 | 8 | 7 | 1 | 2 | 1538 | 624 | 3 | 1871 | 300 | 3691 |
| Segment 8 | 7 | 6 | 4 | 4 | 4 | 12 | 1985 | 1985 | 2 | 383 | 1714 | 2256 |
| Potomac | 50 | 51 | 3 | 2 | 48 | 52 | 1490 | 1413 | 3 | 184 | 1356 | 1700 |
| Rappahannock | 35 | 33 | 4 | 7 | 29 | 44 | 1573 | 1574 | 2 | 168 | 1455 | 1692 |
| Mobjack Bay | 34 | 34 | 4 | 4 | 30 | 38 | 2397 | 2397 | 2 | 448 | 2081 | 2714 |
| York | 36 | 36 | 4 | 2 | 34 | 39 | 295 | 2295 | 2 | 202 | 2152 | 2438 |
| James | 60 | 33 | 4 | 75 | 4 | 170 | 1834 | 1834 | 2 | 119 | 1750 | 1918 |

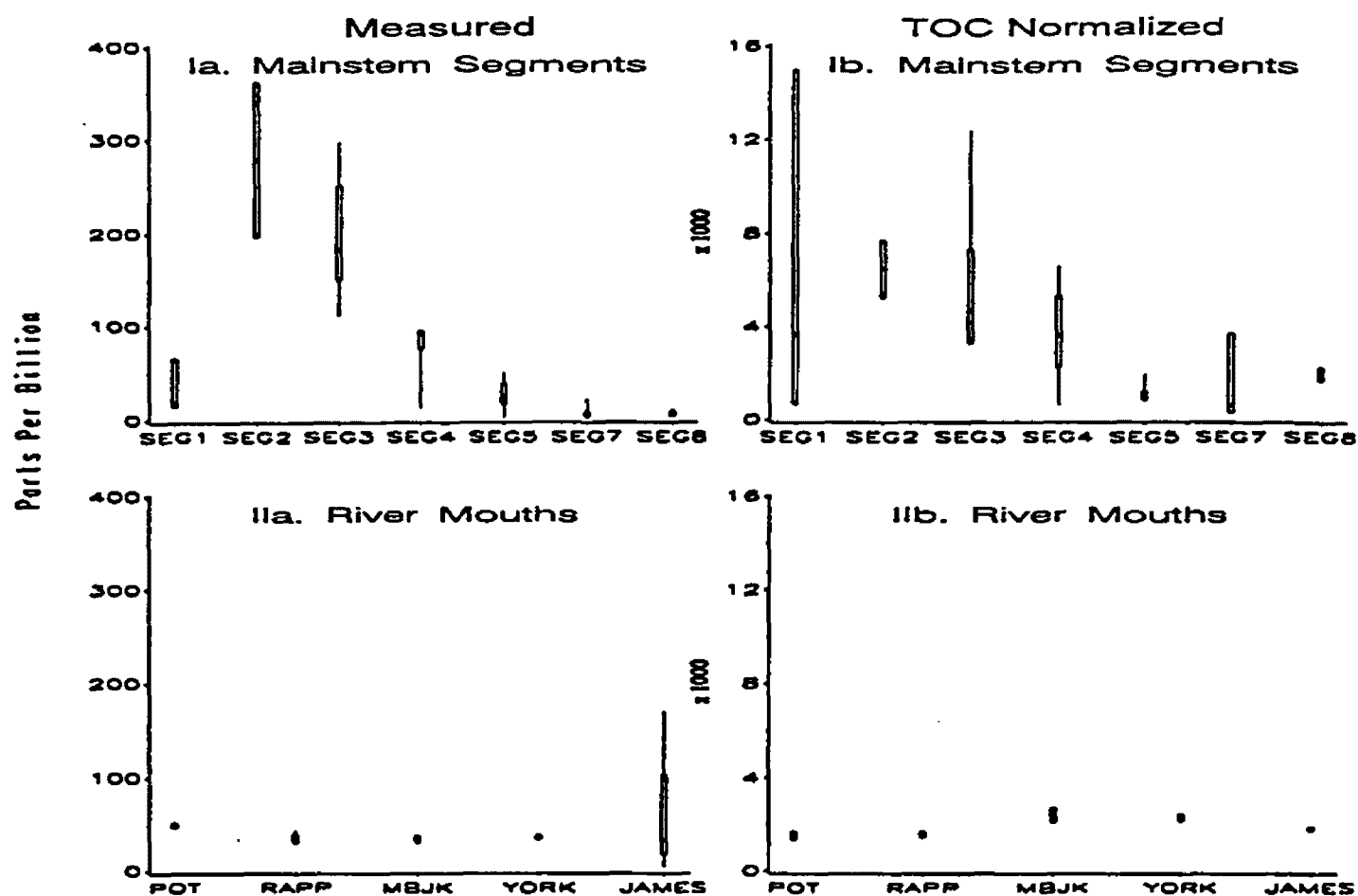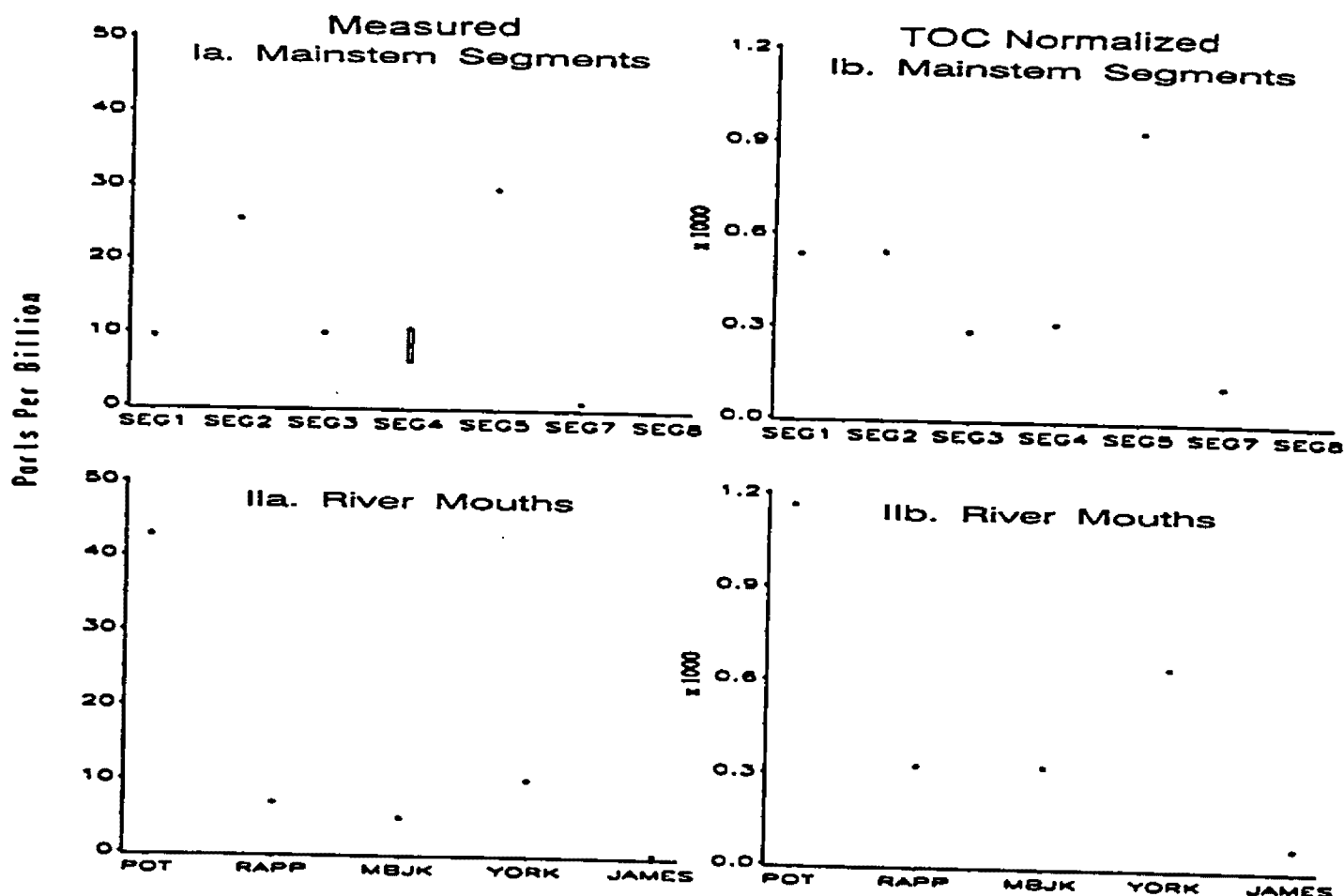# Figure 3.18 Chrysene concentrations (ppb) in mainstem sediments



Figure 3.18 Summary statistics for measured and total organic carbon normalized sediment concentrations of chrysene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment chrysene concentrations are 220 ppb and 1700 ppb, respectively (MacDonald, 1993).

# Dibenzo[a,h]anthracene

Dibenzo[a,h]anthracene is a low molecular weight PAH not listed as a Chesapeake Bay Program Toxics of Concern (Chesapeake Bay Program 1991a). The median concentration of dibenzo[a,h]anthracene in mainstem sediments was 10 ppb and the maximum concentration, found at the mouth of the Potomac River in 1991, was 43 ppb (Table 3.23 and Figure 3.21). With the exception of the Potomac River mouth station, all measurements were below the NOEL concentration of 31 ppb. The PEL concentration of 320 ppb was also never exceeded (Table 3.23 and MacDonald, 1993). Toxic effects to aquatic biota due to the measured sediment concentrations of dibenzo[a,h]anthracene are not likely at any of the sampled mainstem Bay stations.

Table 3.23 Summary statistics for dibenzo[a,h]anthracene in Chesapeake Bay mainstem sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment. A " - " means no data is available for the segment/station.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 13 | 10 | 12 | 13 | 0.15 | 43 | 463 | 325 | 12 | 323 | 68 | 1162 |
| Segment 1 | 9 | 9 | 1 | | 9 | 9 | 531 | 531 | 1 | | 531 | 531 |
| Segment 2 | 25 | 25 | 1 | | 25 | 25 | 540 | 540 | 1 | | 540 | 540 |
| Segment 3 | 10 | 10 | 1 | | 10 | 10 | 286 | 286 | 1 | | 286 | 286 |
| Segment 4 | 8 | 8 | 2 | 3 | 6 | 11 | 314 | 314 | 2 | 4 | 311 | 317 |
| Segment 5 | 30 | 30 | 1 | | 30 | 30 | 937 | 937 | 1 | | 937 | 937 |
| Segment 7 | 1 | 1 | 1 | | 1 | 1 | 112 | 112 | 1 | | 112 | 112 |
| Segment 8 | | | 0 | | | 0 | | | 0 | | | |
| Potomac | 43 | 43 | 1 | | 43 | 43 | 1162 | 1162 | 1 | | 1162 | 1162 |
| Rappahannock | 7 | 7 | 1 | | 7 | 7 | 325 | 325 | 1 | | 325 | 325 |
| Mobjack Bay | 5 | 5 | 1 | | 5 | 5 | 326 | 326 | 1 | | 326 | 326 |
| York | 10 | 10 | 1 | | 10 | 10 | 647 | 647 | 1 | | 647 | 647 |
| James | 0.15 | 0.15 | 1 | | 0.15 | 0.15 | 68 | 68 | 1 | | 68 | 68 |

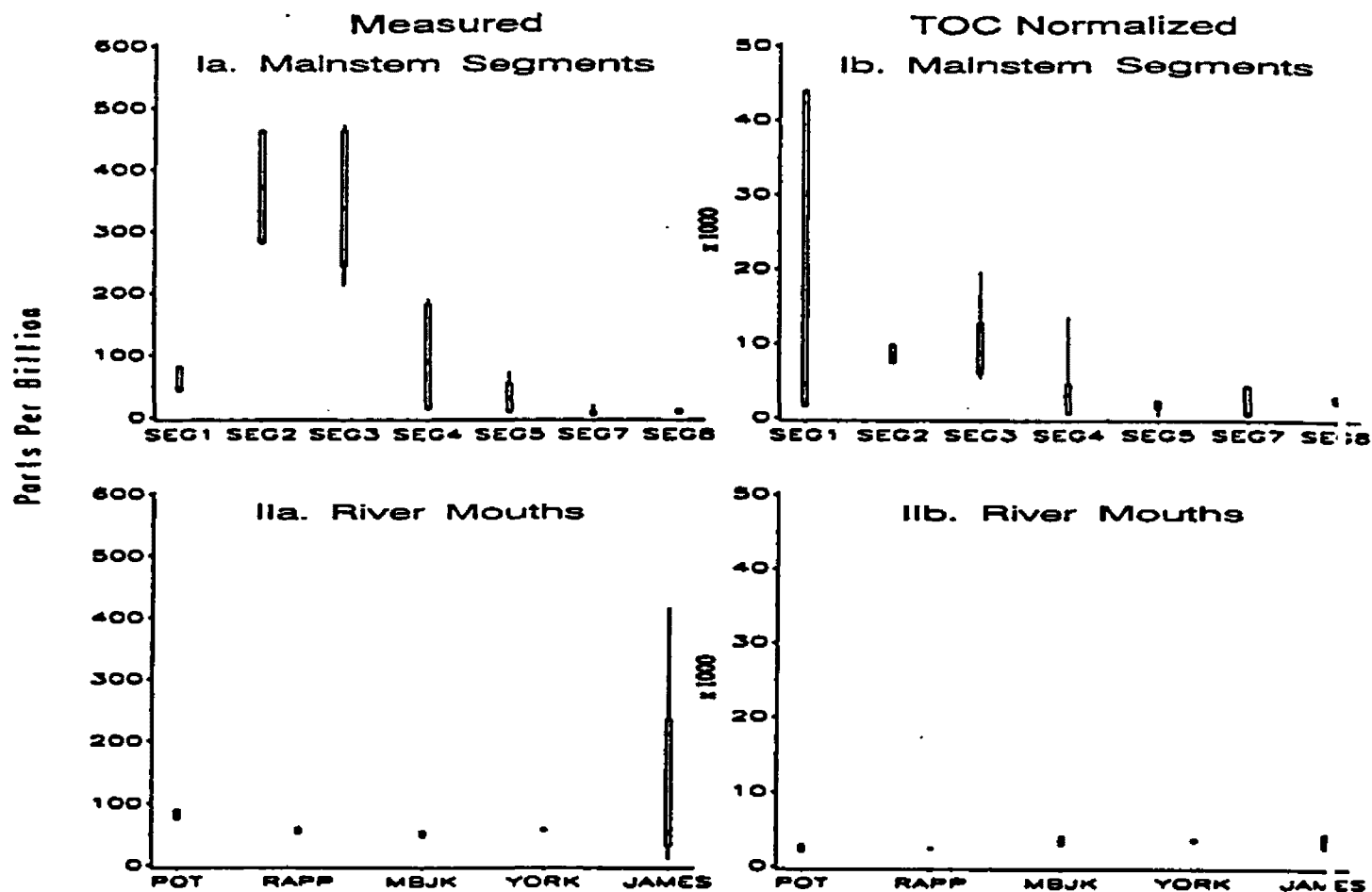# Figure 3.19 Dibenzo(a,h)anthracene concentrations (ppb) in mainstem sediments



Figure 3.19 Summary statistics for measured and total organic carbon normalized sediment concentrations of dibenzo(a,h)anthracene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment dibenzo(a,h)anthracene concentrations are 31 ppb and 320 ppb, respectively (MacDonald, 1993).

## Fluoranthene

Fluoranthene, a high molecular weight PAH among the Chesapeake Bay Toxics of Concern, is currently being reviewed by EPA for carcinogenicity (Chesapeake Bay Program, 1991a, 1991b). Fluoranthene is produced by the high temperature combustion of coal and petroleum, and is ubiquitous in the environment (Environmental Protection Agency, 1993d). The median concentration of fluoranthene in mainstem Bay sediments was 52 ppb (Table 3.24). The maximum value of 472 ppb was found at station MCB3.2 in segment three in 1984 (Table 3.24 and Figure 3.20).

The NOEL and PEL concentrations for fluoranthene are 380 and 3200 ppb, respectively (MacDonald, 1993). Median fluoranthene concentrations in all segments and at all river mouth stations were less than the NOEL concentration of 380 ppb (Table 3.24 and MacDonald, 1993). Only the maximum sediment fluoranthene concentrations measured in segments two and three and the James River exceeded the NOEL concentration. No measurements exceeded the PEL concentration (Table 3.24 and MacDonald, 1993). Toxic effects to aquatic biota due to the measured concentrations of fluoranthene in mainstem Bay sediments are not likely at the sampled locations.

Table 3.24 Summary statistics for fluoranthene in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 97 | 52 | 55 | 129 | 2 | 472 | 5358 | 2967 | 39 | 7546 | 346 | 44000 |
| Segment 1 | 56 | 44 | 3 | 22 | 43 | 82 | 16735 | 4607 | 3 | 23660 | 1599 | 44000 |
| Segment 2 | 371 | 371 | 2 | 129 | 280 | 462 | 8649 | 8649 | 2 | 1700 | 7447 | 9851 |
| Segment 3 | 344 | 337 | 6 | 110 | 211 | 472 | 10267 | 8841 | 6 | 5450 | 5364 | 19667 |
| Segment 4 | 97 | 90 | 6 | 84 | 12 | 191 | 4340 | 3208 | 6 | 4858 | 609 | 13643 |
| Segment 5 | 36 | 31 | 7 | 25 | 6 | 74 | 1648 | 1722 | 6 | 779 | 346 | 2478 |
| Segment 7 | 7 | 4 | 8 | 7 | 2 | 21 | 1831 | 731 | 3 | 2198 | 400 | 4362 |
| Segment 8 | 10 | 9 | 4 | 4 | 5 | 15 | 2596 | 2596 | 2 | 641 | 2143 | 3049 |
| Potomac | 84 | 88 | 3 | 8 | 74 | 89 | 2488 | 2486 | 3 | 478 | 2011 | 2967 |
| Rappahannock | 56 | 54 | 4 | 5 | 51 | 63 | 2432 | 2432 | 2 | 13 | 2423 | 2441 |
| Mobjack Bay | 51 | 51 | 4 | 5 | 44 | 57 | 3512 | 3512 | 2 | 791 | 2953 | 4071 |
| York | 57 | 58 | 4 | 2 | 54 | 60 | 3507 | 3507 | 2 | 187 | 3375 | 3639 |
| James | 132 | 53 | 4 | 190 | 10 | 415 | 3444 | 3444 | 2 | 1264 | 2550 | 4338 |

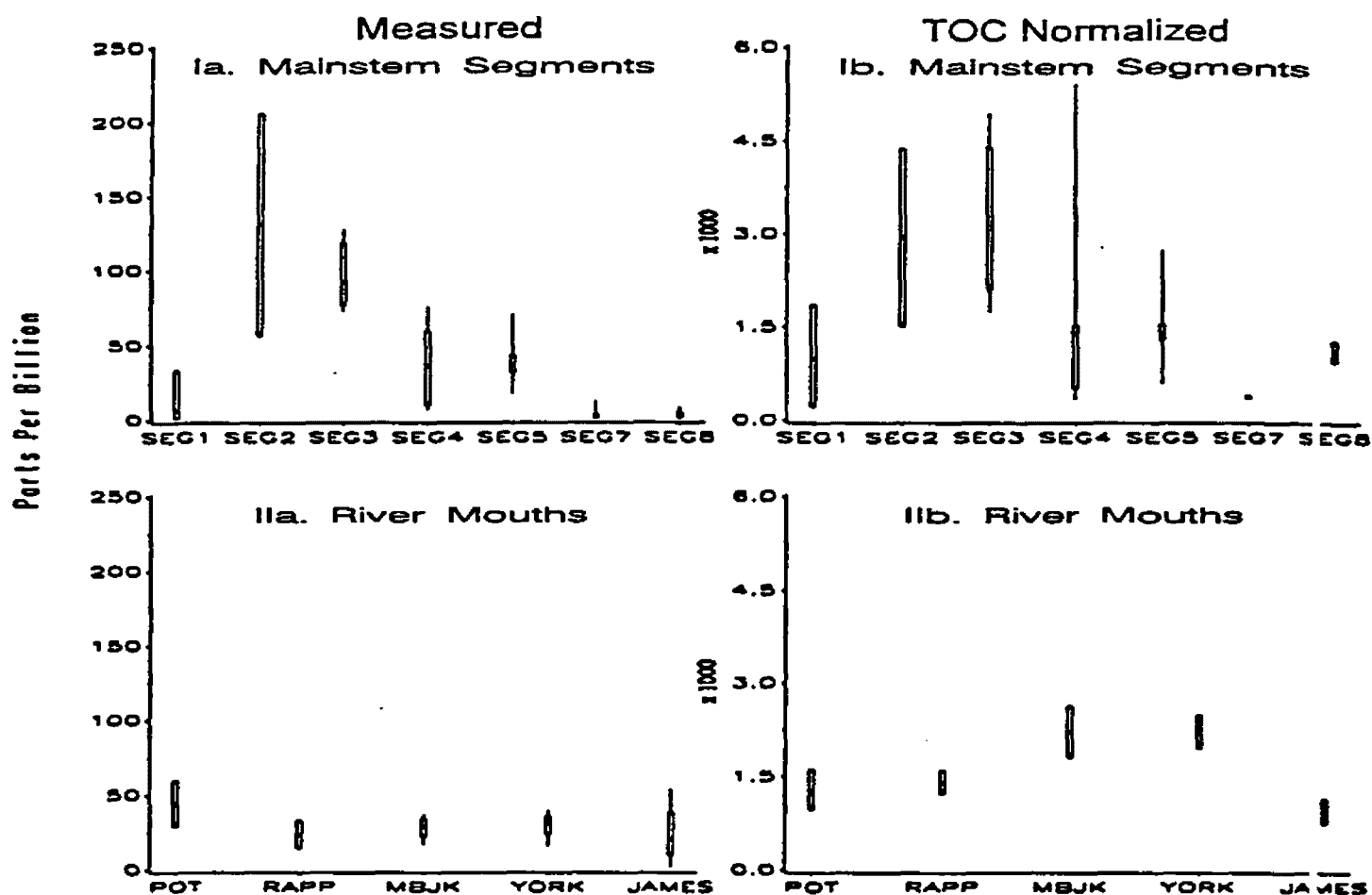# Figure 3.20 Fluoranthene concentrations (ppb) in mainstem sediments



Figure 3.20  Summary statistics for measured and total organic carbon normalized sediment concentrations of fluoranthene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by:  I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment fluoranthene concentrations are 380 ppb and 3200 ppb, respectively (MacDonald, 1993).

Indeno[1,2,3-cd]pyrene

Indeno[1,2,3-cd]pyrene is a PAH not listed as a Chesapeake Bay Toxics of Concern (Chesapeake Bay Program, 1991a). The median sediment concentration of indeno[1,2,3-cd]pyrene in the mainstem Bay was 30 ppb. The maximum value of 206 ppb was found in segment two at station MCB2.2 in 1991 (Table 3.25 and Figure 3.21). No sediment quality guidelines or criteria for this compound were found in the literature.

Table 3.25 Summary statistics for indeno[1,2,3-cd]pyrene in Chesapeake Bay mainstem sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth; and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 36 | 30 | 52 | 38 | 1 | 206 | 1751 | 1500 | 36 | 1266 | 223 | 5429 |
| Segment 1 | 13 | 6 | 3 | 17 | 1 | 33 | 1026 | 1000 | 3 | 816 | 223 | 1854 |
| Segment 2 | 131 | 131 | 2 | 105 | 57 | 206 | 2951 | 2951 | 2 | 2029 | 1516 | 4386 |
| Segment 3 | 98 | 92 | 5 | 25 | 73 | 128 | 3075 | 2150 | 5 | 1492 | 1750 | 4958 |
| Segment 4 | 38 | 37 | 6 | 28 | 7 | 76 | 1774 | 1408 | 6 | 1861 | 345 | 5429 |
| Segment 5 | 40 | 37 | 6 | 18 | 18 | 71 | 1514 | 1397 | 5 | 771 | 600 | 2731 |
| Segment 7 | 4 | 2 | 7 | 4 | 1 | 13 | 380 | 380 | 2 | 28 | 360 | 400 |
| Segment 8 | 4 | 2 | 4 | 4 | 2 | 9 | 1118 | 1118 | 2 | 237 | 951 | 1286 |
| Potomac | 44 | 44 | 3 | 15 | 29 | 60 | 1277 | 1243 | 3 | 330 | 967 | 1624 |
| Rappahannock | 24 | 24 | 4 | 11 | 14 | 34 | 1416 | 1416 | 2 | 261 | 1231 | 1600 |
| Mobjack Bay | 28 | 30 | 4 | 9 | 17 | 37 | 2229 | 2229 | 2 | 585 | 1815 | 2643 |
| York | 30 | 32 | 4 | 10 | 16 | 40 | 2231 | 2231 | 2 | 280 | 1963 | 2500 |
| James | 24 | 21 | 4 | 22 | 2 | 54 | 952 | 952 | 2 | 280 | 753 | 1150 |

# Figure 3.21 Indeno(1,2,3-cd)pyrene concentrations (ppb) in mainstem sediments
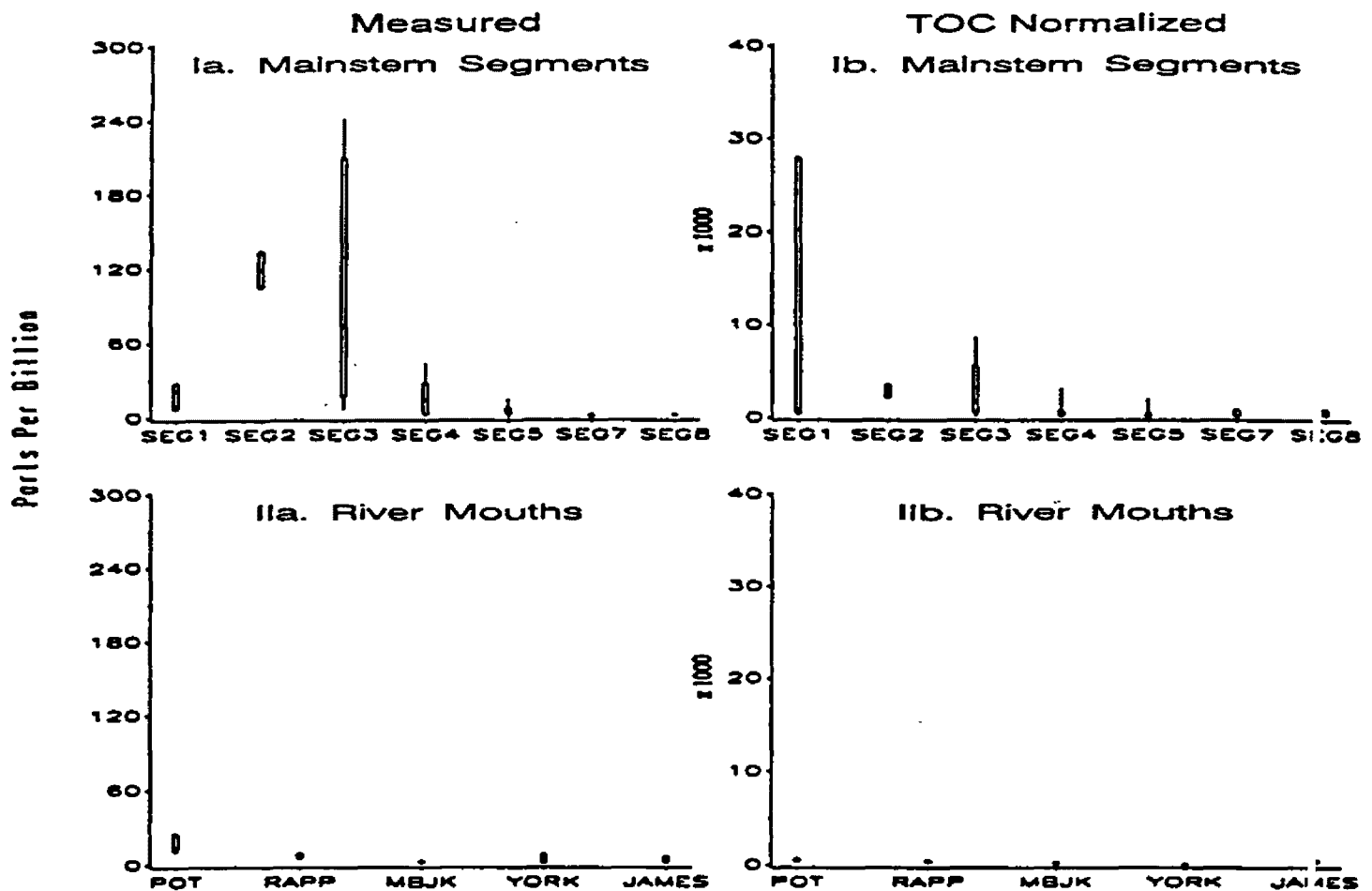


Figure 3.21 Summary statistics for measured and total organic carbon normalized sediment concentrations of indeno(1,2,3-cd)pyrene in the Chesapeake Bay mainstem. The box anc whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; anc II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and ir Mobjack Bay. The NOEL and PEL values for measured sediment indeno(1,2,3-cd)pyrene concentrations are not available due to insufficient data (MacDonald, 1993).

**Naphthalene**

Naphthalene is a low molecular weight PAH on the Chesapeake Bay Toxics of Concern list (Chesapeake Bay Program, 1991a). Its potential carcinogenicity has not been quantified, but it is listed as a hazardous substance on numerous regulatory lists such as RCRA and SARA (Chesapeake Bay Program, 1991b).

The median sediment concentration of naphthalene in the mainstem Bay was 6 ppb. The maximum sediment naphthalene concentration of 241 ppb was found at station CB3.2 in segment three in 1984 (Table 3.26 and Figure 3.22). MacDonald (1993) lists the NOEL and PEL concentrations for naphthalene as 130 ppb and 1100 ppb, respectively. The NOEL concentration was only exceeded by measured concentrations in segment two and three (Table 3.26). The PEL concentration was not exceeded by any measured concentration (Tabl 3.26). Toxic effects to aquatic biota due to the measured naphthalene concentrations in the sediment are not likely to be observed at the mainstem Bay stations sampled.

Table 3.26 Summary statistics for naphthalene in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | | Normalized | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 22 | 6 | 55 | 49 | 0.2 | 241 | | 1746 | | | 4546 | 9 | 28000 |
| Segment 1 | 19 | 22 | 3 | 11 | 7 | 28 | | 9741 | 426 | 39 | 15814 | 404 | 28000 |
| Segment 2 | 120 | 120 | 2 | 21 | 105 | 134 | | 2901 | 818 | 3 | 937 | 2239 | 3563 |
| Segment 3 | 104 | 74 | 6 | 104 | 7 | 241 | | 3107 | 2901 | 2 | 3446 | 152 | 8750 |
| Segment 4 | 18 | 15 | 6 | 16 | 3 | 44 | | 870 | 1811 | 6 | 1137 | 148 | 3143 |
| Segment 5 | 6 | 5 | 7 | 5 | 0.2 | 15 | | 520 | 254 | 6 | 761 | 9 | 2035 |
| Segment 7 | 2 | 1 | 8 | 1 | 0.4 | 4 | | 419 | 285 | 6 | 403 | 100 | 872 |
| Segment 8 | 2 | 2 | 4 | 1 | 2 | 3 | | 600 | 600 | 3 | 445 | 286 | 915 |
| Potomac | 16 | 13 | 3 | 8 | 11 | 25 | | 475 | 367 | 2 | 200 | 353 | 706 |
| Rappahannock | 7 | 7 | 4 | 2 | 5 | 10 | | 396 | 396 | 3 | 124 | 308 | 484 |
| Mobjack Bay | 3 | 3 | 4 | 1 | 2 | 4 | | 200 | 200 | 2 | 121 | 114 | 286 |
| York | 5 | 4 | 4 | 4 | 1 | 10 | | 97 | 97 | 2 | 39 | 70 | 125 |
| James | 4 | 5 | 4 | 3 | 1 | 7 | | 401 | 401 | 2 | 143 | 300 | 02 |

# Figure 3.22 Naphthalene concentrations (ppb) in mainstem sediments
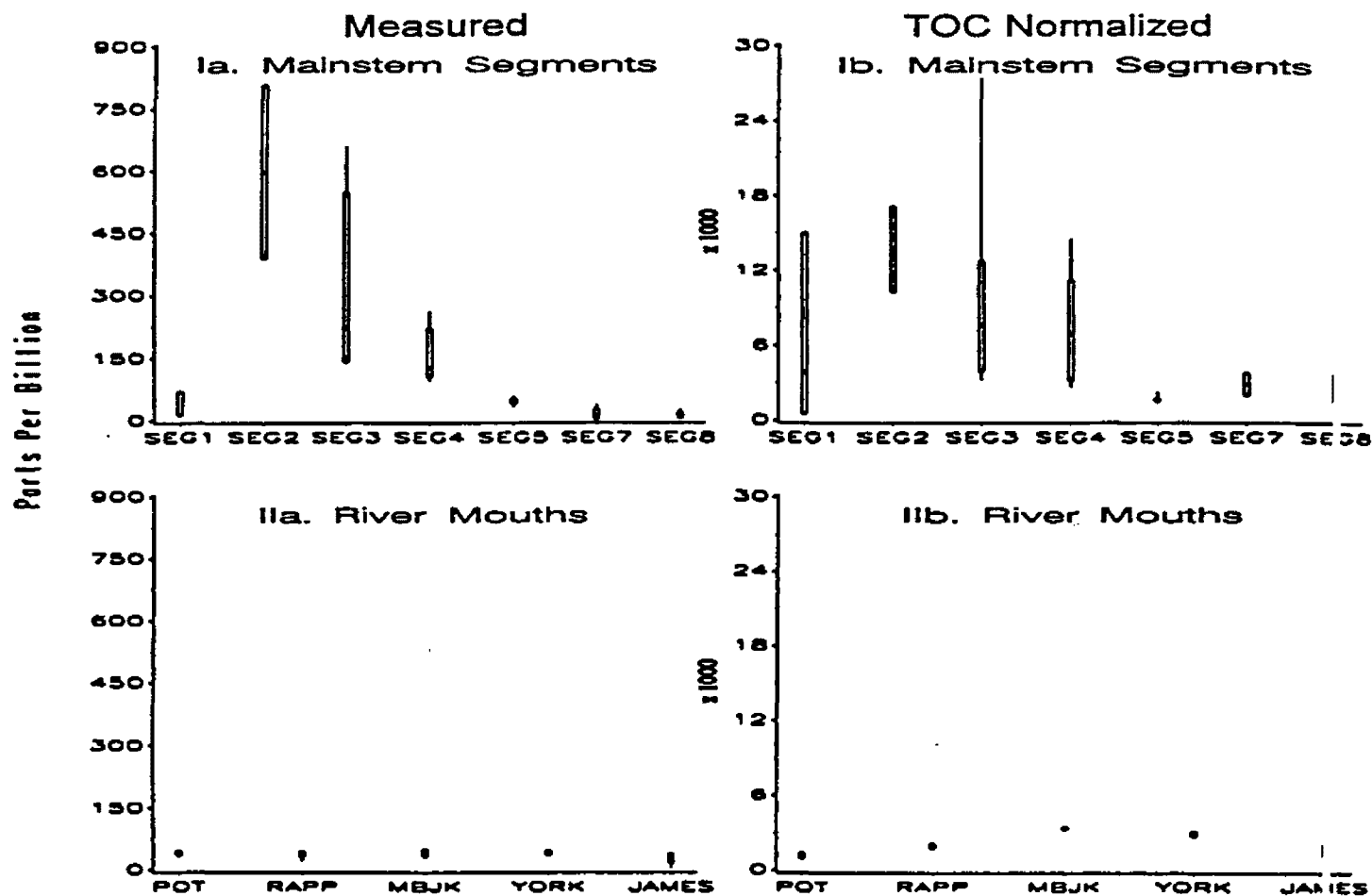


Figure 3.22 Summary statistics for measured and total organic carbon normalized sediment concentrations of naphthalene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment naphthalene concentrations are 130 ppb and 1100 ppb, respectively (MacDonald, 1993).

## Perylene

Perylene is a low molecular weight PAH not listed as a Chesapeake Bay Program Toxic of Concern. Perylene has long been considered an indicator of natural terrestrial inputs, and may be derived from plant pigments under reducing conditions (Bouloubassi and Saliot, 1993). The median and maximum sediment concentrations of perylene in the mainstem Bay were 42 ppb and 807 ppb, respectively, with the maximum concentration found in segment two (Table 3.27 and Figure 3.23) in 1991. No sediment quality guidelines or criteria for this compound were found in the literature.

Table 3.27 Summary statistics for perylene in Chesapeake Bay mainstem sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 98 | 42 | 52 | 163 | 2 | 807 | 5303 | 3178 | 36 | 5852 | 483 | 27500 |
| Segment 1 | 32 | 13 | 3 | 32 | 13 | 69 | 6444 | 3849 | 3 | 7598 | 483 | 15000 |
| Segment 2 | 598 | 598 | 2 | 296 | 389 | 807 | 13780 | 13780 | 2 | 4857 | 10346 | 17215 |
| Segment 3 | 342 | 223 | 5 | 245 | 137 | 660 | 11036 | 7690 | 5 | 9961 | 3227 | 27500 |
| Segment 4 | 156 | 127 | 6 | 70 | 94 | 262 | 7596 | 6953 | 6 | 4614 | 2660 | 14556 |
| Segment 5 | 45 | 45 | 6 | 10 | 31 | 59 | 1709 | 1619 | 5 | 339 | 1367 | 2269 |
| Segment 7 | 15 | 11 | 7 | 14 | 2 | 38 | 2902 | 2902 | 2 | 1270 | 2004 | 3800 |
| Segment 8 | 11 | 8 | 4 | 10 | 2 | 26 | 2601 | 2601 | 2 | 1574 | 1488 | 3714 |
| Potomac | 41 | 43 | 3 | 6 | 35 | 46 | 1231 | 1299 | 3 | 244 | 960 | 1433 |
| Rappahannock | 39 | 44 | 4 | 12 | 21 | 46 | 1961 | 1961 | 2 | 271 | 1769 | 2152 |
| Mobjack Bay | 42 | 45 | 4 | 11 | 27 | 50 | 3416 | 3416 | 2 | 119 | 3332 | 3500 |
| York | 41 | 41 | 4 | 7 | 34 | 50 | 2952 | 2952 | 2 | 286 | 2750 | 3154 |
| James | 27 | 32 | 4 | 17 | 3 | 42 | 1669 | 1669 | 2 | 610 | 1237 | 2100 |

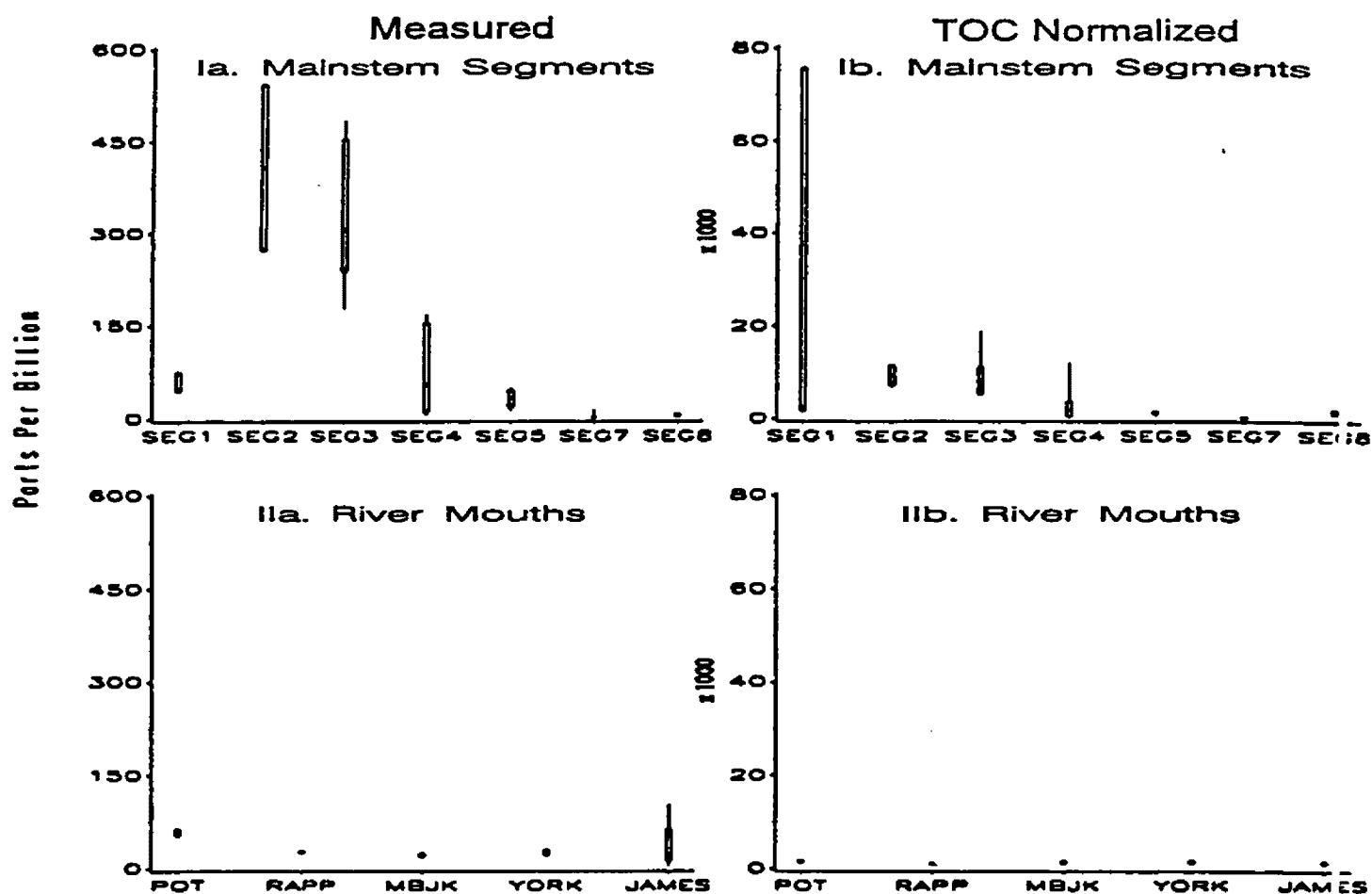# Figure 3.23 Perylene concentrations (ppb) in mainstem sediments

Figure 3.23 Summary statistics for measured and total organic carbon normalized sediment concentrations of perylene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment perylene concentrations are not available due to insufficient data (MacDonald, 1993).

## Phenanthrene

Phenanthrene is a low molecular weight PAH not listed as a Chesapeake Bay Toxics of Concern. Phenanthrene has some industrial uses, and is naturally present in coal and petroleum, as well as being a combustion product (Environmental Protection Agency, 1993e). The median and maximum sediment phenanthrene concentrations in the mainstem Bay were 27 ppb and 543 ppb, respectively (Table 3.28), with the maximum concentration found in segment two (Table 3.28 and Figure 3.24) in 1991.

In segments two and three, all the measured concentrations of phenanthrene were above the NOEL concentration of 140 ppb. No mainstem measurement exceeded the PEL concentration of 1200 ppb (Table 3.28 and MacDonald, 1993). Toxic effects to aquatic biota due to the measured concentrations of phenanthrene in sediments are not likely in the sampled areas of the mainstem Bay.

Table 3.28 Summary statistics for phenanthrene in mainstem Chesapeake Bay sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 76 | 27 | 52 | 125 | 1 | 543 | 5470 | 1668 | 36 | 12821 | 200 | 76000 |
| Segment 1 | 56 | 46 | 3 | 18 | 45 | 46 | 26749 | 1538 | 3 | 42654 | 1710 | 76000 |
| Segment 2 | 407 | 407 | 2 | 193 | 271 | 543 | 9496 | 9396 | 2 | 3095 | 7207 | 1158 |
| Segment 3 | 332 | 305 | 5 | 133 | 179 | 485 | 10266 | 10517 | 5 | 5607 | 5155 | 18917 |
| Segment 4 | 75 | 56 | 6 | 73 | 6 | 168 | 3469 | 1998 | 6 | 4393 | 313 | 1200 |
| Segment 5 | 33 | 35 | 6 | 15 | 14 | 50 | 1266 | 1167 | 5 | 453 | 636 | 1808 |
| Segment 7 | 4 | 2 | 7 | 5 | 1 | 15 | 314 | 314 | 2 | 161 | 200 | 428 |
| Segment 8 | 6 | 7 | 4 | 2 | 3 | 8 | 1611 | 1611 | 2 | 662 | 1143 | 2079 |
| Potomac | 57 | 54 | 3 | 6 | 52 | 64 | 1678 | 1800 | 3 | 218 | 1426 | 1808 |
| Rappahannock | 27 | 28 | 4 | 2 | 23 | 29 | 1088 | 1088 | 2 | 15 | 1077 | 1099 |
| Mobjack Bay | 22 | 23 | 4 | 3 | 17 | 24 | 1438 | 1438 | 2 | 391 | 1162 | 1714 |
| York | 26 | 27 | 4 | 5 | 19 | 32 | 1427 | 1427 | 2 | 280 | 1229 | 1625 |
| James | 38 | 24 | 4 | 44 | 3 | 103 | 1299 | 1299 | 2 | 281 | 1100 | 1498 |

# Figure 3.24 Phenanthrene concentrations (ppb) in mainstem sediments
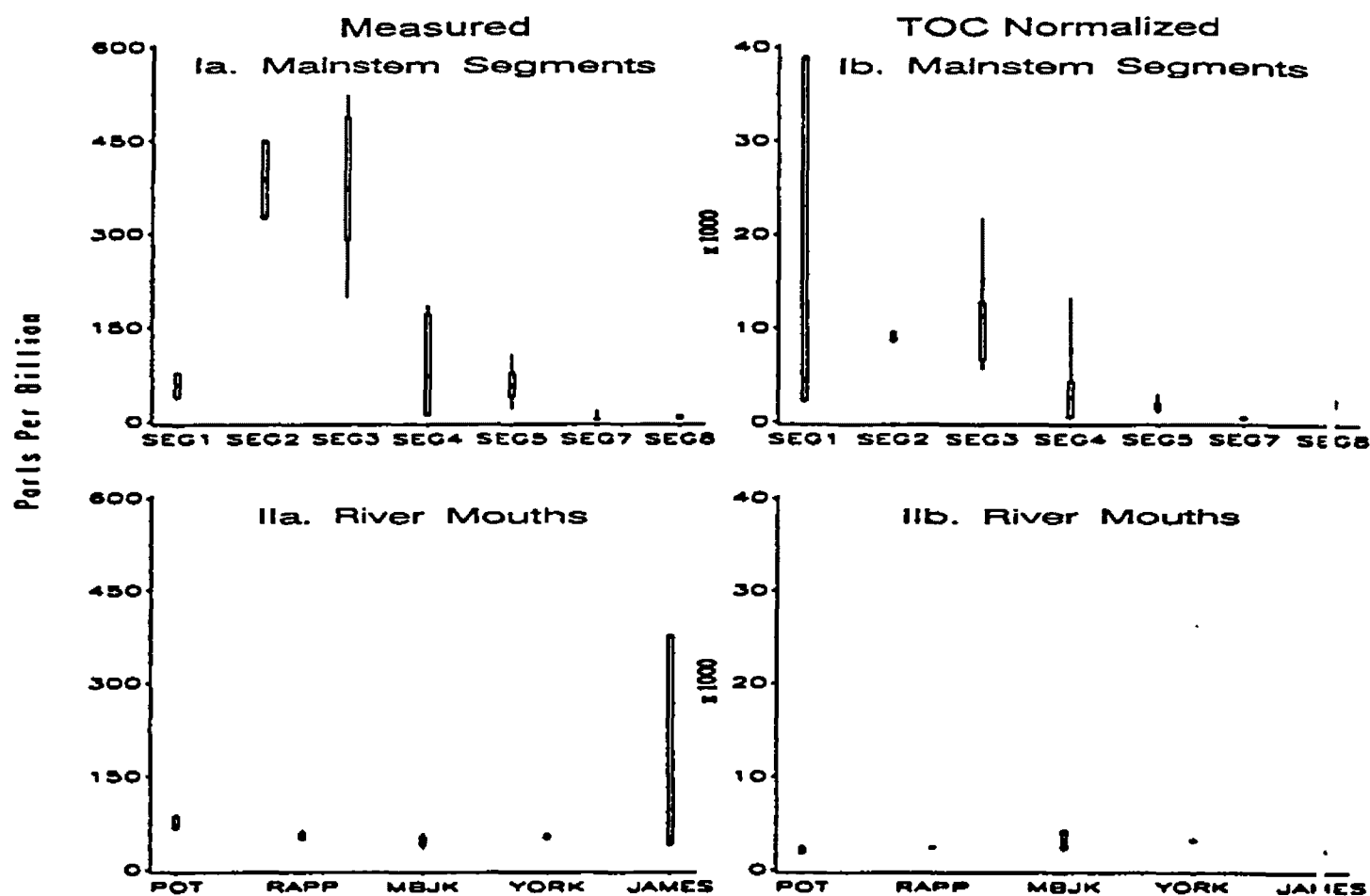


Figure 3.24 Summary statistics for measured and total organic carbon normalized sediment concentrations of phenanthrene in the Chesapeake Bay mainstem. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations are aggregated by: I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment phenanthrene concentrations are 140 ppb and 1200 ppb, respectively (MacDonald, 1993).

Pyrene

Pyrene is a high molecular weight PAH not listed as a Chesapeake Bay Toxics of Concern (Chesapeake Bay Program, 1991a). The median sediment concentration of pyrene in the mainstem Bay was 51 ppb (Table 3.29). The maximum sediment pyrene concentration of 523 ppb was found at station MCB3.2 in segment three (Table 3.29 and Figure 3.25) in 1984. Sediment pyrene concentrations above the NOEL concentration of 290 ppb were observed in segments two and three and the James River mouth stations, but no measurement exceeded the PEL concentration of 1900 ppb (Table 3.26, Figure 3.25, and MacDonald, 1993). Toxic effects to aquatic biota due to the measured pyrene concentrations in the sediment are not likely at the mainstem Bay stations sampled.

Table 3.29 Summary statistics for pyrene in Chesapeake Bay mainstem sediments. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 100 | 523 | 51 | 133 | 2 | 523 | 5331 | 2462 | 35 | 7433 | 300 | 39000 |
| Segment 1 | 59 | 79 | 3 | 20 | 39 | 79 | 15232 | 4465 | 3 | 20614 | 2230 | 39000 |
| Segment 2 | 388 | 450 | 2 | 38 | 326 | 450 | 9134 | 9134 | 2 | 656 | 8670 | 9597 |
| Segment 3 | 375 | 523 | 5 | 135 | 199 | 523 | 11680 | 11402 | 5 | 6419 | 5730 | 21792 |
| Segment 4 | 88 | 186 | 6 | 80 | 9 | 186 | 4009 | 2686 | 6 | 4801 | 443 | 13286 |
| Segment 5 | 60 | 108 | 6 | 31 | 21 | 108 | 1786 | 1539 | 5 | 814 | 955 | 3038 |
| Segment 7 | 5 | 19 | 7 | 6 | 2 | 19 | 398 | 398 | 2 | 138 | 300 | 496 |
| Segment 8 | 7 | 12 | 4 | 4 | 4 | 12 | 2113 | 2113 | 2 | 564 | 1714 | 2512 |
| Potomac | 75 | 87 | 3 | 10 | 67 | 87 | 2226 | 2400 | 3 | 352 | 1821 | 2458 |
| Rappahannock | 54 | 64 | 4 | 7 | 48 | 64 | 2417 | 2417 | 2 | 63 | 2372 | 2462 |
| Mobjack Bay | 46 | 59 | 4 | 11 | 33 | 59 | 3208 | 3208 | 2 | 1422 | 2203 | 4214 |
| York | 53 | 57 | 4 | 4 | 49 | 57 | 3148 | 3148 | 2 | 121 | 3063 | 3234 |
| James | 156 | 377 | 3 | 191 | 40 | 377 | 2000 | 2000 | 1 | | 2000 | 2000 |

# Figure 3.25 Pyrene concentrations (ppb) in mainstem sediments



Figure 3.25  Summary statistics for measured and total organic carbon normalized sediment concentrations of pyrene in the Chesapeake Bay mainstem.  The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data.  If there are less than four values, the rectangle's bottom and top represent the range.  A dash indicates only a single value is available.  Stations are aggregated by:  I. Chesapeake Bay Program mainstem segments; and II. stations at the mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOEL and PEL values for measured sediment pyrene concentrations are 290 ppb and 1800 ppb, respectively (MacDonald, 1993).

## Spatial Distribution of Individual Chlorinated Hydrocarbons

DDT and its metabolites and various PCB congeners were widely detected in mainstem Bay sediments (Table 3.30). However, most other chlorinated hydrocarbon compounds detected in the mainstem Bay were found at only a few stations (Table 3.30). Thus, individual tables of summary statistics are presented only for DDT and PCBs. Information is presented on the frequency of detection and range of measured concentrations for each chlorinated hydrocarbon detected in mainstem sediments. The compounds found at each mainstem station are also listed by station in Table 3.31.

Table 3.30 Frequency of detection and range of observed concentrations of pesticides, PCB congeners, and other chlorinated organic compounds detected in mainstem Chesapeake Bay sediments in 1991. Units are parts per billion (ppb), dry weight. The total number of stations sampled was 16. The nominal detection limit for all compounds was 0.01 ppb.

| Compound | Frequency | Min.(ppb) | Max.(ppb) |
|---|---|---|---|
| 2,2',3,5',6 pentachlorobiphenyl (PCB-95) | 9 | 0.04 | 1.12 |
| 2,2',3,4,4',5' hexachlorobiphenyl (PCB-138) | 12 | 0.02 | 1.64 |
| 2,2',4,4',5,5' hexachlorobiphenyl (PCB-153) | 8 | 0.12 | 2.32 |
| 2,2',3,4,4',5,5' heptachlorobiphenyl (PCB-180) | 9 | 0.01 | 0.82 |
| 2,2',3,4',5,5',6 heptachlorobiphenyl (PCB-187) | 8 | 0.06 | 0.50 |
| 2,2',3,4',5 pentachlorobiphenyl/ 2,2',4,5,5' pentachlorobiphenyl (PCB-90/101) | 10 | 0.03 | 1.10 |
| 2,3',4,4',5 pentachlorobiphenyl/ 2,2',3,4',5',6 hexachlorobiphenyl (PCB-118/149) | 11 | 0.13 | 2.34 |
| 2,2',3,3',4,4',5 heptachlorobiphenyl/ 2,3,3',4,4',5,6 heptachlorobiphenyl (PCB-170/190) | 6 | 0.01 | 0.19 |
| 4-4'-DDD | 12 | 0.04 | 2.10 |
| 4-4'-DDE | 14 | 0.02 | 2.30 |
| 4-4'-DDT | 10 | 0.10 | 1.60 |
| trans-Nonachlor | 4 | 0.06 | 0.25 |
| cis-Nonachlor | 1 | 0.20 | 0.20 |
| Chlordane(1) | 1 | 0.45 | 0.45 |
| Chlordane(3) | 1 | 0.14 | 0.14 |
| Chlordane(5) | 2 | 0.10 | 0.16 |
| Chlordane(7) | 4 | 0.08 | 0.23 |
| cis-Chlordane | 2 | 0.72 | 0.75 |
| trans-Chlordane | 1 | 0.15 | 0.15 |
| Dicofol | 4 | 0.12 | 0.32 |
| Dieldrin | 2 | 0.27 | 0.31 |
| Octochlorodibenzo-p-dioxin (OCDD) | 13 | 0.01 | 2.67 |

Source: PCB congeners number equivalent from McFarland, V.A. and J.U. Clarke, 1989.

Table 3.31 Pesticides, PCB congeners, and other chlorinated organic compounds detected at each Chesapeake Bay mainstem station sampled for organic chemical contaminants in 1991.

| Location | Compound | Concentration (ppb) |
|---|---|---|
| **Segment 1** | | |
| **MCB1.1** | PCB-95 | 0.11 |
| | PCB-90/101 | 0.16 |
| | PCB-118/149 | 0.89 |
| | PCB-153 | 1.24 |
| | PCB-138 | 1.25 |
| | PCB-187 | 0.22 |
| | PCB-180 | 0.82 |
| | PCB-170/190 | 0.19 |
| | trans-Nonachlor | 0.17 |
| **Segment 2** | | |
| **MCB2.1** | PCB-95 | 0.41 |
| | PCB-90/101 | 0.35 |
| | PCB-118/149 | 1.29 |
| | PCB-153 | 1.42 |
| | PCB-138 | 0.61 |
| | PCB-187 | 0.16 |
| | PCB-180 | 0.32 |
| | Chlordane(5) | 0.10 |
| **MCB2.2** | PCB-95 | 0.84 |
| | PCB-90/101 | 0.70 |
| | PCB-118/149 | 1.64 |
| | PCB-138 | 1.45 |
| | PCB-187 | 0.26 |
| | PCB-180 | 0.78 |
| | PCB-170/190 | 0.09 |
| | Chlordane(7) | 0.12 |
| **Segment 3** | | |
| **MCB3.1** | PCB-95 | 0.43 |
| | PCB 90/101 | 0.28 |
| | PCB-118/149 | 1.41 |
| | PCB-153 | 1.79 |
| | PCB-138 | 1.63 |
| | PCB-187 | 0.22 |
| | PCB-180 | 0.56 |
| | PCB-170/190 | 0.11 |
| | 4-4'-DDD | 1.95 |
| | 4-4'-DDE | 1.55 |
| | 4-4-DDT | 1.30 |
| | Dicofol | 0.32 |
| | OCDD | 0.20 |

**Table 3.31 (continued)**

| Location | Compound | Concentration (ppb) |
|---|---|---|
| MCB3.2 | PCB-95 | 0.71 |
| | PCB-90/101 | 0.61 |
| | PCB-118/149 | 1.60 |
| | PCB-153 | 1.75 |
| | PCB-138 | 1.52 |
| | PCB-187 | 0.14 |
| | | |
| MCB3.2 | PCB-180 | 0.45 |
| | PCB-170/190 | 0.02 |
| | 4-4'-DDD | 1.70 |
| | 4-4'-DDE | 1.20 |
| | 4-4-DDT | 0.50 |
| | Dicofol | 0.17 |
| | OCDD | |
| MCB3.3C | PCB-95 | 1.04 |
| | PCB-90/101 | 1.03 |
| | PCB-118/149 | 2.28 |
| | PCB-153 | 2.28 |
| | PCB-138 | 1.41 |
| | PCB-187 | 0.49 |
| | PCB-180 | 0.57 |
| | PCB-170/190 | 0.18 |
| | 4-4'-DDD | 1.70 |
| | 4-4'-DDE | 2.30 |
| | 4-4-DDT | 0.35 |
| | trans-Nonachlor | 0.24 |
| | cis-Nonachlor | 0.20 |
| | Chlordane(1) | 0.45 |
| | Chlordane(3) | 0.14 |
| | Chlordane(5) | 0.16 |
| | Chlordane(7) | 0.20 |
| | cis-Chlordane | 0.73 |
| | trans-Chlordane | 0.15 |
| | Dicofol | 0.12 |
| | Dieldrin | 0.29 |
| | OCDD | 0.53 |
| Segment 4 | | |
| MCB4.1C | PCB-90/101 | 0.09 |
| | PCB-118/149 | 0.24 |
| | PCB-153 | 0.12 |
| | PCB-138 | 0.02 |
| | 4-4'-DDD | 0.10 |
| | 4-4'-DDE | 0.10 |
| | OCDD | 0.73 |
| | | |
| MCB4.3C | OCDD | 2.67 |

Table 3.31 (continued)

| Location | Compound | Concentration (ppb) |
|---|---|---|
| **Segment 5** | | |
| **CB5.1** | PCB-138 | 0.03 |
| | OCDD | 0.63 |
| **CB5.4** | 4-4'-DDE | 0.02 |
| **Segment 7** | | |
| **CB7.3E** | —— | —— |
| **CB7.1S** | OCDD | 0.33 |
| **Segment 8** | | |
| **CB8.1E** | PCB-118/149 | 0.13 |
| | PCB-138 | 0.01 |
| | OCDD | 0.02 |
| **Potomac River Mouth** | | |
| **MLE2.3** | PCB-95 | 0.66 |
| | PCB-90/101 | 0.40 |
| | PCB-118/149 | 1.05 |
| | PCB-138 | 1.50 |
| | PCB-187 | 0.09 |
| | PCB-180 | 0.03 |
| | 4-4'-DDD | 0.70 |
| | 4-4'-DDE | 1.00 |
| | 4-4'-DDT | 0.90 |
| | OCDD | 2.14 |
| Rappahannock River Mouth | | |
| **LE3.6** | PCB-95 | 0.04 |
| | PCB-90/101 | 0.03 |
| | PCB-118/149 | 0.10 |
| | PCB-153 | 0.02 |
| | PCB-138 | 0.03 |
| | 4-4'-DDD | 0.04 |
| | 4-4'-DDE | 0.03 |
| | OCDD | 0.46 |
| Mobjack Bay | | |

| WE4.1 | 4-4'-DDE | 0.60 |
| | OCDD | 0.82 |

James River Mouth

| LE5.5 | — | — |

<u>York River Mouth</u>

| WE4.2 | PCB-95 | 0.10 |
| | PCB-90/101 | 0.10 |
| | PCB-118/149 | 0.25 |
| | PCB-153 | 0.33 |
| | PCB-138 | 0.43 |
| | PCB-187 | 0.06 |
| | | |
| | PCB-180 | 0.04 |
| | PCB-170/190 | 0.01 |
| | 4-4'-DDD | 0.30 |
| | 4-4'-DDE | 0.10 |
| | 4-4-DDT | 0.80 |
| | OCDD | 0.49 |

## Total Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are a class of organic compounds containing two linked hydrocarbon rings with various numbers of chlorine atoms, usually from two to nine. PCBs are extremely persistent anthropogenic compounds that have been widely used in electrical transformers. The U.S. banned production of PCBs in the late 1970s, but poor operating and disposal practices involving products and equipment containing PCBs still lead to environmental contamination (Latimer et. al, 1990). Surveys such as the EPA Mussel Watch Program, and the NOAA National Status and Trends Program show no clear evidence of a large-scale, nationwide decrease in the concentration of these compounds in aquatic environments (Kennish et. al, 1992).

Total PCBs is on the list of Chesapeake Bay Toxics of Concern (Chesapeake Bay Program, 1991a). The EPA considers PCBs probable human carcinogens, although there is conflicting evidence regarding carcinogenicity (Chesapeake Bay Program, 1991b). PCBs can pose both acute toxic effects to estuarine organisms and are also known to produce chronic, sublethal effects such as reproductive deficiencies (Kennish, et. al, 1992). PCBs are also of concern because they have considerable potential to accumulate in the tissues of aquatic organisms (MacDonald, 1993).

PCBs, like PAHs, are a variable mixture of compounds. In the method used in 1991 to monitor sediment contaminants in the mainstem of Chesapeake Bay, the quantity of total PCBs present was estimated based on the assumption that a suite of eight of the PCB congeners that were quantified accounted for 44.9% of total PCBs. This assumption was based on analysis of a mixture of Aroclor 1254 and 1260 (commercial mixtures of PCBs) which most closely matched the patterns of congener abundance observed in the sediment samples (Unger, et al., 1992).

The concentrations of total PCBs were much higher in the upper Bay (segments one, two, and three) than in the lower Bay (segments four through eight) (Table 3.32 and Figure 3.26). The median mainstem Bay concentration was 7.6 ppb. The maximum value of 15.5 ppb was found at station MCB3.3C in segment three. Even the maximum measured concentration does not exceed the PEL concentration of 260 ppb or the NOEL concentration of 24 ppb (MacDonald, 1993). Toxic effects to aquatic biota are not likely to result from the measured sediment concentrations of PCBs measured at the monitored stations in the mainstem Bay.

Table 3.32 Summary statistics for total PCBs in Chesapeake Bay mainstem sediments. Values are in ppb dry weight. Statistics are presented for all mainstem stations; Chesapeake Bay Program segments which divide the Bay into latitudinal segments with segment 1 at the mouth of the Susquehanna River and segment 8 at the Bay mouth and for stations located at the mouths of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay, near the mouth of the York River. Concentrations are in ppb dry weight. Normalized values are measured values divided by the fraction total organic carbon in the sediment.

| Region | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean - μ | Median | N | SD - σ | Min | Max | Mean - μ | Median | N | SD - σ | Min | Max |
| Mainstem | 6.4 | 7.6 | 12 | 5.5 | 0.1 | 15.5 | 207.9 | 236.1 | 12 | 156.4 | 2.2 | 455.6 |
| Segment 1 | 8.1 | 8.1 | 1 | | 8.1 | 8.1 | 455.6 | 455.6 | 1 | | 455.6 | 455.6 |
| Segment 2 | 9.9 | 9.9 | 2 | 4.1 | 7.0 | 12.8 | 181.9 | 181.9 | 2 | 129.6 | 90.3 | 273.6 |
| Segment 3 | 12.4 | 11.2 | 3 | 2.8 | 10.3 | 15.5 | 313.7 | 248.1 | 3 | 115.1 | 246.4 | 446.6 |
| Segment 4 | 0.8 | 0.8 | 1 | | 0.8 | 0.8 | 23.1 | 23.1 | 1 | | 23.1 | 23.1 |
| Segment 5 | 0.1 | 0.1 | 1 | | 0.1 | 0.1 | 2.2 | 2.2 | 1 | | 2.2 | 2.2 |
| Segment 7 | | | 0 | | | | | | 0 | | | |
| Segment 8 | 0.5 | 0.5 | 1 | | 0.5 | 0.5 | 323.2 | 323.2 | 1 | | 323.2 | 323.2 |
| Potomac | 8.3 | 8.3 | 1 | | 8.3 | 8.3 | 225.8 | 225.8 | 1 | | 225.8 | 225.8 |
| Rappahannock | 0.5 | 0.5 | 1 | | 0.5 | 0.5 | 21.1 | 21.1 | 1 | | 21.1 | 21.1 |
| York Mouth | 2.2 | 2.2 | 1 | | 2.2 | 2.2 | 139.2 | 139.2 | 1 | | 139.2 | 139.2 |

# Figure 3.26 Total PCBs concentrations (ppb) in mainstem sediments
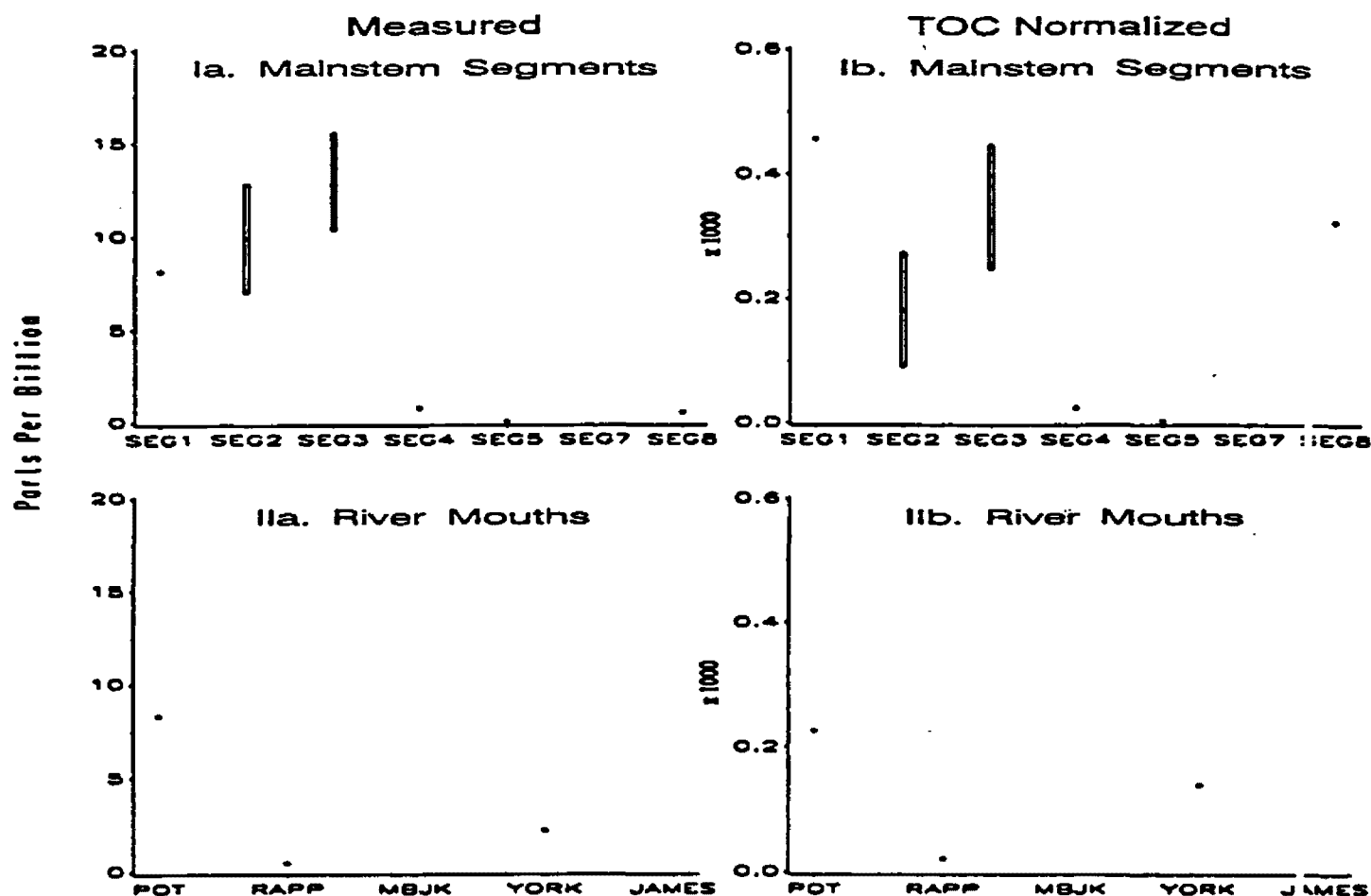


Figure 3.26 Summary statistics for measured and total organic carbon normalized sedimer [ concentrations of total PCBs in the Chesapeake Bay mainstem. The box and whisker plot ; illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and range ; (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top represent the range. A dash indicates only a single value is available. Stations an : aggregated by: I. Chesapeake Bay Program mainstem segments. and II. stations at th : mouth of the Potomac, Rappahannock, York and James Rivers, and in Mobjack Bay. The NOE . and PEL values for measured sediment total PCBs concentrations are 24 ppb and 260 ppt, respectively (MacDonald, 1993).

## DDT and its metabolites

DDT is a broad spectrum organochlorine insecticide which was previously used extensively in agricultural applications, although it is no longer registered for use in North America (MacDonald, 1993). DDT is still of concern because residues of DDT and its metabolites (DDE and DDD) are highly toxic and persistent in the environment and have a high potential to bioaccumulate. DDT has not been identified as a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a).

The highest sediment concentrations of DDT, DDE, and DDD were found at the mouth of the York River (Table 3.33). Elsewhere within the mainstem Bay, concentrations were generally the highest in segment three in the middle mainstem Bay and declined towards the mouth of the Bay. Sediment DDT concentrations were below detection limits in most of the lower mainstem Bay.

MacDonald (1993) lists NOEL and PEL values of 1.7 ppb and 130 ppb for DDE, and 4.5 ppb and 270 ppb for total DDT. MacDonald (1993) determined that there were insufficient data for the determination of NOEL and PEL values for DDE and DDT. Long and Morgan (1990) provide ER-L and ER-M values of 2 ppb and 20 ppb for DDD and 1 ppb and 7 ppb for DDT. Comparison of the data with these sediment quality guidelines indicate that the measured sediment concentrations of DDT and its metabolites were generally below their respective ER-L or NOEL values, although these values were sometimes slighly exceeded in segments two through four (Table 3.33). All measured concentrations were well below ER-M and PEL guidelines (Table 3.33). The measured concentrations of DDT are overestimates, as there was interference from PCB and chlordane congeners in measuring the concentration of p-DDT (Unger, et al., 1992). Toxic effects to aquatic biota due to the measured concentrations of DDT in sediment are not likely at the monitored stations in the mainstem Bay.

## Aldrin/Dieldrin

Aldrin is an organochlorine pesticide previously used to control a broad spectrum of pests in both domestic and agricultural applications (MacDonald, 1993). Aldrin is quickly biotransformed into dieldrin in aquatic ecosystems (MacDonald, 1993). Dieldrin was formerly one of the more widely used domestic pesticides, but, like aldrin, its use is currently restricted (MacDonald, 1993). Both aldrin and dieldrin are listed with a secondary group of toxic substances under consideration for inclusion on the Chesapeake Bay Toxics of Concern List (Chesapeake Bay Program, 1991a).

Dieldrin was only detected at one station, MCB3.3C in the central trough in the middle mainstem Bay, at a concentration of 0.29 ppb (Table 3.31). MacDonald (1993) felt there were insufficient data to use in developing NOEL and PEL concentrations for dieldrin, and Long and Morgan (1990) placed a low level of confidence in their ER-L and ER-M values of 0.002 ppb and 8 ppb, respectively. The measured dieldrin concentration is well below the ER-M concentration, but above the ER-L concentration. Toxic effects due to the measured dieldrin concentrations in sediments are unlikely at the mainstem Bay stations sampled.

Table 3.33  Concentrations of DDT, DDD, and DDE in Chesapeake Bay mainstem sediments. Concentrations are in ppb dry weight.

| Station | Location | p-DDE | p-DDD | Station |
|---------|----------|-------|-------|---------|
| MCB1.1 | Segment 1 | 0.90 | 0.70 | 0.90 |
| MCB2.1 | Segment 1 | 1.5 | 1.5 | 0.1 |
| MCB2.2 | Segment 2 | 1.8 | 1.9 | 1.4 |
| MCB3.1 | Segment 3 | 1.8 | 2.1 | 1.6 |
| MCB3.2 | Segment 3 | 1.2 | 1.7 | 0.5 |
| MCB3.3C | Segment 3 | 2.3 | 1.7 | 0.3 |
| MCB4.1C | Segment 4 | 2.3 | 1.7 | 0.4 |
| MCB4.3C | Segment 4 | 0.10 | 0.1 | <0.01 |
| MCB5.1 | Segment 5 | <0.01 | <0.01 | <0.01 |
| CB5.4 | Segment 5 | 0.02 | <0.01 | <0.01 |
| CB7.1S | Segment 7 | <0.01 | <0.01 | <0.01 |
| CB7.3E | Segment 7 | <0.01 | <0.01 | <0.01 |
| CB8.1E | Segment 8 | <0.01 | <0.01 | <0.01 |
| | | | | |
| MLE2.3 | Potomac R. Mouth | 1.00 | 0.70 | 0.90 |
| LE3.6 | Rapp. River Mouth | 0.03 | 0.04 | <0.01 |
| WE4.1 | Mobjack Bay | 0.6 | <0.01 | <0.01 |
| WE4.2 | York River Mouth | 0.10 | 0.30 | 0.80 |
| LE5.5 | James River Mouth | <0.01 | <0.01 | <0.01 |

## Chlordane

Chlordane, a Chesapeake Bay Toxic of Concern, is a broad-spectrum chlorinated hydrocarbon pesticide which was used prior to 1980 in a wide variety of applications, including termite control, wood preservatives, home and garden insecticides, and pesticides for use on livestock (Chesapeake Bay Program, 1991a,b; MacDonald, 1993). In 1978 its use was severely restricted, and its sale and distribution has been prohibited since 1988. Although its use has been discontinued, it is of concern because it is a persistent compound with a tendency to accumulate in sediments and bioaccumulate in biota (MacDonald, 1993).

Technical chlordane, which was the mixture used as an insecticide, consists of approximately 60% chlordane isomers (primarily cis and trans chlordane) and 40 percent related compounds such as heptachlor, heptachlor epoxide, cis and trans nonachlor, and various chlordenes (MacDonald, 1993; Ney, 1990). Chlordane can degrade under natural environmental conditions to photoisomers which may have greater toxicity and bioaccumulation potential than the original compounds (Chesapeake Bay Program, 1991b).

Chlordane isomers or related compounds were detected at only 4 of the 18 mainstem stations (Table 3.31). The maximum observed sum of all chlordane compounds detected at a station was less than 2 ppb. Long and Morgan (1990) list the ER-L and ER-M of total chlordane at 0.5 and 2 ppb, but placed low confidence in these values due to a relative scarcity of data. MacDonald (1993) did not develop NOEL and PEL chlordane concentrations due to the scarcity of data.

## Other Chlorinated Pesticides

The cis or trans form of nonachlor was found at 2 of the 18 mainstem stations sampled, with maximum values of 0.20 ppb and 0.21 ppb respectively, both of which occurred at station MCB3.3C in the center trough of the middle mainstem Bay (Table 3.31). No sediment quality guidelines or criteria relating to this compound were found in the literature.

Dicofol, an acaricide (Windholz, et al., 1983), was detected at three of the mainstem stations, with a maximum concentration of 0.32 ppb at station MCB3.1 in the middle mainstem Bay (Table 3.31). No sediment quality guidelines or criteria could be found for this compound in the literature.

## Dioxins and furans

Polychlorinated di-p-dioxins (PCDDs) and polychlorinated difurans (PCDFs) consist of two benzene rings linked by one (PCDDs) or two (PCDFs) oxygen atoms. There are 75 possible chlorinated dioxin congeners and 135 possible chlorinated difuran congeners. These compounds are generally produced unintentionally, either during chemical manufacturing, the production of bleached paper products, or during the incomplete combustion of materials containing chlorine atoms and organic compounds. The most significant sources of dioxins include the wood preservative pentachlorophenol, municipal incinerators, and pulp and paper mills utilizing chlorine. PCBs are the most significant source of furans. These substances have been associated with acute and chronic toxicity and cancer (MacDonald, 1993).

The only member of this class of compounds detected at concentrations above the detection limit of 0.01 ppb in the mainstem was octochlorodibenzo-p-dioxin (OCDD), which was detected at low concentrations at 13 of the 18 mainstem samples, all within the middle and lower mainstem Bay. Concentrations ranged from 0.01 ppb to 2.67 ppb. The maximum value was found at station MCB4.3C in the central trough of segment four (Table 3.31). No sediment guidelines or criteria relating to this compound were found in the literature. Many compounds in this class commonly occur in the environment at concentrations in the range of parts per billion or lower. The methods used in the monitoring program were not specifically designed to detect such small concentrations of these compounds, as such analyses are very costly.

**Comparison With Data From NOAA Sediment Sampling Programs**

Various programs conducted by the National Oceanic and Atmospheric Administration (NOAA), including the National Status and Trend Program, Mussel Watch, and the Benthic Surveillance Project, collected data on sediment contaminant concentrations at several stations in Chesapeake Bay between 1984-1987 (National Oceanographic and Atmospheric Administration, 1991; Figure 3.27). The median data from each station are listed in Table 3.34, alongside comparable data collected by Maryland and Virginia with the support of the EPA Chesapeake Bay Program. All NOAA data for both trace metals and organic compounds were normalized for grain size by dividing measured sediment chemical contaminant concentrations by the fraction of silt and clay in the sediment. Samples consisting of less than 20 percent silt and clay were not included in the analysis. All the data from the Chesapeake Bay Program monitoring program presented here have been normalized in the same way as the NOAA data facilitate comparison between the two sets of data.

The data on sediment trace metal concentrations from NOAA and the Chesapeake Bay Program monitoring programs are generally similar (Table 3.34). The markedly higher chromium concentrations in the NOAA data are probably due to the stronger sediment digestion used by NOAA in analyzing trace metal concentrations, as NOAA performed a "total" metal type of analysis and the states' used a "total recoverable" type of metal analysis. The large differences in the estimates of the concentration of total PCBs between the two data sets may also reflect different methods, as there is a degree of subjectivity in determining how data on individual PCB congeners are used to estimate total PCBs. The large differences in estimates of total DDTs are not easily attributable to differences in analytical methods.

Figure 3.27  Location of stations in the mainstem Chesapeake Bay monitored for sediment contaminants by the National Oceanic and Atmospheric Administration.  Source:  National Oceanographic and Atmosperic Administration, 1991.



CBMP
CBHP

CBHG

CBIB

CBCC

CBDP
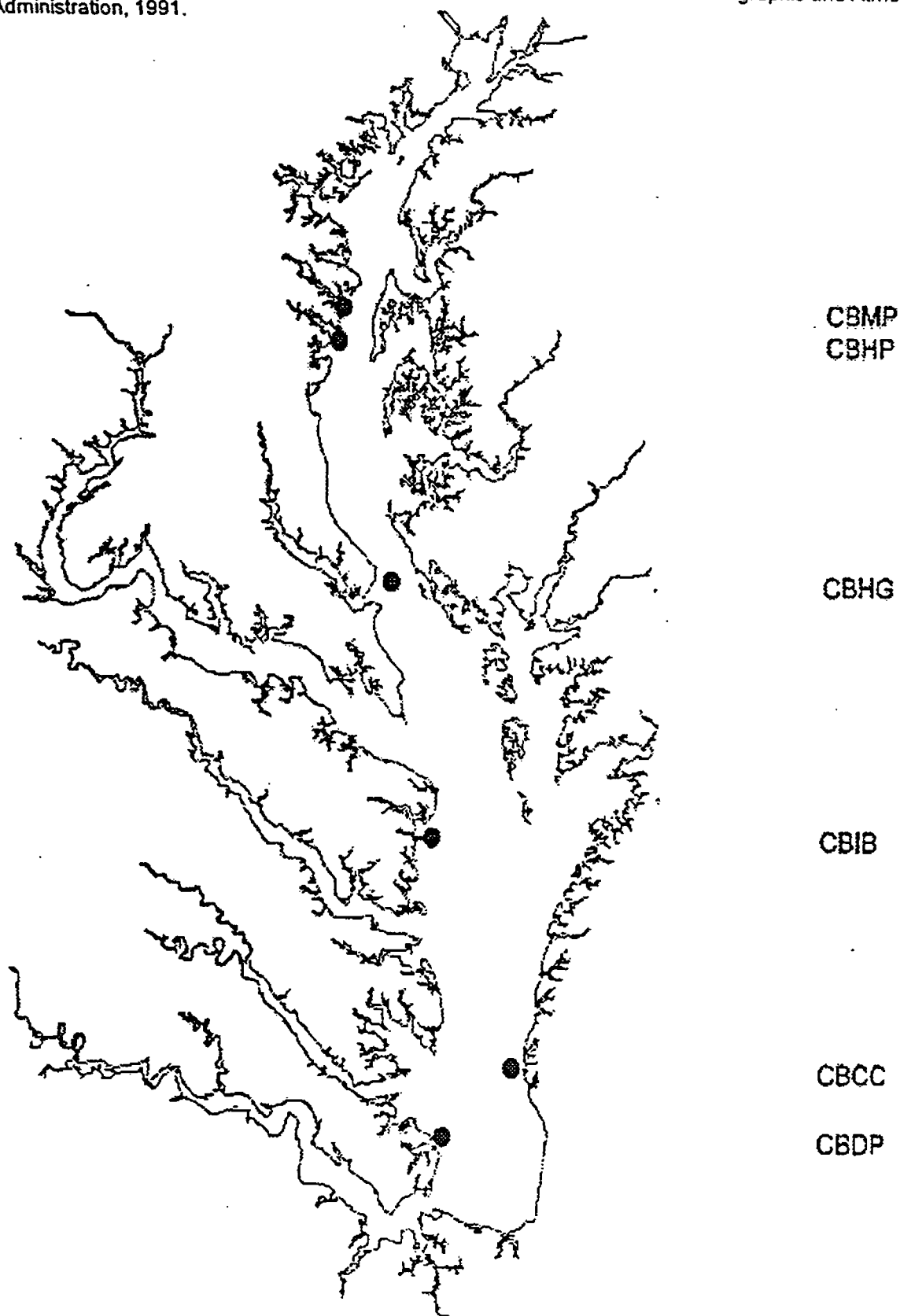
Table 3.34 Mean sediment trace metal and organic contaminant concentrations from NOAA and Maryland/Virginia/CBP sediment monitoring programs in the Chesapeake Bay mainstem. Station names and codes refer to stations sampled by NOAA. The segment refers to the approximate location of the NOAA sediment stations in the segmentation scheme used by Chesapeake Bay Program (see Figure 3.1) Units are ppm for trace metal concentrations and ppb for organic contaminant concentrations. All data are normalized with respect to fraction silt and clay, with samples less than 20% silt and clay excluded from analysis. NOAA data are from NOAA, 1991.

| NOAA Station | Code | Seg. | NOAA | CBP |
|---|---|---|---|---|
| **Arsenic** | | | | |
| Upper Ches. Bay MD | UCB | 3 | 18 | 24.4 |
| Ches. Bay MD | CBMP | 3 | 23 | 24.4 |
| Ches. Bay MD | CBHP | 4 | 17 | 16.4 |
| Mid. Ches. Bay VA | MCB | 5 | 32 | 11.7 |
| Ches. Bay VA | CBIB | 5 | 16 | 11.7 |
| Ches. Bay VA | CBCC | 7 | 13 | 6.7 |
| Ches. Bay VA | CBDP | 8 | 13 | nd |
| Low. Ches. Bay VA | LCB | 7 | 12 | 6.7 |
| **Cadmium** | | | | |
| Upper Ches. Bay MD | UCB | 3 | 0.87 | 0.48 |
| Ches. Bay MD | CBMP | 3 | 0.60 | 0.48 |
| Ches. Bay MD | CBHP | 4 | 0.59 | 0.42 |
| Mid. Ches. Bay VA | MCB | 5 | 1.00 | 0.42 |
| Ches. Bay VA | CBIB | 5 | 0.51 | 0.43 |
| Ches. Bay VA | CBCC | 7 | 0.47 | 0.20 |
| Ches. Bay VA | CBDP | 8 | 0.47 | nd |
| Low. Ches. Bay VA | LCB | 7 | 0.50 | 0.20 |
| **Chromium** | | | | |
| Upper Ches. Bay MD | UCB | 3 | 180 | 40 |
| Ches. Bay MD | CBMP | 3 | 120 | 40 |
| Ches. Bay MD | CBHP | 4 | 110 | 43 |
| Mid. Ches. Bay VA | MCB | 5 | 170 | 42 |
| Ches. Bay VA | CBIB | 5 | 63 | 42 |
| Ches. Bay VA | CBCC | 7 | 86 | 32 |
| Ches. Bay VA | CBDP | 8 | 54 | nd |
| Low. Ches. Bay VA | LCB | 7 | 130 | 32 |
| **Copper** | | | | |
| Upper Ches. Bay MD | UCB | 3 | 65 | 32 |
| Ches. Bay MD | CBMP | 3 | 53 | 32 |
| Ches. Bay MD | CBHP | 4 | 49 | 28 |
| Mid. Ches. Bay VA | MCB | 5 | 42 | 22 |
| Ches. Bay VA | CBIB | 5 | 29 | 22 |
| Ches. Bay VA | CBCC | 7 | 25 | 15 |

| NOAA Station | Code | Seg. | NOAA | CBP |
|---|---|---|---|---|
| Ches. Bay VA | CBDP | 8 | 22 | nd |
| Low. Ches. Bay VA | LCB | 7 | 24 | 15 |

Lead

| | | | | |
|---|---|---|---|---|
| Upper Ches. Bay MD | UCB | 3 | 70 | 49.8 |
| Ches. Bay MD | CBMP | 3 | 74 | 49.8 |
| | | | | |
| Ches. Bay MD | CBHP | 4 | 68 | 37.4 |
| Mid. Ches. Bay VA | MCB | 5 | 85 | 30.9 |
| Ches. Bay VA | CBIB | 5 | 28 | 30.9 |
| Ches. Bay VA | CBCC | 7 | 36 | 13.5 |
| Ches. Bay VA | CBDP | 8 | 36 | nd |
| Low. Ches. Bay VA | LCB | 7 | 33 | 13.5 |

Mercury

| | | | | |
|---|---|---|---|---|
| Upper Ches. Bay MD | UCB | 3 | 0.29 | 0.06 |
| Ches. Bay MD | CBMP | 3 | 0.23 | 0.06 |
| Ches. Bay MD | CBHP | 4 | 0.21 | 0.06 |
| Mid. Ches. Bay VA | MCB | 5 | 0.10 | 0.06 |
| Ches. Bay VA | CBIB | 5 | 0.12 | 0.06 |
| Ches. Bay VA | CBCC | 7 | 0.082 | 0.07 |
| Ches. Bay VA | CBDP | 8 | 0.13 | nd |
| Low. Ches. Bay VA | LCB | 7 | 0.086 | 0.07 |

Nickel

| | | | | |
|---|---|---|---|---|
| Upper Ches. Bay MD | UCB | 3 | 75 | 46.9 |
| Ches. Bay MD | CBMP | 3 | 66 | 46.9 |
| Ches. Bay MD | CBHP | 4 | 56 | 33.2 |
| Mid. Ches. Bay VA | MCB | 5 | 67 | 26.7 |
| Ches. Bay VA | CBIB | 5 | 36 | 26.7 |
| Ches. Bay VA | CBCC | 7 | 35 | 15.2 |
| Ches. Bay VA | CBDP | 8 | 33 | nd |
| Low. Ches. Bay VA | LCB | 7 | 33 | 15.2 |

Zinc

| | | | | |
|---|---|---|---|---|
| Upper Ches. Bay MD | UCB | 3 | 320 | 224 |
| Ches. Bay MD | CBMP | 3 | 390 | 224 |
| Ches. Bay MD | CBHP | 4 | 300 | 226 |
| Mid. Ches. Bay VA | MCB | 5 | 320 | 188 |
| Ches. Bay VA | CBIB | 5 | 120 | 188 |
| Ches. Bay VA | CBCC | 7 | 120 | 73 |
| Ches. Bay VA | CBDP | 8 | 80 | nd |
| Low. Ches. Bay VA | LCB | 7 | 140 | 73 |

Total PAHs

| | | | | |
|---|---|---|---|---|
| Upper Ches. Bay MD | UCB | 3 | 3800 | 5058 |
| Ches. Bay MD | CBMP | 3 | 6400 | 5058 |
| Ches. Bay MD | CBHP | 4 | 4300 | 2201 |

Table 3.34, continued

| NOAA Station | Code | Seg. | NOAA | CBP |
|---|---|---|---|---|
| Mid. Ches. Bay VA | MCB | 5 | 610 | 2139 |
| Ches. Bay VA | CBIB | 5 | 740 | 2139 |
| Ches. Bay VA | CBCC | 7 | 120 | 595 |
| Ches. Bay VA | CBDP | 8 | 680 | nd |
| Low. Ches. Bay VA | LCB | 7 | 530 | 595 |
| Ches. Bay | | | | |

Total DDT

| | | | | |
|---|---|---|---|---|
| Upper Ches. Bay MD | UCB | 3 | 14 | 4.1 |
| Ches. Bay MD | CBMP | 3 | 14 | 4.1 |
| Ches. Bay MD | CBHP | 4 | 14 | 0.012 |
| Mid. Ches. Bay VA | MCB | 5 | 1.2 | 0.03 |
| Ches. Bay VA | CBIB | 5 | 2.6 | 0.03 |
| Ches. Bay VA | CBCC | 7 | 2.4 | 0.03 |
| Ches. Bay VA | CBDP | 8 | 7.1 | nd |
| Low. Ches. Bay VA | LCB | 7 | 2.7 | 0.03 |

Total PCB

| | | | | |
|---|---|---|---|---|
| Upper Ches. Bay MD | UCB | 3 | 270 | 12 |
| Ches. Bay MD | CBMP | 3 | 92 | 0.85 |
| Ches. Bay MD | CBHP | 4 | 110 | 0.85 |
| Mid. Ches. Bay VA | MCB | 5 | 13 | 0.08 |
| Ches. Bay VA | CBIB | 5 | 6.3 | 0.008 |
| Ches. Bay VA | CBCC | 7 | 1.3 | bdl |
| Ches. Bay VA | CBDP | 8 | 20 | nd |
| Low. Ches. Bay VA | LCB | 7 | 54 | bdl |

# Tributaries

This chapter discusses data from sediment contaminant monitoring programs in the tidal tributaries of Chesapeake Bay, excluding the Elizabeth River, Baltimore Harbor (Patapsco River), Back River, the Anacostia and upper Potomac Rivers. Information on sediment contamination in the listed areas is presented separately because focused studies or data in addition to the State monitoring programs is available and because these areas are widely regarded as having the highest levels of sediment contamination in the Chesapeake Bay.

## Sediment Contaminant Monitoring Programs in the Tidal Tributaries of Chesapeake Bay

The Maryland Department of Environment (MDE) conducts a sediment contaminant monitoring program in the tidal tributaries of the Chesapeake Bay within the state of Maryland. The stations selected for monitoring of sediment contaminants are a subset of the Chesapeake Bay Program's water quality monitoring stations (Magnien et al., 1990). Sediments have generally been sampled at Maryland tributary monitoring stations annually since 1986, although only a few of the stations were sampled in the first year of the monitoring program. Data on sediment concentrations of metals and total organic carbon and sediment grain size distribution are available for each year of sampling (1986 - 1991). Data on sediment concentrations of polycyclic aromatic hydrocarbons are available for sediment samples collected in 1986, 1987, and 1991. Data on sediment concentrations of pesticides and PCBs are available from 1991 only. In 1986, 13 of the Maryland tributary stations were sampled in October and December. In 1987, four of Maryland's eastern tributary stations (MET.1, MET2.2, MET2.3, AND MET3.1), all in the region called "Northeast Rivers," were sampled in November. All other samples, in all years, were collected between March and July.

In Virginia, sediment contaminant monitoring programs have been coordinated by the Virginia Department of Environmental Quality (VADEQ). In 1985 and 1986, many of the Chesapeake Bay Program water quality monitoring stations in the Rappahannock, York, and James rivers were analyzed only for sediment organic chemical contaminants with the support of the Chesapeake Bay Program (Fig. 4.1b). One station in each of these tributaries was again sampled for organic chemical contaminants in 1991 in conjunction with that year's mainstem sediment contaminant monitoring program.

The VADEQ has collected monitoring data on sediment trace metal concentrations only in the James River (Fig. 4.1c). Data on sediment trace metal concentrations and percent silt and clay particles is available from single samples collected in 1985 and 1986 (except for one sample collected in 1990) from 29 stations located above and below selected wastewater treatment outfalls throughout the tidal portion of the James River and some of its tributaries. These samples were collected as part of a study of the effects of industrial, municipal, and federal facility wastewater effluents on the concentrations of toxic organic compounds and metals in nearby sediments and shellfish tissue (deFur et al., 1987). While the sediment samples are identified as "ambient" samples, the focus of sampling effort towards point sources of potentially toxic chemicals probably biases the data toward higher concentrations of sediment contaminants compared to what would be collected from stations which are selected to be representative of the general area in which they are located.

## Data Analysis

The MDE and VADEQ sediment contaminant monitoring stations were assigned to "regions" based on expectations of similar sources of chemical contaminants, e.g., the Potomac River or the Southeastern Rivers and Bays region on the lower eastern shore of Maryland. With the exception of the VADEQ data on sediment trace metal concentrations in the James River, results for each tributary station are shown graphically within the context of adjacent tributaries assigned to the same region. The MDE and

VADEQ monitoring station designations are listed in Table 4.1 to facilitate comparisons to water quality data available in other reports, e.g., Magnien et al., 1990; Magnien et al., 1992. The locations of the monitoring stations are shown in Figures 4.1a-c.

Medians, quartiles and the minimum and maximum values of bulk concentrations of each chemical contaminant are presented in tables and displayed graphically. The graphical presentation provides a measure of central tendency (median), dispersion (quartiles), and range. Statistics are also presented for trace metal concentrations normalized by the fraction of silt and clay particles in the sediment and for PAH concentrations normalized by the fraction of total organic carbon in the sediment. Because of the much higher density of stations in the James River sampled for trace metals compared to that in other tributary regions, statistics on these stations were calculated separately from the Maryland stations and the Virginia stations sampled for organic contaminants.

### Sediment Characteristics

Information on grain size, salinity range, and sedimentation rates is available for most stations and is provided in Table 4.1. More details on sediment accumulation rates are listed in Appendix A. Excluding the stations in the James River sampled for trace metal concentrations, muddy sand (silt and clay between 10 percent and 50 percent; Table 1.1) is the most common sediment type among the tributary stations (Table 4.2 and Figure 4.2), and was found at 64 percent of 64 stations. Stations classified as mud and sandy mud comprised 22 percent and 14 percent of these stations, respectively, with no stations that would be classified as sand (silt and clay less than 10 percent) (Table 4.2 and Figure 4.2).

The stations in the James River sampled for trace metal concentrations had a much lower average percentage of silt and clay particles compared to the Maryland tributary stations and the stations in the Rappahannock, York, and James Rivers sampled for organic contaminants in 1991 (Table 4.2). Almost 18 percent of the James River trace metal stations are sand, 53 percent are muddy sand, with sandy mud and mud constituting about 9 percent and 12 percent of the stations, respectively.

Median concentrations of total organic carbon were roughly three to four percent in the northeastern, northwestern, and western tributaries (Table 4.3 and Figure 4.3). Tributary stations on the eastern shore including the Chester and Choptank Rivers and stations further south had lower total organic carbon content, with median concentrations of approximately two to two and a half percent. Total organic carbon concentration data from the Virginia tributaries were based on a single measurement in each tributary.

# Figure 4.1a Maryland Tributary Sediment Contaminant Monitoring Stations and Regions
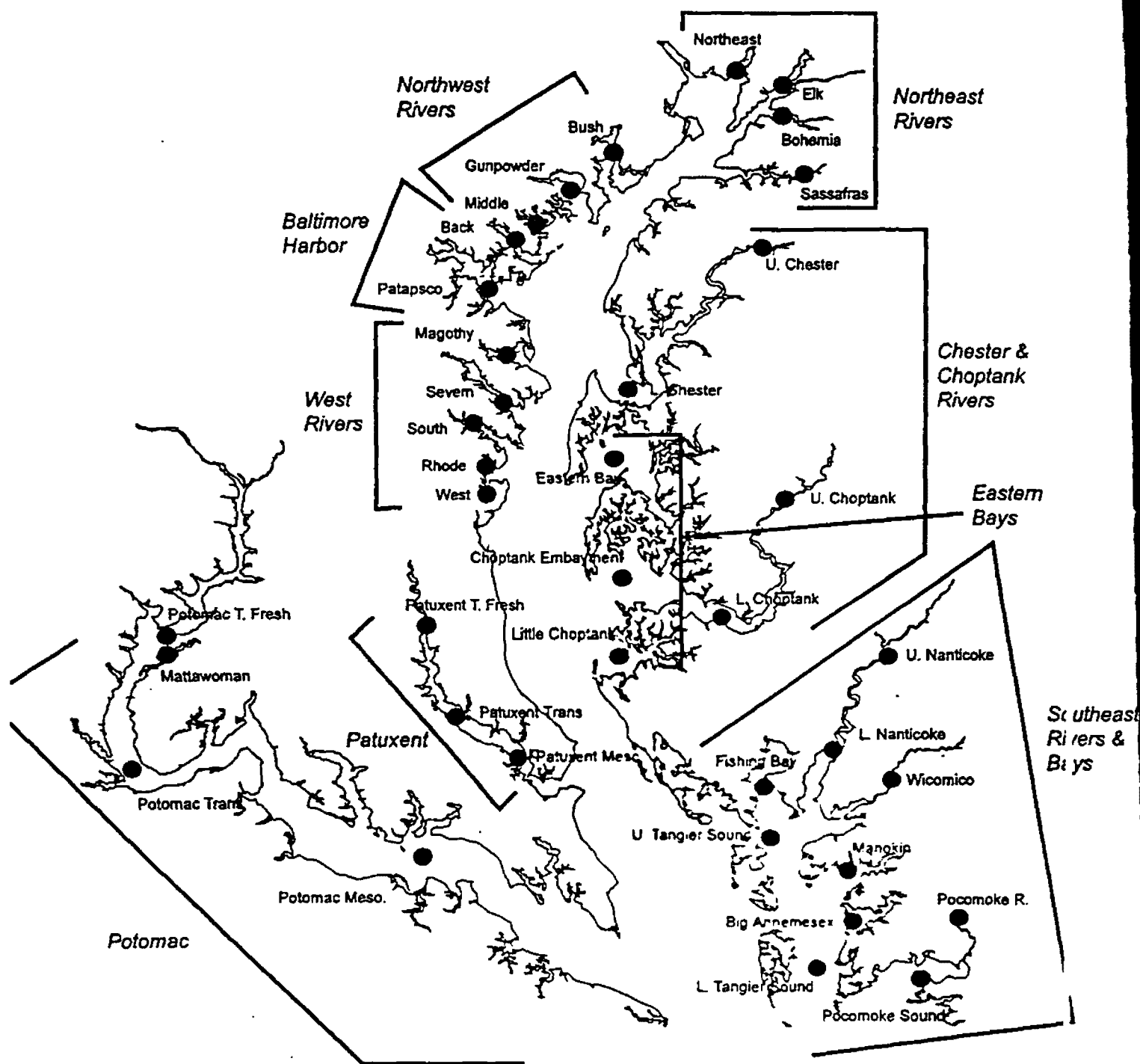
Figure 4.1b. Virginia tributary stations monitored for sediment concentrations of polycyclic aromatic hydrocarbons. Stations RET3.1, RET4.1 and TF5.5 were also monitored for chlorinated hydrocarbons in 1991.Figure 4.1c. Stations in the James River monitored for sediment concentrations of trace metals by the Virginia Department of Environmental Quality. Stations apparently off of the river are properly located on tributaries to the James River but exceed the river boundaries of the Geographic Information System.
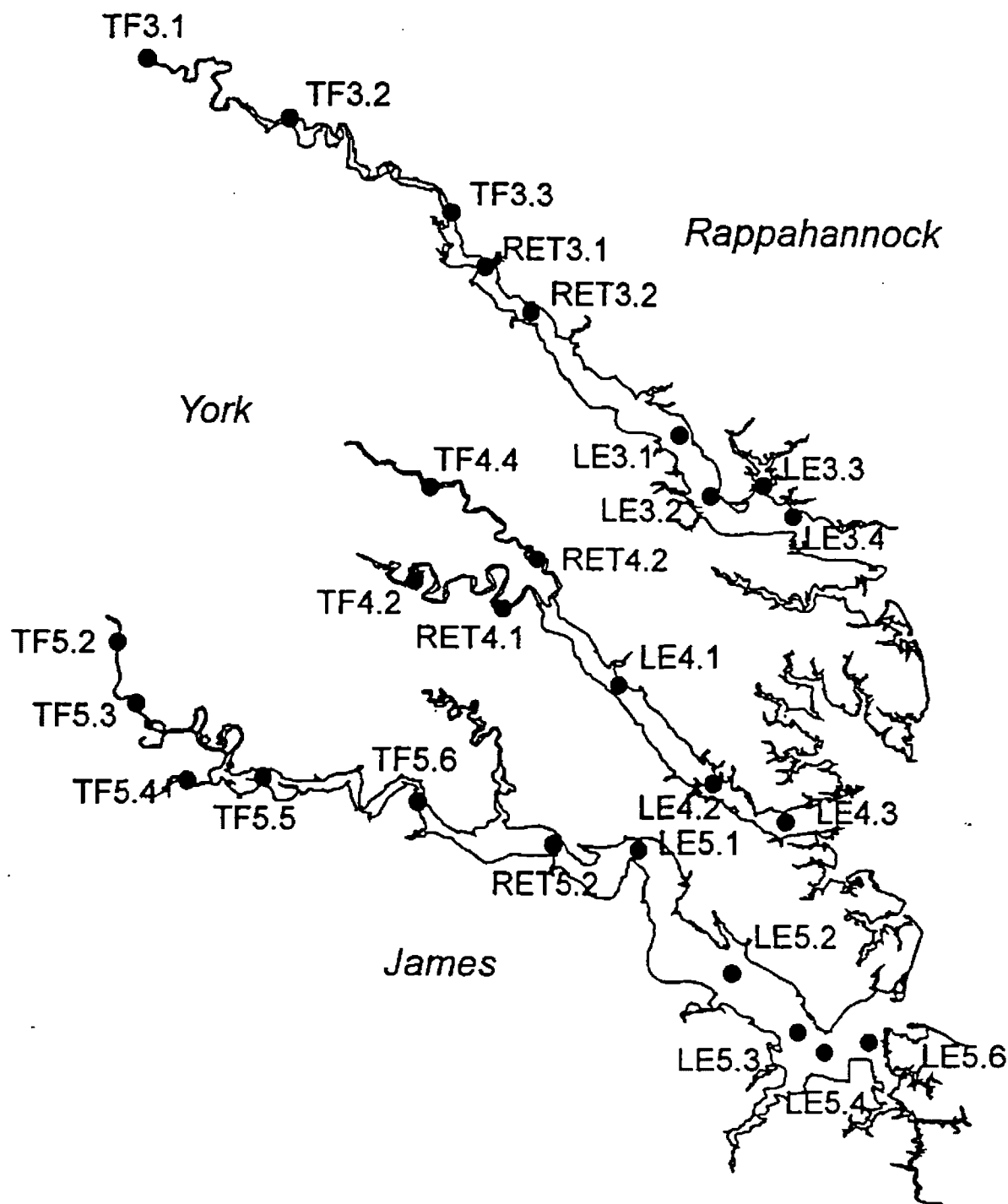
Figure 4.1c James River Stations Monitored
for Trace Metals

RP
DS
FC
PC
RM
FF
VC
AT
IC
PM
AC
AH
HP
ACT
PS

VS
HW
FE
DB
FEA2
IIJ
NN
IIS
HN

CB
SG
HA
SN79
SN81
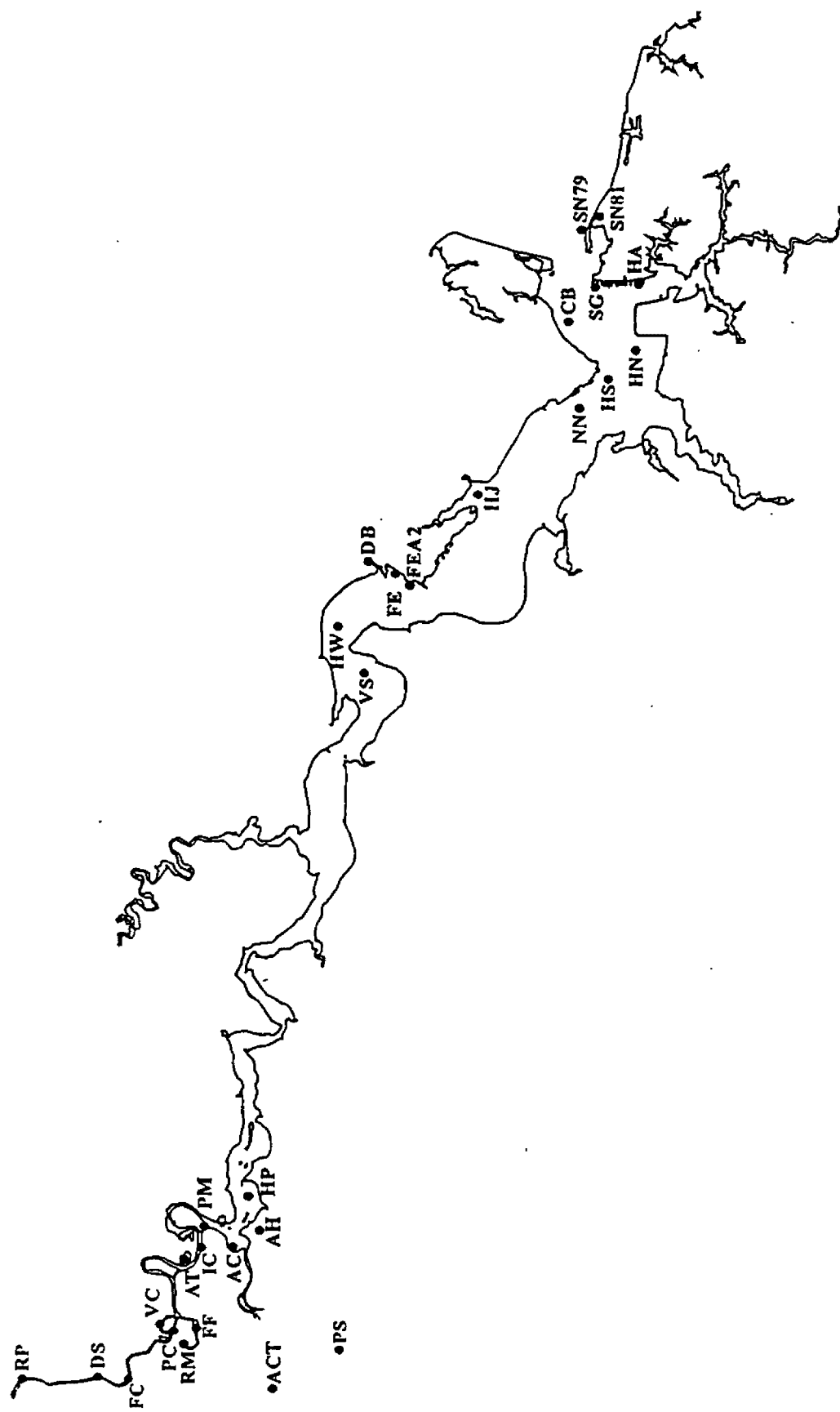
Figure 4.1c James River stations monitored for sediment trace concentrations by the
Virginia Department of Environmental Quality. Stations off the river are properly located
but exceed the river boundaries of our GIS.

Table 4.1. Tributary region and station descriptions. Grain size categories: MUD (% silt & clay ≥ 85%), SM (sandy mud, % silt and clay < 50%), MS (muddy sand, % silt & clay < 50%).

| Region | Station | Station Code | Description | Grain Size | Comments |
|---|---|---|---|---|---|
| Northwestern Rivers (N.W. Rivers) | BUSH | MWT1.1 | Bush R. E. of Gum Pt. | MUD | Average salinity for region is 1-10 ppt. Sediment accumulation rate is 0.2 cm/yr for Middle R; Average silt & clay = 86%. |
| | GUNP | MWT2.1 | Gunpowder R. E. of Oliver Pt. | MUD | |
| | MIDD | MWT3.1 | Middle R. E. of Wilson Pt. | SM | |
| Western Rivers (Western R.) | MAG | MWT6.1 | Magothy R. N of S. Ferry Pt. | SM | Median salinity about 10 ppt. Sediment accumulation rate is 0.14-0.23 cm/yr for Magothy; ≈0.17 cm/yr for "western shore." Average silt & clay = 74%. |
| | SEV | MWT7.1 | Severn R. above Rte 50-301 bridge | SM | |
| | SOUTH | MWT8.1 | South R. S of Poplar Pt. | SM | |
| | RHODE | MWT8.2 | Rhode R. between Flat & Big Is. | SM | |
| | WEST | MWT8.3 | West R. upstream of R6 | SM | |
| Patuxent River (PAT) | TIDFR | PXT0402 | Tidal fresh near Nottingham. | SM | Salinity varies as indicated. Sediment accumulation average |

| TRANS | XED4892 | Salinity transition near Jack's Cr. | MUD | for western shore is 0.30 cm/yr; upstream, midstream, and downstream are 0.39, 0.37, and 0.17 cm/yr respectively. Average silt & clay = 87%. |
| MESO | XDE5339 | Mesohaline SSW of Jack B. Sandspit/NE of Sandgates | MUD | |

Table 4.1 (continued).

| Region | Station | Station Code | Description | Grain size | Comments |
|---|---|---|---|---|---|
| Potomac River (Potomac R.) | MATWMN TIDFR | MAT0016 XEA6596 | Mattawoman Cr. Tidal Fresh near Indianhead | MUD SM | Salinity varies as indicated. Sediment accumulation for TIDFR ranges from 0.22-1.74 cm/yr; at TRANS 0.40-1.46 cm/yr; and at MESO from 0.17-0.79 cm/yr. Average silt & clay = 84.7%. |
| | TRANS | XDA1177 | Salinity transition near Maryland Pt. | MUD | |
| | MESO | MLE2.2 | Mesohaline off Ragged Pt. | SM | |
| Northeast Rivers (N.E. Rivers) | NE | MET1.1 | Northeast R. off Hance Pt. | MUD | Salinity is less than 1 ppt for all stations. No sediment accumulation rates have been estimated. Average silt & clay = 76%. |
| | BOH | MET2.2 | Bohemia R. off Old Nack Pt. | SM | |
| | ELK | MET2.3 | Elk R. off Oldfield Pt. | SM | |
| | SASS | MET3.1 | Sassafras R. near Rte. 213 bridge | SM | |
| Chester & Choptank Rivers (Ches. & Chop.) | UCHES | MET4.1 | Chester R. at Crumpton | SM | Salinity at upper stations is tidal fresh (<1 ppt); at lower stations mesohaline (>10 ppt). No sediment accumulation rates have been estimated. Average silt & clay = 72%. |
| | LCHES | MET4.2 | Chester R. S of Eastern Neck Is. | SM | |
| | UCHOP | MET5.1 | Choptank R. at Ganey Wharf | SM | |
| | LCHOP | MMET5.2 | Choptank R. at Rte. 50 bridge | SM | |
| East Bays (E. Bays) | EBAY | MEE1.1 | Eastern Bay between Tilghman Pt. and Parsons Is. | SM | All stations have mesohaline salinity. No sediment accumulation rates have been estimated. Average silt & clay = 80. |
| | CHOPEM | MEE2.1 | Choptank Embayment bet. Todds Pt & Nelson Pt. | SM | |
| | LITCHOP | MEE2.2 | Little Choptank R. west of Ragged Pt. | MUD | |

Table 4.1 (continued)

| Region | Station | Station Code | Description | Grain size | Comments |
|---|---|---|---|---|---|
| Southeastern Rivers & Bays (S.E. Rivers) | FB | MEE3.0 | Fishing Bay | SM | UN and PR stations are in the upper rivers and have salinity < 1 ppt. Other stations have salinities > 10 ppt. No sediment accumulation rates have been estimated. Average silt & clay = 65.4%. |
| | NT | MEE3.1 | North Tangier Sound | SM | |
| | ST | MEE3.2 | South Tangier Sound | SM | |
| | PSD | MEE3.3 | Pocomoke Sound | SM | |
| | UN | MET6.1 | Upper Nanticoke R. | SM | |
| | LN | MET6.2 | Lower Nanticoke R. | SM | |
| | WI | MET7.1 | Wicomico R. | SM | |
| | MN | MET8.1 | Manokin R. | MS | |
| | BA | MET9.1 | Big Annemessex R. | SM | |
| | PR | MET10.1 | Pocomoke R. | SM | |
| Rappahannock River | | TF3.1 | Tidal Fresh Area | MS | No metals data; Organics data only for 1985 and 1986. |
| | | TF3.2 | " | MUD | |
| | | TF3.3 | " | SM | |
| | | RET3.1 | Salinity transition area. | SM | TOC data for RET3.1 in 1991 only. Organics data for 1985 and 1986. Sediment characteristics ranged widely; 50% silt & clay at RET3.1, 94% at RET3.2. |
| | | RET3.2 | | MUD | |
| | | LE3.1 | Lower estuarine salinity area. | SM | No metals data; Organics data only for 1985 and 1986. Grain size is based on a single sample for each station. |
| | | LE3.2 | " | SM | |
| | | LE3.3 | " | SM | |
| | | LE3.4 | | SM | |
| York River | | TF4.2 | Tidal fresh salinity. | MS | No metals data; Organics data only for 1985 and 1986. Grain size based on a single sample for each station. |
| | | TF4.4 | " | MS | |

Table 4.1 (Continued)

| Region | Station Code | Description | Grain Size | Comments |
|---|---|---|---|---|
| York River | RET4.1 | Salinity transition area. | MUD | TOC data for RET4.2 in 1991 only. Organics data for 1985 and 1986. |
| | RET4.2 | | SM | |
| | LE4.1 | Lower estuarine salinity area. | SM | No metals data; Organics data only for 1985 and 1986. Grain size based on a single sample for each station. |
| | LE4.2 | " | SM | |
| | LE4.3 | " | SM | |
| James River | TF5.2 | Tidal fresh salinity. | MS | TOC data for TF5.5 in 1991 only. Organics data for 1985 and 1986. |
| | TF5.3 | " | MUD | |
| | TF5.4 | " | SM | |
| | TF5.5 | " | SM | |
| | TF5.6 | " | MS | |
| | RET5.2 | Salinity transition area. | MS | Grain size based on a single sample. |
| | LE5.1 | Lower estuarine salinity area. | MUD | Post-European sediment accumulation estimate > 0.30 cm/yr. Grain size based on a single sample for each station. |
| | LE5.2 | " | SM | |
| | LE5.3 | " | MS | |
| | LE5.4 | " | MS | |
| | LE5.6 | " | SM | |
| | AC001A | Tidal fresh area | MS | VADEQ trace metal stations. See Fig. 4.1C |
| | ACT001A | | SAND | |
| | AH001A | | SAND | |
| | AT001A | | MS | |
| | DS001A | | MS | |
| | FC001A | | MUD | |
| | FF001A | | MS | |
| | HP001A | | MS | |
| | IC001A | | MS | |
| | PC001A | | MS | |
| | PM001A | | MUD | |
| | PS001A | | MS | |
| | RM001A | | MS | |

| Station | Sediment | Notes |
|---|---|---|
| RP001A | SM | VADEQ trace metal stations. See Fig. 4.1C |
| VC004A | SAND | |
| DB001A | MUD | salinity transition area. |
| FE001A | SAND | |
| FEA2 | MS | |
| HW001A | MUD | |
| VS011A | SM | |
| CB002A | SAND | Lower estuarine salinity area |
| MA001A | MS | |
| HJ001A | SM | |
| HW001A | MS | VADEQ trace metal stations. See Fig. 4.1C |
| HS001A | SAND | |
| NN017A | MS | |
| SG001A | MS | |
| SN079A | SAND | SN stations indicate Sewells Point Naval Complex |
| SN081A | MUD | |

**Table 4.2.** Summary statistics for percent silt and clay in tributary sediments.

| Area | Mean | Median | N | SD | Min | Max |
|------|------|--------|---|----|----|-----|
| All | 69 | 79 | 240 | 27 | 2 | 99 |
| Maryland* | 75 | 81 | 181 | 20 | 12 | 99 |
| Northwestern Rivers | 86 | 90 | 13 | 12 | 66 | 98 |
| Western Rivers | 73 | 77 | 27 | 19 | 22 | 99 |
| Patuxent River | 87 | 90 | 15 | 12 | 49 | 97 |
| Potomac River | 84 | 88 | 16 | 33 | 88 | 97 |
| Northeastern Rivers | 76 | 80 | 19 | 38 | 80 | 99 |
| Chester & Choptank | 71 | 79 | 22 | 14 | 79 | 94 |
| Eastern Bays | 79 | 89 | 23 | 12 | 89 | 99 |
| Southeastern Rivers | 65 | 67 | 21 | 18 | 67 | 99 |

VIRGINIA SEDIMENT SAMPLES FOR ORGANIC COMPOUNDS

| Area | Mean | Median | N | SD | Min | Max |
|------|------|--------|---|----|----|-----|
| Rappahannock R. | 91 | 97 | 19 | 37 | 97 | 99 |
| York River | 73 | 95 | 35 | 6 | 95 | 97 |
| James River | 46 | 47 | 36 | 2 | 47 | 99 |

VIRGINIA SEDIMENT SAMPLES FOR TRACE METALS

| Area | Mean | Median | N | SD | Min | Max |
|------|------|--------|---|----|----|-----|
| James River | 37 | 26 | 32 | 3 | 26 | 99 |

Figure 4.2. Summary statistics for the percentage of silt and clay in sediment samples from Chesapeake Bay tributaries. Virginia samples are single samples taken in 1991 for organic contaminants. The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from individual Maryland tributary station between 1986 and 1991. The box and whisker plots for the James River represent statistics for groups of stations aggregated by segment. (continued)
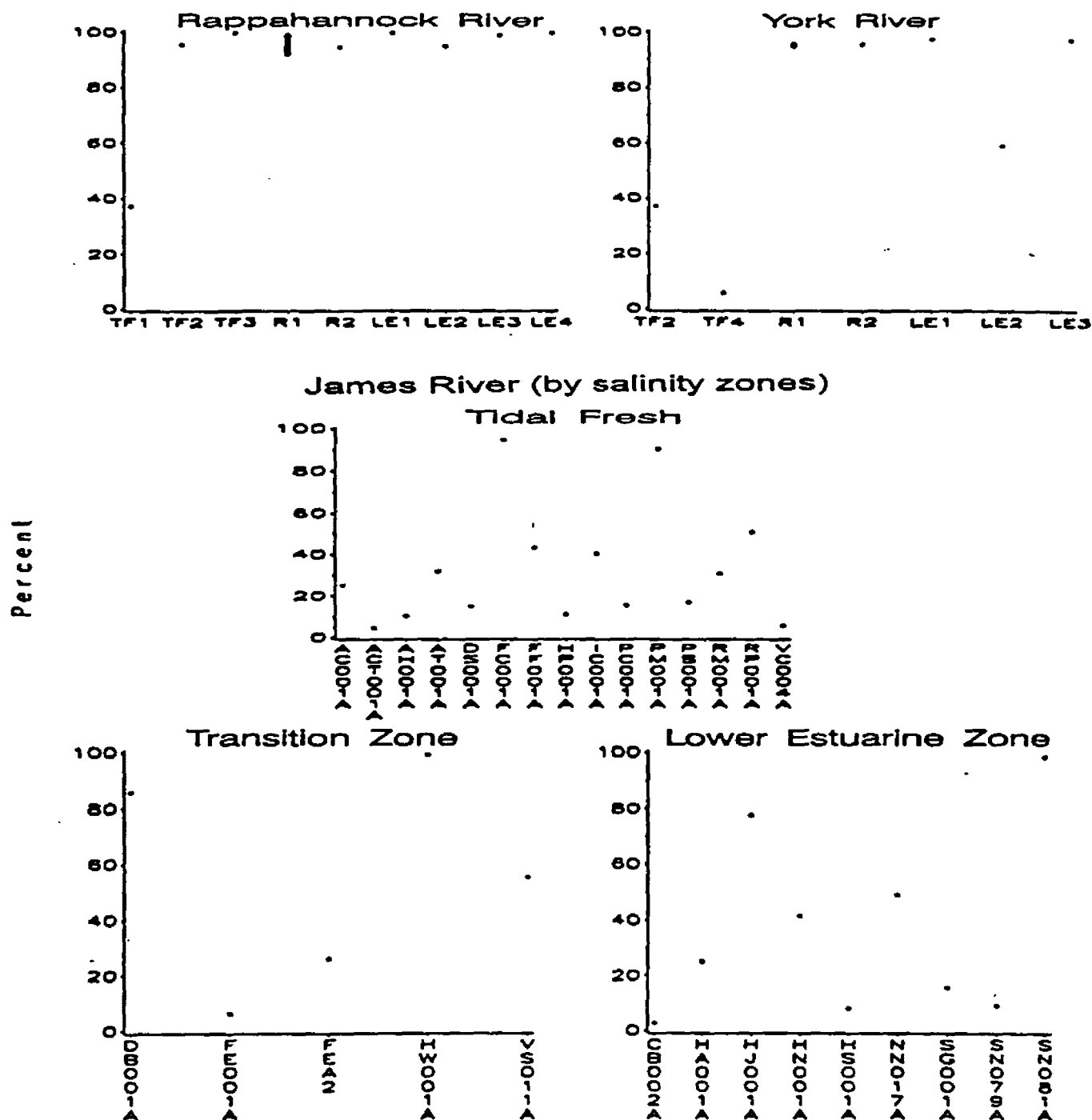
# Figure 4.2 Percentage silt and clay
## in tributary sediments
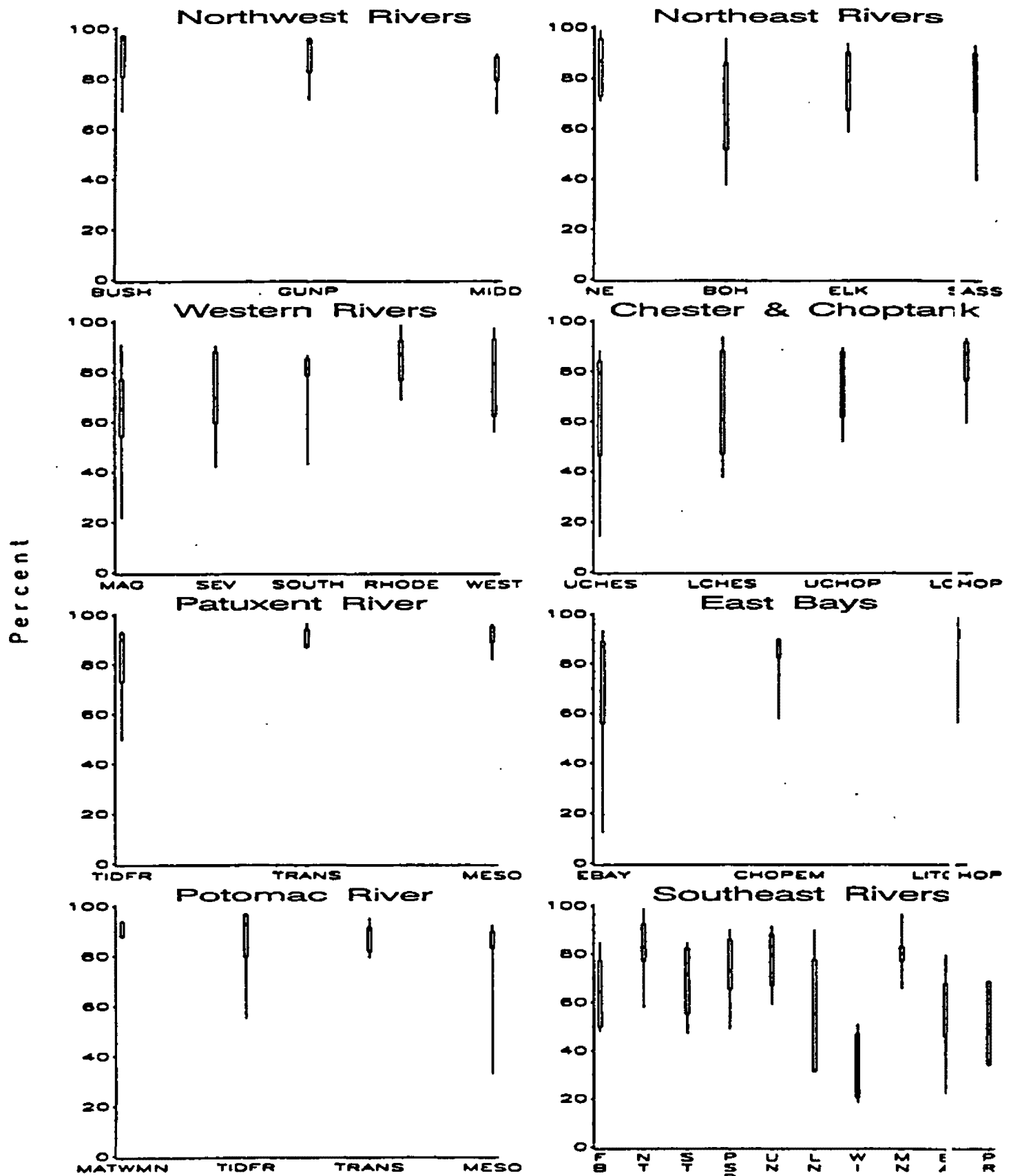
| Table 4.3 Summary statistics for total organic carbon in tributary sediments. Concentrations are in per cent dry weight | | | | | | |
|---|---|---|---|---|---|---|
| AREA | MEAN-µ | MEDIAN | N | SD-σ | MIN | MAX |
| All | 3.32 | 3.18 | 184 | 1.25 | 0.67 | 6.80 |
| Northwestern Rivers | 3.47 | 3.68 | 13 | 0.59 | 2.60 | 4.21 |
| Western Rivers | 4.06 | 3.68 | 27 | 1.32 | 2.18 | 6.52 |
| Petuxent River | 3.48 | 3.47 | 15 | 0.74 | 1.99 | 4.67 |
| Potomac river | 3.14 | 3.21 | 19 | 0.41 | 2.44 | 3.84 |
| Northeastern Rivers | 3.77 | 3.67 | 20 | 0.90 | 1.57 | 4.99 |
| Chester & Choptank | 3.66 | 2.65 | 19 | 1.77 | 1.39 | 6.39 |
| Eastern Bays | 2.31 | 1.97 | 16 | 0.80 | 1.50 | 3.72 |
| Southeastern Rivers | 2.92 | 2.65 | 52 | 1.37 | 0.67 | 6.80 |
| Rappahannock River | 2.92 | 2.92 | 1 | | 2.92 | 2.92 |
| York River | 4.02 | 4.02 | 1 | | 4.02 | 4.02 |
| James River | 4.21 | 4.21 | 1 | | 4.21 | 4.21 |

Figure 4.3. Summary statistics for the percentage of total organic carbon in sediment samples from Chesapeake Bay tributaries. The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from each tributary station. (continued)
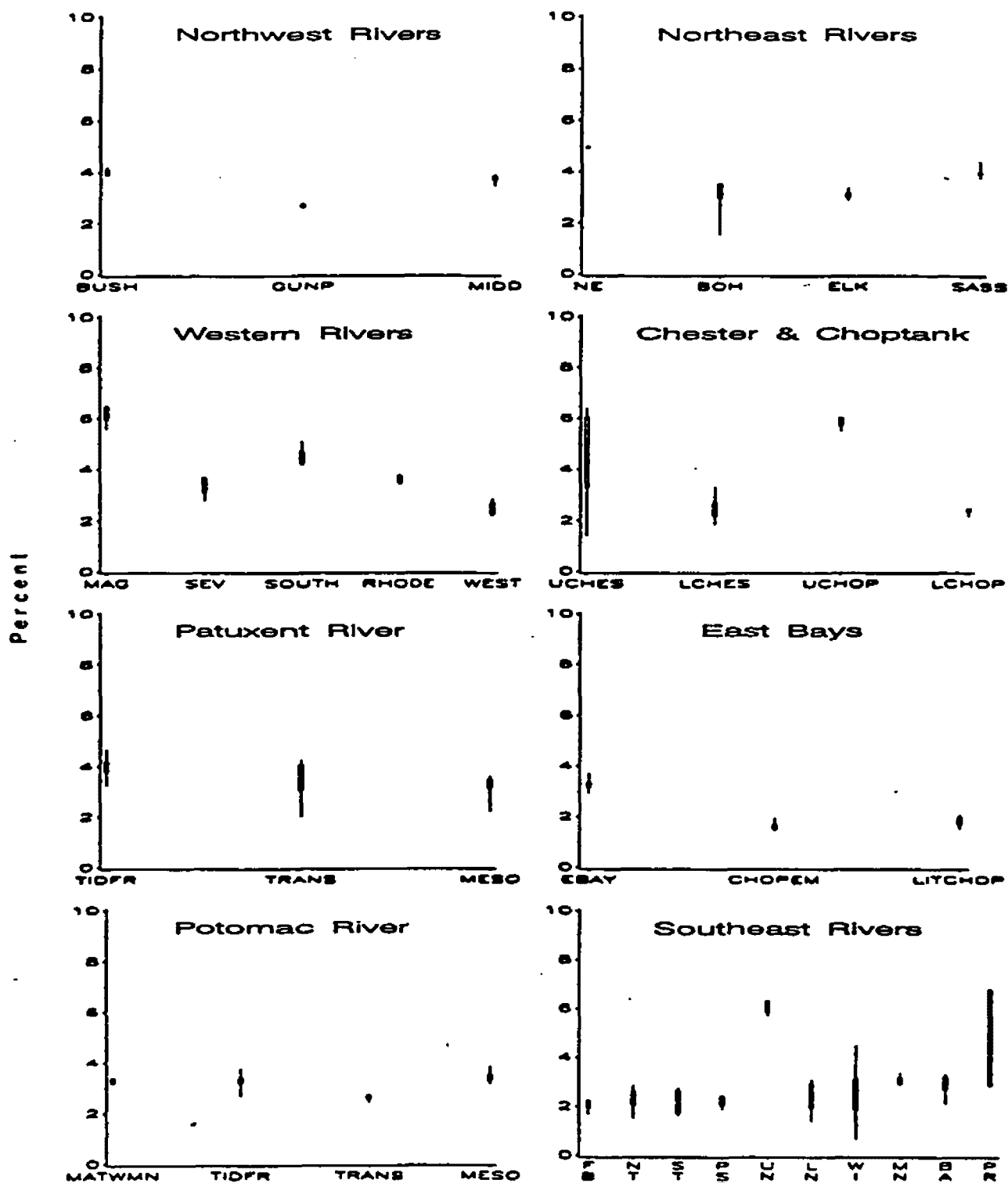
# Figure 4.3 Percentage total organic carbon
## in tributary sediments
(continued)
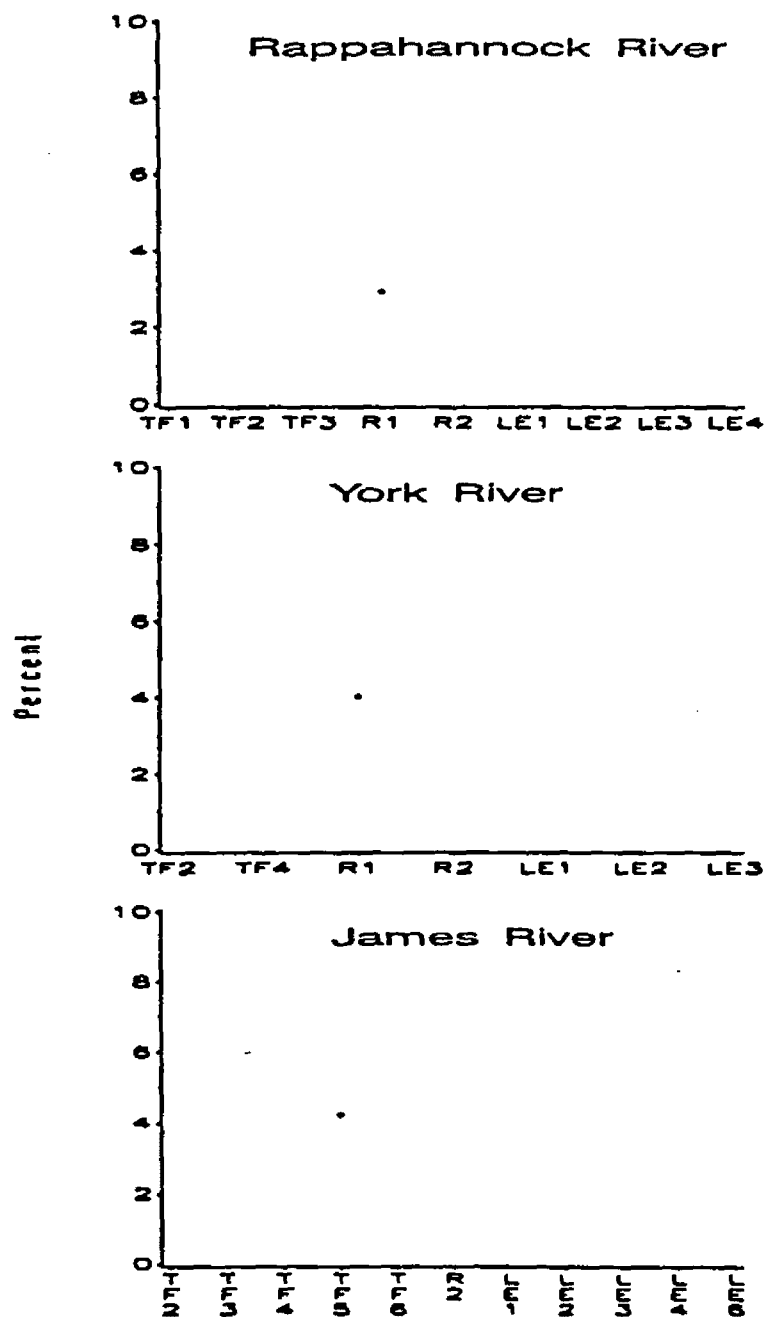


Figure 4.3 Summary statistics for percentage total organic carbon in Chesapeake Bay tributaries. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) in data collected for each station. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. Data presented are for individual stations. See Table 4.1 for interpretation of station name abbreviations.

## General Patterns in the Spatial Distribution of Trace Metals

Spatial distribution patterns within and among the Chesapeake Bay tidal tributaries were similar for most of the trace metals measured. The highest sediment concentrations of trace metals in tributarie examined in this chapter were generally found in the tributaries located in the urbanized area around Baltimore within the Western, Northwestern, and Northeastern Rivers regions (Figures 4.3-4.10). The only exception to this spatial pattern was cadmium, a metal for which the tidal fresh station of the Patuxent River had the highest median concentration of any station (Figure 4.5). For many trace metals (i.e., copper, lead, nickel, and zinc), the Western shore tributaries showed a gradient of decreasing concentration from north to south, with the Magothy and Severn rivers often having much higher metal concentrations than those seen in the Rhode and West rivers (Figures 4.6-4.7, 4.9-4.10).

The Patuxent, Potomac, Chester, and Choptank Rivers generally had intermediate sediment concentrations of most trace metals, while stations in the Eastern Bays and Southeastern Rivers and Bay regions in Maryland generally had the lowest sediment concentrations of most trace metals (Figures 4.3-4.10). Again, cadmium concentrations did not follow this distribution, as some samples from the Southeastern Rivers and Bays Region had sediment cadmium concentrations which were considerably above those from some of the more populated areas such as Potomac River and Northeast Rivers regions.

Trace metal concentrations in the James River were generally within the range found in the group of Maryland tributary regions with the lowest trace metal concentrations. However, one or both of the stations in the lower estuarine portion of the James River near Sewells Point Naval Complex (SN79 an SN81) exhibited sediment concentrations of all the trace metals which were markedly higher than thos observed elsewhere in the James River, and which were comparable to, or higher than, the highest concentrations found in the Maryland tributaries. The Virginia Water Control Board concluded that there was evidence of the accumulation of trace metals in the sediments at these stations near the Sewells Point Naval Complex wastewater outfalls (deFur et al., 1987).

Among the Maryland tributary stations, the major trends in measured (bulk) trace metal concentrations generally also apply to trace metal concentrations normalized to the fraction of the sediment consisting of clay and silt particles. Thus, the spatial pattern in measured sediment trace metal concentrations probably largely reflects differences in metal loadings among the different tributaries, and does not result solely from differences in sediment grain size distributions. The spatial pattern in sediment trace metal concentrations also generally parallels differences in population density in the different watersheds.

In the James River, in contrast, median normalized trace metal concentrations were generally among the highest of all the tributary regions, whereas median measured (bulk) metal concentrations were among the lowest of all tributary regions. This may be because of higher trace metal loadings to these stations, most likely due to their proximity to wastewater outfalls. Alternatively, a substantial fraction of the trace metals in the James River sediments may be associated with sand particles. It is generally difficult to draw conclusions regarding sediment contaminant concentrations when the sediment samples have a high proportion of sand (National Oceanographic and Atmospheric Administration, 1991), as was the case with many of the James River sediment samples analyzed for trace metals.

Within all but the most and least contaminated tributary stations in Maryland, average sediment concentrations of most trace metals were within the range bracketed by the No Observable Effect Leve (NOEL) and the Probable Effects Level (PEL) concentrations determined by MacDonald (1993). The NOEL concentration for arsenic was exceeded by the median measured concentrations at all tributary stations. In contrast, the NOEL concentration for cadmium was exceeded by the average measured cadmium concentration at only about 25 percent of the Maryland monitoring stations. Average sediment concentrations of the other trace metals (chromium, copper, lead, mercury, and zinc) exceeded the NOEL concentrations at about 72, 28, 56, 42, and 89 percent respectively of the Maryland monitoring stations.

The average sediment trace metal concentrations in Maryland tributary sediments exceeded the PEL concentration only in the case of zinc in the Magothy and Severn rivers, tributaries located in heavily urbanized areas. Current sediment quality guidelines for nickel are inadequate for assessing the likelihood of toxicity due to sediment concentrations of this trace metal (Long et al., 1995). Based on measured sediment contaminant concentrations compared to the PELs, toxicity to aquatic biota is not likely at most of the Maryland tributary stations sampled, with the exception of the stations in the Magothy and Severn rivers, where toxicity due to sediment concentrations of zinc is likely.

Among the stations sampled in the James River, sediment concentrations of all trace metals except arsenic were below NOEL concentrations at the majority of stations. The NOEL concentration of 8 ppm was exceeded at most of the James River stations. At station SN79 and SN81 near the Sewells Point Naval facility, sediment concentrations of all trace metals exceeded their respective NOEL concentrations, and the concentrations of lead, mercury, and zinc exceeded PEL concentrations. Toxicity to aquatic biota due to the measured sediment concentrations of trace metals is not likely at the James River stations sampled, with the exception of the stations near Sewells Point Naval Complex where toxicity due to sediment concentrations of lead, mercury, and zinc is likely.

Refer back to the section of Chapter 3 covering the mainstem metals for a description of the sources of each metal and information on which metals are on the Chesapeake Bay Program Toxics of Concern list and to Table 1.2 for sediment quality guidelines and criteria.

**General Patterns in the Spatial Distribution of Polycyclic Aromatic Hydrocarbons**

Higher concentrations of most polycyclic aromatic hydrocarbons (PAHs) were found in sediments from the Northwestern, Western, and Northeastern Rivers regions than in the other tributary regions. The maximum sediment concentration of the majority of the PAH compounds measured occurred in the Sassafras River in 1987. The maximum concentrations of many of the PAHs found at this station were usually over twice as high as maximum concentrations at other tributary stations. However, sediment PAH concentrations found at this location in 1991 were dramatically lower than those found in 1987, and the same was true for sediment PAH concentrations found in 1992 (Maryland Department of the Environment, preliminary data), and thus the 1987 data may not be representative of typical conditions in the Sassafras River. The sampling station in the Sassafras River is located in a region of intensive recreational boating. The Middle, Magothy, Severn, and Potomac rivers were also notable for relatively high concentrations of PAHs. Concentrations of most PAHs were much lower in the Eastern Bays and Southeastern Rivers and Bays regions than in other tributary regions.

Instances of the average sediment concentrations of PAHs at tributary stations exceeding their NOEL concentration were relatively rare, and no station had an average concentration of any PAH in excess of the PEL concentration, although PEL concentrations were approached in the 1987 sample from the Sassafras River. Thus, toxicity to aquatic biota due to the measured sediment concentrations of PAHs is unlikely in the monitored areas of the tidal tributaries.

**Pesticides and Chlorinated Hydrocarbons**

The data on pesticides and chlorinated organic compounds are all from 1991 samples. Data is available for twenty-seven stations in the Maryland tributaries and three stations in the Virginia tributaries.

Few pesticides and other chlorinated organic compounds were detected at any one station, with the exception of the many different congeners of PCBs detected in the James River. The biological significance of the sediment concentrations of many of the pesticides and PCBs detected in the tributary sediments is difficult to assess, since sediment quality guidelines or criteria are not available for most of these compounds. For the few compounds for which sediment quality guidelines are available, most measured sediment concentrations were slightly above their respective NOEL concentration, but

well below their respective PEL concentration. Thus, toxicity to aquatic biota due to the measured sediment concentrations of pesticides and PCBs is not likely at the stations monitored in the tidal tributaries. For those pesticides still in use, it is not known whether their sediment concentrations at the time of sediment sampling in the spring (often during the period of maximum pesticide applications) persist throughout the year or diminish as the pesticides degrade.

## Spatial Distribution of Individual Trace Metals

### Arsenic

The median sediment arsenic concentration among Maryland tributary stations was 21 ppm, and the maximum sediment concentration was 73 ppm in the lower Patuxent River in 1988 (Table 4.4 and Figure 4.4). The median sediment arsenic concentration among the James River stations was 9 ppm, with a maximum of 37 ppm (Table 4.4 and Figure 4.4).

The analyses of James River sediments for arsenic had a relatively high detection limit (2 to 15 ppm compared to 0.01 ppm for the analyses used for the Maryland samples), and sediment arsenic concentrations were below the detection limit for 11 of the 29 samples from the James River. These samples were excluded from the statistical analyses, and thus the minimum, mean, and median sediment arsenic concentrations in the James River are overestimated in Table 4.4.

Sediment arsenic concentrations in tributary sediments showed less geographic variation than was the case for most other trace metals. Average sediment arsenic concentrations at various stations or regions differed by only about 2-3 times compared to the 4-6 fold variation commonly observed for other trace metals. The pattern of spatial distribution followed the pattern typical of other trace metals, however, with higher concentrations in the Northwestern, Northeastern, and Upper Western Shore tributaries closest to Baltimore; intermediate concentrations in the Patuxent and Potomac Rivers and stations in and near the Chester and Choptank Rivers, and the lowest concentrations at stations on the Maryland lower eastern shore and within the James River (Table 4.4 and Figure 4.4).

Median sediment arsenic concentrations at all of the tributary stations in Maryland and within each region of the James River were above the NOEL of 8 ppm (MacDonald 1993; Table 4.4). Median concentrations at all stations were below the PEL of 64 ppm (MacDonald, 1993), although the PEL was exceeded by individual measurements in the Patuxent and Sassafras (Northeast region) Rivers. Toxicity to aquatic biota due to the measured sediment arsenic concentrations is not likely at the monitored locations in the tidal tributaries.

Figure 4.4. reports summary statistics for concentrations of arsenic in Chesapeake Bay tributary sediments, in parts per million. The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from each station or river segment. Data are for bulk sediment concentrations. Data are presented for individual stations in the Maryland tributaries. The box and whisker plots for the James River represent statistics for groups of stations aggregated by segment. See Table 4.1 for interpretation of station abbreviations. The NOEL and PEL concentrations for sediment arsenic concentrations are 8 ppm and 64 ppm, respectively (MacDonald, 1993).

Table 4.4. Summary statistics for arsenic in tributary sediments. Concentrations are in ppm dry weight. Normalized concentrations are dry weight concentrations divided by the fraction silt and clay sized particles in the sediment..

| Area | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| All | 21 | 210 | 12 | 0.3 | 19 | 73 | 35 | 210 | 26 | 0.5 | 28 | 236 |
| MD stations | 22 | 181 | 12 | 0.3 | 21 | 73 | 32 | 181 | 20 | 0.5 | 28 | 149 |
| N.W. Rivers | 29 | 13 | 13 | 12.3 | 28 | 57 | 35 | 13 | 19 | 14.7 | 33 | 86 |
| Western R. | 27 | 27 | 9 | 11.8 | 28 | 43 | 43 | 27 | 27 | 12.7 | 35 | 149 |
| Patuxent R. | 29 | 15 | 14 | 13.0 | 27 | 73 | 33 | 15 | 14 | 17.9 | 29 | 76 |
| Potomac R. | 20 | 19 | 8 | 7.0 | 20 | 32 | 26 | 19 | 12 | 8.0 | 28 | 52 |
| N.E. Rivers | 32 | 20 | 16 | 8.6 | 28 | 67 | 44 | 20 | 25 | 14.3 | 36 | 116 |
| Ches. & Chop | 22 | 19 | 13 | 3.7 | 21 | 48 | 32 | 19 | 14 | 7.5 | 33 | 55 |
| E. Bays | 21 | 16 | 13 | 0.3 | 18 | 50 | 31 | 16 | 27 | 0.5 | 25 | 120 |
| S.E. Rivers | 15 | 52 | 5 | 3.2 | 15 | 32 | 24 | 52 | 13 | 9.7 | 21 | 84 |
| James River | 11 | 29 | 8 | 2.0 | 9 | 37 | 49 | 29 | 49 | 8.0 | 28 | 236 |

# Figure 4.4a  Arsenic concentrations (ppm)
## in Maryland tributary sediments
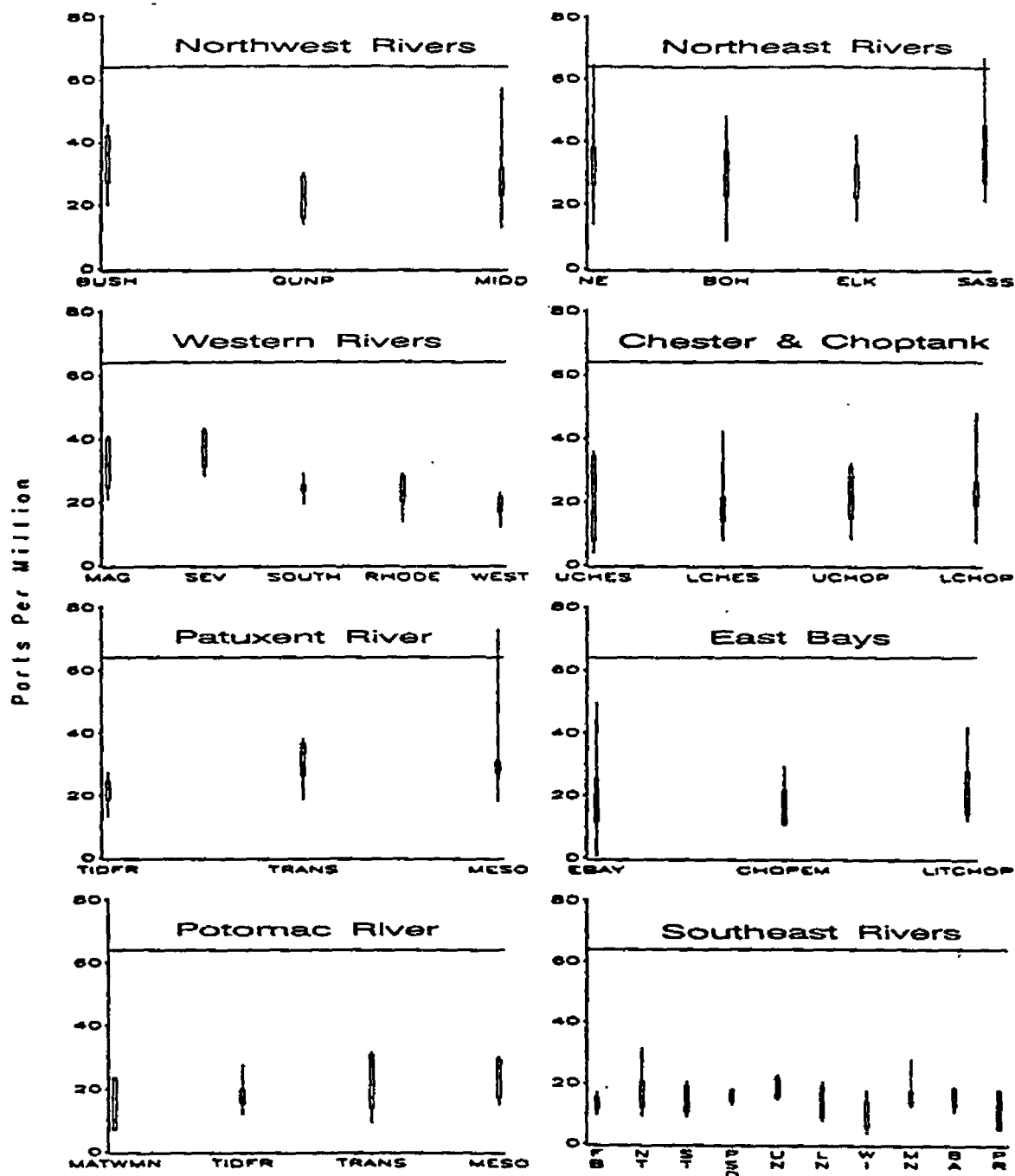


Figure 4.4a  Summary statistics for bulk sediment concentrations of arsenic in Maryland's Chesapeake Bay tributaries, in parts per million.  The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from each station or river segment.  The NOEL and PEL concentrations for sediment   arsenic   concentrations are 8 ppm and 64 ppm, respectively (MacDonald 1993).  The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

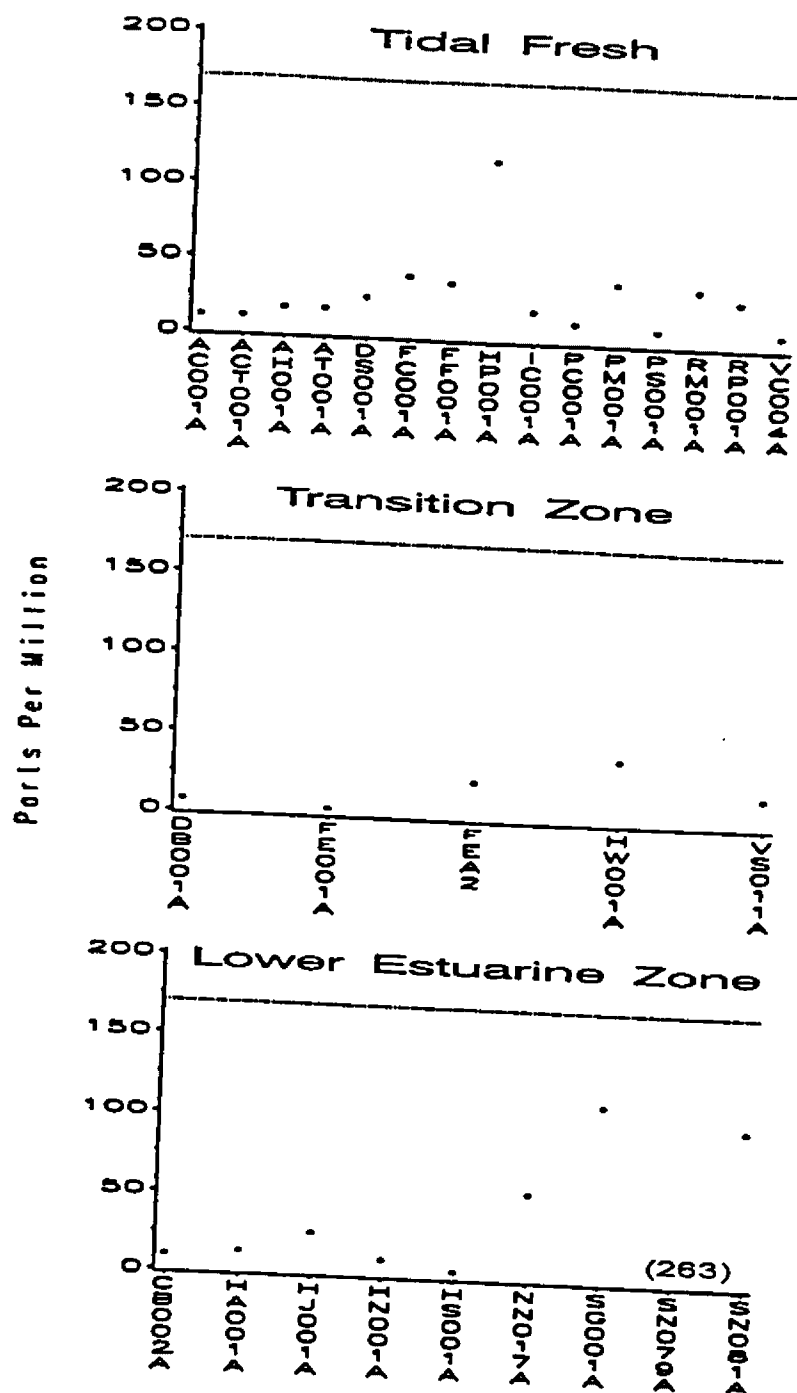# Figure 4.4b Arsenic concentrations (ppm) in James River sediments
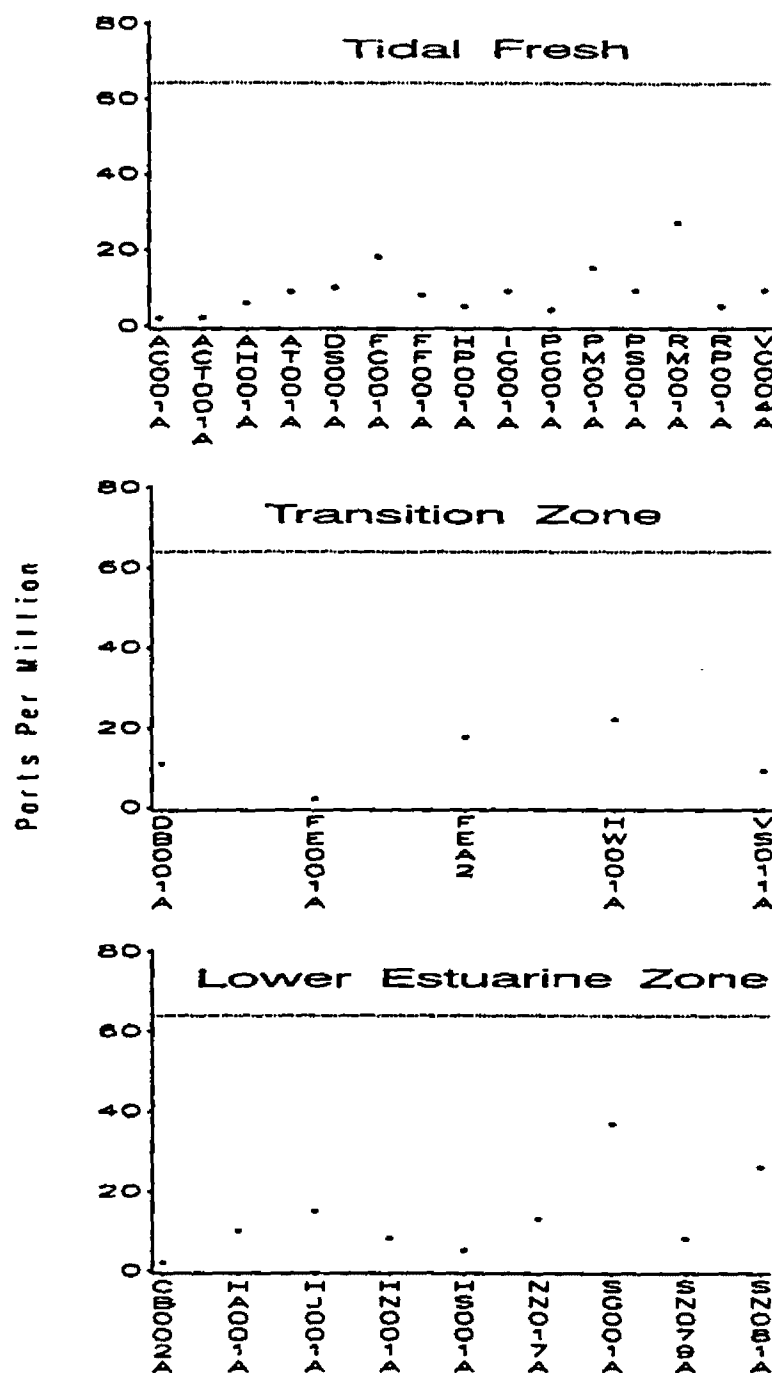


Figure 4.4b Summary statistics for bulk sediment concentrations of arsenic in the James River. Data presented are for individual stations. The NOEL and PEL values for sediment arsenic concentrations are 8 ppm and 64 ppm, respectively (MacDonald 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

*Cadmium*

The median sediment cadmium concentration for all Maryland tributary stations was 0.6 ppm, and the maximum concentration was 3.5 ppm at the tidal fresh station of the Patuxent River in 1990 (Table 4.5 and Figure 4.5). The median cadmium concentration in the James River was 0.20 ppm. Sediment cadmium concentrations at the two stations (SN79 and SN81) located near Sewells Point Naval complex were 4.0 and 6.0 ppm, several times higher than concentrations found at any other station in the James River.

The analyses of James River sediments for cadmium had relatively high detection limits (0.2-0.7 ppm compared to 0.01 ppm for the analyses used for the Maryland samples), and sediment cadmium concentrations were below the detection limit for 21 of the 29 samples from the James River. These samples were excluded from the statistical analyses, and thus the minimum and median sediment cadmium concentrations in the James River given in Table 4.4 are probably overestimated.

The spatial pattern of sediment cadmium concentrations differed from that shown by the other trace metals. For the other trace metals, the highest sediment concentrations were typically found in the Upper Western, Northwestern, and Northeastern Rivers regions, whereas for cadmium, the highest sediment concentrations were found in the Patuxent River and were also relatively high at some of the Southeastern Rivers and Bays stations.

Median sediment cadmium concentrations were above the NOEL of 1.0 ppm (MacDonald, 1993) at several of the Maryland tributary stations, including the tidal fresh and mesohaline stations in the Patuxent River, and the stations in the Middle, Magothy, South and Upper Nanticoke rivers (Table 4.5). The NOEL was also exceeded by individual measurements at one or more stations from every other tributary region in Maryland. The NOEL was exceeded in the James River only at the two Sewells Point Naval Complex stations. The maximum observed concentrations in the Maryland tributaries and in the James River were both well below the PEL of 7.5 ppm. Toxicity to aquatic biota due to the measured sediment concentrations of cadmium is not likely at the monitored stations in the tidal tributaries.

Table 4.5. Summary statistics for cadmium in tributary sediments. Concentrations are in ppm dry weight. Norrialized concentrations are dry weight concentrations divided by the fraction silt and clay sized particles in the sediment.

| Area | Mean | Measured | | | | | Normalized | | | | | |
|------|------|-----|-----|-----|--------|------|------|-----|-----|------|--------|------|
| | | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| All | 0.7 | 210 | 0.7 | 0.01 | 0.6 | 6.0 | 1.5 | 210 | 3.3 | 0.01 | 0.8 | 44.0 |
| MD stations | 0.7 | 181 | 0.6 | 0.01 | 0.6 | 3.5 | 1.2 | 182 | 1.3 | 0.01 | 0.8 | 9.9 |
| N.W. Rivers | 0.7 | 13 | 0.5 | 0.01 | 0.5 | 1.4 | 0.8 | 13 | 0.6 | 0.01 | 0.5 | 1.8 |
| Western R. | 0.9 | 27 | 0.6 | 0.01 | 0.8 | 2.1 | 1.5 | 27 | 1.9 | 0.02 | 1.0 | 9.9 |
| Patuxent R. | 1.4 | 15 | 1.2 | 0.01 | 1.5 | 3.5 | 1.7 | 15 | 1.4 | 0.01 | 1.6 | 3.9 |
| Potomac R. | 0.8 | 19 | 0.4 | 0.18 | 0.7 | 2.0 | 1.1 | 19 | 0.9 | 0.33 | 0.8 | 4.1 |
| N.E. Rivers | 0.5 | 20 | 0.3 | 0.01 | 0.5 | 1.0 | 0.7 | 20 | 0.4 | 0.02 | 0.8 | 1.6 |
| Ches. & Chop. | 0.5 | 19 | 0.4 | 0.01 | 0.4 | 1.6 | 0.8 | 19 | 0.8 | 0.02 | 0.6 | 3.1 |
| E. Bays | 0.5 | 16 | 0.3 | 0.10 | 0.5 | 1.2 | 1.2 | 16 | 2.3 | 0.11 | 0.6 | 9.5 |
| S.E. Rivers | 0.7 | 52 | 0.6 | 0.01 | 0.5 | 2.9 | 1.2 | 52 | 1.2 | 0.01 | 0.8 | 6.2 |
| James River | 0.7 | 29 | 1.2 | 0.20 | 0.20 | 6.0 | 3.63 | 29 | 8.0 | 0.23 | 1.4 | 44.0 |

# Figure 4.5a Cadmium concentrations (ppm)
## in Maryland tributary sediments
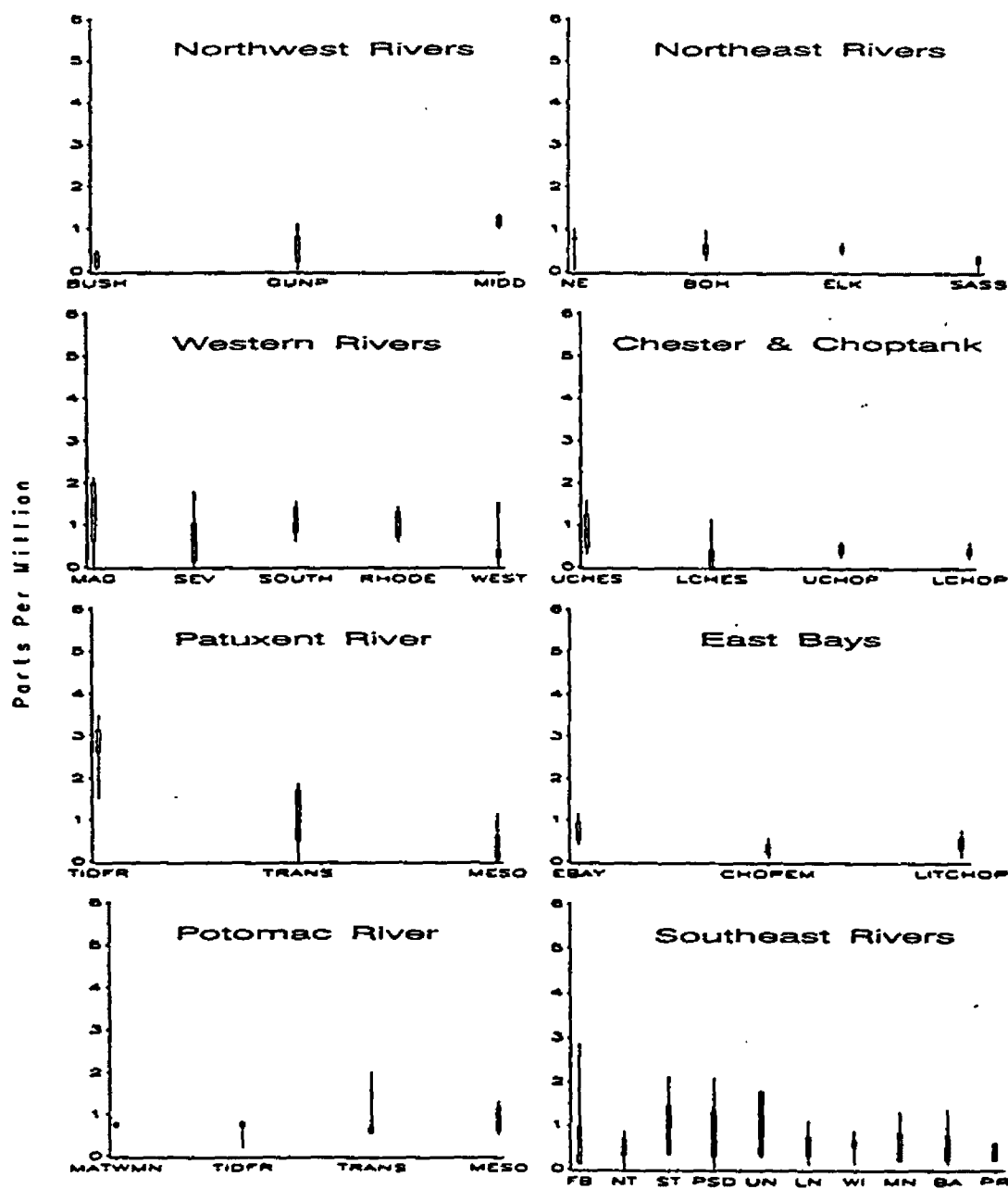


Figure 4.5a   Summary statistics for concentrations of cadmium in Chesapeake Bay tributary sediments, in parts per million.  The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from each station or river segment. Data are for bulk sediment concentrations.  The NOEL and PEL concentrations for sediment cadmium concentrations are 1 ppm and 7.5 ppm, respectively (MacDonald 1993).

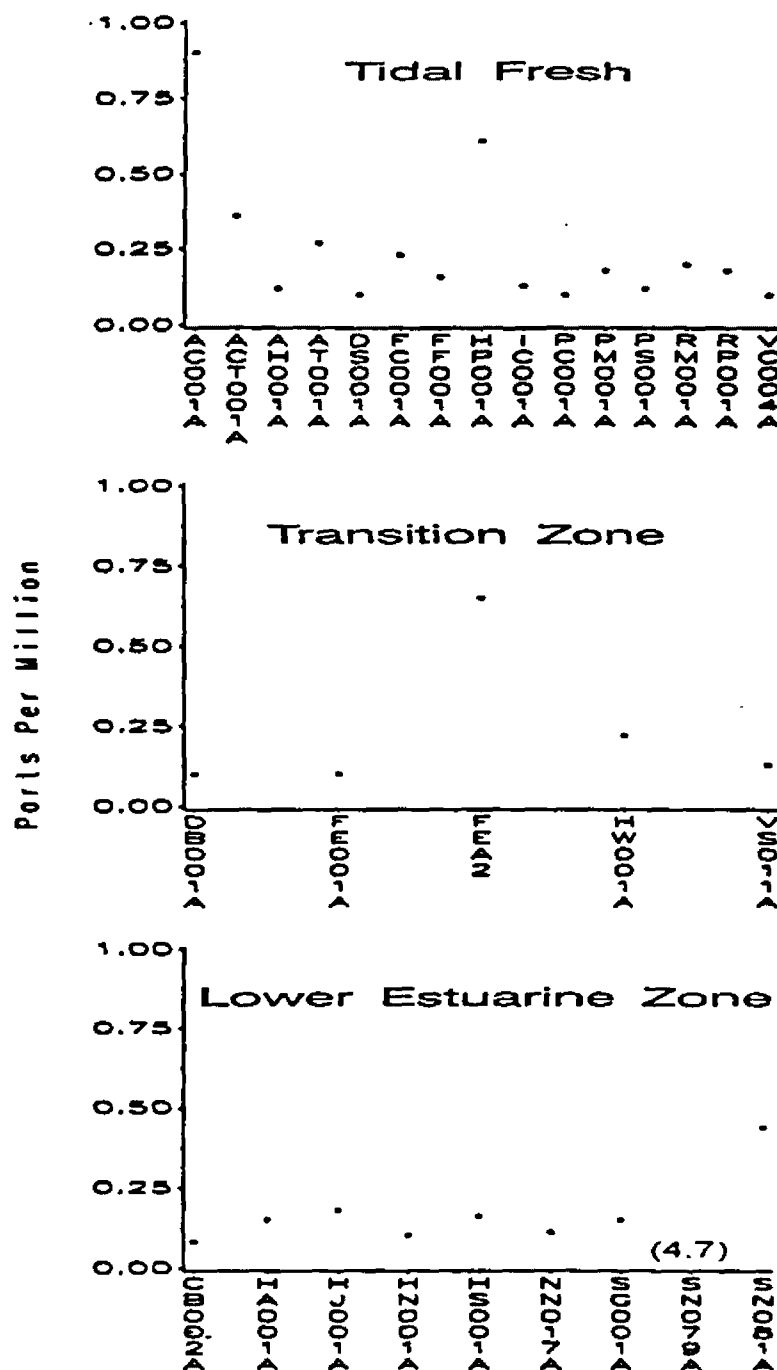# Figure 4.5b Cadmium concentrations (ppm) in James River sediments
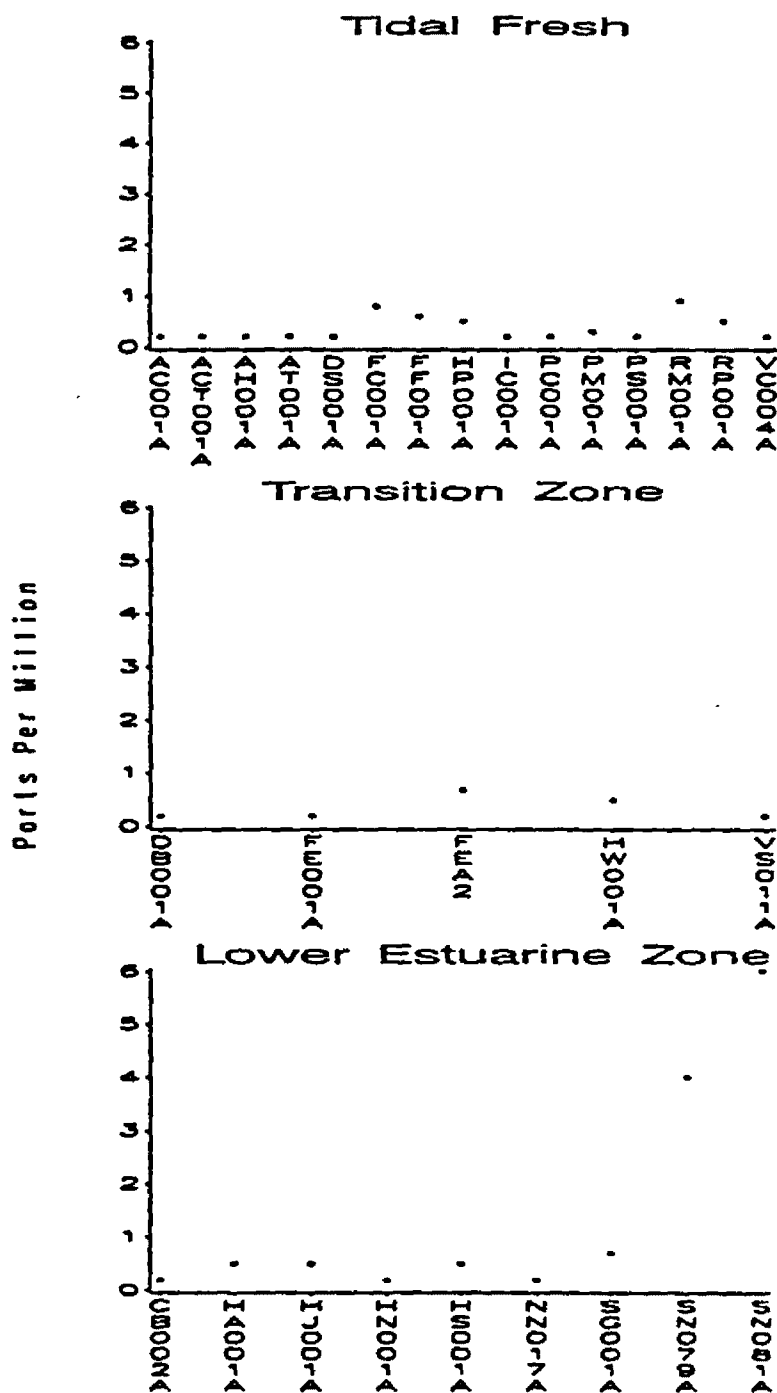


Figure 4.5b Summary statistics for bulk sediment concentrations of cadmium im the James River. Data presented are for individual stations. The NOEL and PEL values for sediment cadmium concentrations are 1 ppm and 7.5 ppm, respectively (MacDonald 1993).

## Chromium

The median chromium sediment concentration for Maryland tributary stations was 50 ppm, with a maximum concentration of 172 ppm at the Severn River in 1990 (Table 4.6 and Figure 4.6). Within the James River, the median chromium concentration was 20 ppm, and the maximum concentration was 136 ppm at station SN81 (Table 4.6 and Figure 4.6). This concentration was much higher than that at any other James River station.

Median sediment chromium concentrations exceeded the NOEL concentration of 33 ppm (MacDonald, 1993) in all Maryland tributary regions except the Southeastern Rivers region, where the NOEL was exceeded at most stations by one or two individual measurements. Median sediment chromium concentrations were below the NOEL within all three segments of the James River. Measured concentrations of chromium never exceeded the PEL concentration of 240 ppm. Toxic effects to aquatic biota due to the measured sediment chromium concentrations are not likely at the monitored locations in the tidal tributaries.

Table 4.6. Summary statistics for chromium in tributary sediments. Concentrations are in ppm dry weight. Normalized concentrations are dry weight concentrations divided by fraction of silt and clay particles in the sediment.

| Area | Measured | | | | | | Normalized | | | | | |
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| All | 54 | 209 | 34 | 5 | 45 | 172 | 87 | 209 | 71 | 17 | 66 | 484 |
| MD stations | 58 | 181 | 34 | 6 | 50 | 172 | 84 | 181 | 65 | 17 | 65 | 468 |
| N.W. Rivers | 69 | 13 | 13 | 46 | 69 | 86 | 82 | 13 | 21 | 48 | 83 | 125 |
| Western R. | 109 | 27 | 28 | 60 | 103 | 172 | 165 | 27 | 84 | 65 | 146 | 468 |
| Patuxent R. | 75 | 15 | 20 | 51 | 68 | 120 | 86 | 15 | 20 | 58 | 82 | 134 |
| Potomac R. | 46 | 19 | 7 | 36 | 45 | 62 | 60 | 19 | 33 | 40 | 52 | 190 |
| N.E. Rivers | 80 | 20 | 34 | 30 | 64 | 158 | 110 | 20 | 54 | 60 | 93 | 286 |
| Ches. & Chop | 42 | 19 | 15 | 15 | 40 | 76 | 65 | 19 | 30 | 33 | 58 | 140 |
| E. Bays | 37 | 16 | 9 | 23 | 36 | 56 | 70 | 16 | 104 | 28 | 42 | 458 |
| S.E. Rivers | 31 | 52 | 15 | 6 | 29 | 79 | 52 | 52 | 29 | 17 | 41 | 181 |
| James R. | 26 | 28 | 24 | 5 | 20 | 136 | 107 | 28 | 102 | 20 | 74 | 484 |

# Figure 4.6a Chromium concentrations (ppm)
## in Maryland tributary sediments
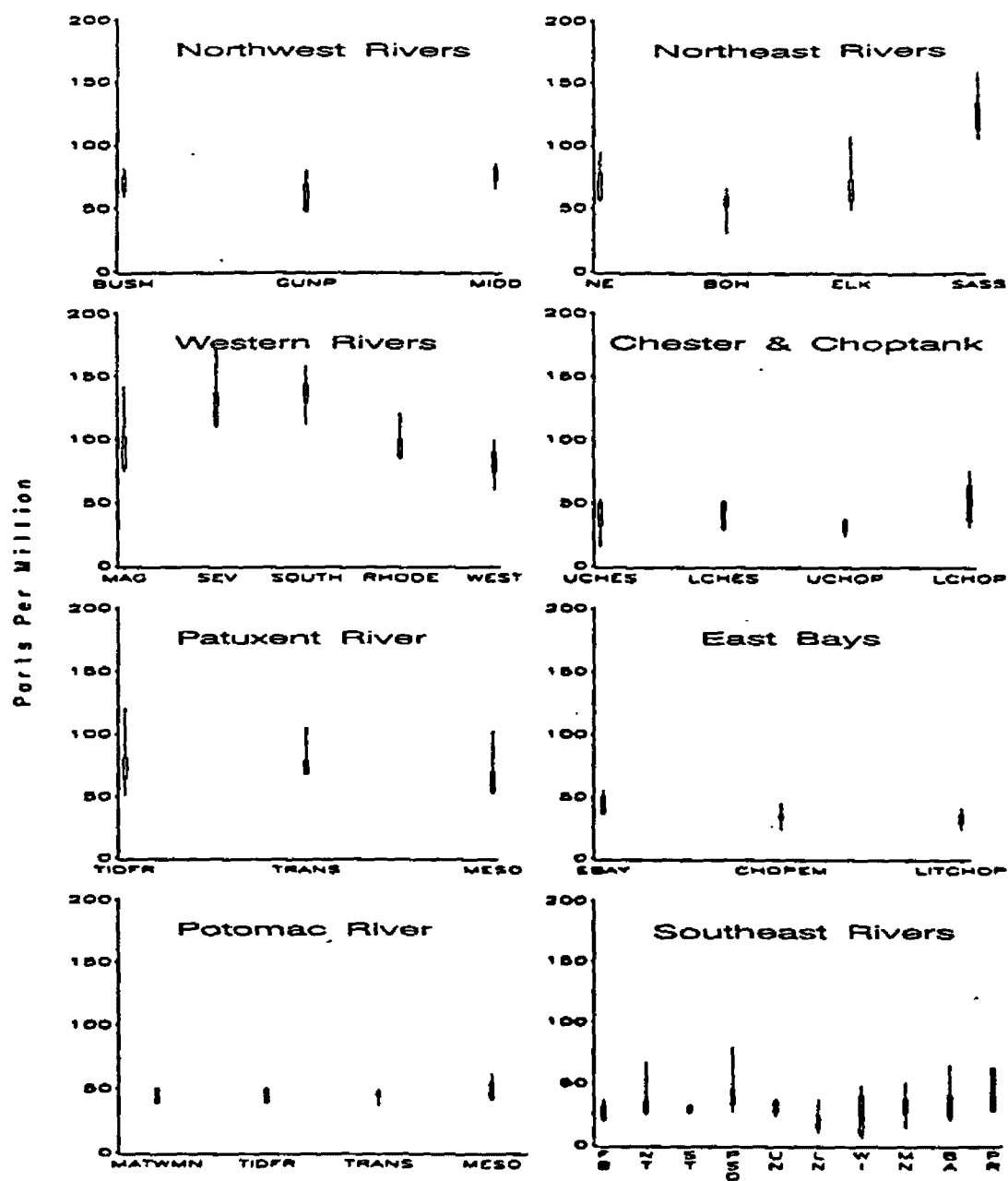


Figure 4.6a   Summary statistics for bulk sediment concentrations of chromium in Maryland's Chesapeake Bay tributaries, in parts per million.  The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from each station or river segment.  The NOEL and PEL concentrations for sediment chromium concentrations are 33 ppm and 240 ppm, respectively (MacDonald 1993).  The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

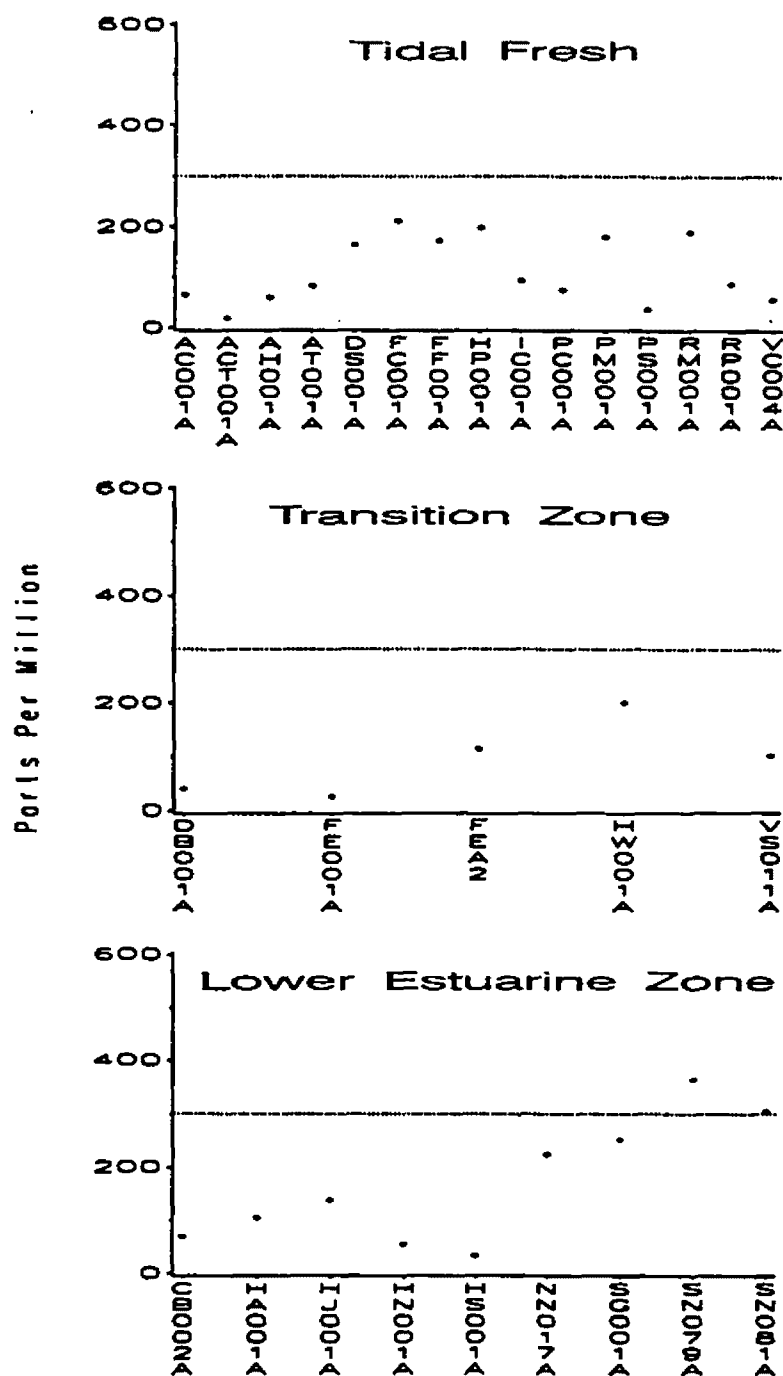# Figure 4.6b Chromium concentrations (ppm) in James River sediments
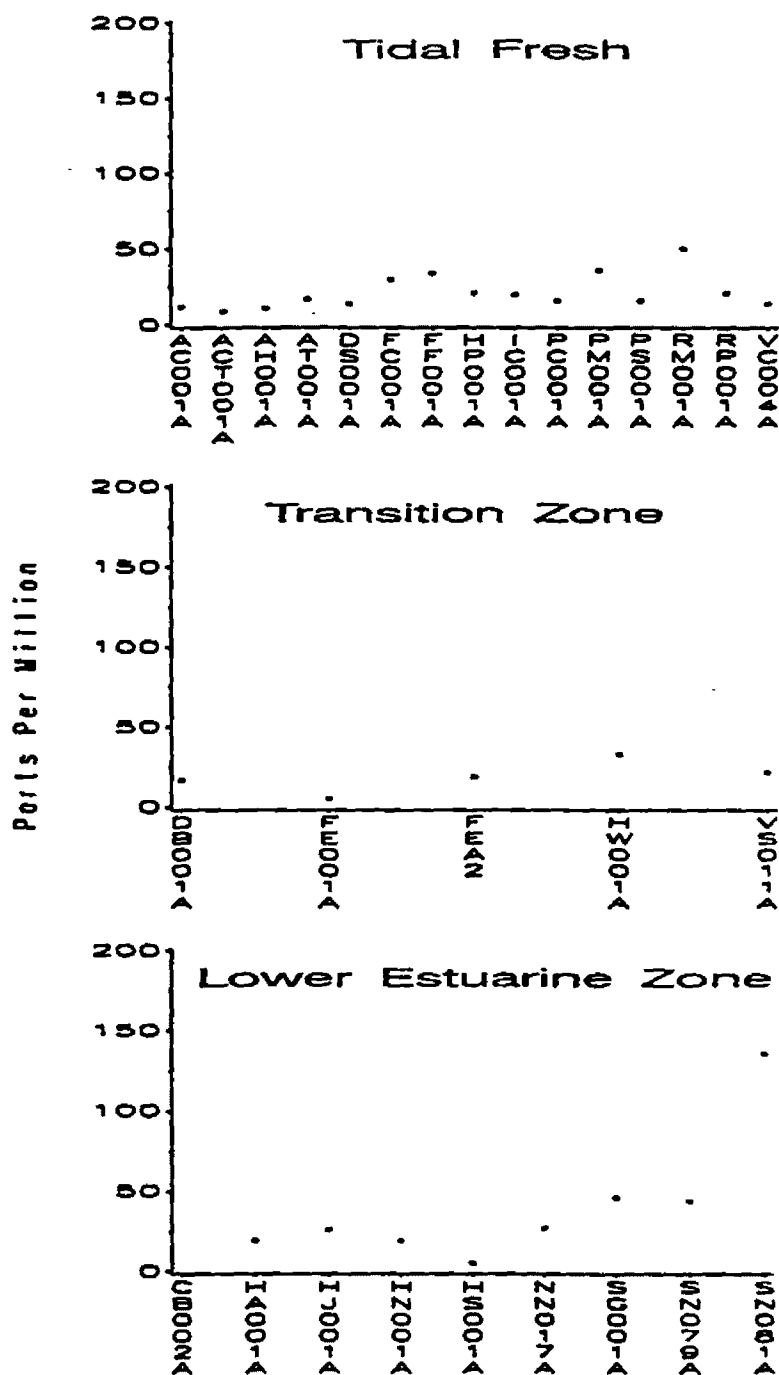


Figure 4.6b Summary statistics for bulk sediment concentrations of chromium in the James River. Data presented are for individual stations. The NOEL and PEL values for sediment chromium concentrations are 33 ppm and 240 ppm, respectively (MacDonald 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.
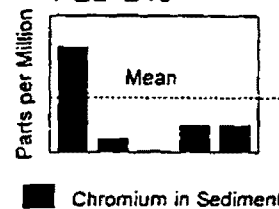
## Copper

The median sediment copper concentration among Maryland tributary stations was 25 ppm and the maxii ium concentration was 112 ppm at the Magothy River in 1990 (Table 4.7 and Figure 4.7). The median copp r concentration in the James River was 19 ppm and the maximum copper concentration in the James River was 26 ppm at station SN79. Stations SN81, SG001, and HP001 also had sediment copper concentrations sever: l times higher than the median concentration for the James River.

The median copper concentrations in the Northwestern, Western, Potomac and Northeastern River regioi s were above the NOEL of 28 ppm (Table 4.7). Maximum concentrations in all Maryland tributary regions exc: pt the Southeastern Rivers regions also exceed the NOEL. Median copper concentration were below the NOEI in the James River. The PEL of 170 ppm is above the highest measurements in Maryland but below the maxim ım value in the James River. Toxic effects to aquatic biota due to the measured sediment copper concentrat ons are not likely at any of the monitored tributary stations except for the highest concentrations in the James Riv :r.

Table 4.7. Summary statistics for copper. Concentrations are in ppm dry weight. Normalized concentrations al ə dry weight concentrations divided by the fraction silt and clay particles in the sediment.

| Area | Measured | | | | | | Normalized | | | | | |
|------|------|-----|----|-----|--------|-----|------|-----|-----|-----|--------|------|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| All | 31 | 210 | 28 | 3 | 24 | 263 | 71 | 210 | 219 | 8 | 36 | 2890 |
| MD stations | 30 | 181 | 21 | 3 | 25 | 112 | 43 | 181 | 45 | 10 | 33 | 460 |
| N.W. Rivers | 55 | 13 | 19 | 34 | 45 | 95 | 67 | 13 | 28 | 36 | 60 | 126 |
| Western R. | 61 | 27 | 21 | 35 | 51 | 112 | 96 | 27 | 79 | 46 | 76 | 460 |
| Patuxent R. | 24 | 15 | 6 | 12 | 23 | 34 | 27 | 15 | 5 | 23 | 26 | 38 |
| Potomac R. | 35 | 19 | 5 | 28 | 36 | 43 | 45 | 19 | 15 | 32 | 41 | 99 |
| N.E. Rivers | 40 | 20 | 13 | 14 | 42 | 61 | 54 | 20 | 21 | 29 | 53 | 127 |
| Ches. & Chop | 16 | 19 | 7 | 3 | 15 | 31 | 25 | 19 | 14 | 13 | 20 | 70 |
| E. Bays | 20 | 16 | 7 | 12 | 17 | 32 | 39 | 16 | 59 | 15 | 24 | 257 |
| S.E. Rivers | 11 | 52 | 4 | 3 | 11 | 22 | 19 | 52 | 10 | 10 | 17 | 6Ζ |
| James River | 38 | 29 | 53 | 3 | 19 | 263 | 240 | 29 | 557 | 8 | 57 | 2890 |

# Figure 4.7b Copper concentrations (ppm) in James River sediments



Figure 4.7b Summary statistics for bulk sediment concentrations of copper in the James River. Data presented are for individual stations. The plots represent statistics for groups of stations aggregated by segment. The NOEL and PEL values for sediment copper concentrations are 28 ppm and 270 ppm, respectively (MacDonald 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

# Figure 4.8a Lead concentrations (ppm)
## in Maryland tributary sediments
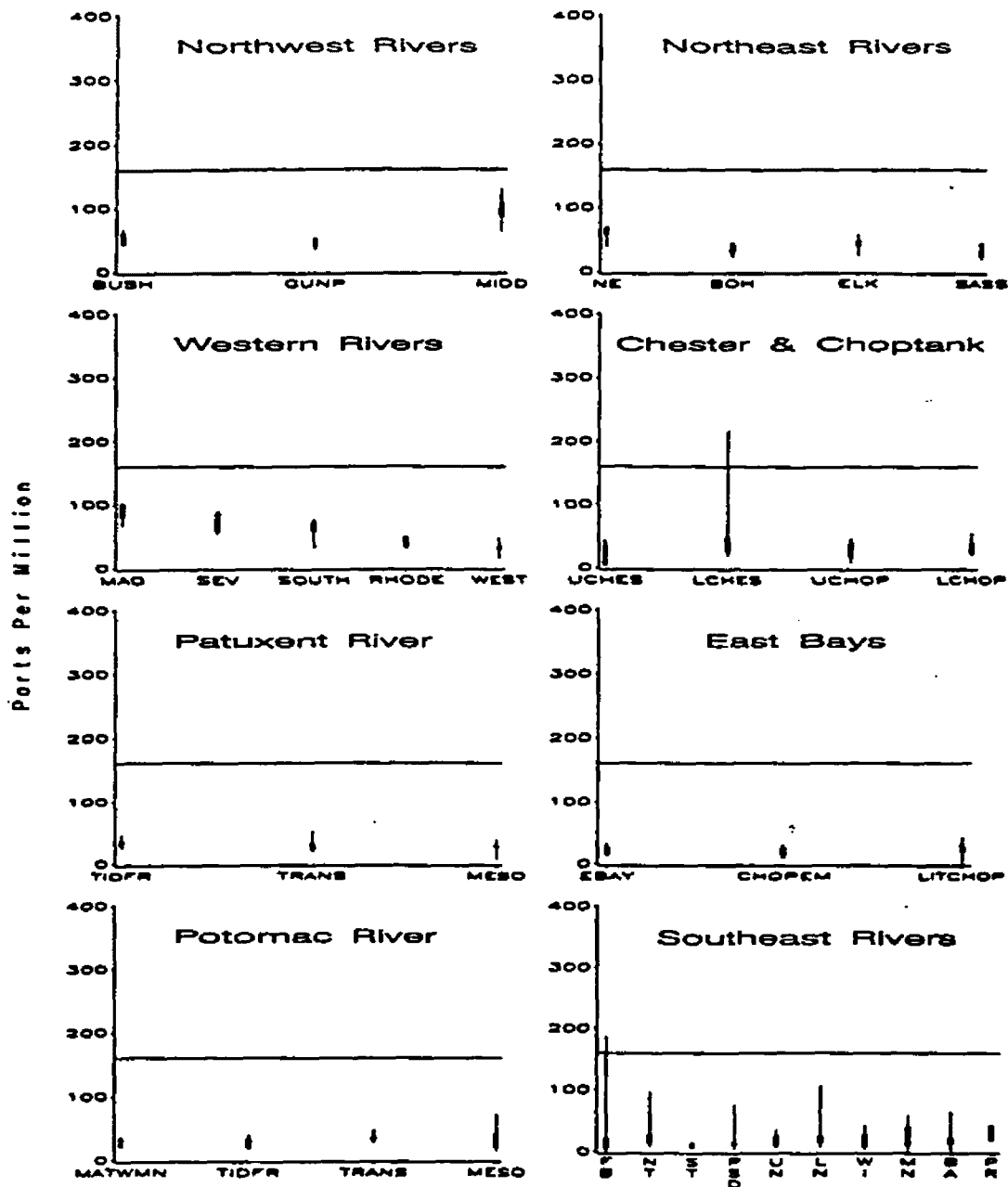


Figure 4.8a  Summary statistics for bulk sediment concentrations of lead in Maryland's Chesapeake Bay tributaries, in parts per million. The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from each station or river segment. The NOEL and PEL concentrations for sediment lead concentrations are 21 ppm and 160 ppm, respectively (MacDonald 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

## Mercury

The median sediment mercury concentration among Maryland tributary stations was 0.08 ppm and the maximum concentration was 0.36 ppm, found in 1989 at both the Sassafras River and the Middle River stations (Table 4.9 and Figure 4.9). The median sediment mercury concentration in the James River was 0.16 ppm and the maximum was 4.66 ppm at station SN79. This maximum concentration was several times higher than that observed at any other station in the James River. Ten of the James River stations had sediment mercury concentrations below the method detection limits, and thus the minimum and median concentrations presented in Table 4.9 are overestimates.

Median sediment mercury concentrations in the Northwestern Rivers, Western Rivers, Potomac River, Northeastern Rivers, and James River regions exceeded the NOEL of 0.1 ppm. No measurements in Maryland exceeded the PEL of 1.4 ppm. In the James River, one observation (at SN79) exceeded the PEL. Toxic effects to aquatic biota due to the measured sediment concentrations of mercury are not likely at any of monitored stations, with the exception of a station in the vicinity of the Sewells Point Naval Complex in the James River.

Table 4.9. Summary statistics for mercury in tributary sediments. Concentrations are in ppm dry weight. Normalized concentrations are dry weight concentrations divided by the fraction silt and clay particles in the sediment.

| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measured | | | | | | Normalized | |
| All | 0.15 | 210 | 0.33 | 0.009 | 0.10 | 4.66 | 0.56 | 210 | 3.69 | 0.012 | 0.15 | 51.21 |
| MD stations | 0.12 | 181 | 0.08 | 0.009 | 0.08 | 0.36 | 0.18 | 181 | 0.17 | 0.012 | 0.13 | 1.31 |
| N.W. Rivers | 0.22 | 13 | 0.07 | 0.099 | 0.23 | 0.36 | 0.26 | 13 | 0.09 | 0.148 | 0.25 | 0.46 |
| Western R. | 0.17 | 27 | 0.08 | 0.038 | 0.16 | 0.31 | 0.28 | 27 | 0.26 | 0.041 | 0.21 | 1.31 |
| Patuxent R. | 0.07 | 15 | 0.02 | 0.038 | 0.06 | 0.11 | 0.08 | 15 | 0.03 | 0.041 | 0.07 | 0.14 |
| Potomac R. | 0.17 | 19 | 0.08 | 0.050 | 0.15 | 0.31 | 0.22 | 19 | 0.14 | 0.056 | 0.17 | 0.56 |
| N.E. Rivers | 0.18 | 20 | 0.10 | 0.050 | 0.17 | 0.36 | 0.27 | 20 | 0.21 | 0.052 | 0.19 | 0.92 |
| Ches. & Chop. | 0.08 | 19 | 0.33 | 0.03 | 0.034 | 0.07 | 0.15 | 19 | 0.13 | 0.09 | 0.054 | 0.10 |
| E. Bays | 0.06 | 16 | 0.02 | 0.047 | 0.05 | 0.11 | 0.12 | 16 | 0.20 | 0.053 | 0.06 | 0.87 |
| S.E. Rivers | 0.06 | 52 | 0.03 | 0.009 | 0.05 | 0.18 | 0 11 | 52 | 0.10 | 0.012 | 0.09 | 0.63 |
| James River | 0.38 | 29 | 0.85 | 0.08 | 0.16 | 4.66 | 3.07 | 29 | 9.44 | 0.12 | 0.65 | 51.21 |

# Figure 4.9b Mercury concentrations (ppm) in James River sediments



Figure 4.9b Summary statistics for bulk sediment concentrations of mercury in the James River. Data presented are for individual stations. The plots represent statistics for groups of stations aggregated by segment. The NOEL and PEL values for sediment mercury concentrations are 0.1 ppm and 1.4 ppm, respectively (MacDonald 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

# Figure 4.10a Nickel concentrations (ppm) in Maryland tributary sediments
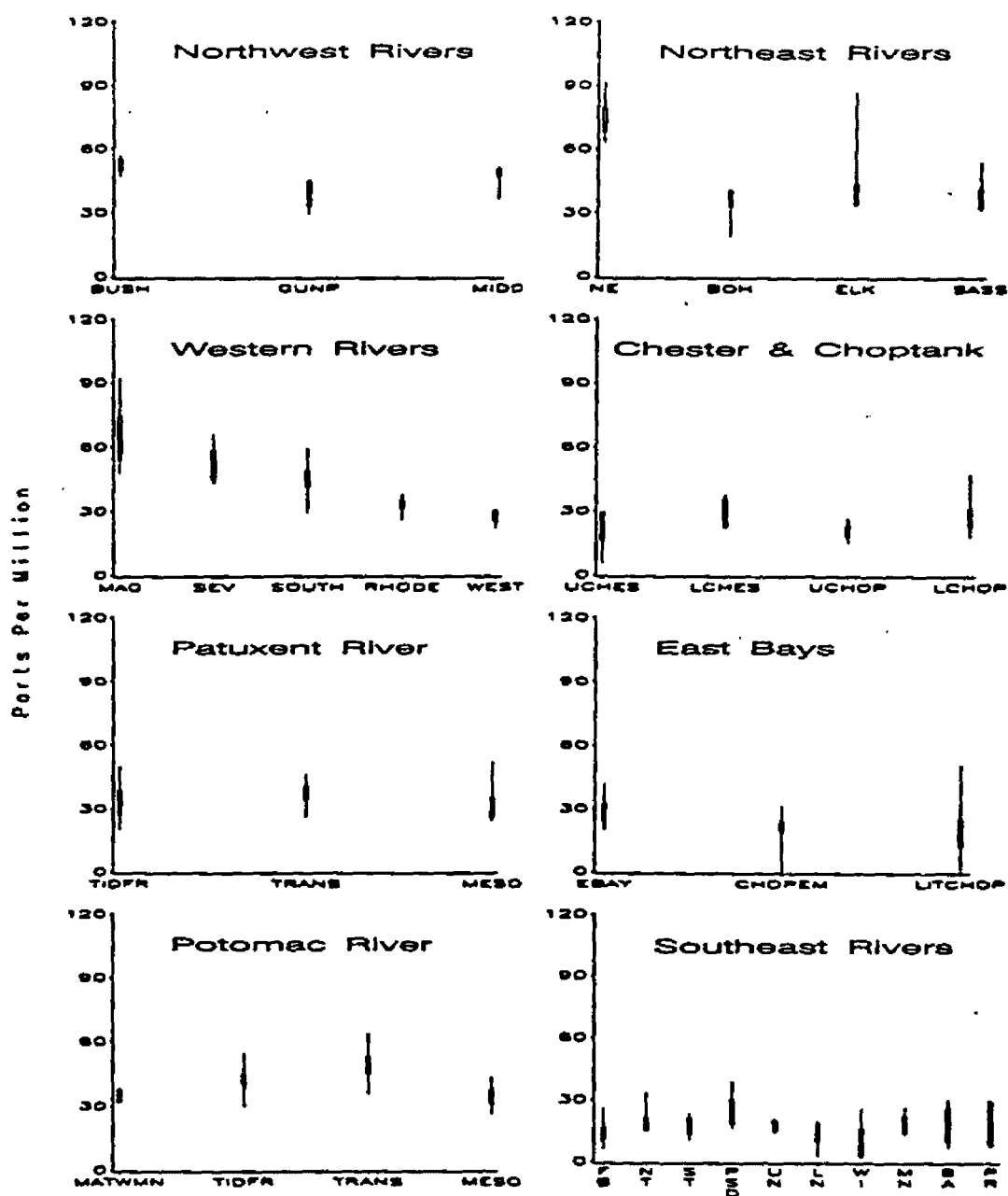


Figure 4.10a  Summary statistics for bulk sediment concentrations of nickel in Maryland's Chesapeake Bay tributaries, in parts per million. The box and whisker plots illustrate the median (central horizontal line), quartiles (extent of rectangle), and ranges (extent of vertical lines) in data collected from each station or river segment. There were insufficient data for development of NOEL and PEL concentrations for sediment concentrations of nickel. Long and Morgan (1990) ER-L and ER-M concentrations for sediment nickel concentrations are 30 ppm and 50 ppm, respectively.

## Zinc

The median sediment zinc concentration among Maryland tributary stations was 146 ppm and the maximum concentration was 525 ppm at the Magothy River station in 1986 (Table 4.11 and Figure 4.11). Within the Jame; River, the median and maximum zinc concentrations were 103 and 364 ppm, respectively (Table 4.11 and Figure 4.11). As for most trace metals, the highest sediment concentrations of zinc were found at the two stations in the vicinity o Sewells Point Naval complex, but the difference between the concentrations at these two station and the other J ames River stations was not as great as with many of the other trace metals.

All Maryland tributary stations had median zinc concentrations near or above the NOEL of 68 ppm. In Maryland median zinc concentrations exceeded the PEL of 300 ppm in the Magothy and Severn Rivers, and individual measurements above the PEL were also observed in the Northeast, Middle and South rivers. Median sediment ;inc concentrations in all three segments of the James River were above the NOEL, but the PEL was exceeded only ;t the two stations near Sewells Point Naval Complex. Toxicity to aquatic biota due to the measured sediment zinc concentrations is not likely at the tributary stations monitored, except for the Magothy and Severn River stations, is well as the stations in the James River near the Sewells Point Naval Complex.

Table 4.11. Summary statistics for zinc in tributary sediments. Concentrations are in ppm dry weight. Normalized concentrations are dry weight concentrations divided by fraction silt and clay particles in the sediment..

| Area | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| All | 158 | 209 | 92 | 18 | 139 | 525 | 299 | 209 | 403 | 48 | 203 | 4000 |
| MD stations | 162 | 180 | 92 | 24 | 146 | 525 | 240 | 180 | 224 | 59 | 192 | 2431 |
| N.W. Rivers | 232 | 13 | 49 | 173 | 216 | 315 | 279 | 13 | 81 | 182 | 281 | 438 |
| Western R. | 306 | 27 | 92 | 184 | 289 | 525 | 491 | 27 | 419 | 213 | 386 | 2431 |
| Patuxent R. | 150 | 14 | 27 | 99 | 146 | 193 | 174 | 14 | 23 | 144 | 168 | 221 |
| Potomac R. | 192 | 19 | 34 | 131 | 192 | 272 | 244 | 19 | 97 | 146 | 217 | 581 |
| N.E. Rivers | 204 | 20 | 60 | 87 | 192 | 354 | 277 | 20 | 77 | 174 | 249 | 461 |
| Ches. & Chop. | 117 | 19 | 34 | 29 | 114 | 174 | 180 | 19 | 83 | 93 | 156 | 463 |
| E. Bays | 108 | 16 | 30 | 64 | 101 | 170 | 203 | 16 | 295 | 76 | 123 | .1297 |
| S.E. Rivers | 80 | 52 | 28 | 24 | 77 | 160 | 134 | 52 | 61 | 59 | 117 | 410 |
| James River | 128 | 29 | 88 | 18 | 103 | 364 | 665 | 29 | 851 | 48 | 413 | 4000 |

# Figure 4.11b Zinc concentrations (ppm) in James River sediments



Figure 4.11b Summary statistics for bulk sediment concentrations of zinc in the James River. Data presented are for individual stations. The plots represent statistics for groups of stations aggregated by segment. NOEL and PEL values for sediment zinc concentrations are 68 and 300 ppm, respectively. The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

# NORTHWEST RIVER
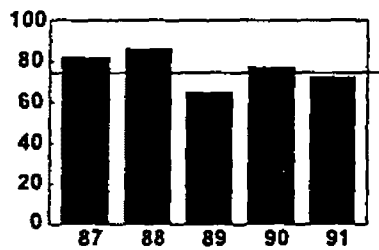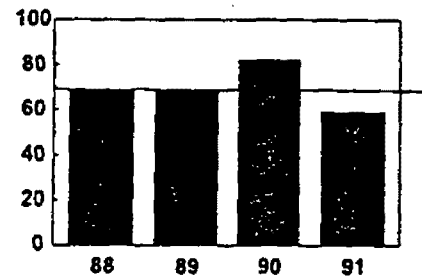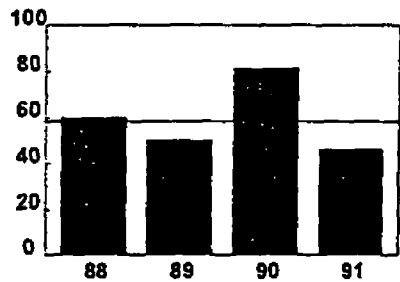
Bush River

Gunpowder River

Middle River

CHROMIUM

Yearly measurements of chromium concentration in sediments (ppm).

PEL=240

Mean

Chromium in Sediment

# NORTHWEST RIVERS
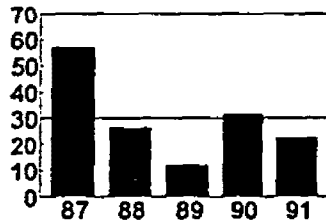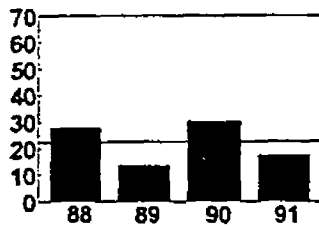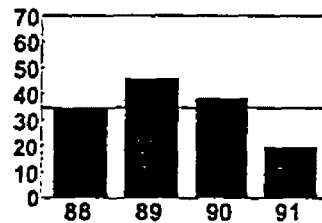
**Bush River**

**Gunpowder River**

**Middle River**

## ARSENIC

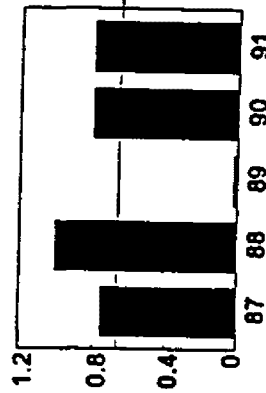Yearly measurements of arsenic concentration in sediments (ppm).

## PEL=64

Parts per Million

Mean

■ Arsenic Sediment

# NORTHWEST RIVERS



**Bush River**

**Gunpowder River**

**Middle River**

## MERCURY

Yearly measurements
of mercury concentration
in sediments (ppm).

PEL=1.4

Mean

■ Mercury in Sediment

# NORTHWEST RIVERS



Bush River

Gunpowder
River

Middle River

**COPPER**
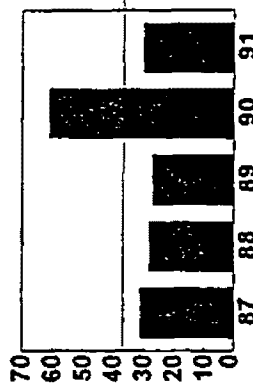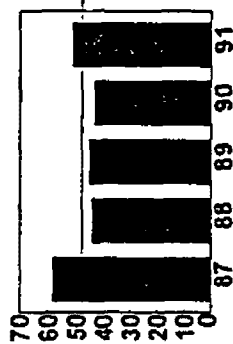
Yearly measurements
of copper concentration
in sediments (ppm).

PEL=270

Parts per Million

Mean
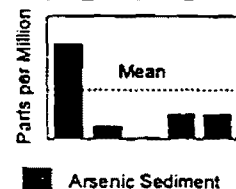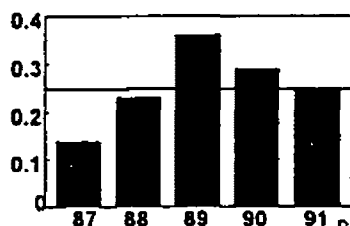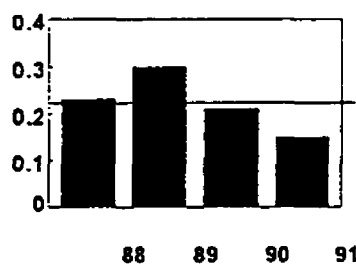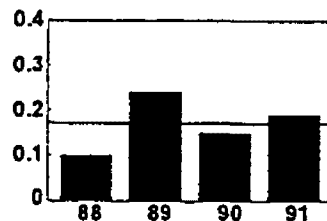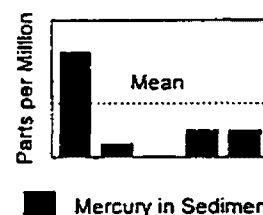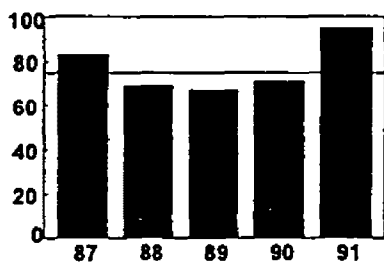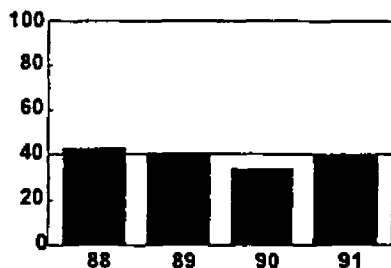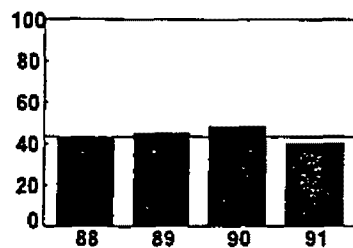
■ Copper in Sediment
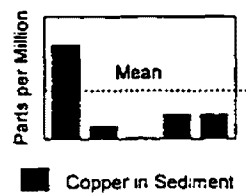
Figure 4.13 Distribution of metals in the Southeastern Rivers and bays. (Next 8 pages)

       A. Arsenic
       B. Cadmium
       C. Chromium
       D. Copper
       E. Lead
       F. Mercury
       G. Nickel
       H. Zinc.

# SOUTHEASTERN RIVERS & BAYS



## ARSENIC

Yearly measurements of arsenic concentration in sediments (ppm).

PEL=64

Mean

■ Arsenic in Sediment

Upper Nanticoke River

Lower Nanticoke River

Fishing Bay

Wicomico River

Manokin River

North Tangier Sound

Big Annemesex River

Pocomoke River

South Tangier Sound
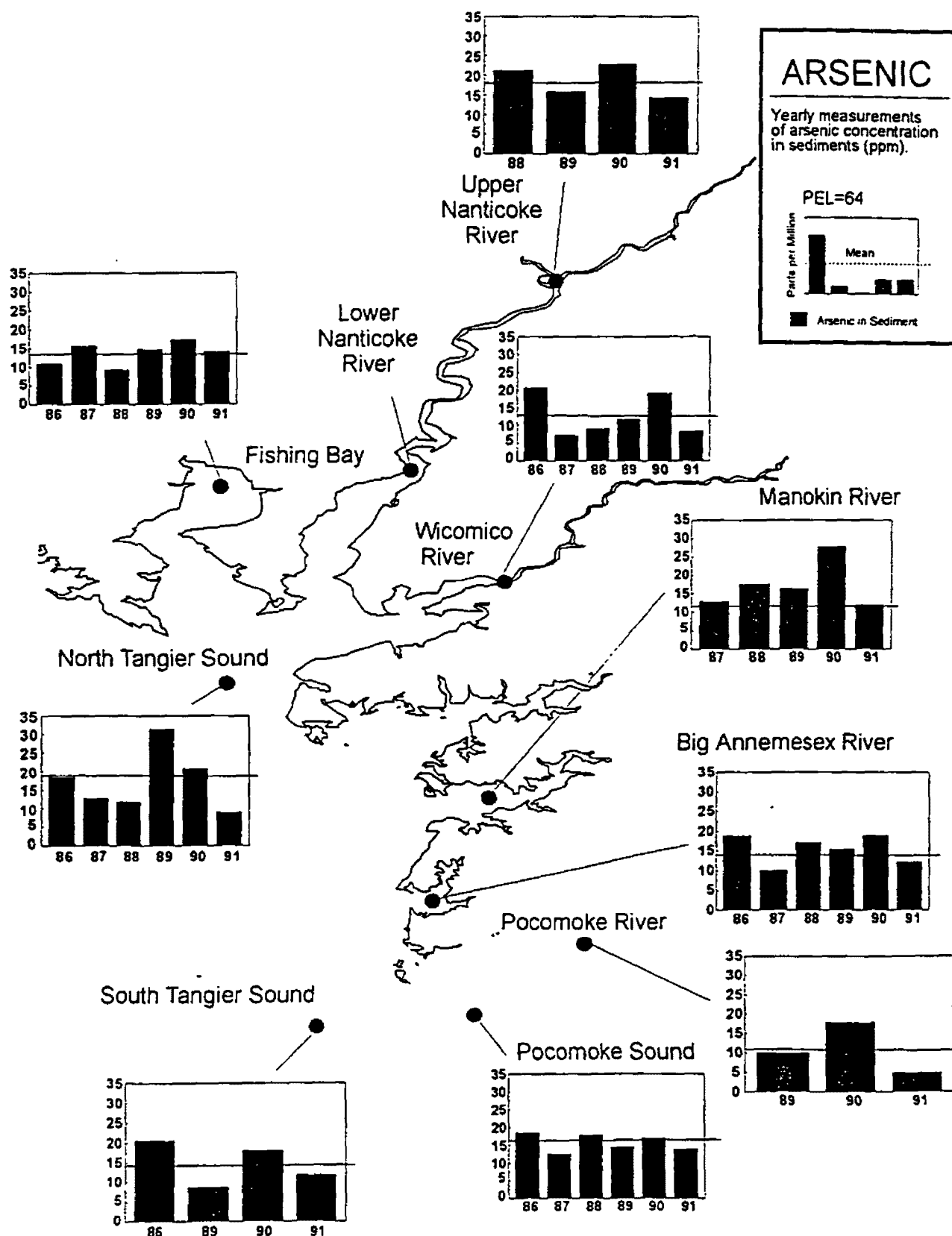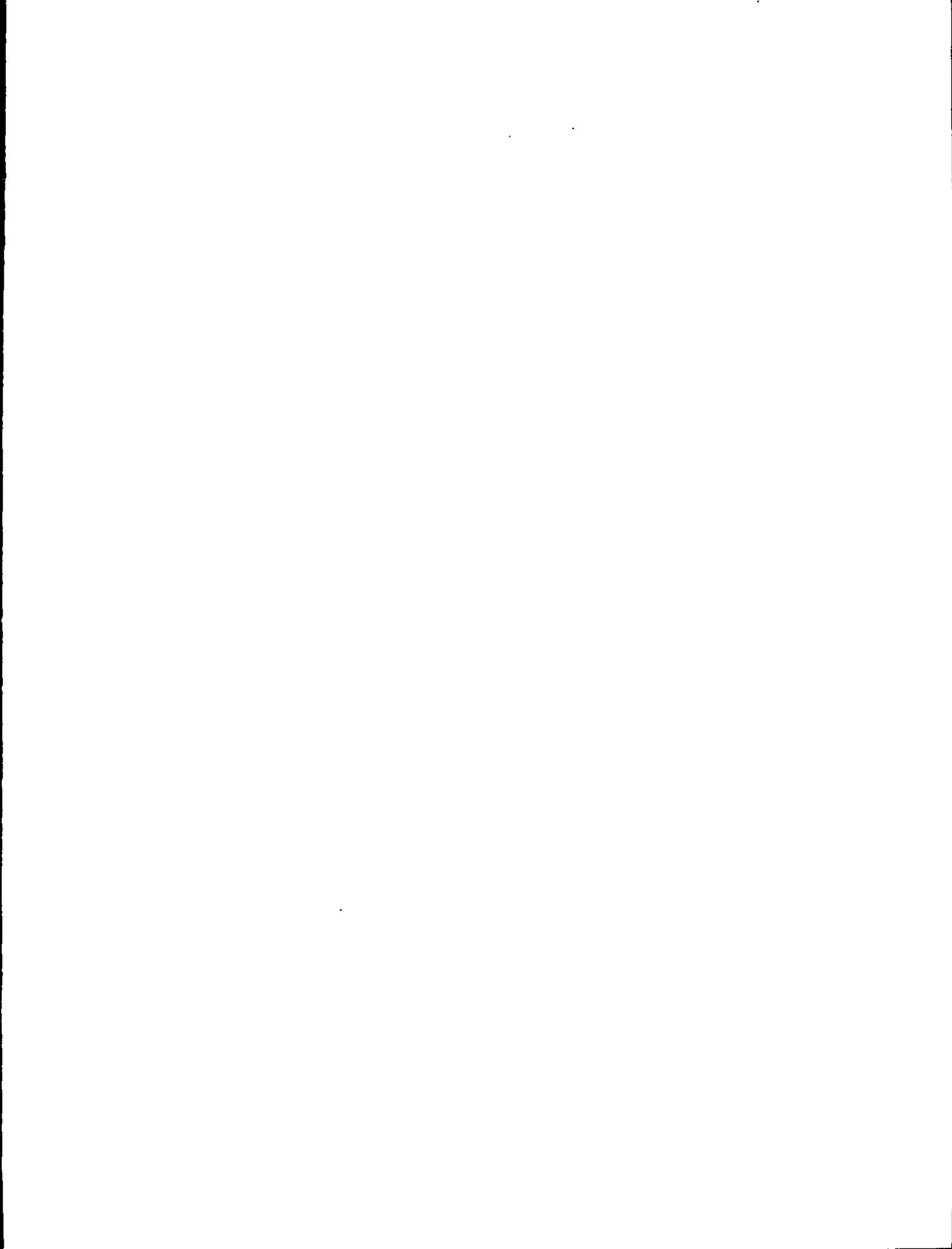
Pocomoke Sound

# SOUTHEASTERN RIVERS & BAYS

**CHROMIUM**

Yearly measurements of chromium concentration in sediments (ppm).
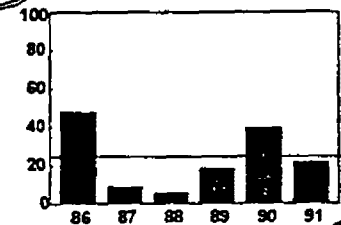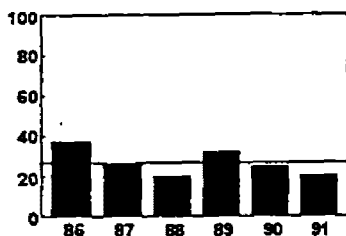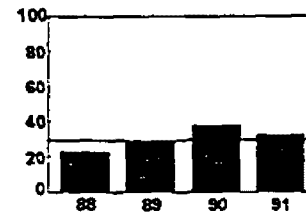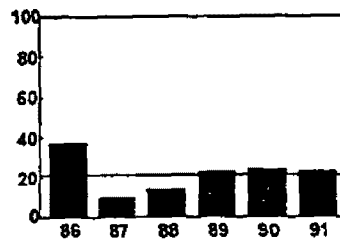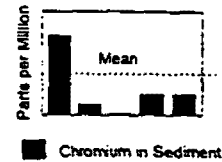
PEL=240

Mean

■ Chromium in Sediment

Upper Nanticoke River

Lower Nanticoke River

Fishing Bay

Wicomico River
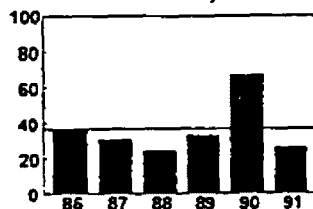
Manokin River
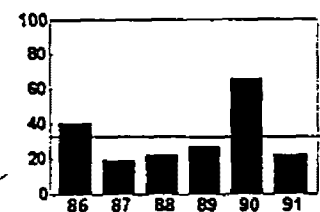
North Tangier Sound

Big Annemesex River
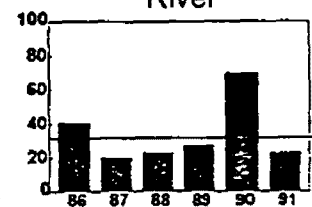
South Tangier Sound
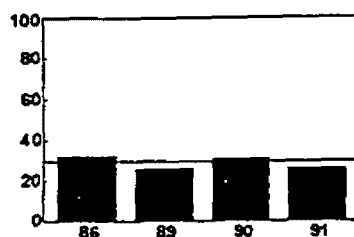
Pocomoke River
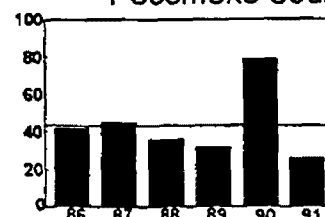
Pocomoke Sound

# SOUTHEASTERN RIVERS & BAYS



**LEAD**

Yearly measurements of arsenic concentration in sediments (ppm).
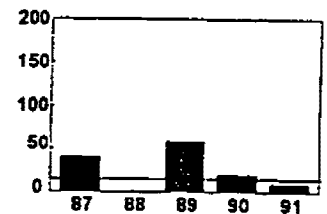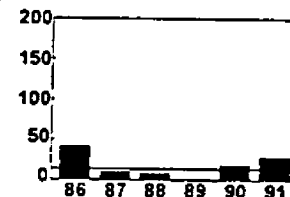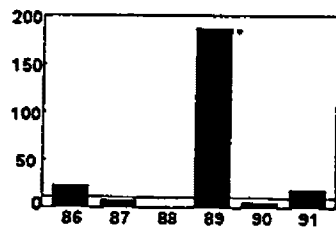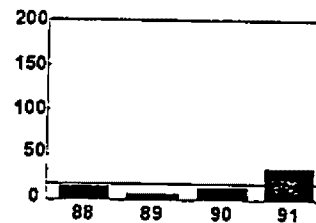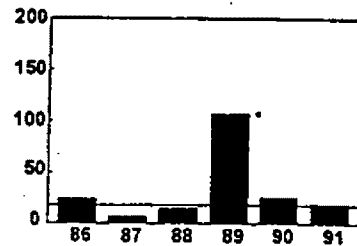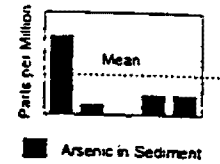
PEL=160

■ Arsenic in Sediment

Upper Nanticoke River

Lower Nanticoke River

Fishing Bay

Wicomico River

Manokin River

North Tangier Sound

Big Annemesex River
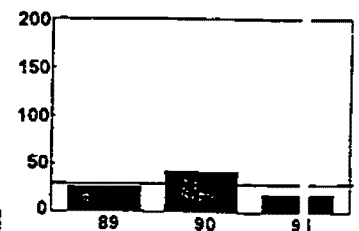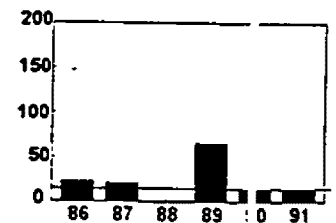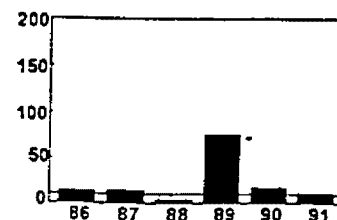
South Tangier Sound

Pocomoke River

Pocomoke Sound
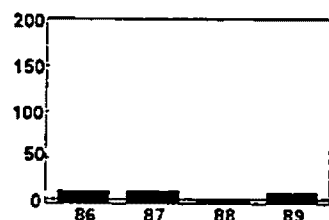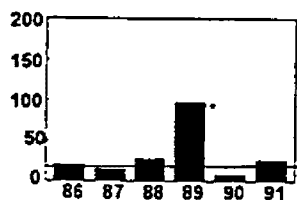
*these values may have resulted from contamination.

# SOUTHEASTERN RIVERS & BAYS

## NICKEL

Yearly measurements of nickel concentration in sediments (ppm).

ER-M=51.6

Parts per Million

Mean

■ Nickel in Sediment

Upper Nanticoke River

Lower Nanticoke River

Fishing Bay

Wicomico River

Manokin River

North Tangier Sound

South Tangier Sound

Big Annemesex River

Pocomoke River

Pocomoke Sound
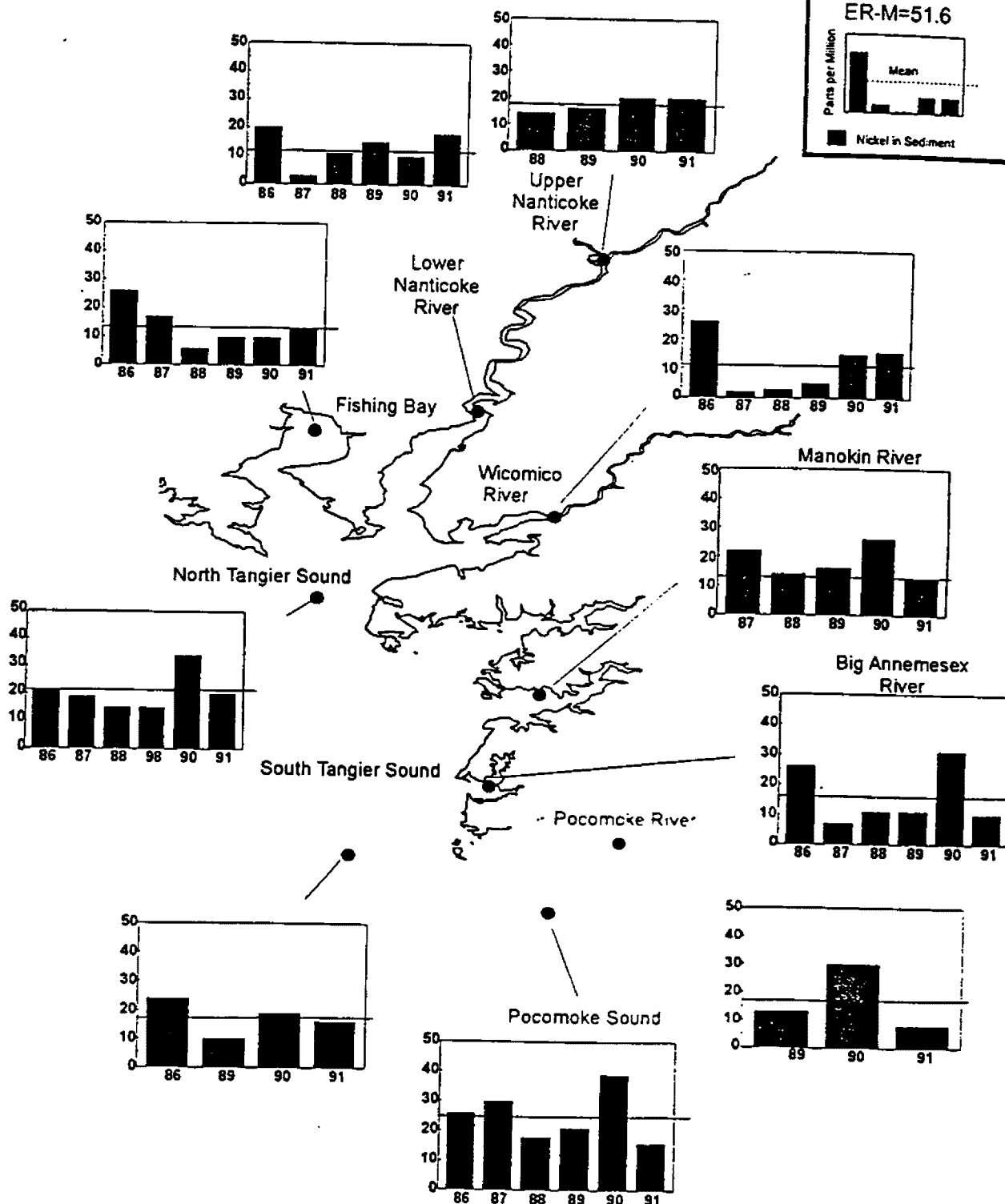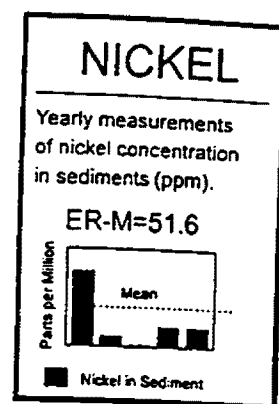
Figure 4.14  Distribution of metals in the Northeast Rivers. (Next 8 pages)

A. Arsenic
B. Cadmium
C. Chromium
D. Copper
E. Lead
F. Mercury
G. Nickel
H. Zinc.

**ARSENIC**

Yearly measurements of arsenic concentration in sediments (ppm).

PEL=64

Mean
Arsenic Sediment

Parts per Million
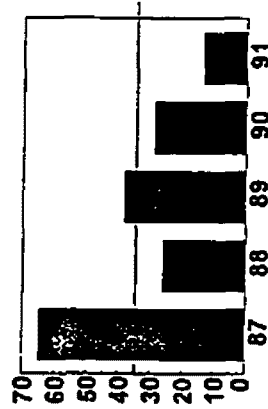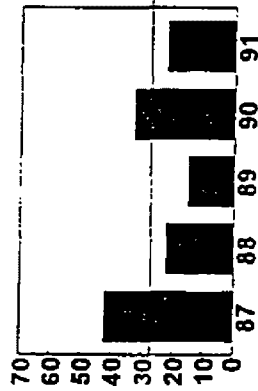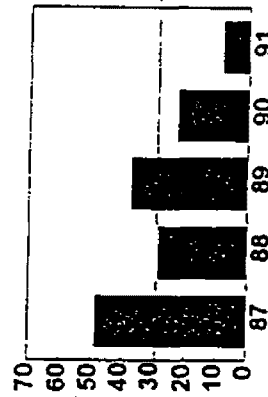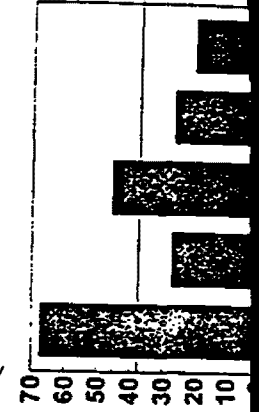
**NORTHEAST RIVERS**

Northeast River

Elk River

Bohemia River
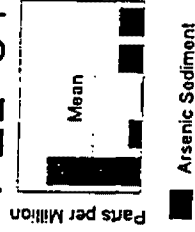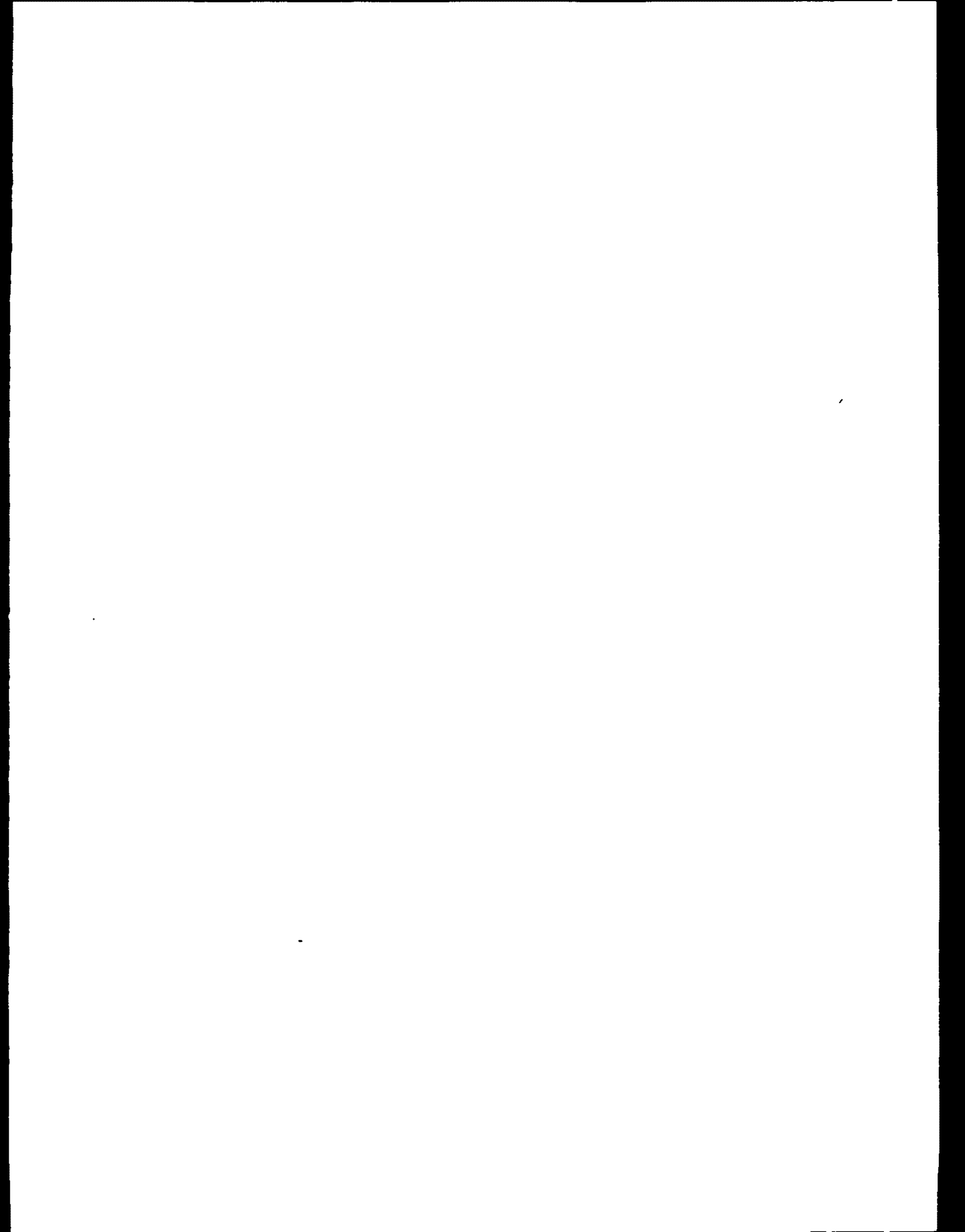
Sassafras River

CADMIUM

Yearly measurements of cadmium concentration in sediments (ppm).

PEL=7.5
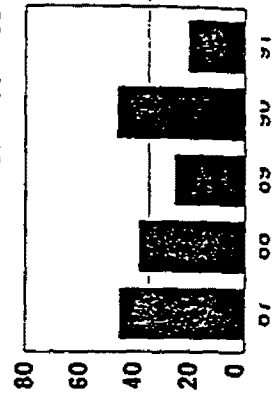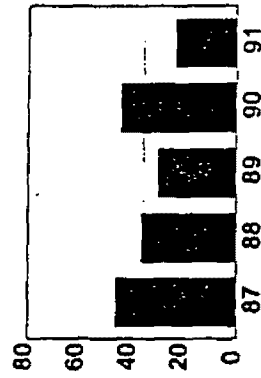
NORTHEAST RIVERS

Northeast River
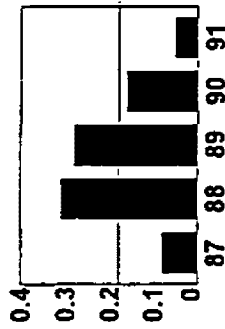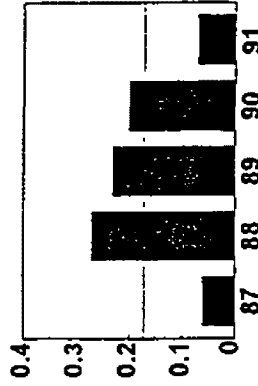
Elk River

Bohemia River

Sassafras River

NORTHEAST RIVERS

CHROMIUM

Yearly measurements of chromium concentration in sediments (ppm).

PEL=240

Mean

Chromium in Sediment

Parts per Million
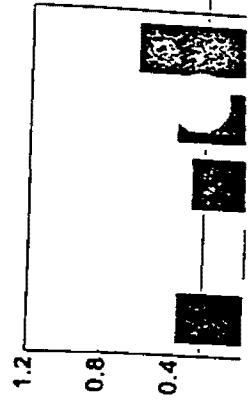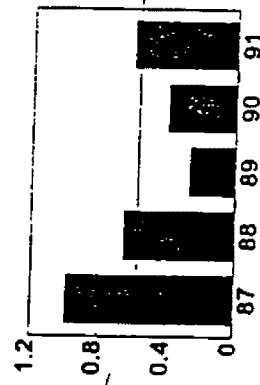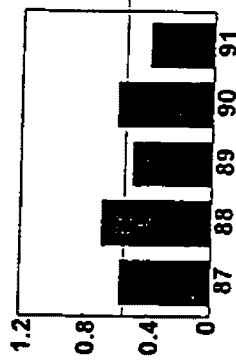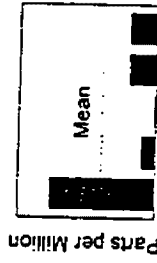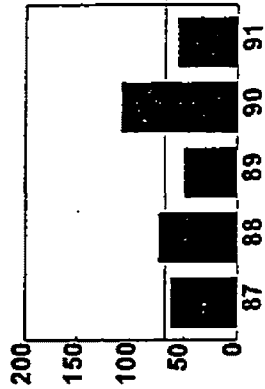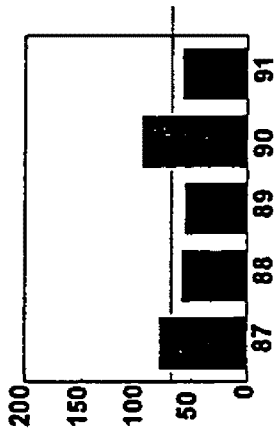
Northeast River

Elk River

Bohemia River

Sassafras River

COPPER

Yearly measurements of copper concentration in sediments (ppm).

PEL=170

Mean

Copper in Sediment

Parts per Million

NORTHEAST RIVERS

Northeast River

Elk River

Bohemia River

Sassafras River

LEAD

Yearly measurements of lead concentration in sediments (ppm).

PEL=110 PPM
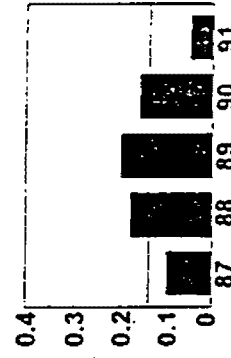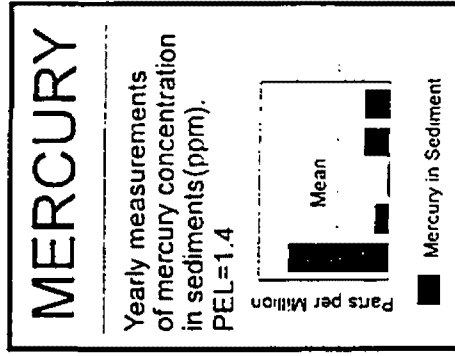
Mean

Lead in Sediment

NORTHEAST RIVERS

Northeast River

Elk River

Bohemia River

Sassafras River

NORTHEAST RIVERS

MERCURY

Yearly measurements of mercury concentration in sediments(ppm). PEL=1.4

Mean

Parts per Million

Mercury in Sediment

Elk River

Bohemia River
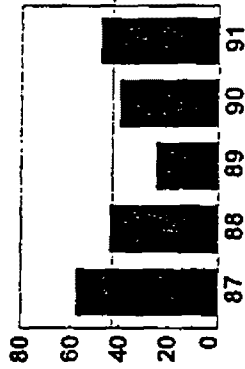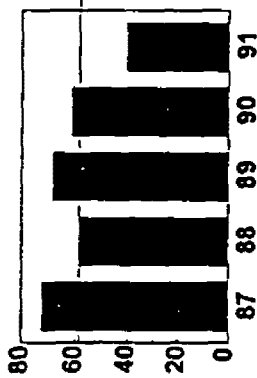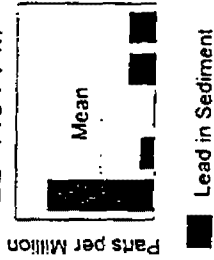
Sassafras River

Northeast River

NORTHEAST RIVERS

NICKEL

Yearly measurements of nickel concentration in sediments (ppm).

ER-M=51.6

Mean

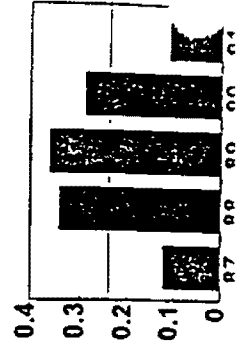Parts per Million

Nickel in Sediment

Northeast River

Elk River

Bohemia River

Sassafras River

# NORTHEAST RIVERS

## ZINC
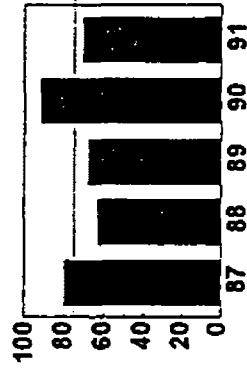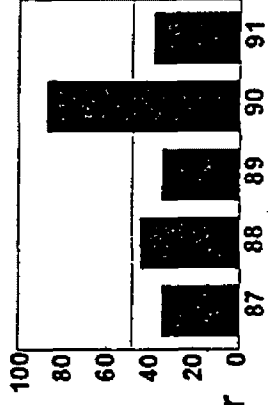
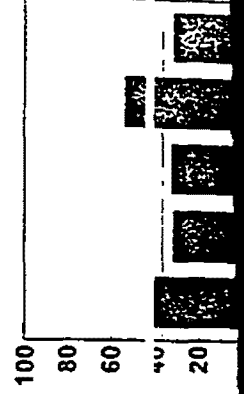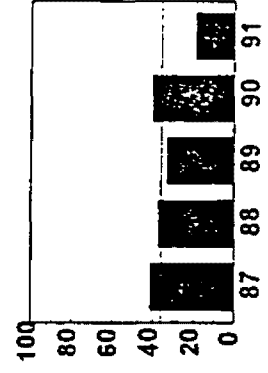Yearly measurements of zinc concentration in sediments (ppm).

Mean

Parts per Million

Zinc In Sediment
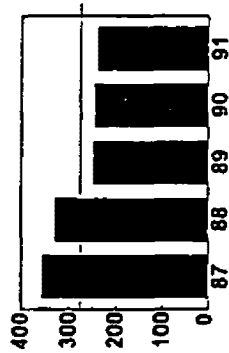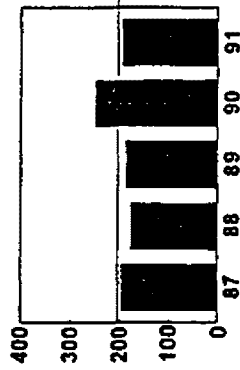
**Northeast River**

**Elk River**
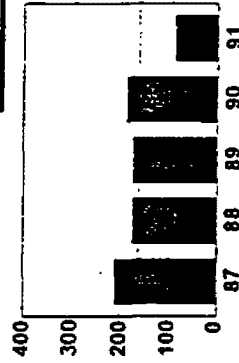
**Bohemia River**
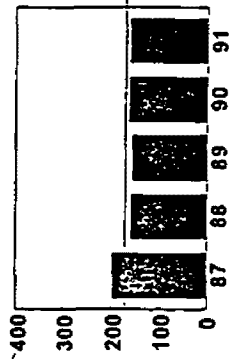
**Sassafrass River**
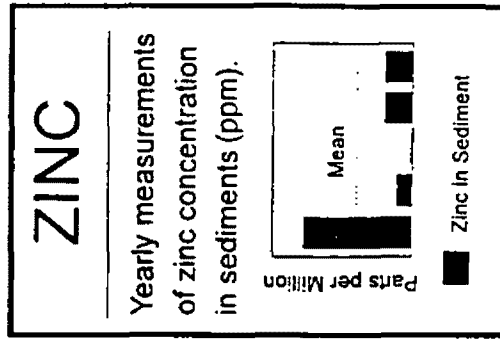
Figure 4.15 Distribution of metals in the Eastern bays. (Next 8 pages)

A. Arsenic
B. Cadmium
C. Chromium
D. Copper
E. Lead
F. Mercury
G. Nickel
H. Zinc.

# EASTERN BAYS

Eastern Bay

Choptank Embayment

Little Choptank River

**ARSENIC**

Yearly measurements of arsenic concentration in sediments (ppm).

PEL=64

Mean

■ Arsenic in Sediment

# EASTERN BAYS



Eastern Bay

Choptank Embayment

Little
Choptank
River

## CADMIUM

Yearly measurements
of cadmium concentration
in sediments (ppm).

### PEL=7.5

Parts per Million

Mean

■ Cadmium in Sediment

# EASTERN BAYS



Eastern Bay

Choptank Embayment

Little
Choptank
River
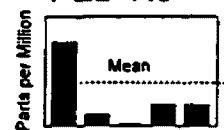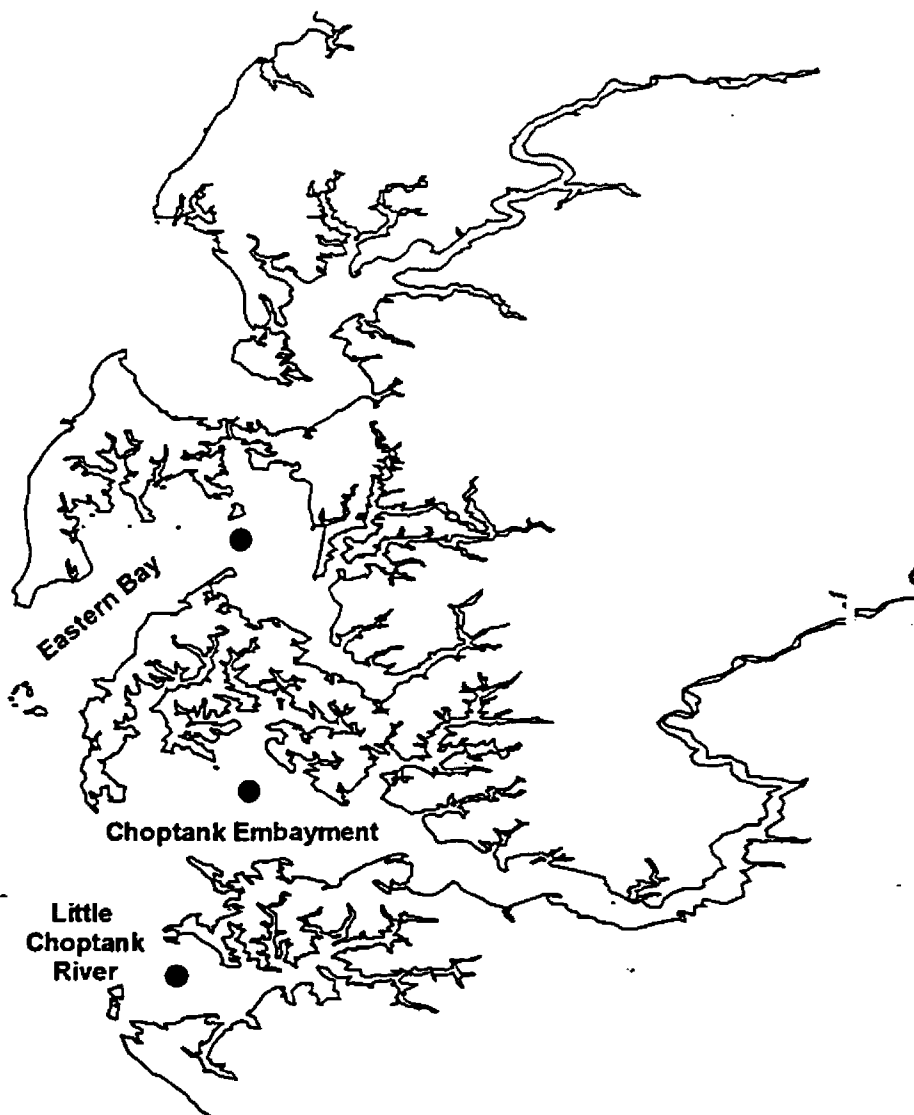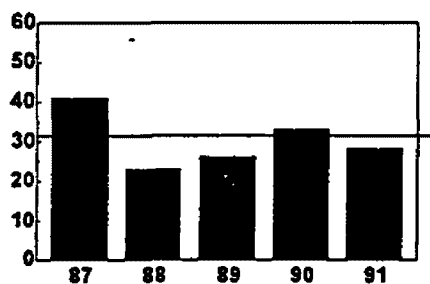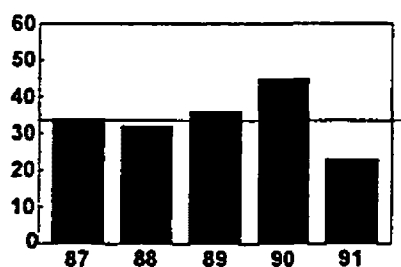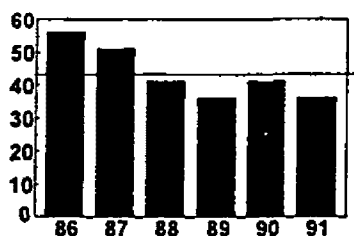
## CHROMIUM

Yearly measurements
of chromium concentration
in sediments (ppm).

PEL=240

Chromium in Sediment

# EASTERN BAYS

Eastern Bay

Choptank Embayment

Little
Choptank
River

## COPPER

Yearly measurements
of copper concentration
in sediments (ppm).

PEL=170

Mean

Copper in Sediment

# EASTERN BAYS



Eastern Bay

Choptank Embayment

Little Choptank River

## LEAD

Yearly measurements of lead concentration in sediments (ppm).

PEL=160

Mean

Parts per Million

Lead in Sediment

# EASTERN BAYS



Eastern Bay

Choptank Embayment

Little Choptank River

**MERCURY**

Yearly measurements of mercury concentration in sediments (ppm).

PEL=1.4

Parts per Million

Mean

Mercury in Sediment

# EASTERN BAYS



Map of Eastern Bays showing nickel concentration measurements at three locations: Eastern Bay, Choptank Embayment, and Little Choptank River.

Eastern Bay (top chart):
- 86: 42
- 87: 32
- 88: 26
- 89: 20
- 90: 30
- 91: 23

Choptank Embayment (middle chart):
- 87: 21
- 88: 19
- 89: 23
- 90: 32
- 91: —

Little Choptank River (bottom chart):
- 87: 22
- 88: 12
- 89: 48
- 90: 24
- 91: —

## NICKEL

Yearly measurements of nickel concentration in sediments (ppm).

ER-M=51.6

Parts per Million — Mean — Nickel in Sediment

# EASTERN BAYS



Eastern Bay

Choptank Embayment

Little
Choptank
River

## ZINC

Yearly measurements
of zinc concentration
in sediments (ppm).
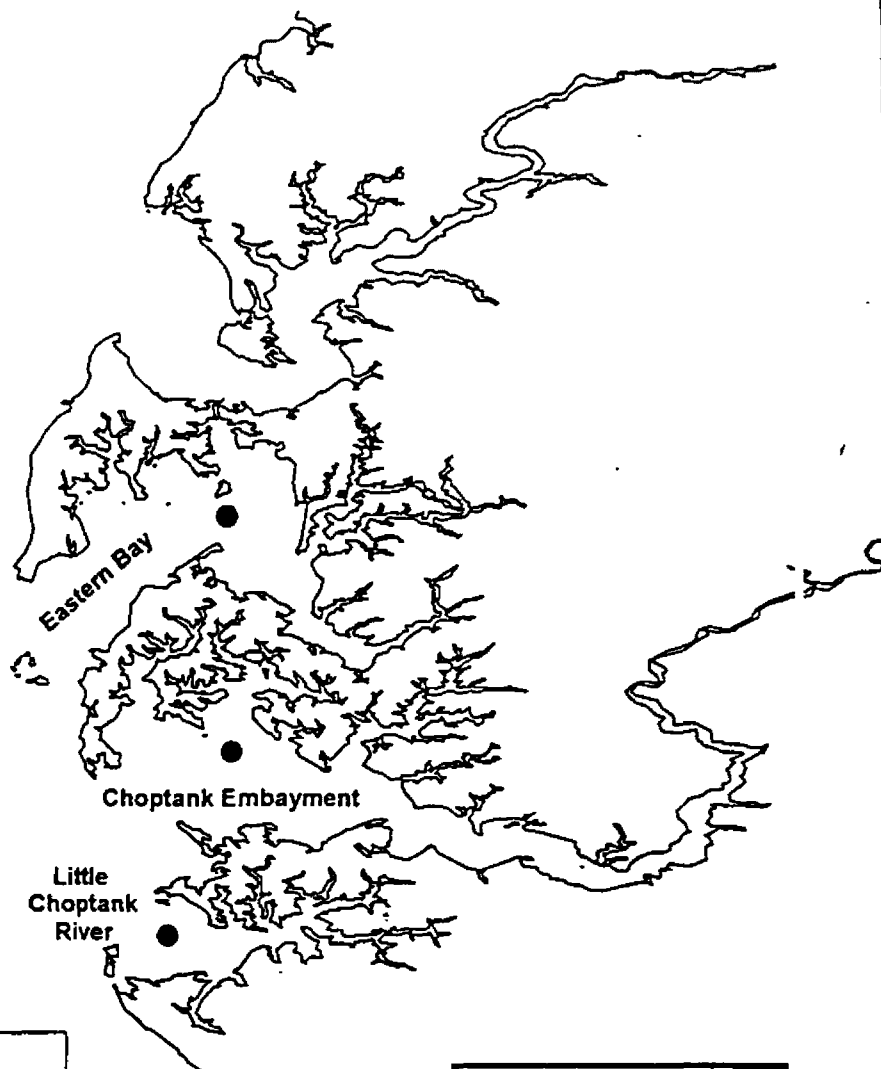
PEL=300

Mean
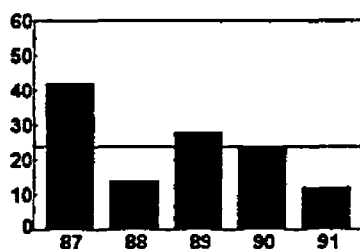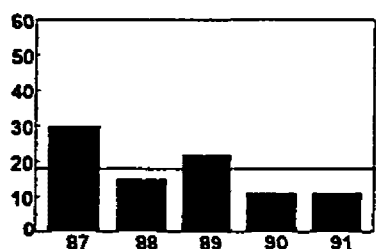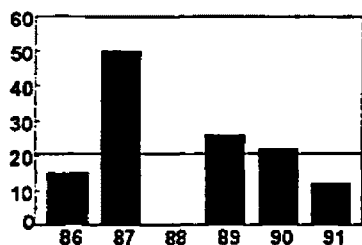
Zinc in Sediment

Figure 4.16  Distribution of metals in the Patuxent River. (Next 8 pages)

       A. Arsenic
       B. Cadmium
       C. Chromium
       D. Copper
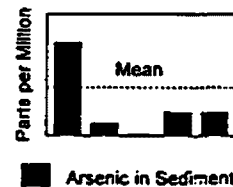       E. Lead
       F. Mercury
       G. Nickel
       H. Zinc.
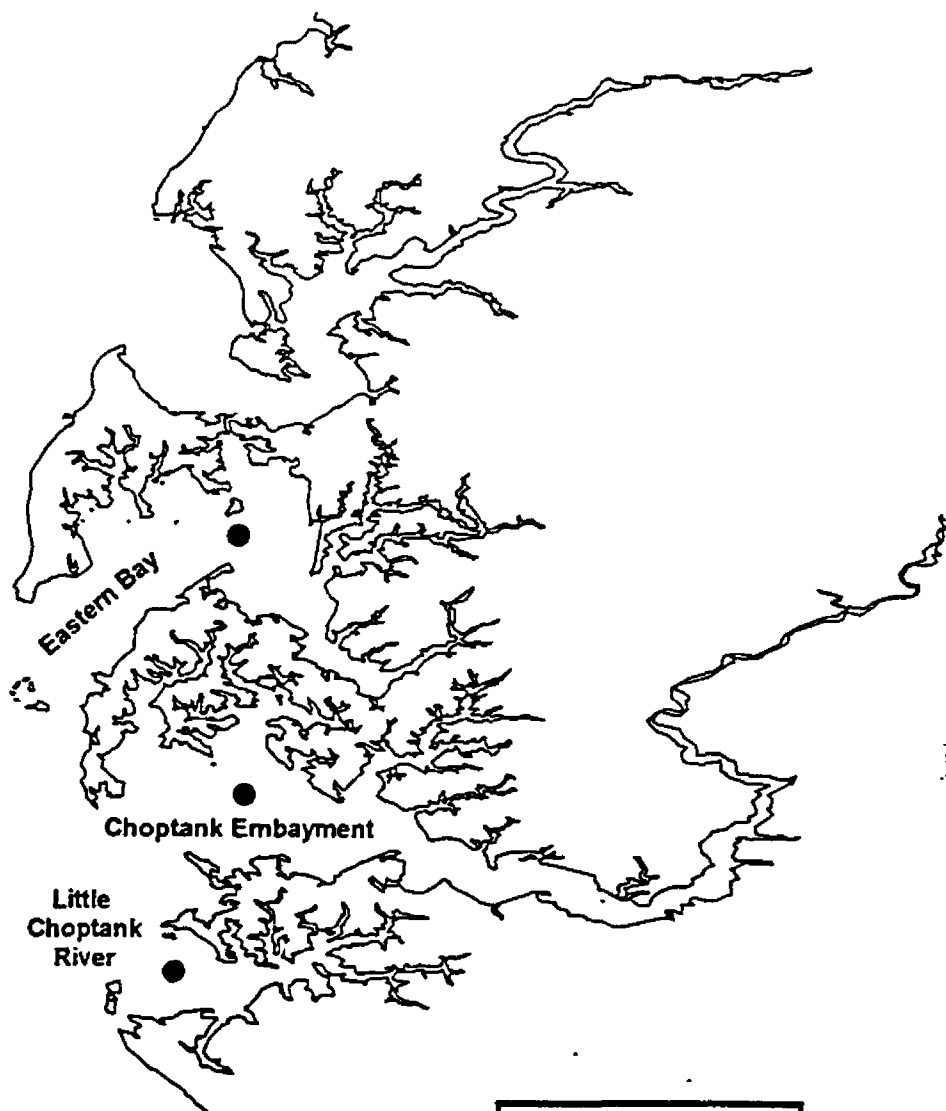
# PATUXENT
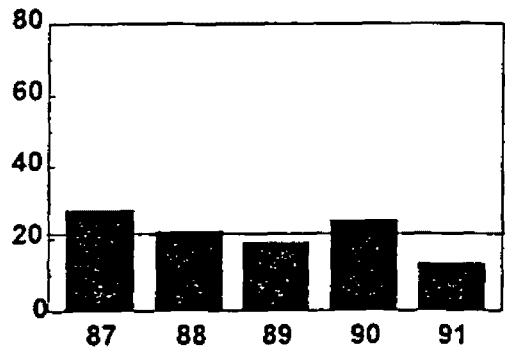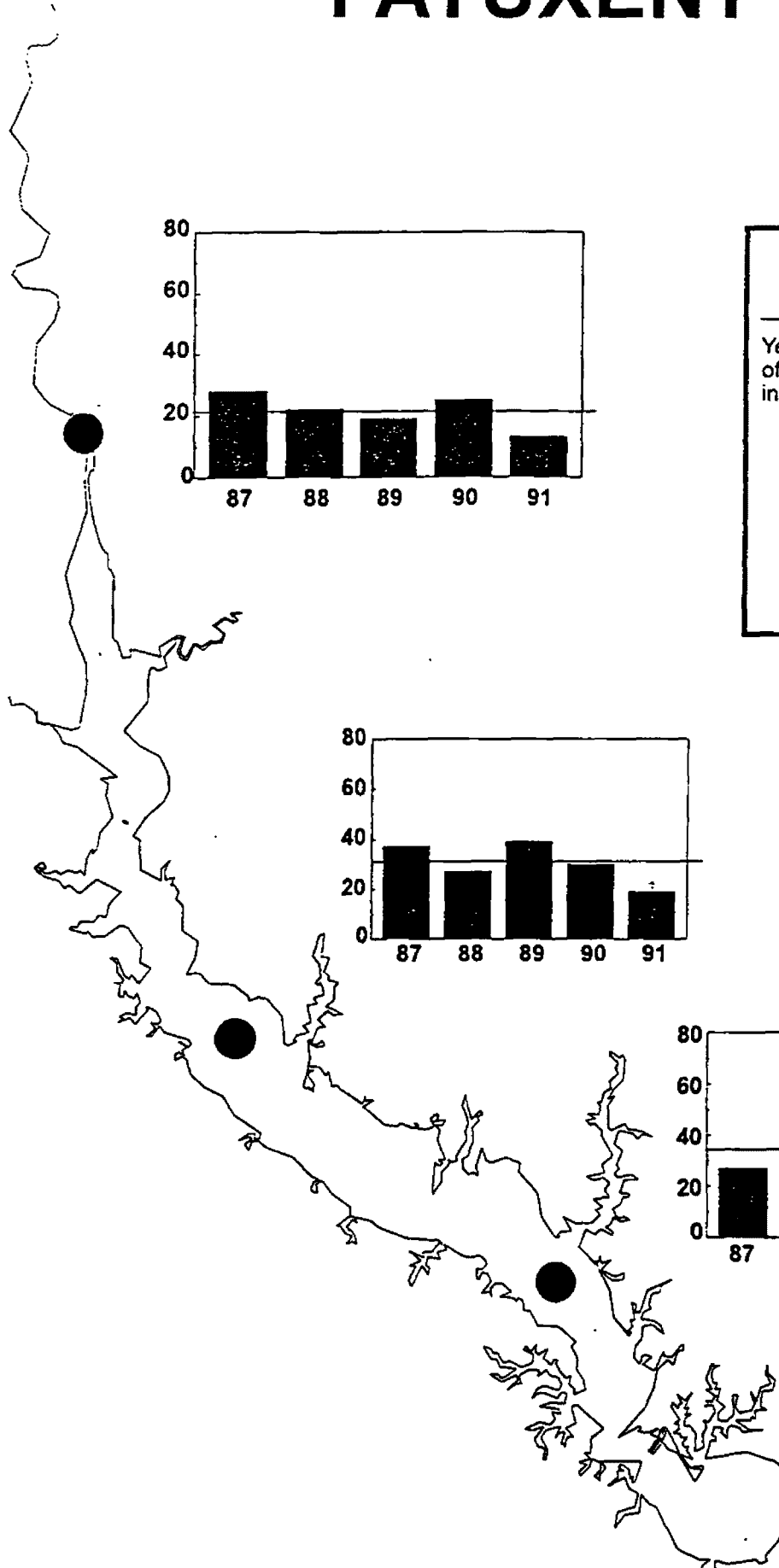


ARSENIC

Yearly measurements of arsenic concentration in sediments (ppm).

PEL=64

Arsenic in Sediment
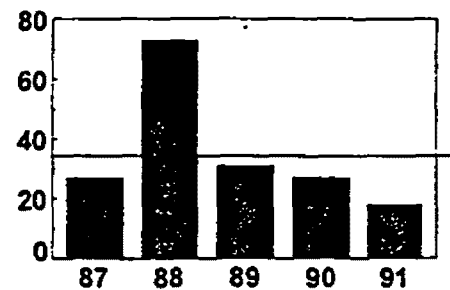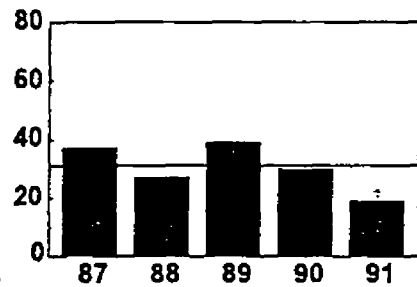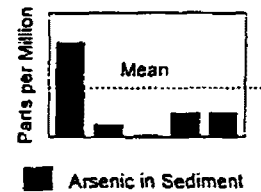
# PATUXENT

**CADMIUM**
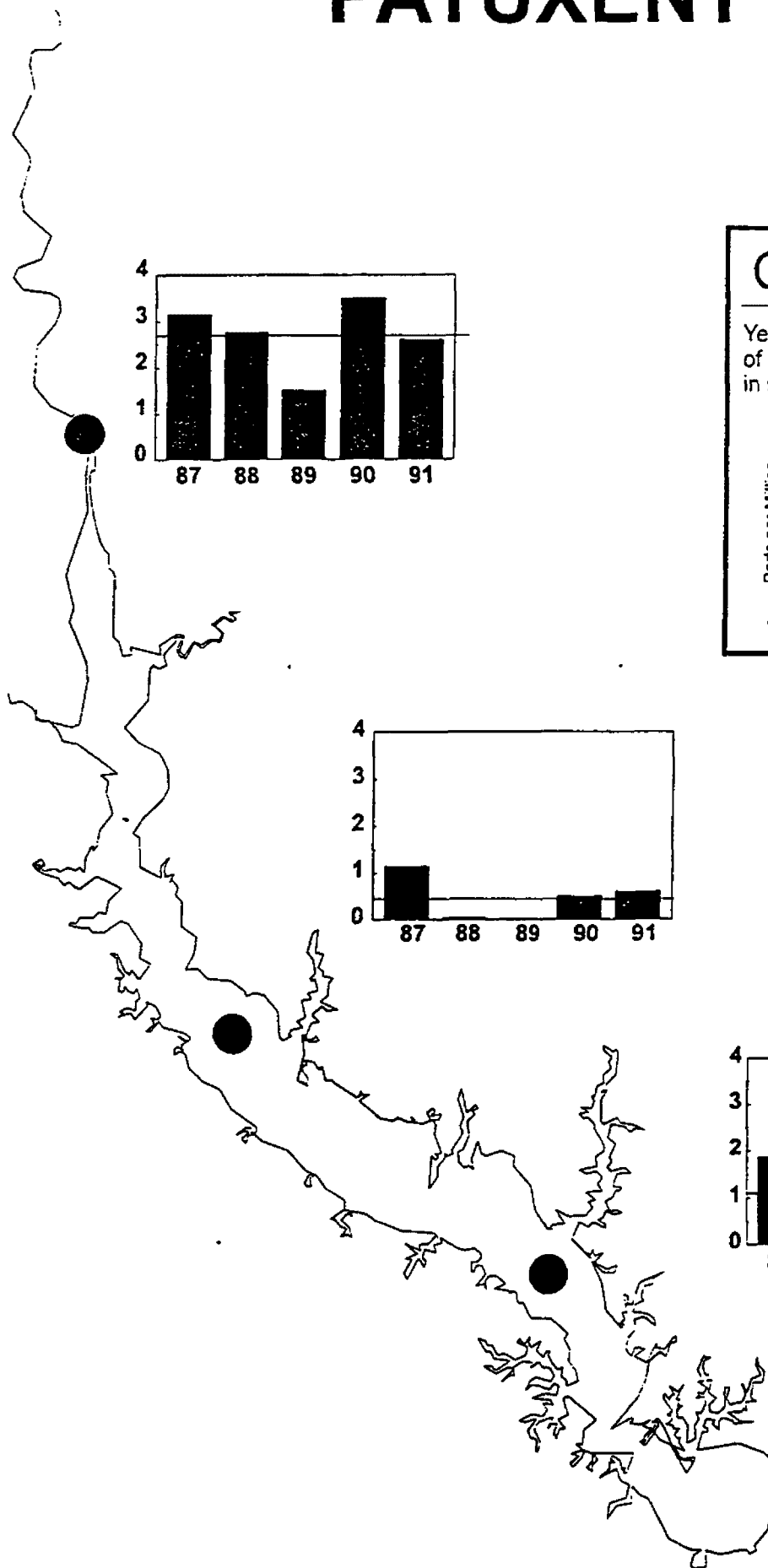
Yearly measurements
of cadmium concentration
in sediments (ppm).

PEL=7.5

Cadmium in Sediment
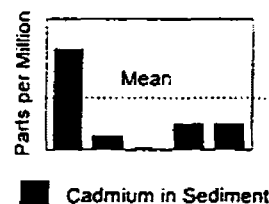
# PATUXENT



## CHROMIUM

Yearly measurements of copper concentration in sediments (ppm).

PEL=240

Mean
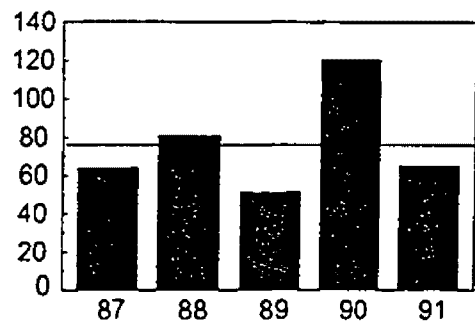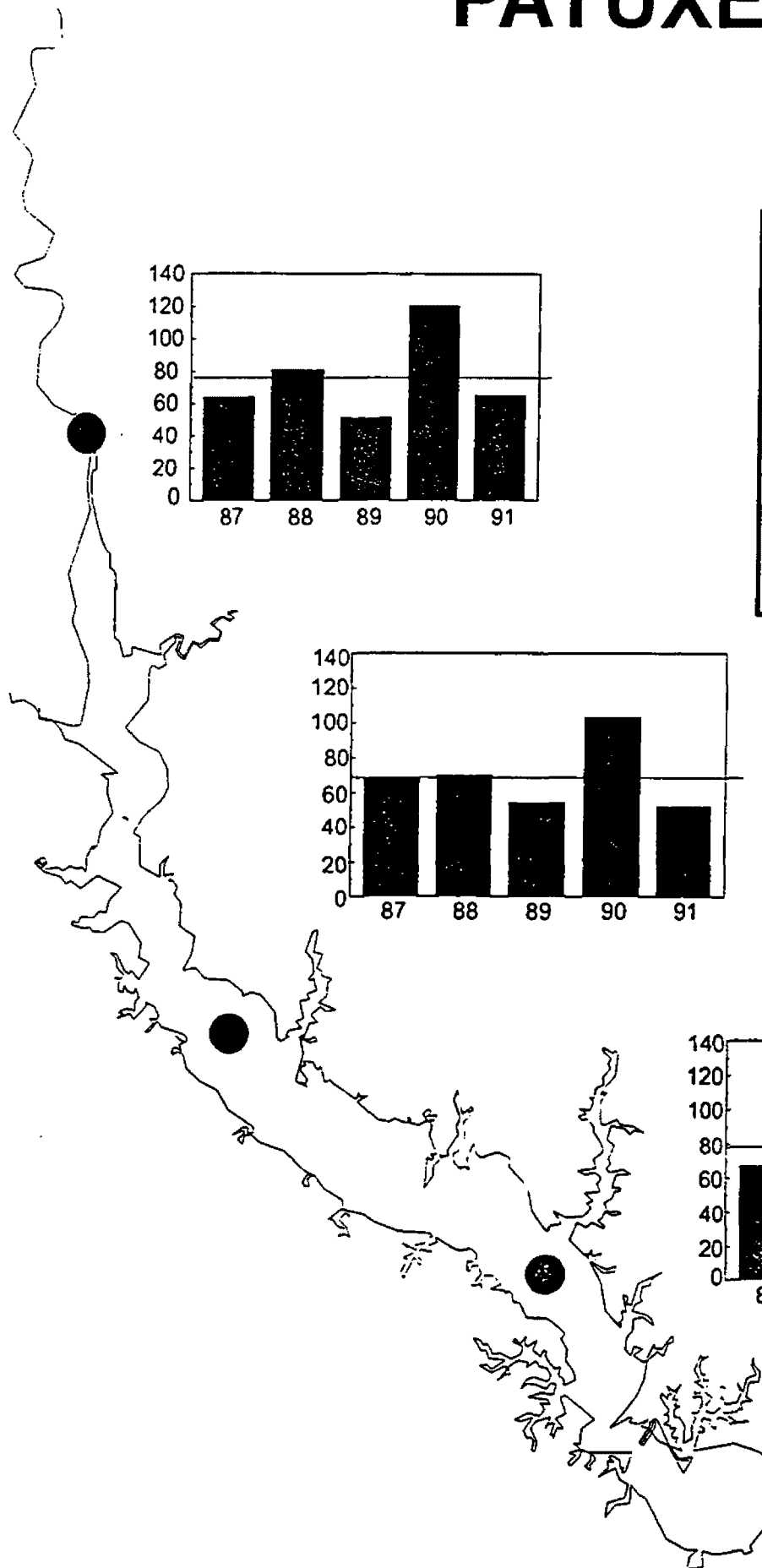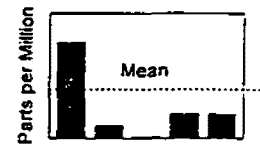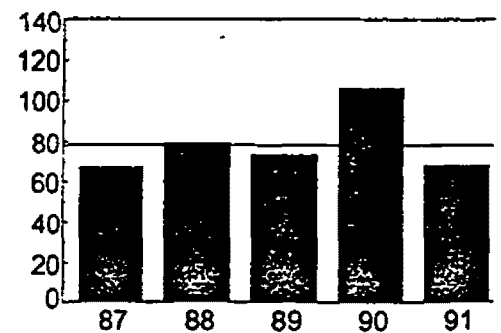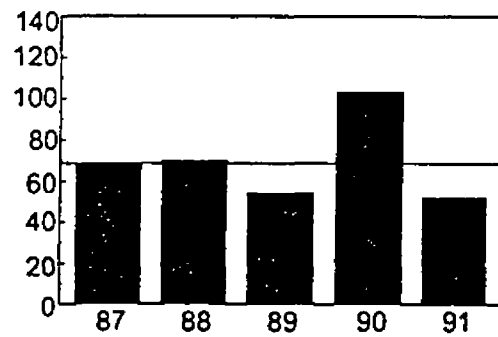
■ Copper in Sediment

# PATUXENT

COPPER

Yearly measurements
of copper concentration
in sediments (ppm).

PEL=170

Parts per Million

Mean

■ Copper in Sediment

# PATUXENT



Chart (top): Yearly lead measurements
- 87: 30
- 88: 25
- 89: 36
- 90: 30
- 91: 46

## LEAD

Yearly measurements of lead concentration in sediments (ppm).

PEL=160

Parts per Million

Mean

■ Lead in Sediment

Chart (middle):
- 87: 32
- 88: 20
- 89: 52
- 90: 22
- 91: 25

Chart (bottom):
- 87: 26
- 88: 28
- 89: 37
- 90: 28
- 91: 7
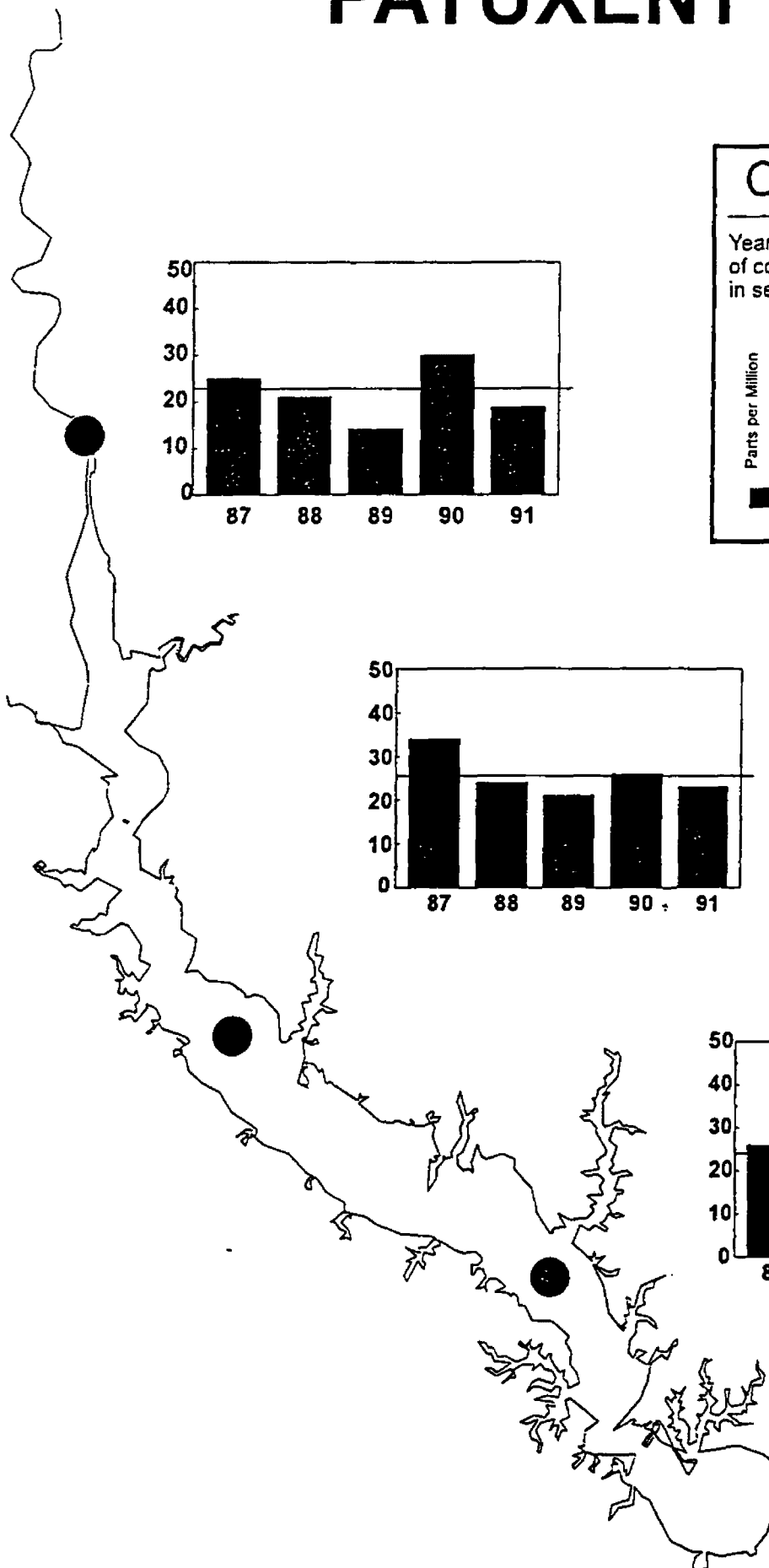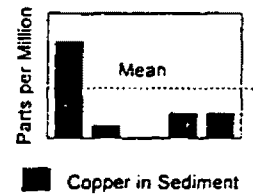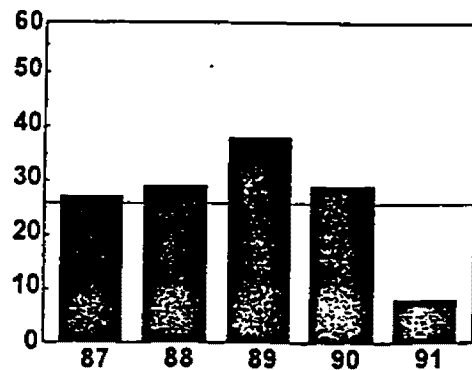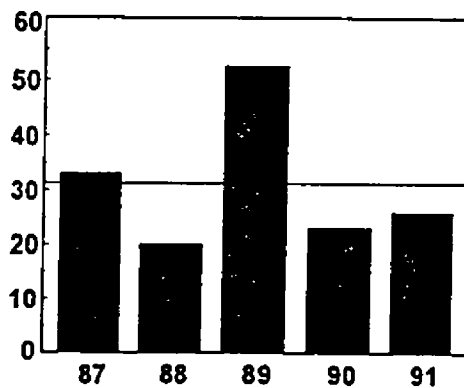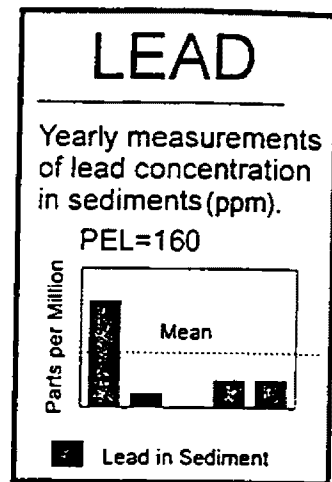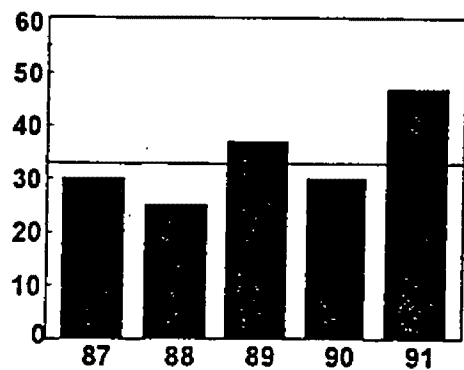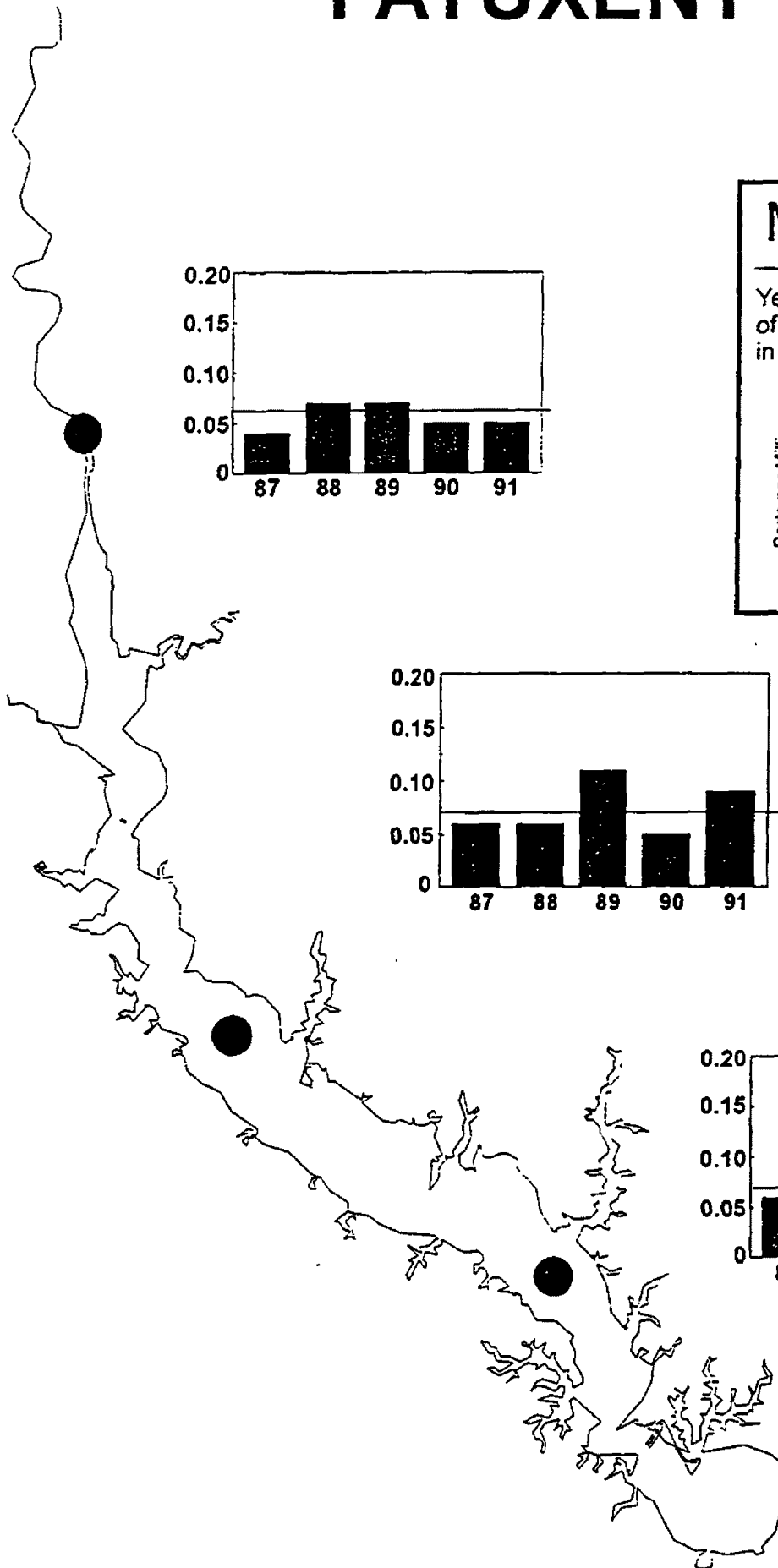
# PATUXENT

MERCURY

Yearly measurements
of mercury concentration
in sediments (ppm).

PEL=1.4
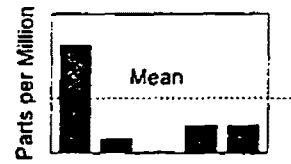
Mercury in Sediment

# PATUXENT
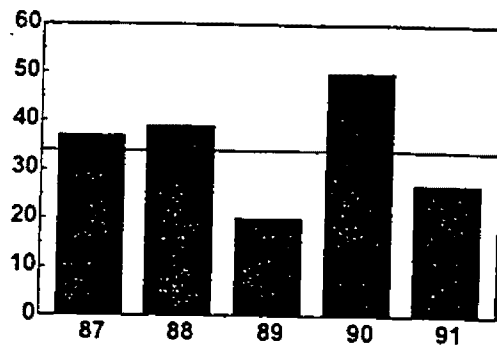


**NICKEL**

Yearly measurements of nickel concentration in sediments (ppm).

ER-M=51.6
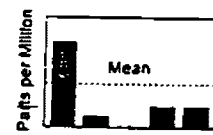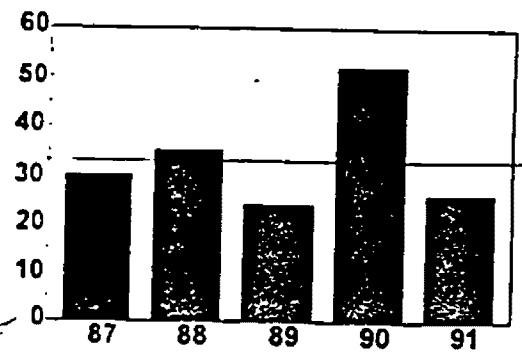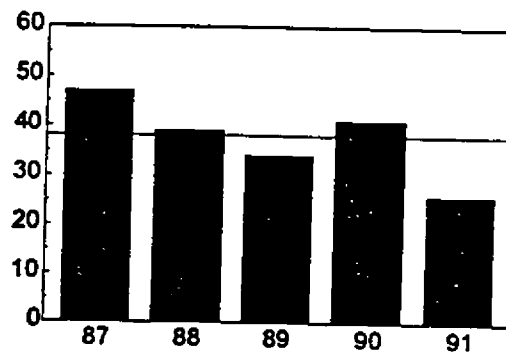
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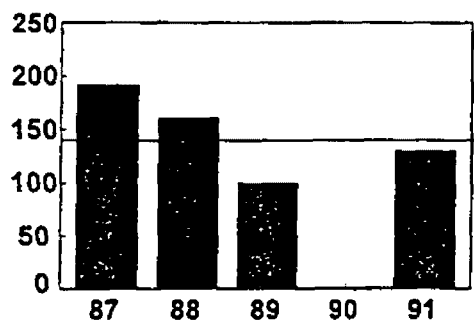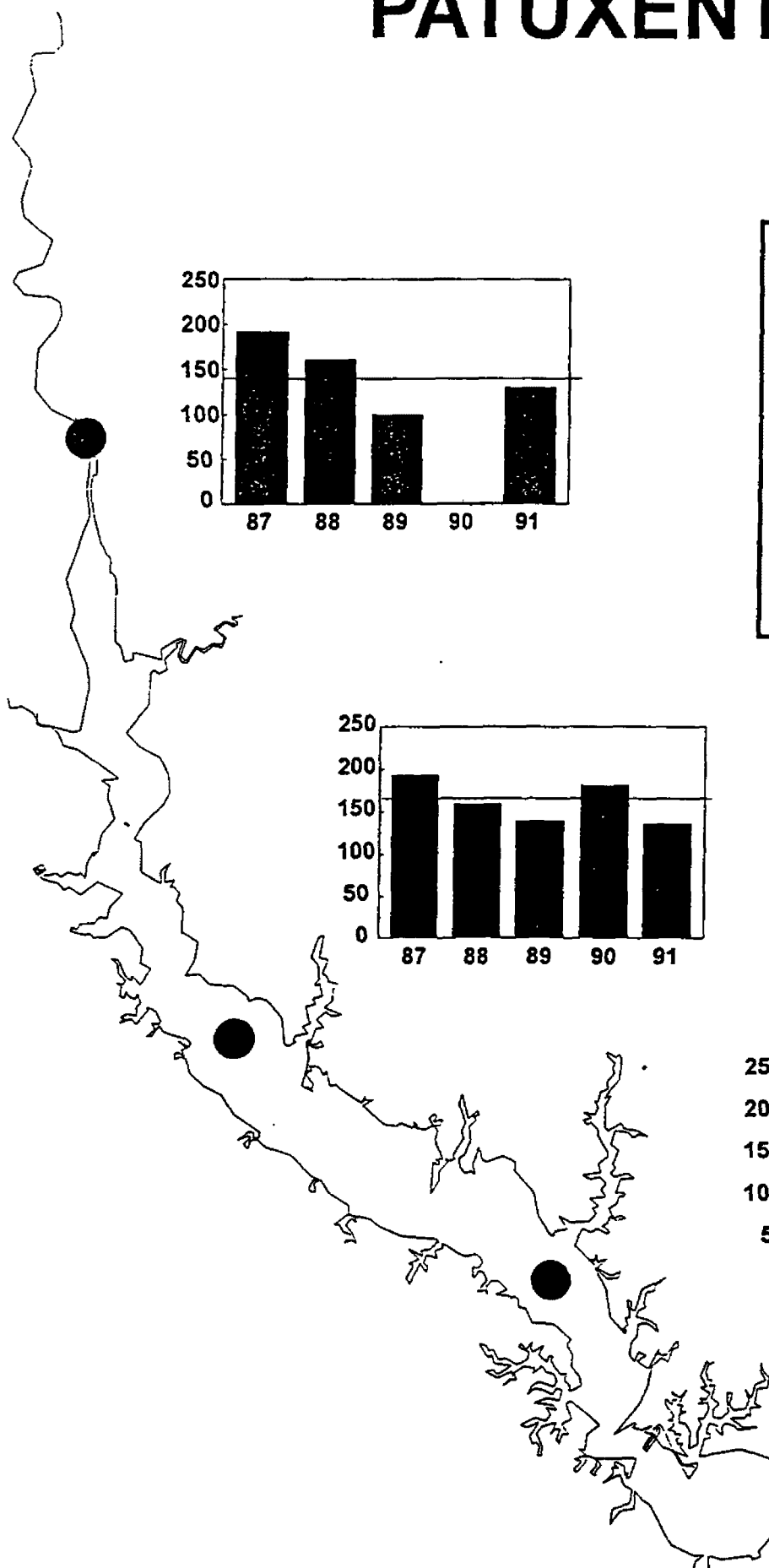


ZINC

Yearly measurements of zinc concentration in sediments (ppm).

PEL=300
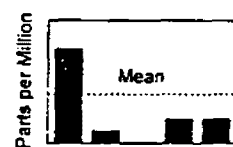
Zinc in Sediment
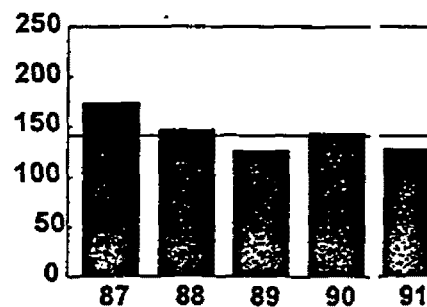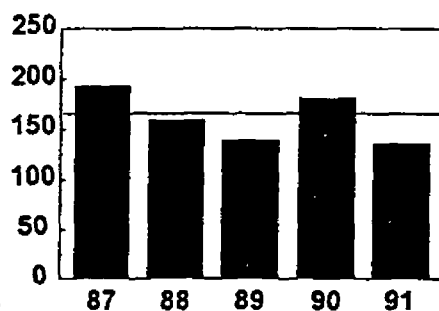
Figure 4.17  Distribution of metals in the Potomac River. (Next 8 pages)

       A. Arsenic
       B. Cadmium
       C. Chromium
       D. Copper
       E. Lead
       F. Mercury
       G. Nickel
       H. Zinc.

# POTOMAC RIVER



Washington

INDIAN HEAD

MATWMN

MARYLAND POINT

RAGGED POINT

## ARSENIC

Yearly measurements of arsenic concentration in sediments (ppm).

## PEL=64

Parts per Million

Mean

■ Arsenic in Sediment

# POTOMAC RIVER

Washington

INDIAN HEAD

MATWMN

MARYLAND POINT

RAGGED POINT

## CADMIUM

Yearly measurements of cadmium concentration in sediments (ppm).

PEL=7.5

Mean

Parts per Million

■ Cadmium in Sediment

# POTOMAC RIVER



Washington

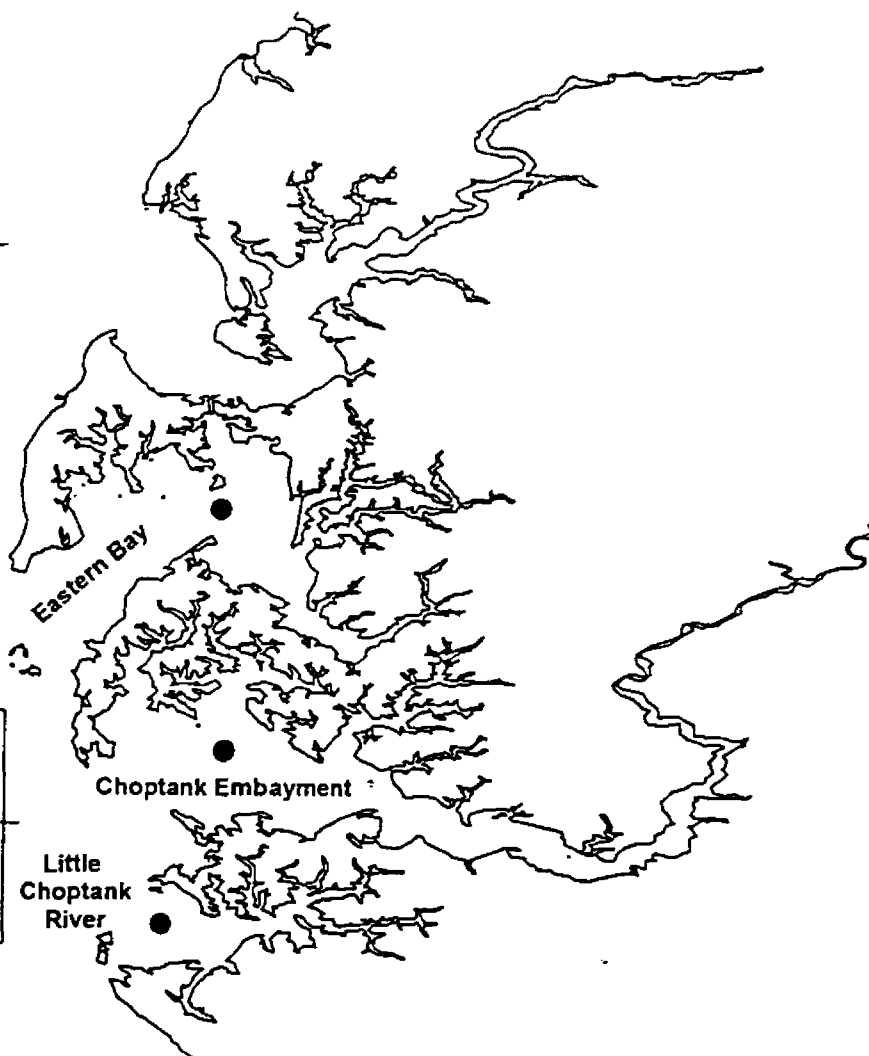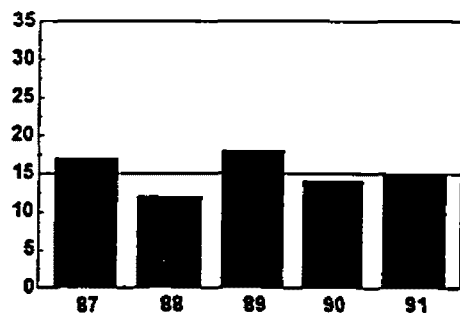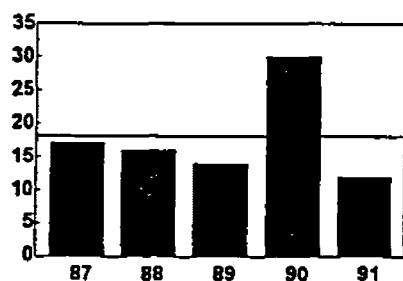INDIAN HEAD

MATWMN

MARYLAND POINT

RAGGED POINT

## CHROMIUM

Yearly measurements of chromium concentration in sediments (ppm).

PEL=240

Parts per Million

Mean

■ Chromium in Sediment

# POTOMAC RIVER

Washington

INDIAN HEAD

MATWMN

MARYLAND POINT

RAGGED POINT

## COPPER

Yearly measurements of copper concentration in sediments (ppm).

PEL=170

Parts per Million

Mean

■ Copper in Sediment

# POTOMAC RIVER

Washington

80
60
40
20
0
89  90  91

INDIAN HEAD

MATWMN

80
60
40
20
0
86  87  88  89  90  91

MARYLAND POINT

80
60
40
20
0
87  88  89  90  91

RAGGED POINT

## LEAD

Yearly measurements
of lead concentration
in sediments (ppm).

PEL=160

Parts per Million

Mean

■ Lead in Sediment

80
60
40
20
0
87  88  89  90  91

# POTOMAC RIVER

Washington

1.0
0.8
0.6
0.4
0.2
0
   89    90    91

INDIAN HEAD

MATWMN

1.0
0.8
0.6
0.4
0.2
0
   87   88   89   90   91

MARYLAND
POINT

RAGGED
POINT

1.0
0.8
0.6
0.4
0.2
0
   87   88   89   90   91

## MERCURY

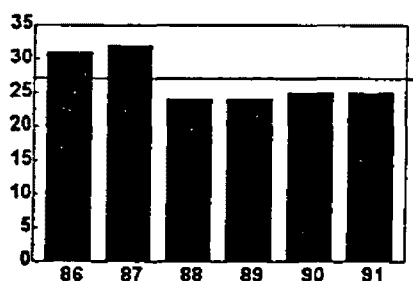Yearly measurements
of mercury concentration
in sediments (ppm).

PEL=1.4

Parts per Million

Mean

■ Mercury in Sediment

1.0
0.8
0.6
0.4
0.2
0
   86   87   88   89   90   91

# POTOMAC RIVER

Washington

INDIAN HEAD

MATWMN

MARYLAND POINT

RAGGED POINT

## NICKEL

Yearly measurements
of nickel concentration
in sediments (ppm).

ERM=51.6

Parts per Million

Mean

■ Nickel in Sediment

Figure 4.18  Distribution of metals in theChester and Choptank  Rivers. (Next 8 pages)

       A. Arsenic
       B. Cadmium
       C. Chromium
       D. Copper
       E. Lead
       F. Mercury
       G. Nickel
       H. Zinc.

# CHESTER AND CHOPTANK
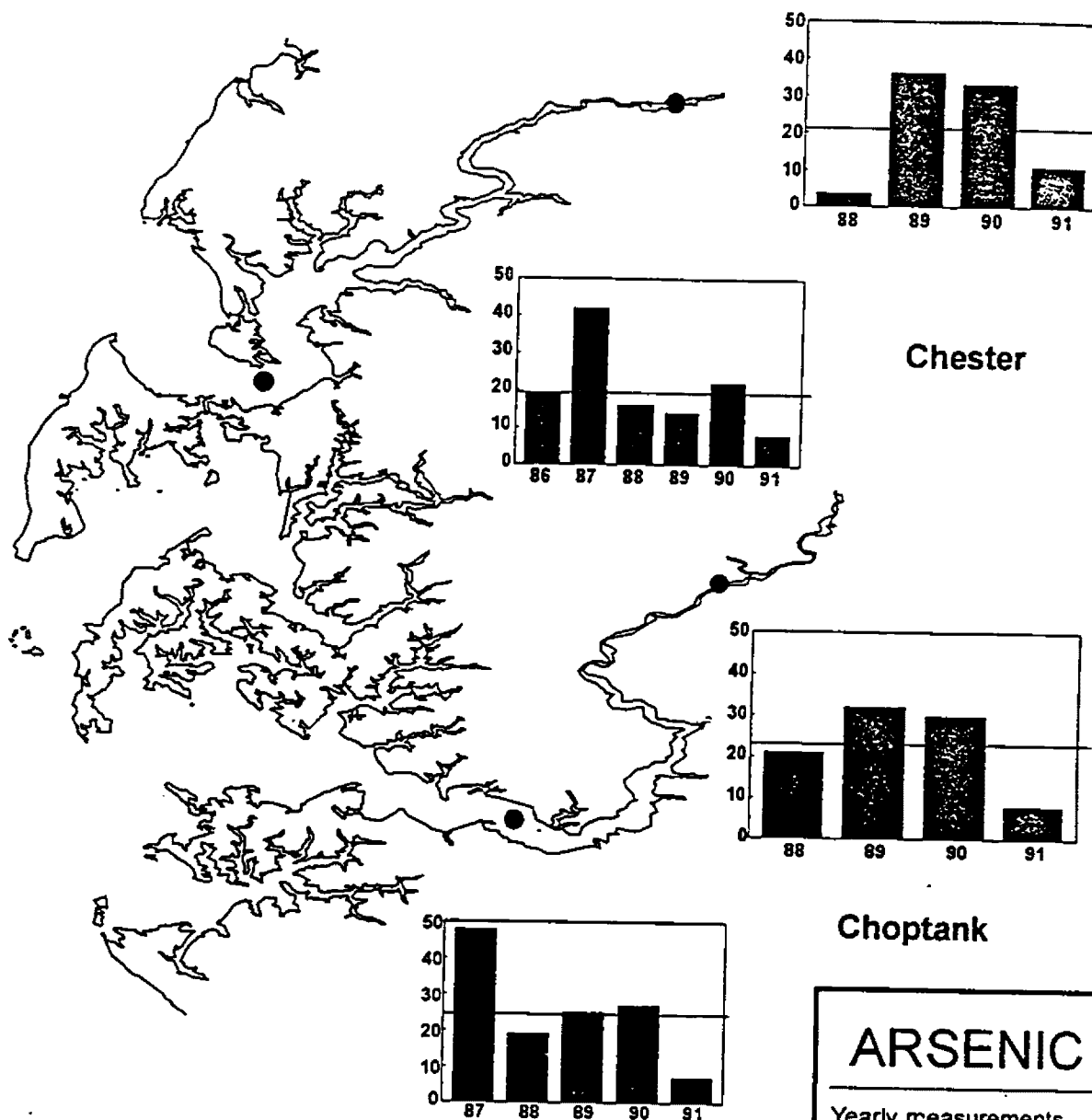


**Chester**

**Choptank**

## ARSENIC

Yearly measurements
of arsenic concentration
in sediments (ppm).

PEL=64

Parts per Million

Mean

■ Arsenic in Sediment
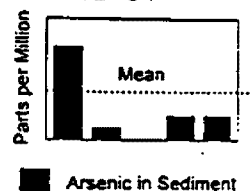
# CHESTER AND CHOPTANK
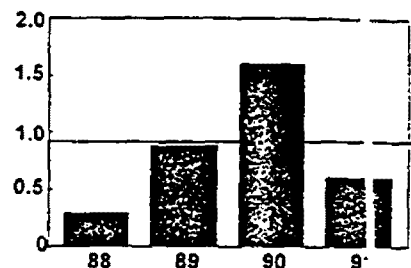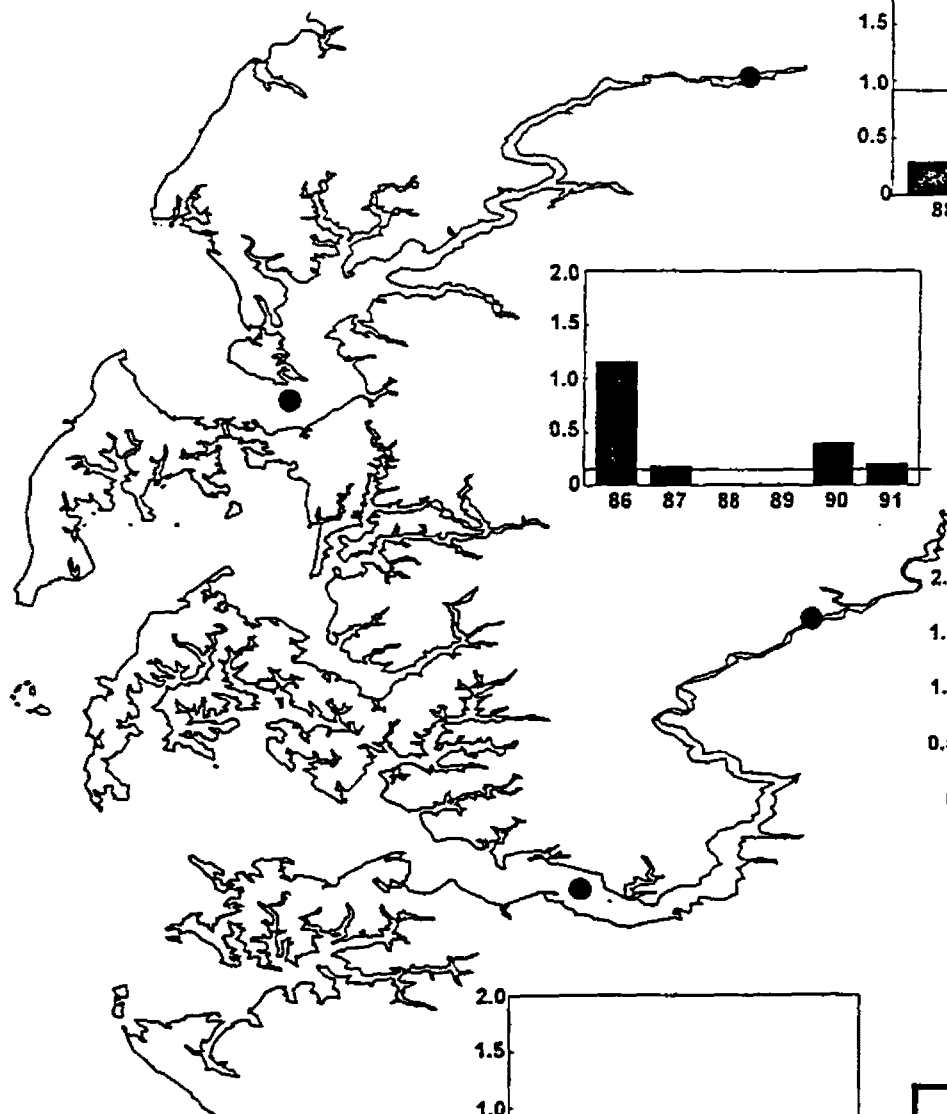


**Chester**
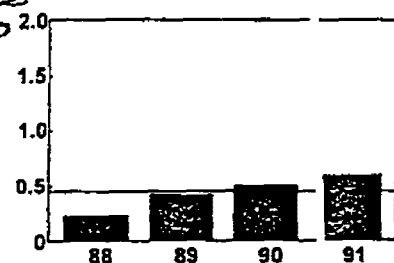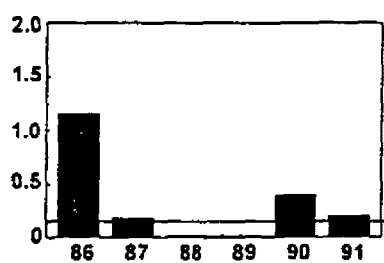
**Choptank**
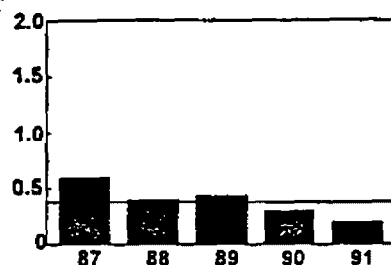
CADMIUM

Yearly measurements
of cadmium concentration
in sediments(ppm).

PEL=7.4

Mean

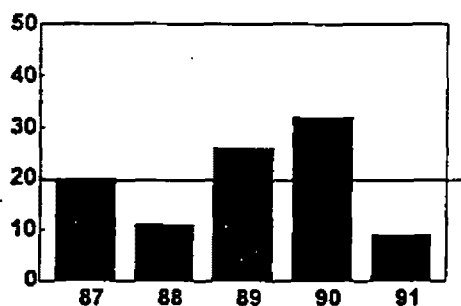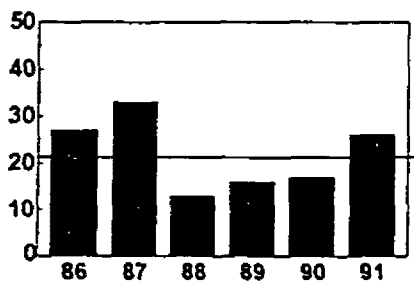Parts per Million
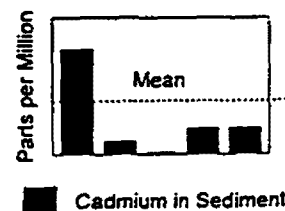
■ Cadmium in Sediment

## Nickel

The median sediment nickel concentrations in Baltimore Harbor and Back River were 46 ppm and 113 ppm, respectively (Table 5.9 and Figure 5.10a). The maximum sediment nickel concentration in the region was 127 ppm in Back River observed in 1987 (Table 5.9). Due to a relative lack of data on the toxicity of sediment nickel concentrations, reliable sediment quality guidelines for nickel are not available (Long, *et al.*, 1990)

There has been little change in the past two decades in sediment nickel concentrations in the Harbor (Figures 5.10b-c). This suggests that either nickel loads to the Harbor area have not declined substantially in this period or that the behavior of nickel in sediments differs from that of the other trace metals. Nickel concentrations did not sh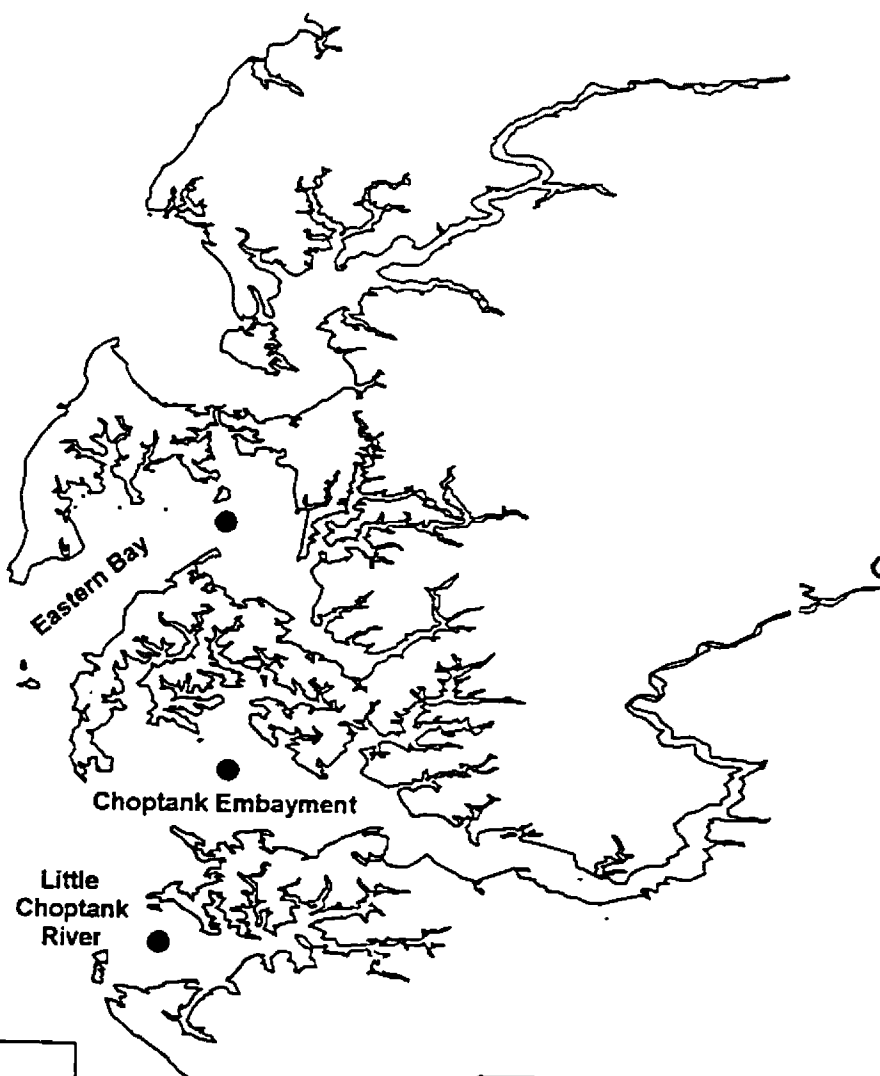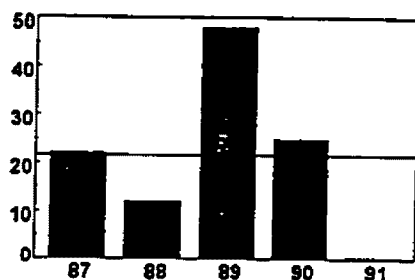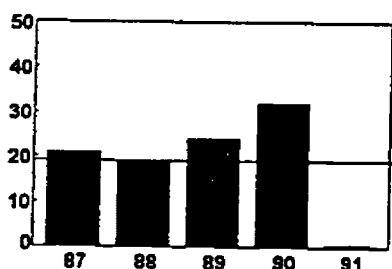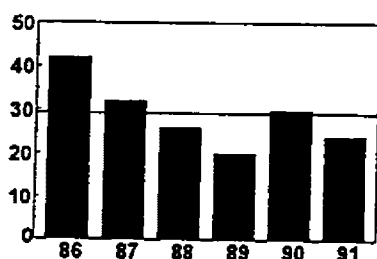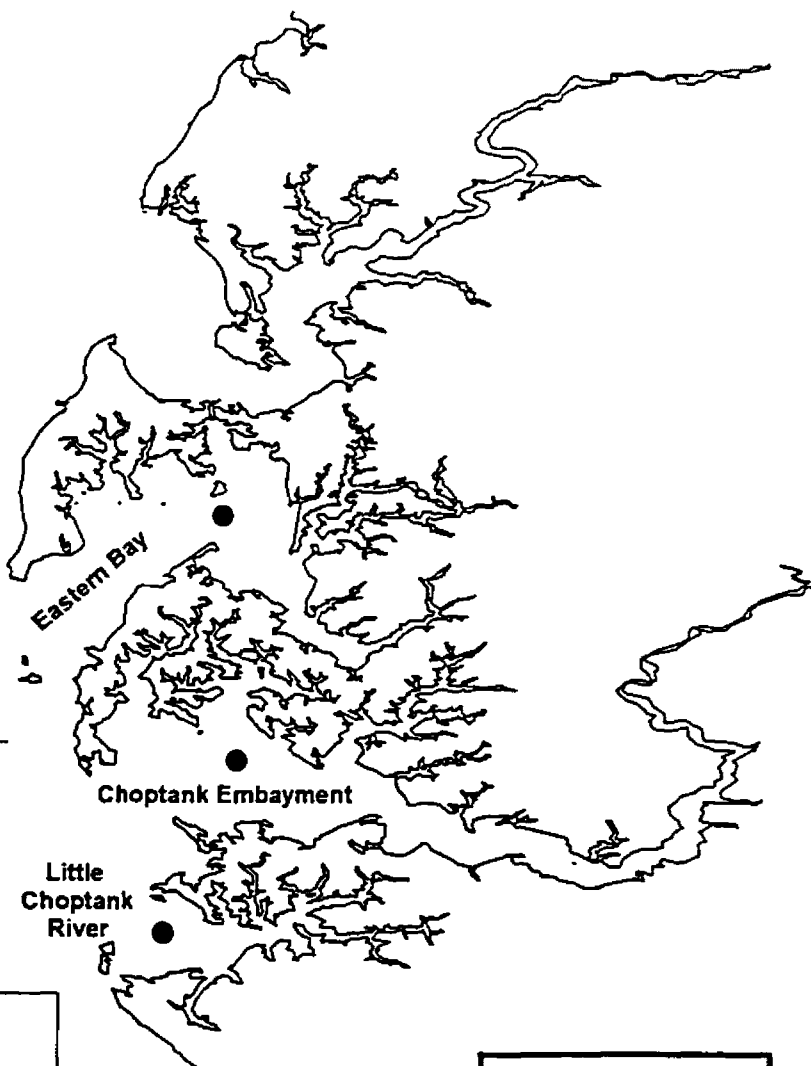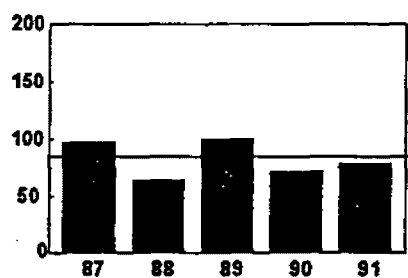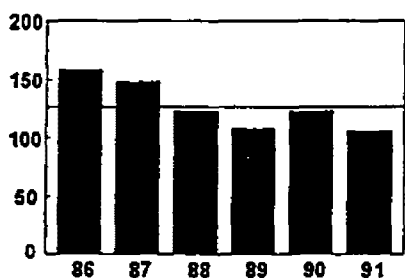ow as much spatial variability as the other trace metals in the 1973 study (Villa and Johnson, 1974), suggesting diffuse rather than point source inputs.

Table 5.9 Summary statistics for nickel in Baltimore Harbor region sediments. Concentrations are in ppm dry weight. Normalized values are dry weight values divided by percent fine grained sediment. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| | | | Measured | | | | | | Normalized | | | |
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 49 | 41 | 13 | 30 | 46 | 93 | 63 | 41 | 19 | 37 | 56 | 118 |
| | | | | | | | | | | | | |
| Center | 49 | 15 | 17 | 30 | 43 | 93 | 56 | 15 | 18 | 37 | 49 | 93 |
| North | 47 | 13 | 10 | 37 | 43 | 65 | 61 | 13 | 20 | 44 | 56 | 118 |
| South | 53 | 13 | 12 | 36 | 51 | 78 | 73 | 13 | 18 | 50 | 68 | 109 |
| | | | | | | | | | | | | |
| Zero | 46 | 13 | 12 | 34 | 43 | 78 | 56 | 13 | 17 | 37 | 49 | 90 |
| One | 49 | 16 | 11 | 30 | 48 | 70 | 68 | 16 | 23 | 44 | 56 | 118 |
| Two | 54 | 12 | 16 | 39 | 50 | 93 | 64 | 12 | 15 | 46 | 63 | 93 |
| | | | | | | | | | | | | |
| MWT5.0C | 42 | 5 | 12 | 34 | 37 | 64 | 47 | 5 | 13 | 37 | 41 | 68 |
| MWT5.0N | 42 | 4 | 3 | 37 | 42 | 45 | 52 | 4 | 11 | 44 | 47 | 68 |
| MWT5.0S | 55 | 4 | 15 | 44 | 49 | 78 | 72 | 4 | 17 | 50 | 75 . | 90 |
| MWT5.1C | 50 | 6 | 14 | 30 | 50 | 70 | 61 | 6 | 17 | 44 | 56 | 87 |
| MWT5.1N | 48 | 5 | 12 | 37 | 42 | 64 | 67 | 5 | 29 | 47 | 56 | 118 |
| MWT5.1S | 48 | 5 | 8 | 36 | 50 | 58 | 76 | 5 | 24 | 52 | 83 | 109 |
| MWT5.2C | 55 | 4 | 25 | 39 | 44 | 93 | 59 | 4 | 23 | 46 | 49 | 93 |
| MWT5.2N | 52 | 4 | 11 | 39 | 52 | 65 | 63 | 4 | 10 | 54 | 62 | 75 |
| MWT5.2S | 57 | 4 | 12 | 49 | 52 | 74 | 70 | 4 | 14 | 60 | 65 | 91 |
| | | | | | | | | | | | | |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 113 | 5 | 9 | 104 | 113 | 127 | 138 | 5 | 36 | 111 | 120 | 198 |

# Figure 5.10a Nickel concentrations (ppm) in Back River and Baltimore Harbor Sediments



Figure 5.10a  Nickel concentrations in sediment in Baltimore Harbor and Back River.  The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data.  The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III.  The NOEL and PEL values for sediment nickel concentrations are unavailable due to insufficient data (MacDonald, 1993).

# Figure 5.10b  Nickel in Baltimore Harbor Sediments
## 1973 v. 1991
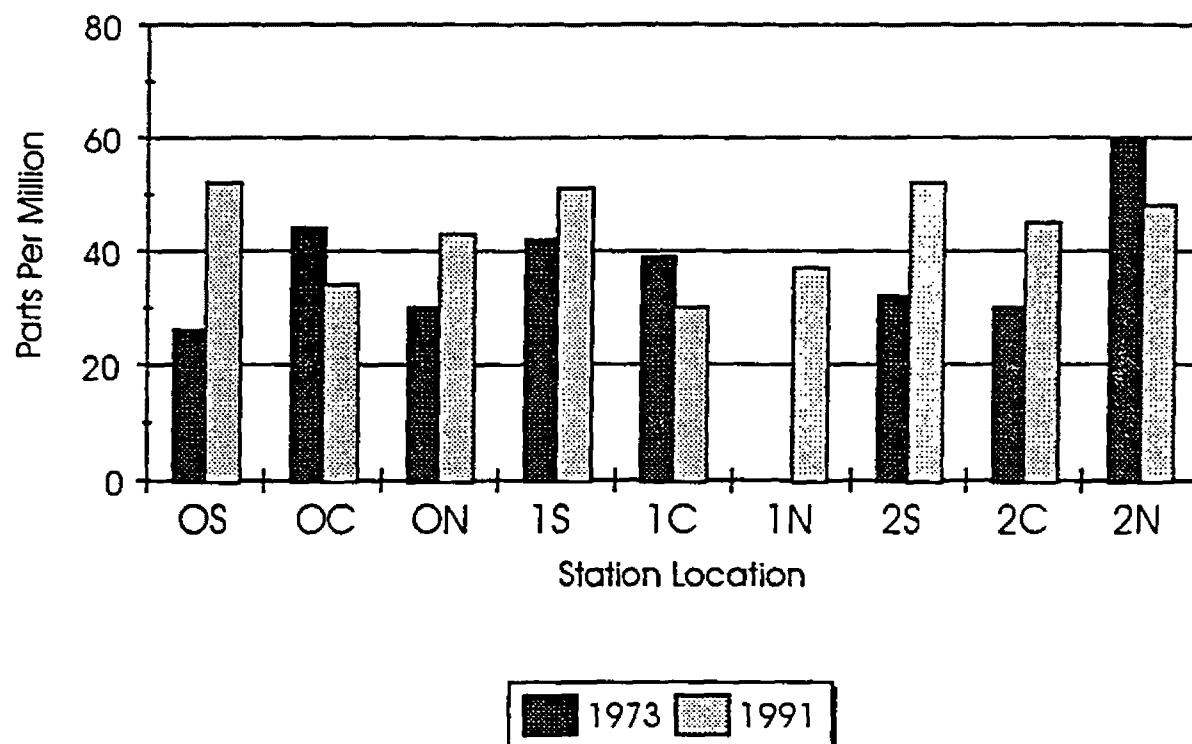


Figure 5.10b   Nickel concentrations in Baltimore Harbor sediments in 1991 (this report) compared to concentrations found in 1973 at nearby locations (Villa and Johnson, 1974).

# Figure 5.10c  Nickel in Baltimore Harbor Sediments
## 1981 v. 1991
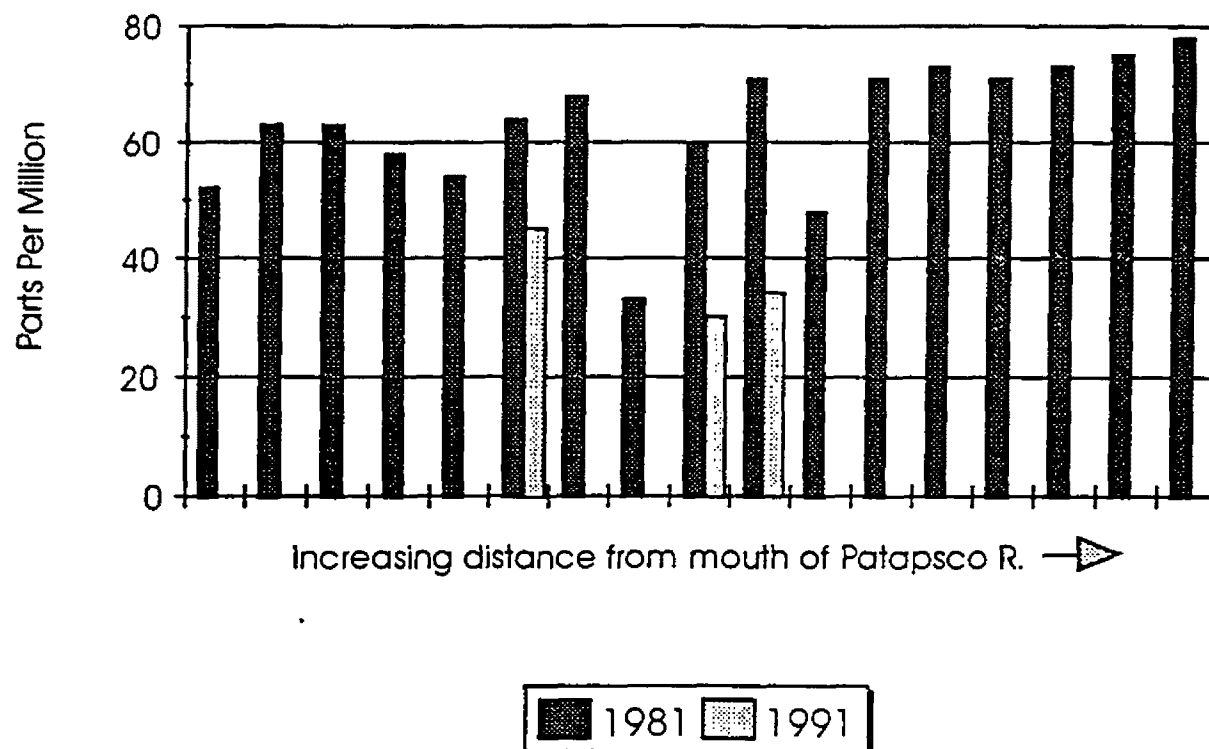


Figure 5.10c   Nickel concentrations in Baltimore Harbor sediments in 1991 (this report compared to concentrations found in 1981 at nearby locations as well as other stations within the dredged channel (Helz et al., 1983).

## Zinc

The median sediment zinc concentrations in Baltimore Harbor and Back River were 413 ppm and 682 ppm, respectively. The maximum concentration in the region, found in 1987 at station MWT5.1N in Baltimore Harbor in 1987, was 937 ppm (Table 5.10 and Figure 11a). Although the maximum zinc concentration was found in Baltimore Harbor, the median concentration of zinc was higher in the Back River than at any of the Harbor stations. All stations had median zinc concentrations which exceeded both the NOEL and PEL concentrations of 68 and 300 ppm, respectively. Toxicity to aquatic biota due to the measured sediment zinc concentrations is likely at all monitored stations in the Baltimore Harbor region, and is most likely at the Back River station.

Comparison of appropriate 1991 data with that from earlier studies shows that zinc concentrations in the Baltimore Harbor have declined significantly in the past two decades (Figures 5.9b-c). The average zinc concentration in 1973 in the Outer Harbor was 710 ppm, and average concentrations were several times higher than this in Colgate Creek, Bear Creek and Old Road Bay (Villa and Johnson, 1974).

Table 5.10 Summary statistics for zinc in Baltimore Harbor region sediments. Concentrations are in ppm dry weight. Normalized values are dry weight values divided by percent silt and clay. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| Area | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 451 | 41 | 133 | 256 | 413 | 937 | 589 | 41 | 262 | 268 | 535 | 1722 |
| Center | 359 | 15 | 64 | 256 | 343 | 492 | 417 | 15 | 93 | 268 | 391 | 654 |
| North | 483 | 13 | 165 | 328 | 413 | 937 | 649 | 13 | 354 | 365 | 562 | 1722 |
| South | 524 | 13 | 99 | 377 | 497 | 750 | 727 | 13 | 179 | 522 | 686 | 1047 |
| Zero | 404 | 13 | 82 | 256 | 413 | 497 | 504 | 13 | 184 | 268 | 450 | 980 |
| One | 443 | 16 | 152 | 297 | 405 | 937 | 634 | 16 | 336 | 357 | 557 | 1722 |
| Two | 510 | 12 | 138 | 311 | 531 | 750 | 621 | 12 | 217 | 334 | 601 | 1021 |
| MWT5.0C | 353 | 5 | 86 | 256 | 343 | 492 | 393 | 5 | 98 | 268 | 361 | 526 |
| MWT5.0N | 381 | 4 | 43 | 328 | 388 | 418 | 476 | 4 | 130 | 365 | 438 | 664 |
| MWT5.0S | 492 | 4 | 5 | 484 | 493 | 497 | 672 | 4 | 214 | 522 | 593 | 980 |
| MWT5.1C | 372 | 6 | 63 | 297 | 353 | 454 | 464 | 6 | 108 | 357 | 454 | 654 |
| MWT5.1N | 499 | 5 | 245 | 369 | 399 | 937 | 742 | 5 | 551 | 423 | 556 | 1722 |
| MWT5.1S | 473 | 5 | 97 | 377 | 422 | 594 | 730 | 5 | 185 | 559 | 686 | 1047 |
| MWT5.2C | 346 | 4 | 43 | 311 | 336 | 401 | 379 | 4 | 31 | 334 | 389 | 404 |
| MWT5.2N | 565 | 4 | 57 | 523 | 543 | 649 | 707 | 4 | 145 | 587 | 676 | 887 |
| MWT5.2S | 620 | 4 | 94 | 527 | 601 | 750 | 778 | 4 | 173 | 611 | 740 | 1021 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 681 | 5 | 27 | 638 | 682 | 708 | 831 | 5 | 210 | 684 | 735 | 1197 |

# Figure 5.11a Zinc concentrations (ppm)
## in Back River and Baltimore Harbor Sediments



I. Baltimore Harbor Stations

II. Transects Along Channel

III. Transects Across Channel

Figure 5.11a Zinc concentrations in sediment in Baltimore Harbor and Back River. The box ar d whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. The Baltimore Harbor stations in I. a e aggregated by their location relative to the central dredged channel in II. and III. The NO EL and PEL values for sediment zinc concentrations are 68 ppm and 300 ppm, respectively (MacDonald, 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

Figure 5.11b Zinc in Baltimore Harbor Sediments
1973 v. 1991
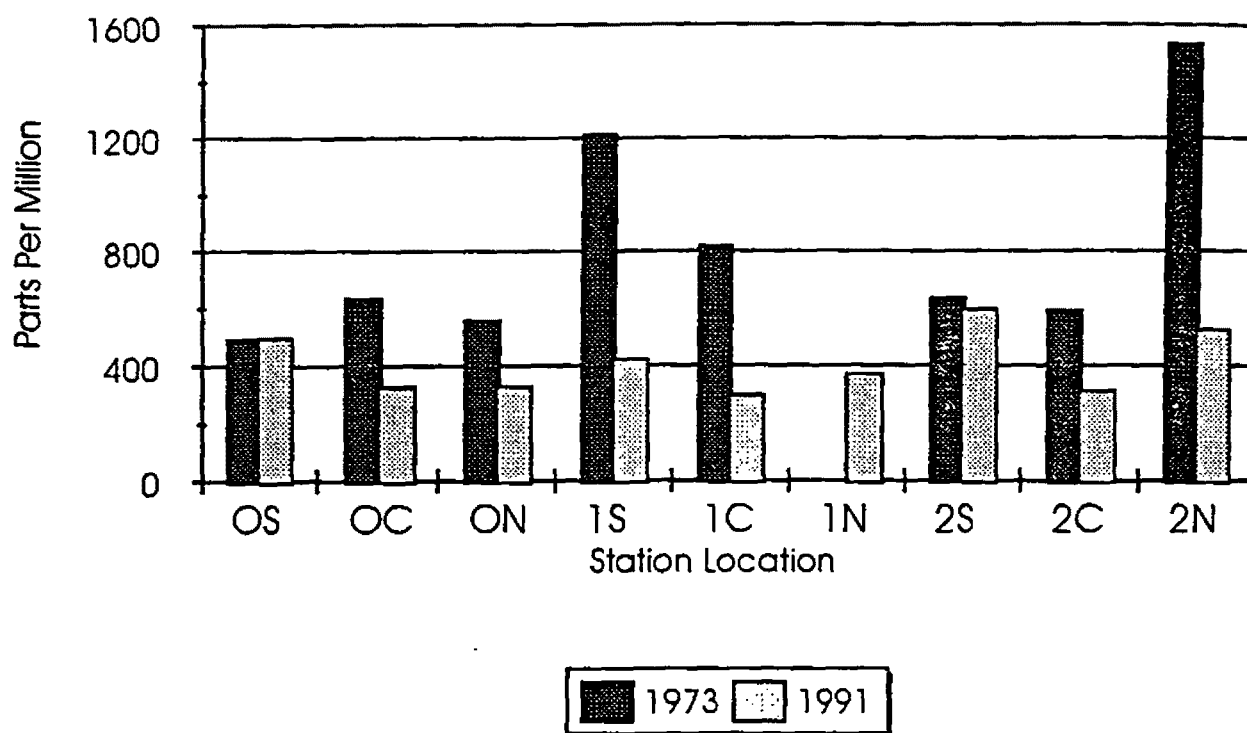
Figure 5.11b Zinc concentrations in Baltimore Harbor sediments in 1991 (this report) compared to concentrations found in 1973 at nearby locations (Villa and Johnson, 1974).

Figure 5.11c  Zinc in Baltimore Harbor Sediments
1981 v. 1991
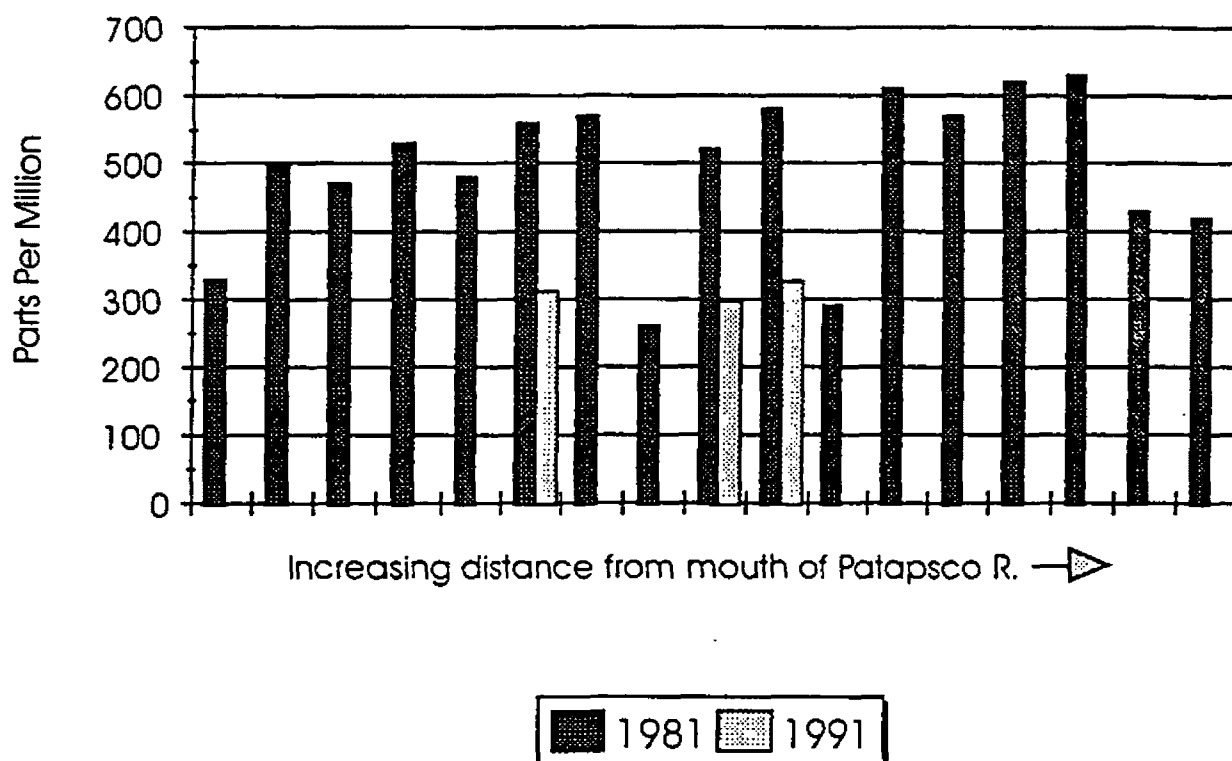
Figure 5.11c  Zinc concentrations in Baltimore Harbor sediments in 1991 (this report) compared to concentrations found in 1981 at nearby locations as well as other stations within the dredged channel (Helz et al.,1983).

## Summary of Sediment Trace Metal Concentrations in Baltimore Harbor and Back River

Sediment trace metal concentrations at the sediment contaminant monitoring stations in Baltimore Harbor and Back River were generally markedly higher than those observed elsewhere in the Bay, except for the Anacostia and Elizabeth Rivers. The Baltimore Harbor region had the highest measurements of sediment concentrations of chromium, lead, and zinc, and the region's maximum sediment concentrations of the other trace metals approached the maximum concentrations found Baywide. Annual measurements of trace metal concentrations in this region are shown in Figures 5.12a-h.

Within Baltimore Harbor, median sediment zinc concentrations exceeded the PEL concentration at all nine stations, and average sediment chromium concentrations exceeded the PEL concentration at six of nine stations (Figure 5.12c). Median sediment lead concentrations were above the PEL concentration at one station (Figure 5.12e). All trace metals, with the exception of cadmium, occurred at average concentrations exceeding the NOEL concentrations at some or all of the Baltimore Harbor stations.

Mean sediment concentrations of cadmium, lead, and nickel were markedly higher at the Back River station compared to the Baltimore Harbor stations, and markedly lower for arsenic, while for most other trace metals, mean concentrations in the Back River and Baltimore Harbor were comparable to one another (Figures 5.12a-h). In Back River, four metals— chromium, lead, and zinc —were found at average sediment concentrations exceeding their PEL values (Figures 5.12c-e and 5.12h).

Figure 5.12a. Annual arsenic concentrations (ppm) in Back River and Baltimore Harbor
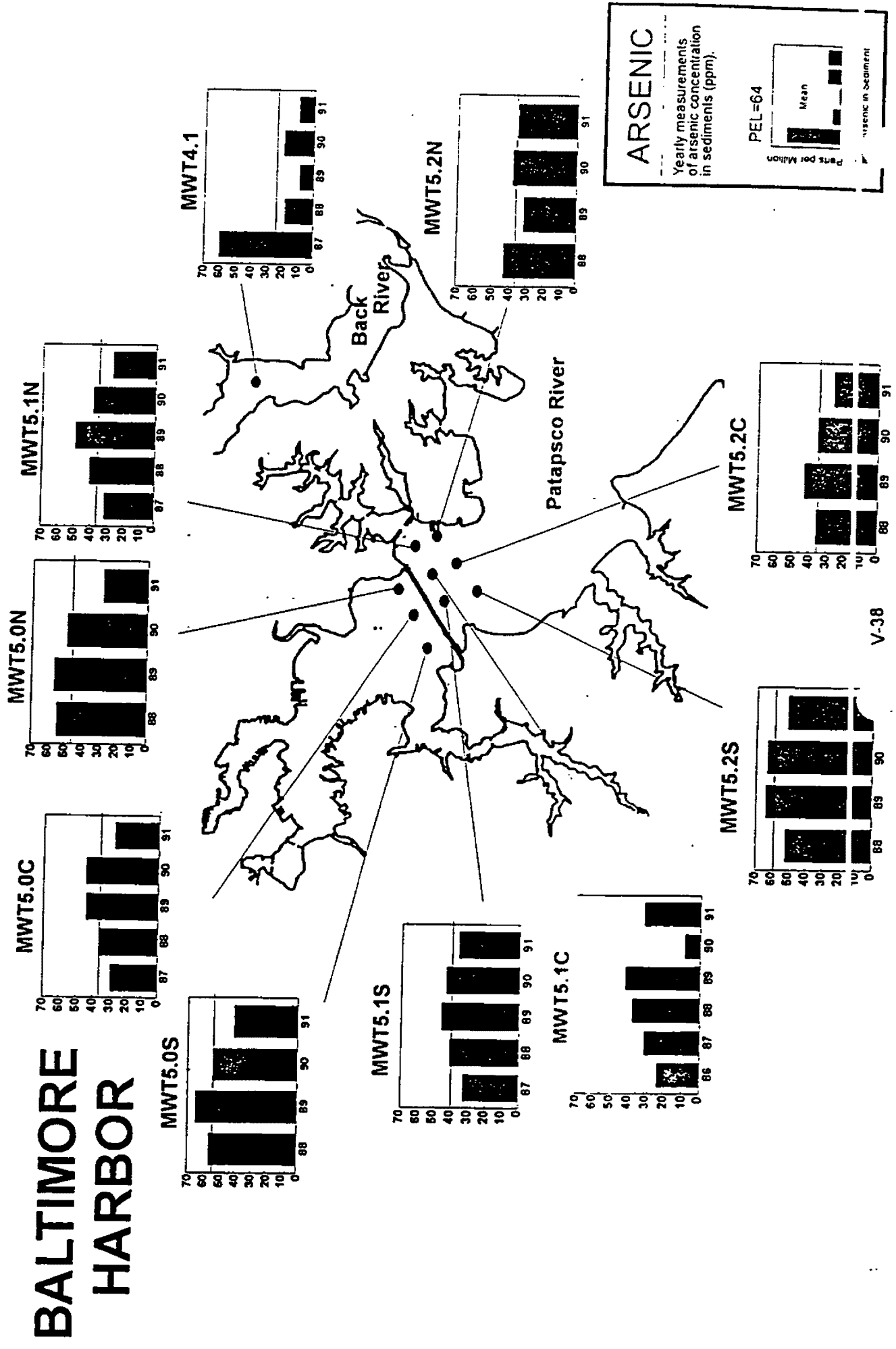
Figure 5.12b. Annual cadmium concentrations (ppm) in Back River and Baltimore Harbor
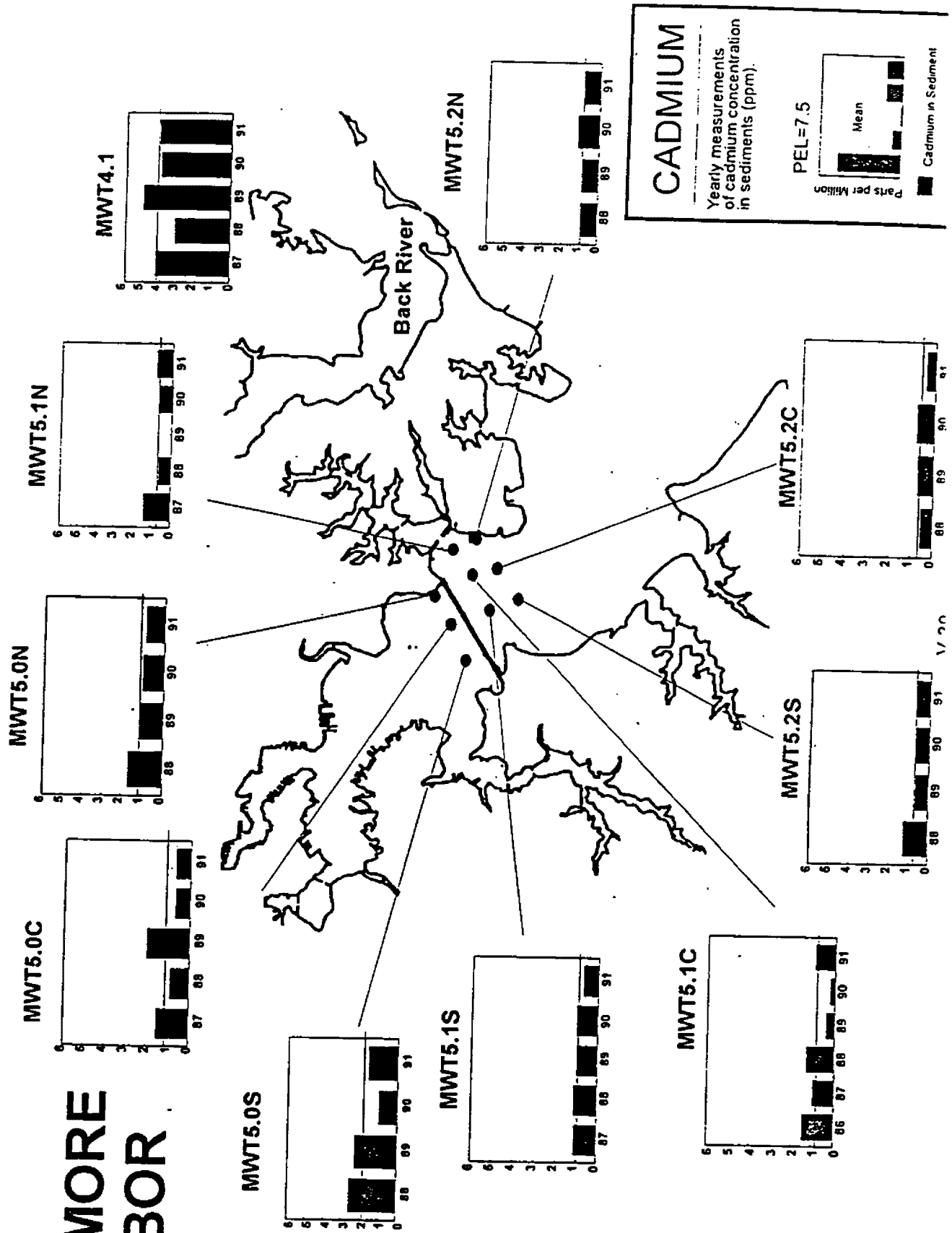


BALTIMORE HARBOR

Figure 5.12c. Annual chromium concentrations (ppm) in Back River and Baltimore Harbor
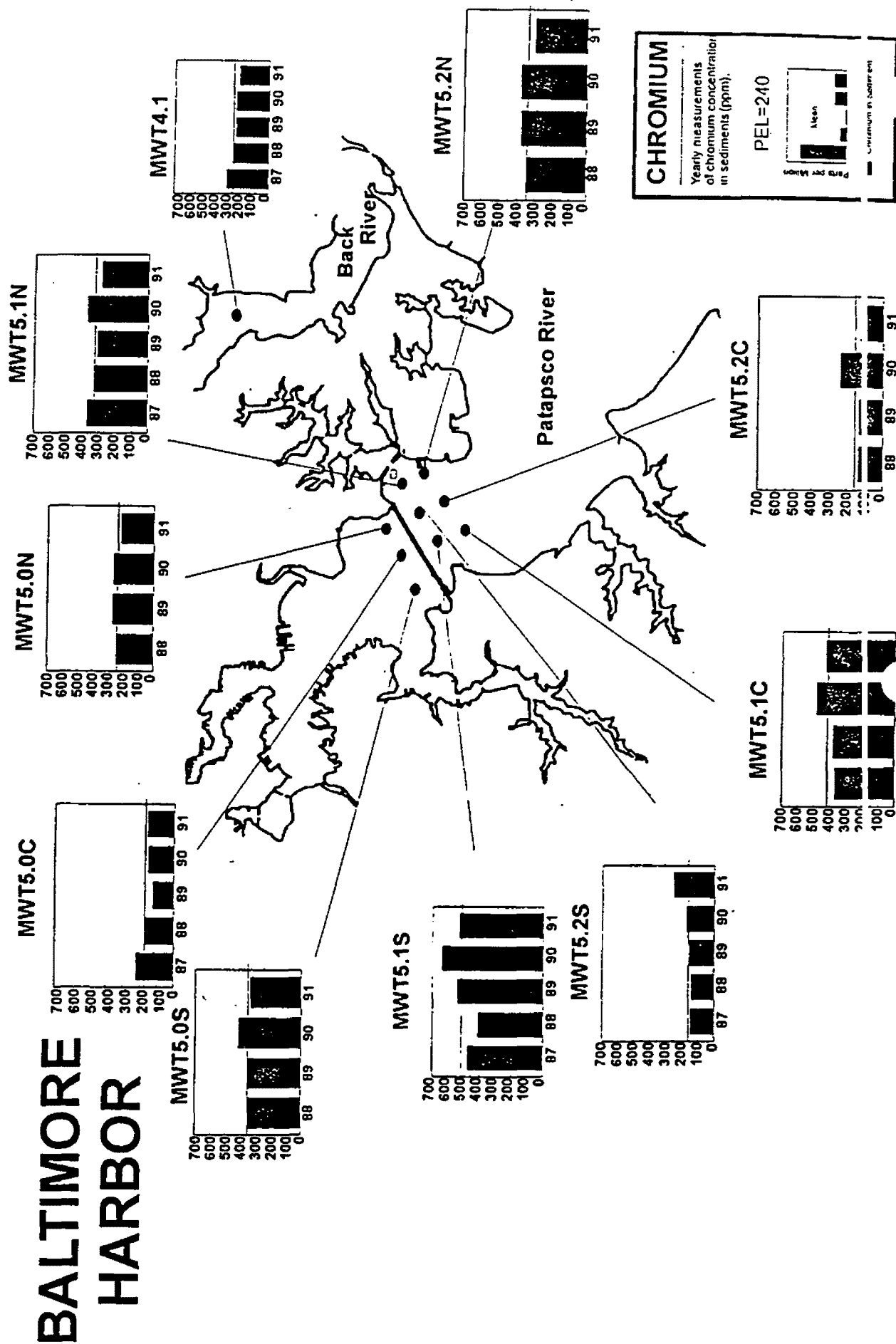
Figure 5.12d. Annual copper concentrations (ppm) in Back River and Baltimore Harbor
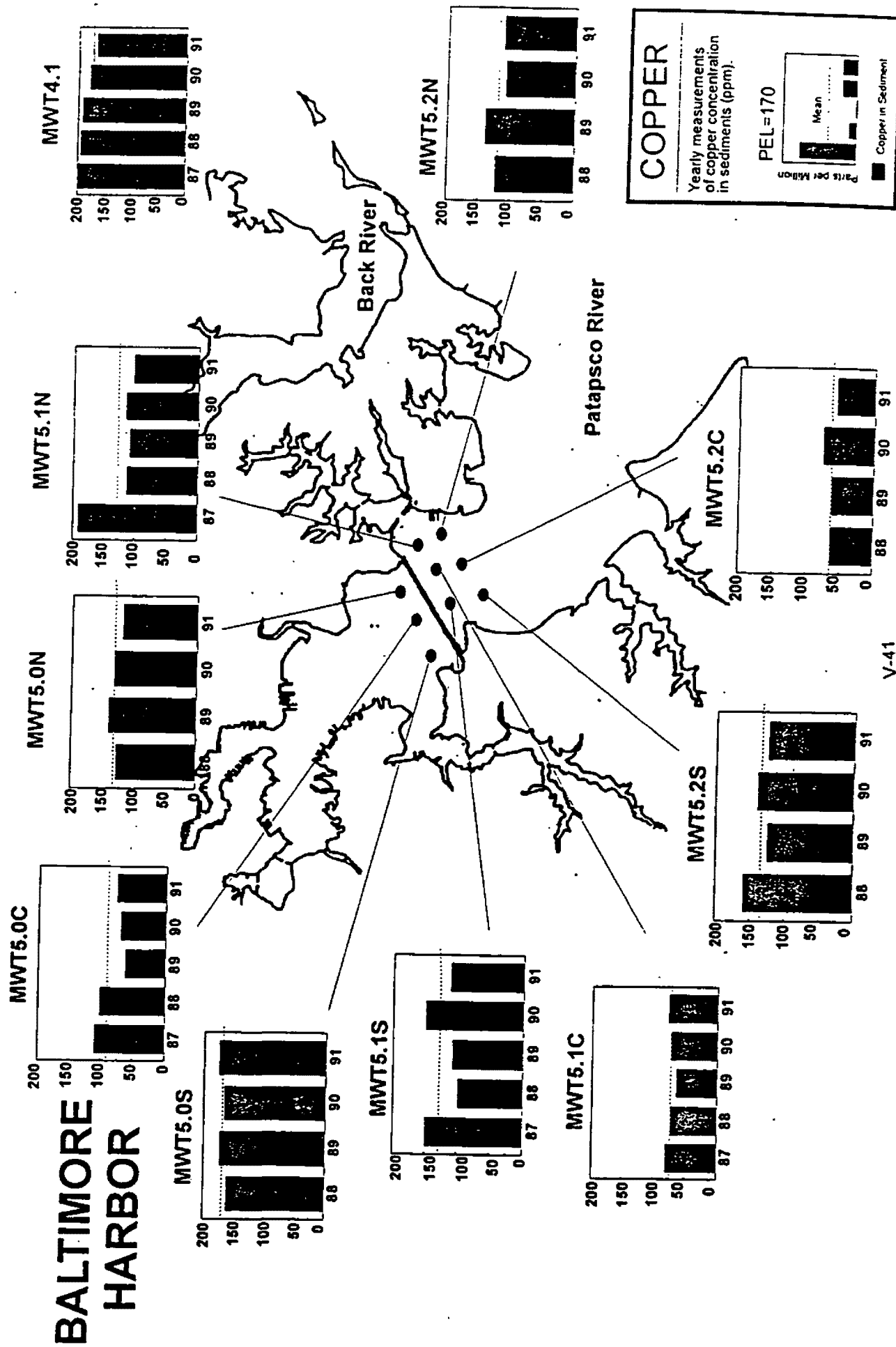
Figure 5.12e. Annual lead concentrations (ppm) in Back River and Baltimore Harbor
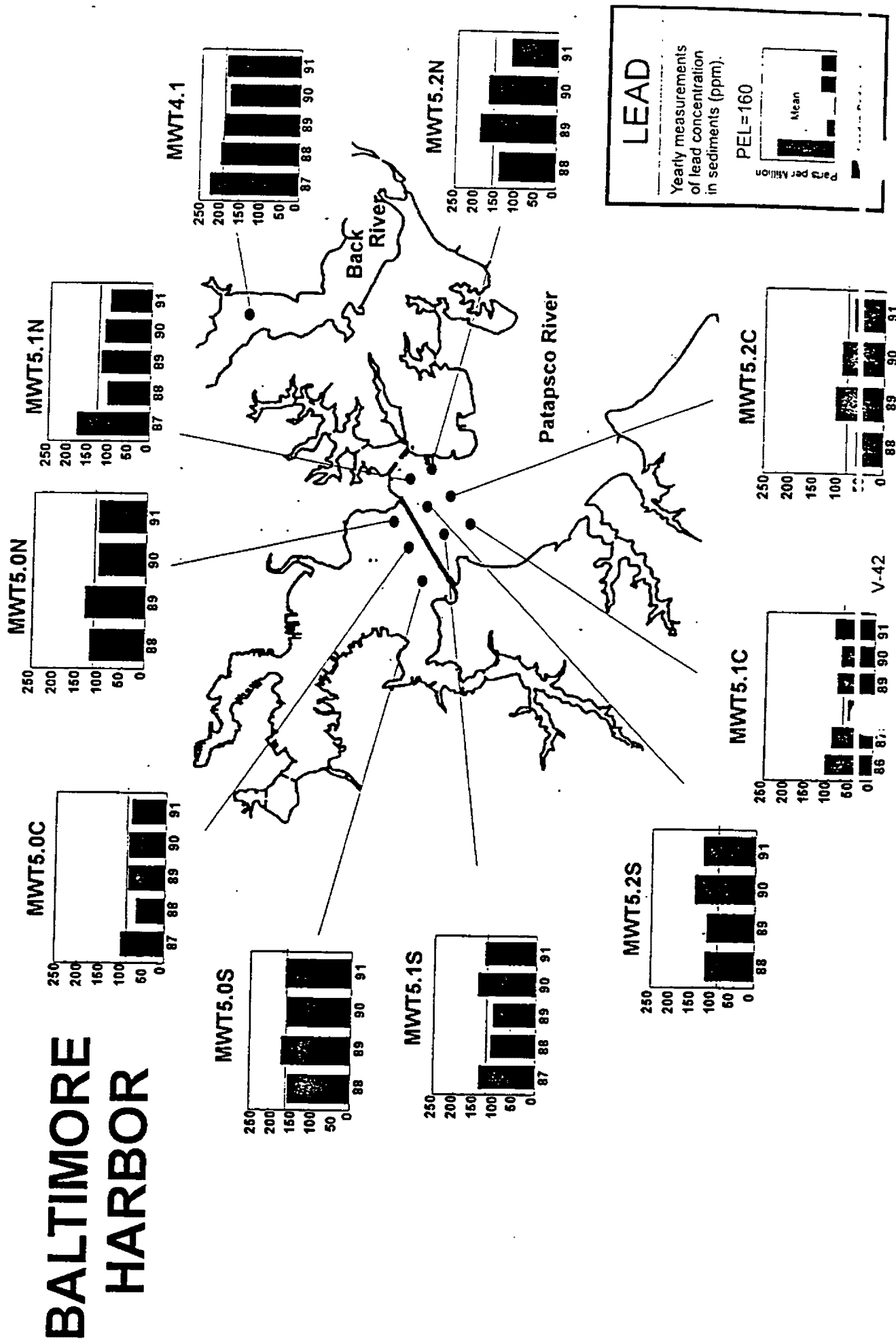


BALTIMORE
HARBOR

Figure 5.12f. Annual mercury concentrations (ppm) in Back River and Baltimore Harbor



V-43
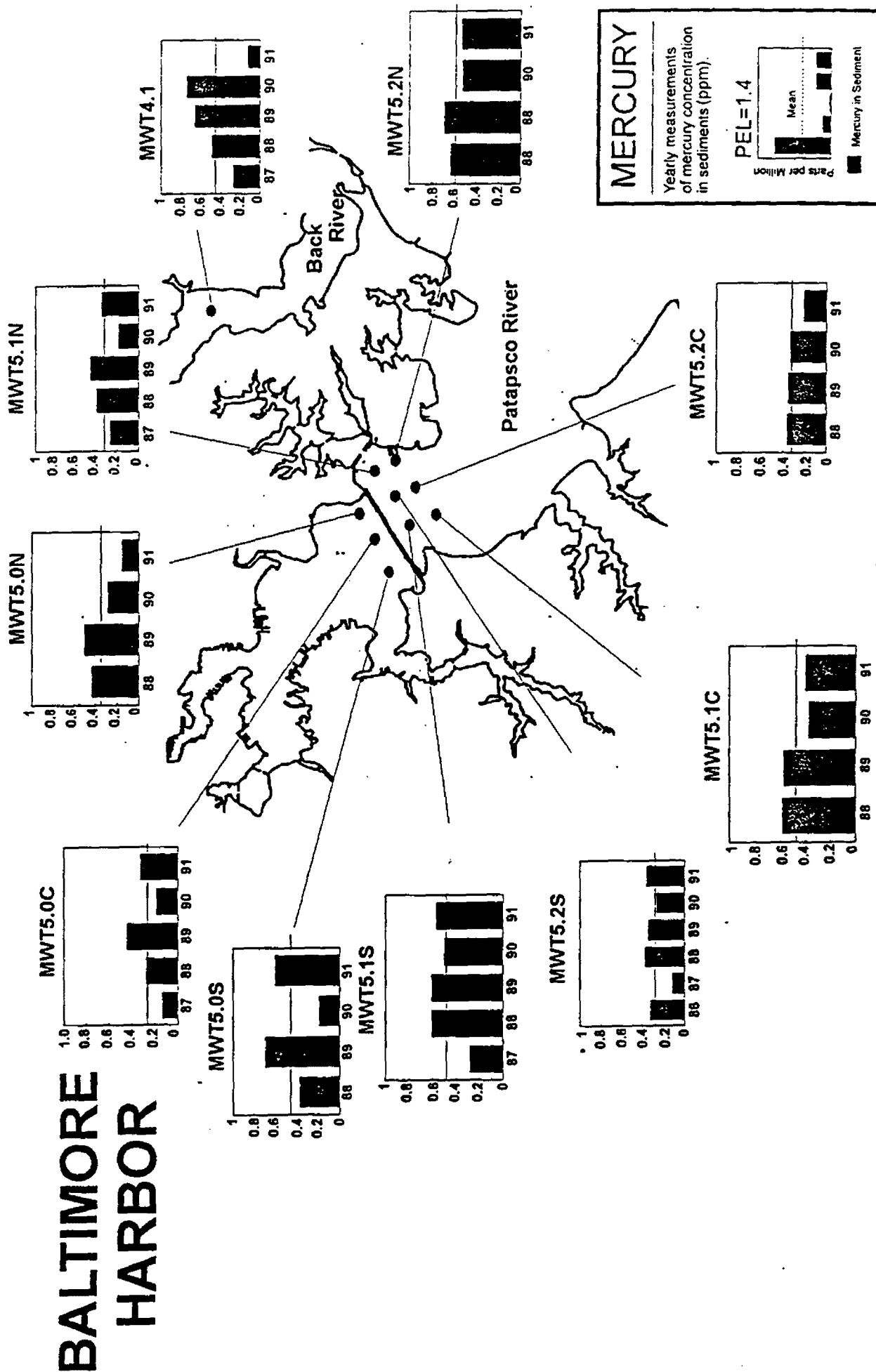
Figure 5.12g. Annual nickel concentrations (ppm) in Back River and Baltimore Harbor
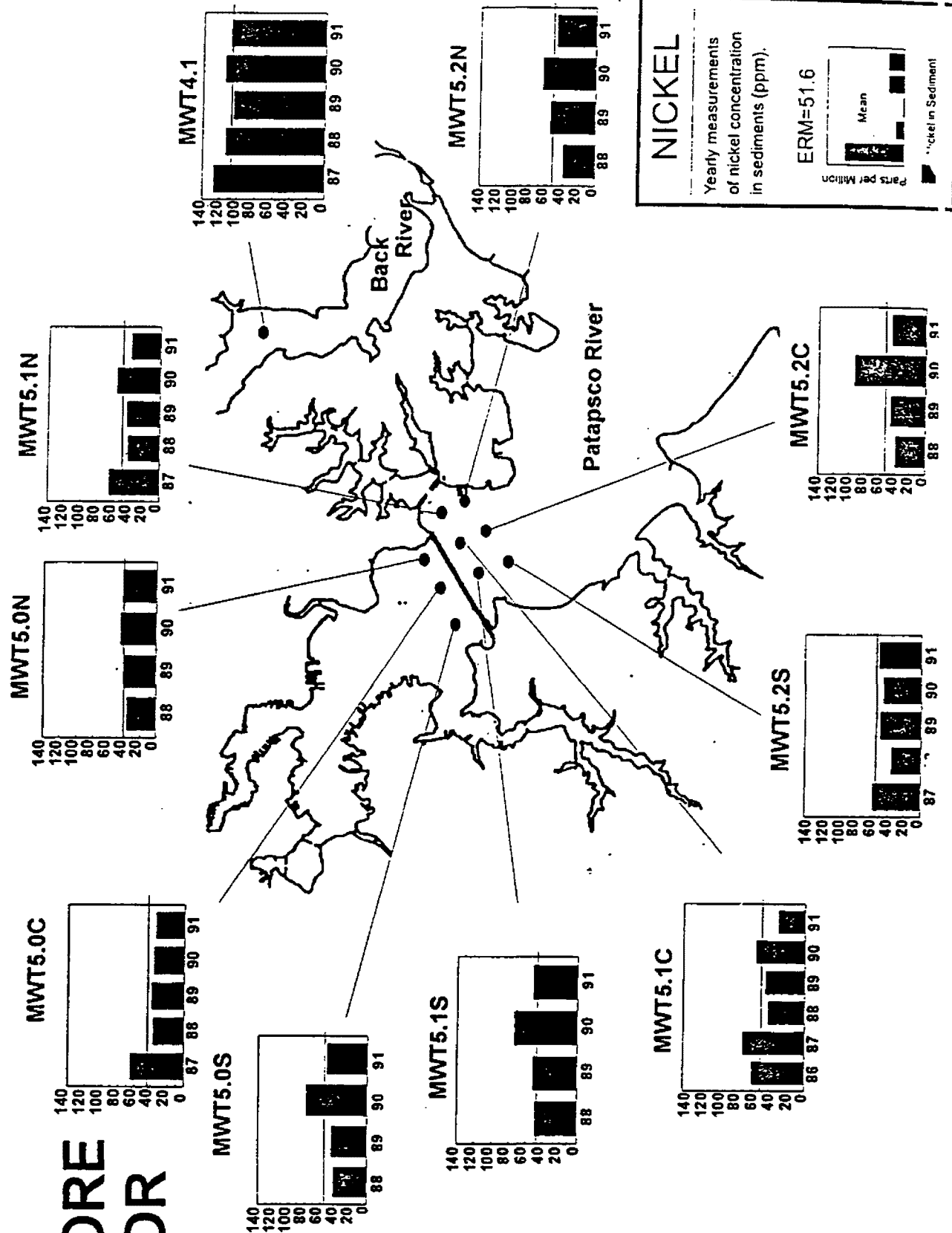
Figure 5.12h. Annual zinc concentrations (ppm) in Back River and Baltimore Harbor



V-45
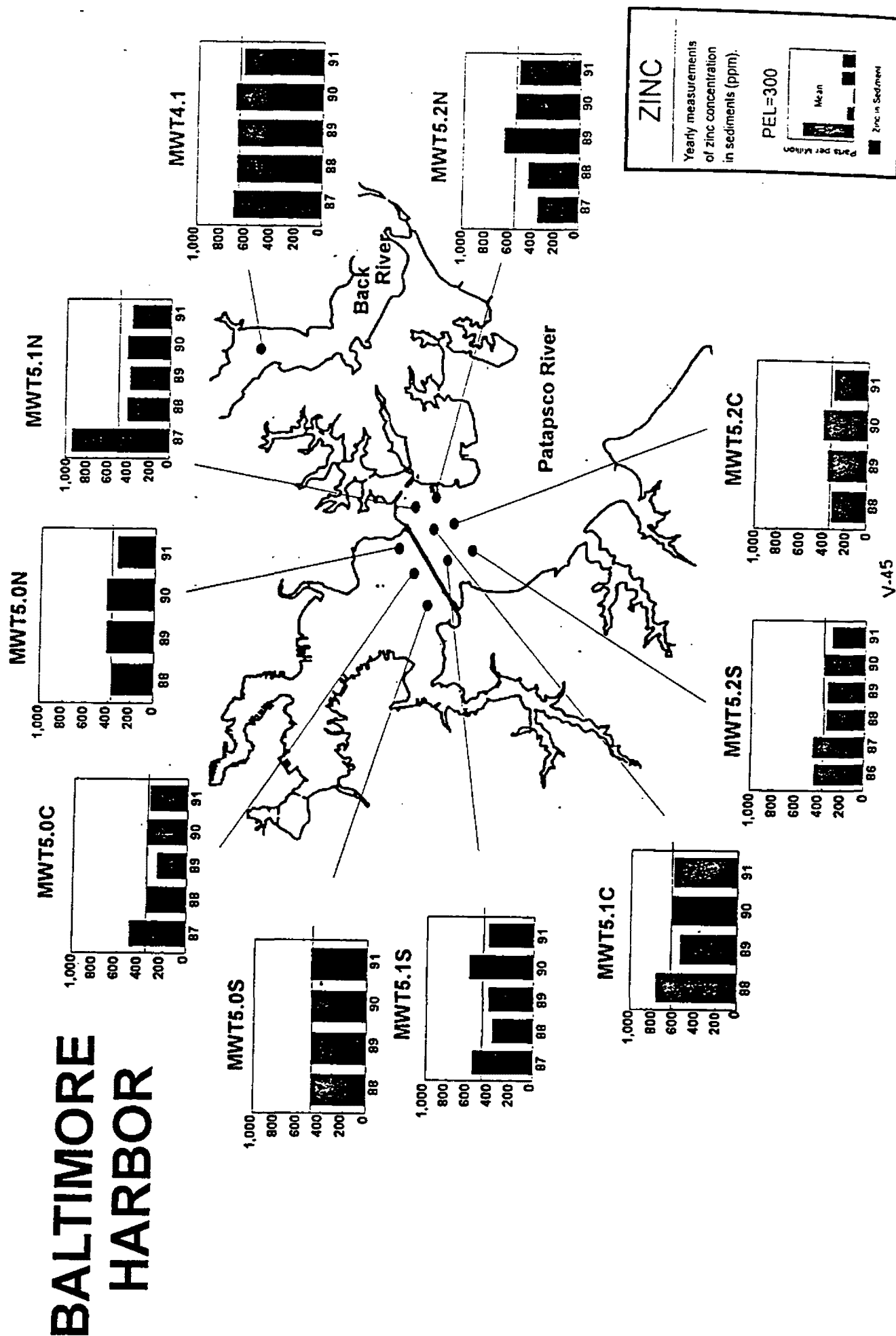
# Spatial Distribution of Individual Polycyclic Aromatic Hydrocarbons

## Anthracene

The median sediment anthracene concentrations in Baltimore Harbor and Back River were 170 ppb and 82 ppb, respectively (Table 5.11). The region's maximum concentration of 926 ppb was found at station MWT5.2N in Baltimore Harbor in 1991 (Table 5.11 and Figure 5.13).

The median concentration exceeded the NOEL concentration of 85 ppb at seven of the nine stations in Baltimore Harbor, but only the single measurement at station MWT5.2N in Baltimore Harbor was in excess of the PEL of 740 ppb (Table 5.11). Note that only one measurement is available for six of the nine stations. Toxic effects to aquatic biota due to the measured concentrations of anthracene in the sediment are not likely at the monitored areas in the region, with the exception of station MWT5.2N in Baltimore Harbor.

Table 5.11 Summary statistics for anthracene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the sediment's fraction total organic carbon. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| Area | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 221 | 13 | 243 | 27 | 170 | 926 | 5590 | 13 | 7180 | 810 | 4420 | 28060 |
| | | | | | | | | | | | | |
| Center | 172 | 6 | 154 | 27 | 139 | 419 | 3650 | 6 | 2830 | 810 | 3480 | 8130 |
| North | 352 | 4 | 393 | 47 | 217 | 926 | 10180 | 4 | 12170 | 1120 | 5780 | 28060 |
| South | 144 | 3 | 113 | 31 | 143 | 257 | 3340 | 3 | 2510 | 820 | 3360 | 5850 |
| | | | | | | | | | | | | |
| Zero | 192 | 4 | 91 | 88 | 203 | 273 | 5270 | 4 | 2790 | 2450 | 5250 | 8130 |
| One | 121 | 6 | 156 | 27 | 40 | 419 | 2100 | 6 | 1840 | 810 | 1110 | 4520 |
| Two | 458 | 3 | 407 | 190 | 257 | 926 | 13000 | 3 | 13040 | 5110 | 5850 | 28060 |
| | | | | | | | | | | | | |
| MWT5.0C | 181 | 2 | 131 | 88 | 181 | 273 | 5290 | 2 | 4020 | 2450 | 5290 | 8130 |
| MWT5.0N | 263 | 1 | . | 263 | 263 | 263 | 7140 | 1 | . | 7140 | 7140 | 7140 |
| MWT5.0S | 143 | 1 | . | 143 | 143 | 143 | 3360 | 1 | . | 3360 | 3360 | 3360 |
| MWT5.1C | 160 | 3 | 225 | 27 | 33 | 419 | 2070 | 3 | 2110 | 810 | 900 | 4520 |
| MWT5.1N | 119 | 2 | 87 | 47 | 109 | 170 | 2770 | 2 | 2330 | 1120 | 2770 | 4420 |
| MWT5.1S | 31 | 1 | . | 31 | 31 | 31 | 820 | 1 | . | 820 | 820 | 820 |
| MWT5.2C | 190 | 1 | . | 190 | 190 | 190 | 5110 | 1 | . | 5110 | 5110 | 5110 |
| MWT5.2N | 926 | 1 | . | 926 | 926 | 926 | 28060 | 1 | . | 28060 | 28060 | 28060 |
| MWT5.2S | 257 | 1 | . | 257 | 257 | 257 | 5850 | 1 | . | 5850 | 5850 | 5850 |
| | | | | | | | | | | | | |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 82 | 2 | 8 | 76 | 82 | 88 | 1440 | 2 | 80 | 1380 | 1440 | 1490 |

# Figure 5.13 Anthracene concentrations (ppb) in Back River and Baltimore Harbor Sediments



I. Baltimore Harbor Stations

II. Transects Along Channel

III. Transects Across Channel

Figure 5.13 Anthracene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment anthracene concentrations are 85 ppb and 740 ppb, respectively (MacDonald, 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

## Benzo[a]anthracene

Benzo[a]anthracene is a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a). The median sediment concentrations of benzo[a]anthracene were 271 ppb and 229 ppb in Baltimore Harbor and Back River, respectively (Table 5.12). The maximum sediment concentration, found in Baltimore Harbor at station MWT5.2N in 1991, was 1902 ppb (Table 5.12 and Figure 5.14).

Sediment concentrations of benzo[a]anthracene above the NOEL concentration of 160 ppb were observed at all but one station in the Baltimore Harbor region (Table 5.12). Measured concentrations exceeded the PEL concentration of 1300 ppb only at station MWT5.2N in Baltimore Harbor. Toxic effects to aquatic biota due to the measured concentrations of benzo[a]anthracene in the sediment are not likely at the monitored areas in the Baltimore Harbor region with the exception of station MWT5.2N in Baltimore Harbor.

Table 5.12 Summary statistics for benzo[a]anthracene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 504 | 13 | 528 | 93 | 271 | 1902 | 12360 | 13 | 14520 | 2770 | 7300 | 57630 |
| Center | 419 | 6 | 428 | 93 | 249 | 1253 | 8230 | 6 | 4620 | 2780 | 6730 | 14230 |
| North | 808 | 4 | 771 | 144 | 594 | 1902 | 23100 | 4 | 23960 | 3440 | 15670 | 57630 |
| South | 268 | 3 | 174 | 104 | 250 | 450 | 6290 | 3 | 3750 | 2770 | 5880 | 10230 |
| Zero | 337 | 4 | 137 | 194 | 339 | 478 | 9280 | 4 | 4340 | 5400 | 8730 | 14230 |
| One | 430 | 6 | 475 | 93 | 185 | 1253 | 8060 | 6 | 7020 | 2770 | 4800 | 19740 |
| Two | 874 | 3 | 894 | 271 | 450 | 1902 | 25050 | 3 | 28250 | 7300 | 10230 | 57630 |
| MWT5.0C | 336 | 2 | 201 | 194 | 336 | 478 | 9820 | 2 | 6240 | 5400 | 9820 | 14230 |
| MWT5.0N | 428 | 1 | . | 429 | 428 | 428 | 11590 | 1 | . | 11590 | 11590 | 11590 |
| MWT5.0S | 250 | 1 | . | 250 | 250 | 250 | 5880 | 1 | . | 5880 | 5880 | 5880 |
| MWT5.1C | 524 | 3 | 635 | 93 | 226 | 1253 | 7480 | 3 | 5470 | 2780 | 6160 | 13490 |
| MWT5.1N | 452 | 2 | 436 | 144 | 452 | 760 | 11590 | 2 | 11520 | 3440 | 11590 | 19740 |
| MWT5.1S | 104 | 1 | . | 104 | 104 | 104 | 2770 | 1 | . | 2770 | 2770 | 2770 |
| MWT5.2C | 271 | 1 | . | 271 | 271 | 271 | 7300 | 1 | . | 7300 | 7300 | 7300 |
| MWT5.2N | 1902 | 1 | . | 1902 | 1902 | 1902 | 57630 | 1 | . | 57630 | 57630 | 57630 |
| MWT5.2S | 450 | 1 | . | 450 | 450 | 450 | 10230 | 1 | . | 10230 | 10230 | 10230 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 229 | 2 | 73 | 178 | 229 | 281 | 3990 | 2 | 1080 | 3230 | 3990 | 4750 |

# Figure 5.14 Benzo(a)anthracene concentrations (ppb) in Back River and Baltimore Harbor Sediments



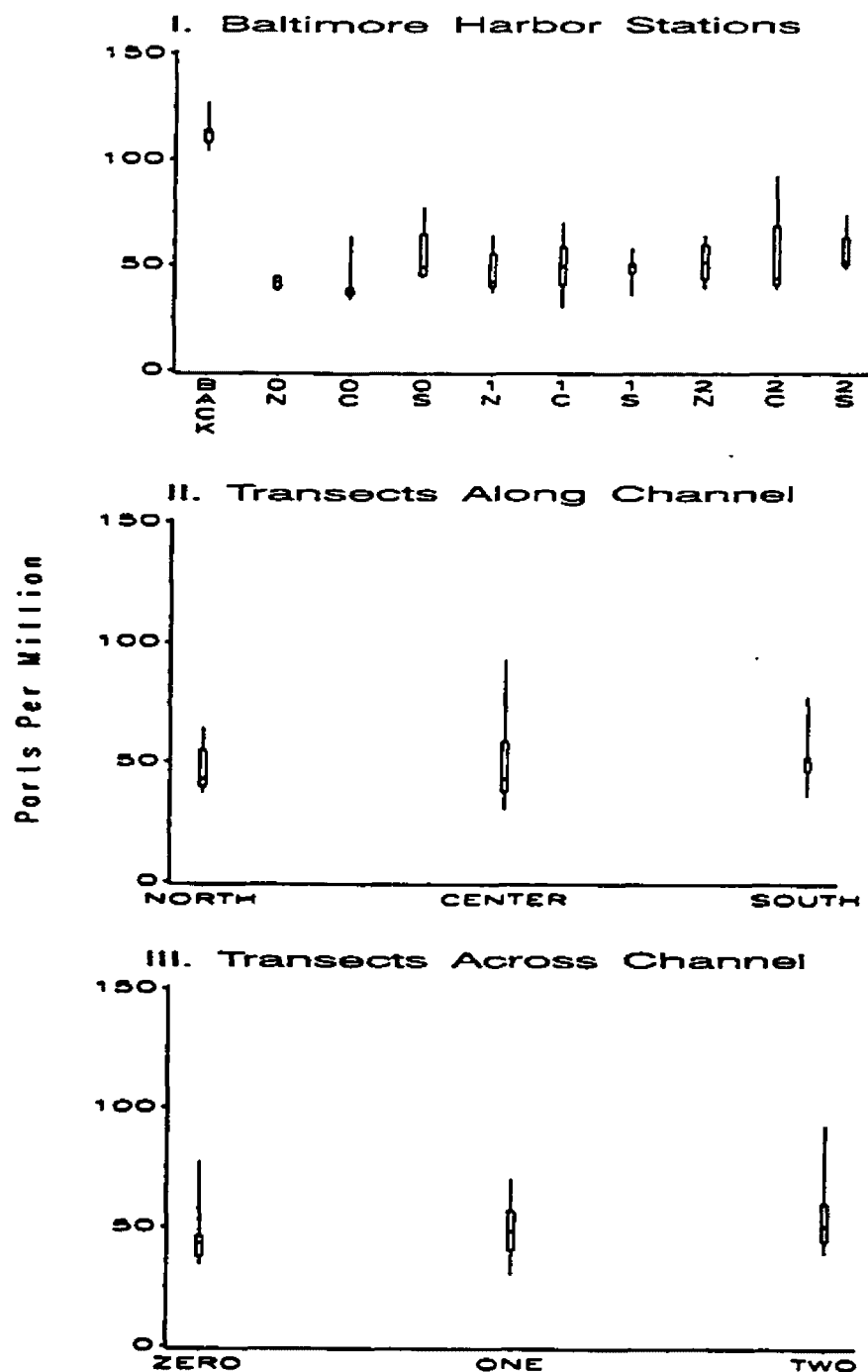Figure 5.14 Benzo(a)anthracene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment benzo(a)anthracene concentrations are 160 ppb and 1300 ppb, respectively (MacDonald, 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

## Benzo[b]fluoranthene

The median sediment concentrations of benzo[b]fluoranthene were 543 ppb and 313 ppb in Baltimore Harbor and Back River, respectively (Table 5.13 and Figure 5.15). The maximum concentration of 3003 ppb was found at the MWT5.2N station in the Baltimore Harbor in 1991. There were insufficient data available for the development of NOEL and PEL guidelines for benzo[b]fluoranthene (MacDonald, 1993).

Table 5.13 Summary statistics for benzo[b]fluoranthene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 759 | 13 | 777 | 172 | 543 | 3003 | 18970 | 13 | 22520 | 4680 | 14590 | 91000 |
| Center | 595 | 6 | 525 | 172 | 437 | 1594 | 12200 | 6 | 6100 | 5150 | 11920 | 20330 |
| North | 1221 | 4 | 1216 | 269 | 807 | 3003 | 35040 | 4 | 37990 | 6440 | 21370 | 91000 |
| South | 472 | 3 | 283 | 176 | 499 | 740 | 11080 | 3 | 6090 | 4680 | 11750 | 16810 |
| Zero | 560 | 4 | 180 | 332 | 591 | 724 | 15240 | 4 | 5570 | 9250 | 15680 | 20330 |
| One | 558 | 6 | 576 | 172 | 258 | 1594 | 10540 | 6 | 7710 | 4680 | 6570 | 23120 |
| Two | 1428 | 3 | 1367 | 543 | 740 | 3003 | 40800 | 3 | 43490 | 14590 | 16810 | 91000 |
| MWT5.0C | 508 | 2 | 248 | 332 | 508 | 683 | 14790 | 2 | 7840 | 9250 | 14790 | 20330 |
| MWT5.0N | 724 | 1 | . | 724 | 724 | 724 | 19620 | 1 | . | 19620 | 19620 | 19620 |
| MWT5.0S | 499 | 1 | . | 499 | 499 | 499 | 11750 | 1 | . | 11750 | 11750 | 11750 |
| MWT5.1C | 671 | 3 | 801 | 172 | 246 | 1594 | 9670 | 3 | 6530 | 5150 | 6700 | 17160 |
| MWT5.1N | 580 | 2 | 439 | 269 | 580 | 890 | 14780 | 2 | 1800 | 6440 | 14780 | 23120 |
| MWT5.1S | 176 | 1 | . | 176 | 176 | 176 | 4680 | 1 | . | 4680 | 4680 | 4680 |
| MWT5.2C | 543 | 1 | . | 540 | 543 | 543 | 14590 | 1 | | 14590 | 14590 | 14590 |
| MWT5.2N | 3003 | 1 | . | 3003 | 3003 | 3003 | 91000 | 1 | | 91000 | 91000 | 91000 |
| MWT5.2S | 740 | 1 | . | 740 | 740 | 740 | 16810 | 1 | | 16810 | 16810 | 16810 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 313 | 2 | 83 | 254 | 313 | 372 | 5450 | 2 | 1190 | 4610 | 5450 | 6290 |

# Figure 5.16 Benzo(k)fluoranthene concentrations (ppb) in Back River and Baltimore Harbor Sediments



I. Baltimore Harbor Stations

II. Transects Along Channel

III. Transects Across Channel

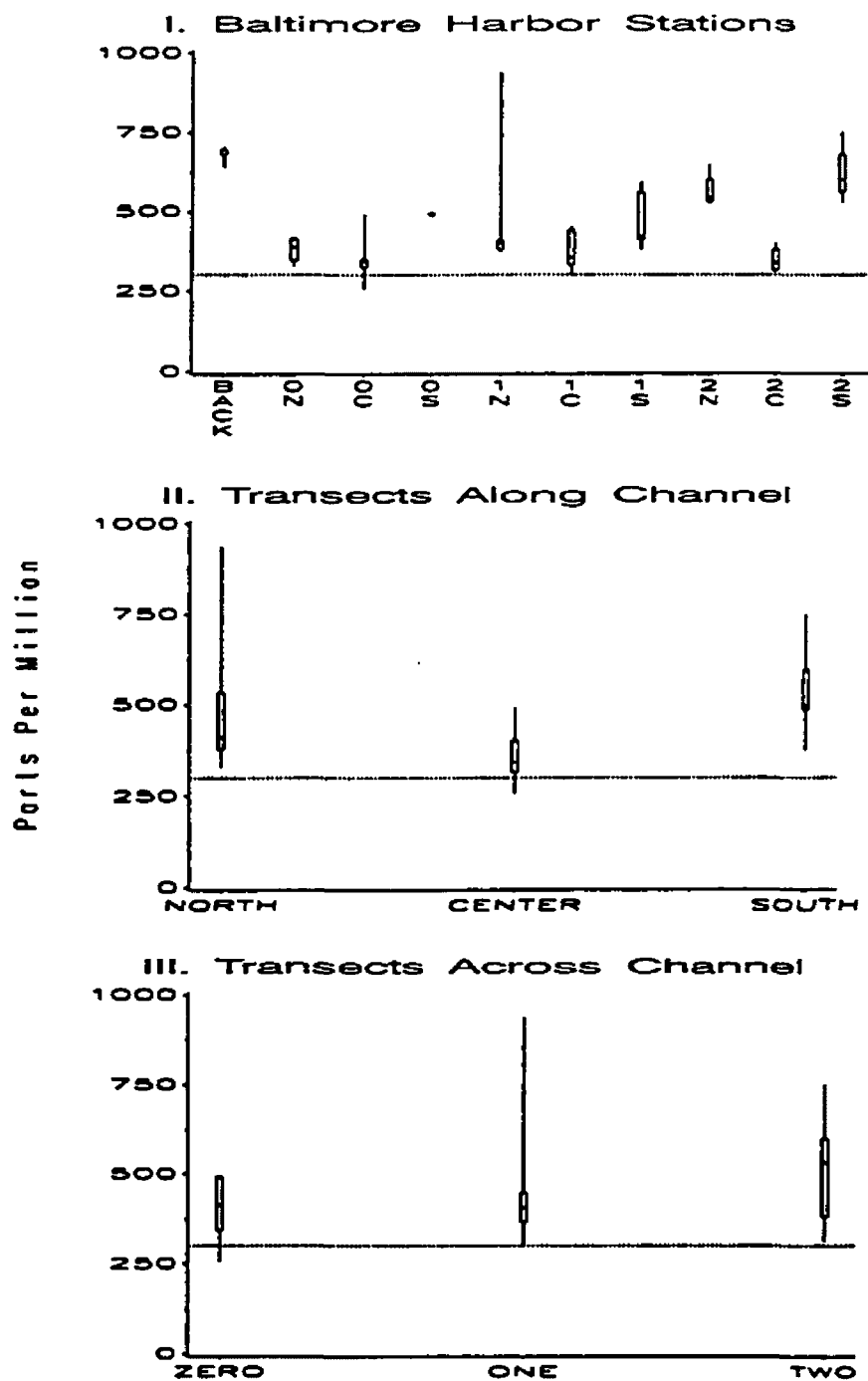Figure 5.16   Benzo(k)fluoranthene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III.   The NOEL and PEL values for sediment benzo(k)fluoranthene concentrations are not available due to insufficient data (MacDonald, 1993).

# Benzo[k]fluoranthene

The median sediment concentrations of benzo[k]fluoranthene in Baltimore Harbor and Back River were 303 ppb and 89 ppb, respectively (Table 5.14). The region's maximum concentration of 1351 ppb was found at station MWT5.2N station in Baltimore Harbor in 1991 (Table 5.14 and Figure 5.16). There were insufficient data available for the development of NOEL and PEL guidelines for benzo[k]fluoranthene (MacDonald, 1993).

Table 5.14 Summary statistics for benzo[k]fluoranthene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH). A "." means no data is available for that station.

| | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 489 | 8 | 394 | 190 | 303 | 1351 | 11930 | 8 | 11880 | 5110 | 7720 | 40950 |
| Center | 414 | 3 | 318 | 190 | 273 | 778 | 7210 | 3 | 1820 | 5110 | 8130 | 8380 |
| North | 688 | 3 | 582 | 263 | 450 | 1351 | 19920 | 3 | 18350 | 7140 | 11690 | 40950 |
| South | 303 | 2 | 26 | 285 | 303 | 322 | 7010 | 2 | 420 | 6710 | 7010 | 7310 |
| Zero | 274 | 3 | 11 | 263 | 273 | 285 | 7330 | 3 | 730 | 6710 | 7140 | 8130 |
| One | 614 | 2 | 232 | 450 | 614 | 778 | 10030 | 2 | 2340 | 8380 | 10030 | 11690 |
| Two | 621 | 3 | 636 | 190 | 322 | 1351 | 17790 | 3 | 20090 | 5110 | 7310 | 40950 |
| MWT5.0C | 273 | 1 | . | 273 | 273 | 273 | 8130 | 1 | . | 8130 | 8130 | 8130 |
| MWT5.0N | 263 | 1 | . | 263 | 263 | 263 | 7140 | 1 | . | 7140 | 7140 | 7140 |
| MWT5.0S | 285 | 1 | . | 285 | 285 | 285 | 6710 | 1 | . | 6710 | 6710 | 6710 |
| MWT5.1C | 778 | 1 | . | 778 | 778 | 778 | 8380 | 1 | . | 8380 | 8380 | 8380 |
| MWT5.1N | 450 | 1 | . | 450 | 450 | 450 | 11690 | 1 | . | 11690 | 11690 | 11690 |
| MWT5.1S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.2C | 190 | 1 | . | 190 | 190 | 190 | 5110 | 1 | . | 5110 | 5110 | 5110 |
| MWT5.2N | 1351 | 1 | . | 1351 | 1351 | 1351 | 40950 | 1 | . | 40950 | 40950 | 40950 |
| MWT5.2S | 322 | 1 | . | 321 | 322 | 322 | 7310 | 1 | . | 7310 | 7310 | 7310 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 89 | 1 | . | 89 | 89 | 89 | 1610 | 1 | . | 1610 | 1610 | 1610 |

# Figure 5.15 Benzo(b)fluoranthene concentrations (ppb) in Back River and Baltimore Harbor Sediments



Figure 5.15 Benzo(b)fluoranthene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment benzo(b)fluoranthene concentrations are not available due to insufficient data (MacDonald, 1993).

## Benzo[g,h,i]perylene

The median sediment concentration of benzo[g,h,i]perylene were 733 ppb and 291 ppb in Baltimore Harbor and Back River, respectively (Table 5.15). The maximum concentration of 4004 ppb was found at the MWT5.2N station in the Baltimore Harbor in 1991 (Table 5.15 and Figure 5.17). There were insufficient data available for the development of NOEL and PEL guidelines for benzo[g,h,i]perylene (MacDonald, 1993).

Table 5.15 Summary statistics for benzo[g,h,i]perylene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 896 | 13 | 1075 | 53 | 733 | 4004 | 22430 | 13 | 31430 | 1590 | 19700 | 121330 |
| Center | 632 | 6 | 700 | 53 | 438 | 1836 | 12580 | 6 | 11510 | 1590 | 11860 | 28470 |
| North | 1456 | 4 | 1736 | 129 | 846 | 4004 | 42280 | 4 | 53560 | 3090 | 22350 | 121330 |
| South | 675 | 3 | 527 | 69 | 927 | 1029 | 15680 | 3 | 12020 | 1840 | 21820 | 23390 |
| Zero | 679 | 4 | 376 | 144 | 809 | 957 | 18260 | 4 | 10330 | 4010 | 20270 | 28470 |
| One | 526 | 6 | 740 | 53 | 100 | 1836 | 9030 | 6 | 10910 | 1590 | 2510 | 25970 |
| Two | 1922 | 3 | 1809 | 733 | 1029 | 4004 | 54800 | 3 | 57640 | 19700 | 23390 | 121330 |
| MWT5.0C | 550 | 2 | 575 | 144 | 550 | 957 | 16240 | 2 | 17290 | 4010 | 16240 | 28470 |
| MWT5.0N | 691 | 1 | . | 691 | 691 | 691 | 18730 | 1 | . | 18730 | 18730 | 18730 |
| MWT5.0S | 927 | 1 | . | 927 | 927 | 927 | 21820 | 1 | . | 21820 | 21820 | 21820 |
| MWT5.1C | 653 | 3 | 1024 | 53 | 70 | 1836 | 7760 | 3 | 10390 | 1590 | 1930 | 19760 |
| MWT5.1N | 565 | 2 | 616 | 129 | 560 | 1000 | 14530 | 2 | 16180 | 3090 | 14530 | 25970 |
| MWT5.1S | 69 | 1 | . | 69 | 69 | 69 | 1840 | 1 | . | 1840 | 1840 | 1840 |
| MWT5.2C | 733 | 1 | . | 733 | 733 | 733 | 19700 | 1 | . | 19700 | 19700 | 19700 |
| MWT5.2N | 4004 | 1 | . | 4004 | 4004 | 4004 | 121330 | 1 | . | 121330 | 121330 | 121300 |
| MWT5.2S | 1029 | 1 | . | 1029 | 1029 | 1029 | 23390 | 1 | . | 23390 | 23390 | 23390 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 291 | 2 | 164 | 175 | 291 | 406 | 5170 | 2 | 3120 | 2960 | 5170 | 7380 |

# Figure 5.17 Benzo(g,h,i)perylene concentrations (ppb) in Back River and Baltimore Harbor Sediments

## I. Baltimore Harbor Stations



## II. Transects Along Channel



## III. Transects Across Channel



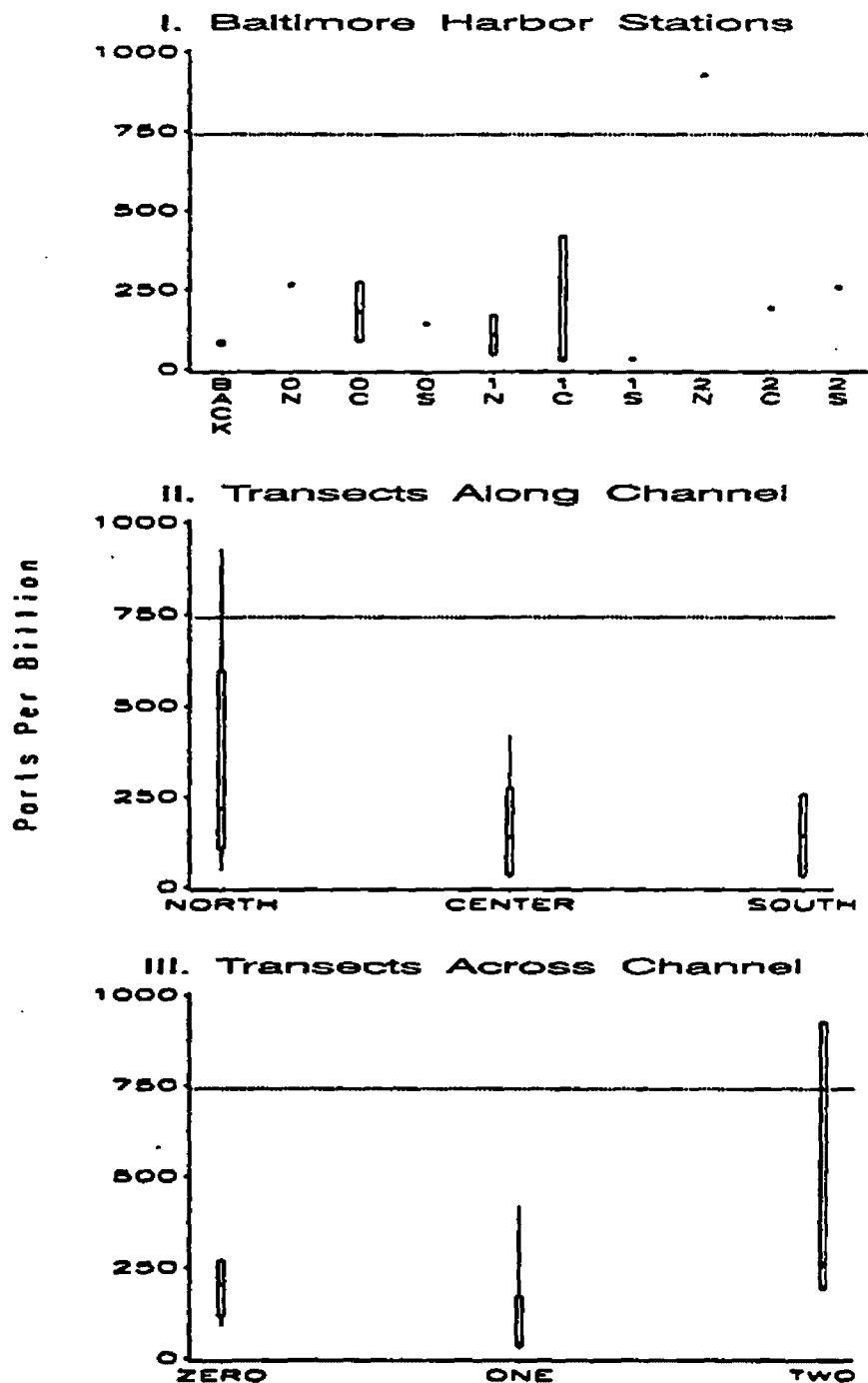Figure 5.17 Benzo(g,h,i)perylene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment benzo(g,h,i)perylene concentrations are not available due to insufficient data (MacDonald, 1993).

## Benzo[a]pyrene

Benzo[a]pyrene, a Chesapeake Bay Toxic of Concern, is considered a probable human carcinogen by EPA (Chesapeake Bay Program, 1991a). The median sediment concentrations of benzo[a]pyrene were 527 ppb and 153 ppb in Baltimore Harbor and Back River, respectively (Table 5.16). The maximum sediment concentration of 3003 ppb was found in Baltimore Harbor at station MWT5.2N in 1991 (Table 5.16 and Figure 5.18).

Sediment concentrations of benzo[a]pyrene above the NOEL concentration of 230 ppb were found at eight of the stations in Baltimore Harbor region, but only the maximum measurement exceeded the PEL concentration of 1700 ppb (Table 5.16 and MacDonald, 1993). Toxic effects to aquatic biota due to the measured concentrations of benzo[a]pyrene in the sediment are not likely in the Baltimore Harbor region, with the exception of station MWT5.2N in Baltimore Harbor.

Table 5.16 Summary statistics for benzo[a]pyrene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 685 | 13 | 802 | 123 | 527 | 3003 | 16930 | 13 | 23030 | 3270 | 13430 | 91000 |
| Center | 494 | 6 | 550 | 125 | 297 | 1569 | 9450 | 6 | 5940 | 3570 | 8110 | 16890 |
| North | 1117 | 4 | 1279 | 187 | 638 | 3003 | 32300 | 4 | 39620 | 4470 | 16870 | 91000 |
| South | 488 | 3 | 332 | 123 | 571 | 772 | 11410 | 3 | 7340 | 3270 | 13430 | 17540 |
| Zero | 471 | 4 | 154 | 242 | 537 | 571 | 12680 | 4 | 4130 | 6740 | 13850 | 16270 |
| One | 481 | 6 | 587 | 123 | 159 | 1569 | 8570 | 6 | 7500 | 3270 | 4110 | 19480 |
| Two | 1376 | 3 | 1425 | 353 | 772 | 3003 | 39340 | 3 | 44920 | 9480 | 17540 | 91000 |
| MWT5.0C | 394 | 2 | 215 | 242 | 394 | 547 | 11500 | 2 | 6740 | 6740 | 11500 | 16270 |
| MWT5.0N | 527 | 1 | . | 527 | 527 | 527 | 14270 | 1 | . | 14270 | 14270 | 14270 |
| MWT5.0S | 571 | 1 | . | 571 | 571 | 571 | 13430 | 1 | . | 13430 | 13430 | 13430 |
| MWT5.1C | 608 | 3 | 832 | 125 | 131 | 1569 | 8070 | 3 | 7640 | 3570 | 3740 | 16890 |
| MWT5.1N | 469 | 2 | 398 | 187 | 469 | 750 | 11980 | 2 | 10610 | 4470 | 11980 | 19480 |
| MWT5.1S | 123 | 1 | . | 123 | 123 | 123 | 3270 | 1 | . | 3270 | 3270 | 3270 |
| MWT5.2C | 353 | 1 | . | 353 | 353 | 353 | 9480 | 1 | . | 9480 | 9480 | 9480 |
| MWT5.2N | 3003 | 1 | . | 3003 | 3003 | 3003 | 91000 | 1 | . | 91000 | 91000 | 91000 |
| MWT5.2S | 772 | 1 | . | 772 | 772 | 772 | 17540 | 1 | . | 17540 | 17540 | 17540 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 153 | 2 | 1 | 152 | 153 | 153 | 2680 | 2 | 130 | 2590 | 2680 | 2770 |

## Chrysene

Chrysene is a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a). Chrysene was detected in the sediments at four of the nine Baltimore Harbor stations and at the Back River station (Table 5.17 and Figure 5.19). The median measured sediment concentrations were 200 ppb and 374 ppb in Baltimore Harbor and Back River, respectively. The maximum concentration of 374 ppb was found at the Back River station in 1987.

Median sediment concentrations of chrysene equal to or exceeding the NOEL concentration of 220 ppb were observed at the Back River station and at two stations in Baltimore Harbor (Table 5.17). All measured sediment concentrations of chrysene were well below the PEL concentration of 1700 ppb. Toxic effects to aquatic biota due to the measured sediment concentrations of chrysene are not likely at any of the sampled locations in the Baltimore Harbor region.

Table 5.17 Summary statistics for chrysene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH). A "." means the value(s) for that station is/are less than the detection limit.

| Area | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 223 | 5 | 68 | 146 | 200 | 296 | 6020 | 5 | 1890 | 4370 | 4790 | 8110 |
| Center | 244 | 3 | 85 | 146 | 291 | 296 | 6850 | 3 | 2140 | 4370 | 8070 | 8110 |
| North | 200 | 1 | . | 200 | 200 | 200 | 4780 | 1 | . | 4780 | 4780 | 4780 |
| South | 180 | 1 | . | 180 | 180 | 180 | 4790 | 1 | . | 4790 | 4790 | 4790 |
| Zero | 291 | 1 | . | 291 | 291 | 291 | 8110 | 1 | . | 8110 | 8110 | 8110 |
| One | 206 | 4 | 64 | 146 | 190 | 296 | 5500 | 4 | 1720 | 4370 | 4790 | 8070 |
| Two | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.0C | 291 | 1 | . | 291 | 291 | 291 | 8110 | 1 | . | 8110 | 8110 | 8110 |
| MWT5.0N | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.0S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.1C | 221 | 2 | 106 | 146 | 221 | 296 | 6220 | 2 | 2610 | 4370 | 6220 | 8070 |
| MWT5.1N | 200 | 1 | . | 200 | 200 | 200 | 4780 | 1 | . | 4780 | 4780 | 4780 |
| MWT5.1S | 180 | 1 | . | 180 | 180 | 180 | 4790 | 1 | . | 4790 | 4790 | 4790 |
| MWT5.2C | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.2N | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.2S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 374 | 1 | . | 374 | 374 | 374 | 6330 | 1 | . | 6330 | 6330 | 6330 |

# Figure 5.19 Chrysene concentrations (ppb) in Back River and Baltimore Harbor Sediments

## I. Baltimore Harbor Stations

## II. Transects Along Channel

## III. Transects Across Channel
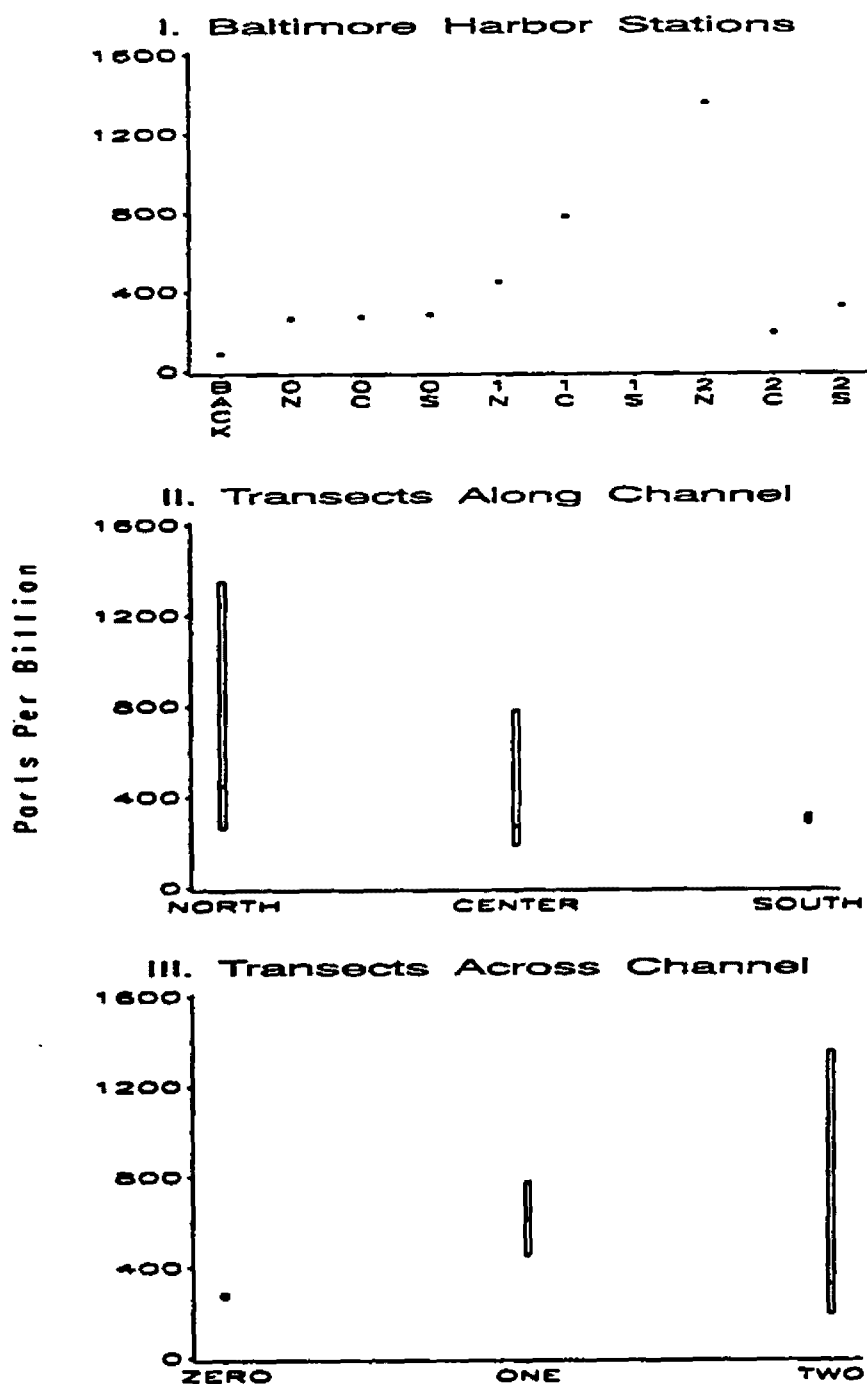
Figure 5.19 Chrysene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment chrysene concentrations are 220 ppb and 1700 ppb, respectively (MacDonald, 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

## Dibenzo[a,h]anthracene

Dibenzo[a,h]anthracene was detected at five of the nine Baltimore Harbor stations as well as the Back River station (Table 5.18 and Figure 5.20). The median sediment concentrations of dibenzo[a,h]anthracene were 68 ppb and 75 ppb in Baltimore Harbor and Back River, respectively. The maximum sediment concentration of dibenzo[a,h]anthracene, found at station MWT5.2N in Baltimore Harbor in 1991, was 2227 ppb.

All median sediment concentrations of dibenzo[a,h]anthracene in the region exceeded the NOEL of 31 ppb, except at the MWT5.0C station, although this single sample, observed in 1987, was only one ppb below the NOEL. The PEL concentration of 320 ppb was exceeded at three Baltimore Harbor stations—MWT5.1C, MWT5.1S, and MWT5.2N. Toxic effects to aquatic biota due to the measured sediment concentrations of dibenzo[a,h]anthracene are possible at all monitored stations in the Baltimore Harbor, and likely to occur at three of these stations.

Table 5.18 Summary statistics for dibenzo[a,h]anthracene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH). A "." means the value(s) for that station is/are less than the detection limit.

| Area | Measured | | | | | | Normalized | | | | | |
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 501 | 7 | 801 | 30 | 68 | 2227 | 12930 | 7 | 24380 | 820 | 1630 | 67490 |
| | | | | | | | | | | | | |
| Center | 251 | 3 | 366 | 30 | 49 | 674 | 3140 | 3 | 3570 | 840 | 1340 | 7260 |
| North | 908 | 3 | 1156 | 68 | 430 | 2227 | 26760 | 3 | 35590 | 1630 | 11170 | 67490 |
| South | 31 | 1 | . | 31 | 31 | 31 | 820 | 1 | . | 820 | 820 | 820 |
| | | | | | | | | | | | | |
| Zero | 30 | 1 | . | 30 | 30 | 30 | 840 | 1 | . | 840 | 840 | 840 |
| One | 250 | 5 | 289 | 31 | 68 | 674 | 4440 | 5 | 4580 | 820 | 1630 | 11170 |
| Two | 2227 | 1 | . | 2227 | 2227 | 2227 | 67490 | 1 | . | 67490 | 67490 | 67490 |
| | | | | | | | | | | | | |
| MWT5.0C | 30 | 1 | . | 30 | 30 | 30 | 840 | 1 | . | 840 | 840 | 840 |
| MWT5.0N | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| MWT5.0S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| MWT5.1C | 362 | 2 | 442 | 49 | 362 | 674 | 4300 | 2 | 4190 | 1340 | 4300 | 7260 |
| MWT5.1N | 249 | 2 | 256 | 68 | 249 | 430 | 6400 | 2 | 6750 | 1630 | 6400 | 11170 |
| MWT5.1S | 31 | 1 | . | 31 | 31 | 31 | 820 | 1 | . | 820 | 820 | 820 |
| MWT5.2C | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| MWT5.2N | 2227 | 1 | . | 2227 | 2227 | 2227 | 67490 | 1 | . | 67490 | 67490 | 67490 |
| MWT5.2S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 75 | 1 | . | 75 | 75 | 75 | 1270 | 1 | . | 1270 | 1270 | 1270 |

# Figure 5.20 Dibenzo(a,h)anthracene concentrations (ppb) in Back River and Baltimore Harbor Sediments

## I. Baltimore Harbor Stations

## II. Transects Along Channel

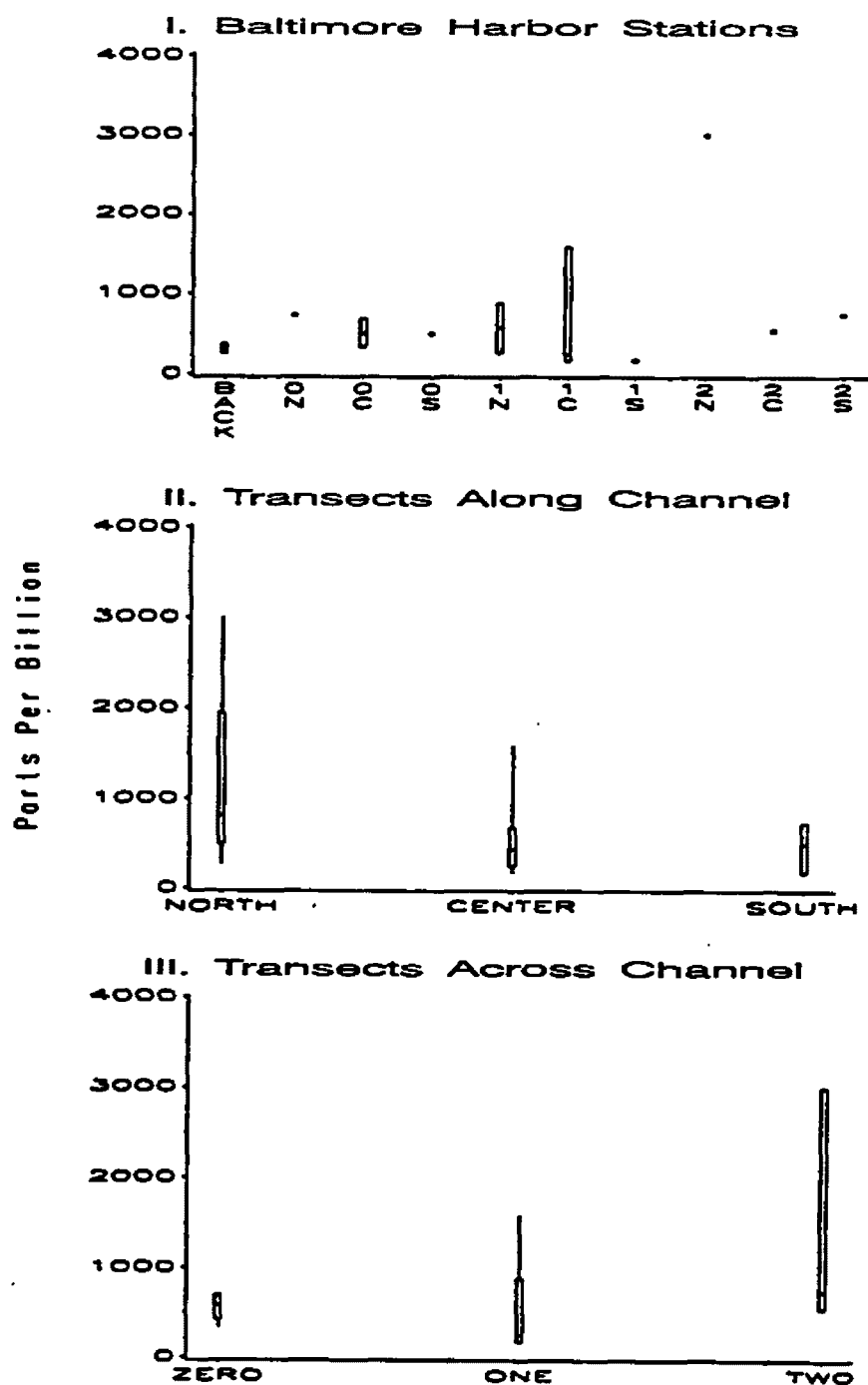## III. Transects Across Channel

Figure 5.20  Dibenzo(a,h)anthracene concentrations in sediment in Baltimore Harbor and Back River.  The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data.  If there are less than four values, the rectangle's bottom and top show the range.  A dash indicates only a single value is available.  The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III.  The NOEL and PEL values for sediment dibenzo(a,h)anthracene concentrations are 31 ppb and 320 ppb, respectively (MacDonald, 1993).  The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

## Fluoranthene

Fluoranthene is a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a). The median sediment concentrations of fluoranthene were 814 ppb and 465 ppb in Baltimore Harbor and Back River, respectively (Table 5.19). The maximum sediment concentration of fluoranthene, found in Baltimore Harbor at station MWT5.2N in 1991, was 4004 ppb (Table 5.19 and Figure 5.21).

Median sediment fluoranthene concentrations above the NOEL concentration of 380 ppb were found at eight of nine stations in Baltimore Harbor and at Back River. The PEL concentration of 3200 ppb was exceeded only at station MWT5.2N in Baltimore Harbor. Toxic effects to aquatic biota due to the measured sediment concentrations of fluoranthene are likely at station MWT5.2N in Baltimore Harbor, but unlikely at the other sampled locations in the Baltimore Harbor region.

Table 5.19 Summary statistics for fluoranthene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion.Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| Area | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 993 | 13 | 1090 | 136 | 814 | 4004 | 24460 | 13 | 30530 | 4070 | 19730 | 121330 |
| Center | 867 | 6 | 861 | 136 | 598 | 2471 | 17340 | 6 | 11300 | 4070 | 16150 | 32530 |
| North | 1507 | 4 | 1692 | 244 | 891 | 4004 | 43620 | 4 | 52500 | 5840 | 23650 | 121330 |
| South | 561 | 3 | 355 | 172 | 642 | 868 | 13140 | 3 | 7770 | 4570 | 15110 | 19730 |
| Zero | 741 | 4 | 344 | 307 | 782 | 1093 | 20290 | 4 | 10590 | 8550 | 20040 | 32530 |
| One | 711 | 6 | 902 | 136 | 313 | 2471 | 12300 | 6 | 9780 | 4070 | 8120 | 26600 |
| Two | 1895 | 3 | 1826 | 814 | 868 | 4004 | 54320 | 3 | 58040 | 19730 | 21890 | 121330 |
| MWT5.0C | 700 | 2 | 556 | 307 | 700 | 1093 | 20540 | 2 | 16960 | 8550 | 20540 | 32530 |
| MWT5.0N | 921 | 1 | . | 921 | 921 | 921 | 24970 | 1 | . | 24970 | 24970 | 24970 |
| MWT5.0S | 642 | 1 | . | 642 | 642 | 642 | 15110 | 1 | . | 15110 | 15110 | 15110 |
| MWT5.1C | 996 | 3 | 1283 | 136 | 382 | 2471 | 13690 | 3 | 11620 | 4070 | 10410 | 26600 |
| MWT5.1N | 552 | 2 | 436 | 244 | 552 | 860 | 14090 | 2 | 11670 | 5840 | 14090 | 22340 |
| MWT5.1S | 172 | 1 | . | 172 | 172 | 172 | 4570 | 1 | . | 4570 | 4570 | 4570 |
| MWT5.2C | 814 | 1 | . | 814 | 814 | 814 | 21890 | 1 | . | 21890 | 21890 | 21890 |
| MWT5.2N | 4004 | 1 | . | 4004 | 4004 | 4004 | 121330 | 1 | . | 121330 | 121330 | 121330 |
| MWT5.2S | 868 | 1 | . | 868 | 868 | 868 | 19730 | 1 | . | 19730 | 19730 | 19730 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 465 | 2 | 47 | 432 | 465 | 498 | 8130 | 2 | 420 | 7840 | 8130 | 8430 |

# Figure 5.21 Fluoranthene concentrations (ppb) in Back River and Baltimore Harbor Sediments

### I. Baltimore Harbor Stations

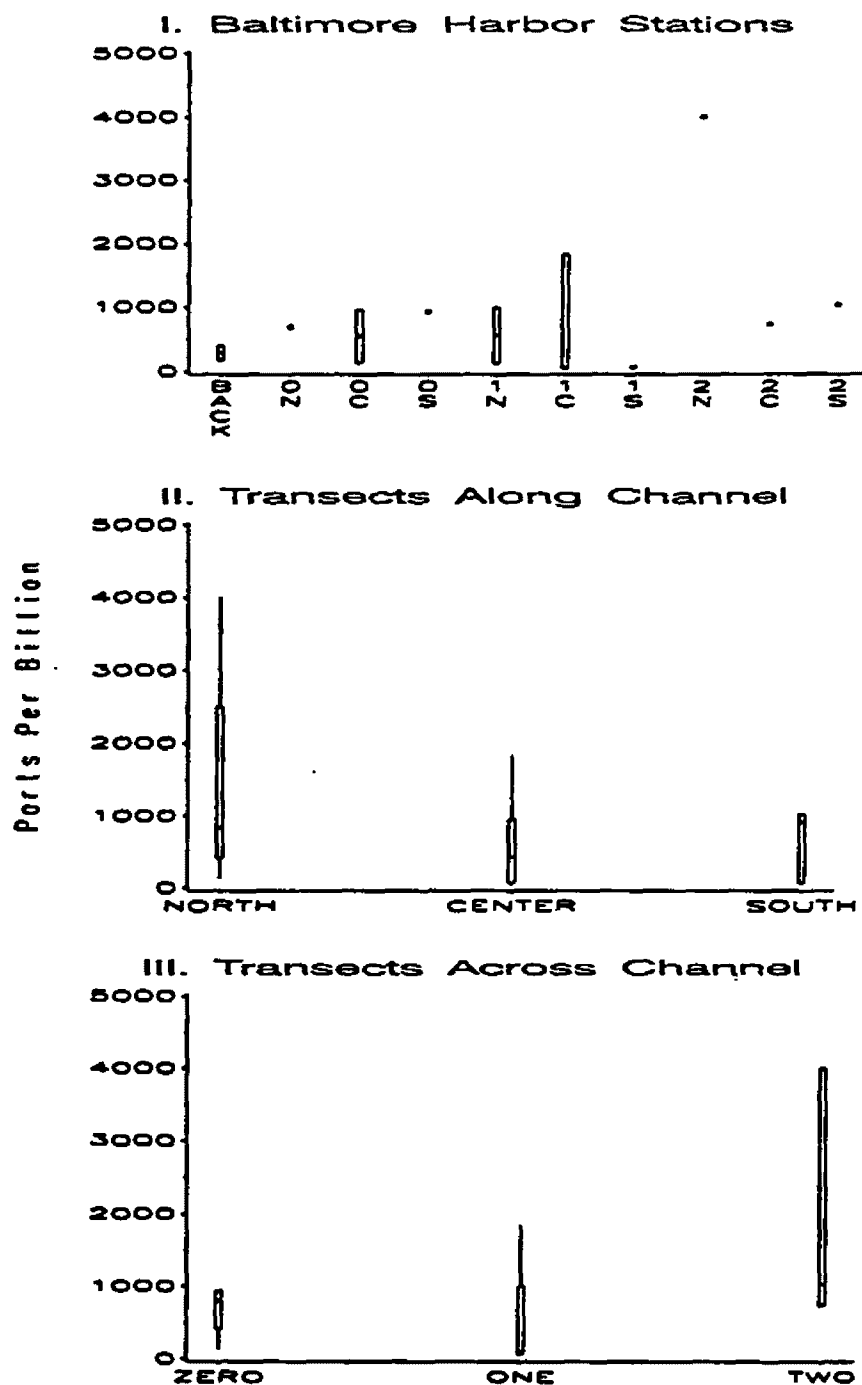### II. Transects Along Channel

### III. Transects Across Channel

Figure 5.21   Fluoranthene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment fluoranthene concentrations are 380 ppb and 3200 ppb, respectively (MacDonald, 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

Indeno[1,2,3-cd]pyrene

The median measured sediment concentrations of indeno[1,2,3-cd]pyrene were 100 ppb and 170 ppb in Baltimore Harbor and Back River, respectively (Table 5.20). The maximum sediment concentration, found at station MWT5.1N in Baltimore Harbor in 1991, was 1100 ppb (Table 5.20 and Figure 5.22). There are no NOEL or PEL concentrations for indeno[1,2,3-cd]pyrene concentrations in sediment due to insufficient data (MacDonald, 1993).

Table 5.20 Summary statistics for indeno[1,2,3-cd]pyrene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH). A "." means the value(s) for that station is/are less than the detection limit.

| Area | Measured | | | | | | Normalized | | | | | |
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 255 | 6 | 415 | 40 | 100 | 1100 | 6670 | 6 | 10760 | 1200 | 2530 | 28570 |
| | | | | | | | | | | | | |
| Center | 802 | 3 | 42 | 40 | 80 | 120 | 2290 | 3 | 1120 | 1200 | 2230 | 3430 |
| North | 609 | 2 | 694 | 118 | 610 | 1100 | 15700 | 2 | 18210 | 2820 | 15700 | 28570 |
| South | 66 | 1 | . | 66 | 66 | 66 | 1760 | 1 | . | 1760 | 1760 | 1760 |
| | | | | | | | | | | | | |
| Zero | 123 | 1 | . | 123 | 123 | 123 | 3430 | 1 | . | 3430 | 3430 | 3430 |
| One | 281 | 5 | 459 | 40 | 82 | 1100 | 7320 | 5 | 11900 | 1200 | 2230 | 28570 |
| Two | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| MWT5.0C | 123 | 1 | . | 123 | 123 | 123 | 3430 | 1 | . | 3430 | 3430 | 3430 |
| MWT5.0N | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.0S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| MWT5.1C | 61 | 2 | 30 | 40 | 61 | 82 | 1720 | 2 | 730 | 1200 | 1720 | 2230 |
| MWT5.1N | 609 | 2 | 694 | 118 | 609 | 1100 | 15700 | 2 | 18210 | 2820 | 15700 | 28570 |
| MWT5.1S | 66 | 1 | . | 66 | 66 | 66 | 1760 | 1 | . | 1760 | 1760 | 1760 |
| MWT5.2C | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.2N | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.2S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 170 | 1 | . | 170 | 170 | 170 | 2880 | 1 | . | 2880 | 2880 | 2880 |

# Figure 5.22 Indeno(1,2,3-cd)pyrene concentrations (ppb) in Back River and Baltimore Harbor Sediments
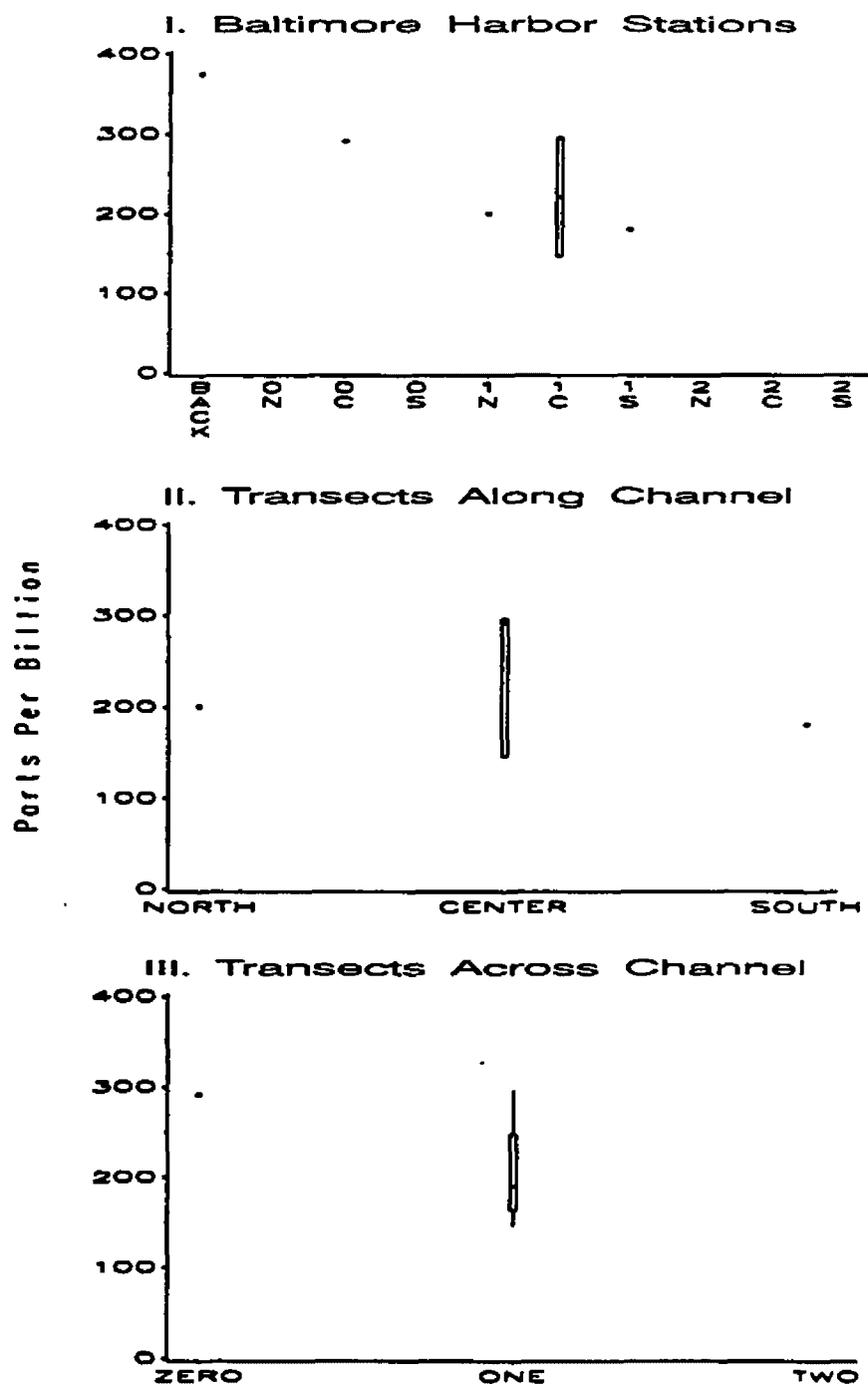


Figure 5.22 Indeno(1,2,3-cd)pyrene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment indeno(1,2,3-cd)pyrene concentrations are not available due to insufficient data (MacDonald, 1993).

## Naphthalene

Data on sediment concentrations of naphthalene, a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a) are only available for 1986 and 1987. The median sediment concentration among the stations for which data exists was 188 ppb in Baltimore Harbor and 175 ppb in Back River (Table 5.21). The maximum sediment concentration of naphthalene was 347 ppb at station MWT5.0C station in Baltimore Harbor in 1987 (Table 5.21 and Figure 5.23).

Median sediment concentrations of naphthalene in excess of the NOEL concentration of 130 ppb were observed at the Back River station and at all of the four stations in Baltimore Harbor with measured concentrations. All measurements were below the PEL concentration of 1100 ppb. Toxicity to aquatic biota due to the measured sediment concentrations of naphthalene are not likely at any of the monitored stations in the Baltimore Harbor region.

Table 5.21 Summary statistics for naphthalene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH). A "." means no data is available for that station.

| | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 224 | 5 | 88 | 133 | 188 | 347 | 6150 | 5 | 2710 | 3540 | 4630 | 9670 |
| Center | 266 | 3 | 89 | 170 | 281 | 347 | 7570 | 3 | 2620 | 4630 | 8410 | 9670 |
| North | 188 | 1 | . | 188 | 188 | 188 | 4500 | 1 | . | 4500 | 4500 | 4500 |
| South | 133 | 1 | . | 133 | 133 | 133 | 3540 | 1 | . | 3540 | 3540 | 3540 |
| Zero | 347 | 1 | . | 347 | 347 | 347 | 9670 | 1 | . | 9670 | 9670 | 9670 |
| One | 193 | 4 | 63 | 133 | 179 | 281 | 5270 | 4 | 2150 | 3540 | 4560 | 8410 |
| Two | . | | 0 | . | . | . | . | 0 | . | . | . | . |
| MWT5.0C | 347 | 1 | . | 347 | 347 | 347 | 9670 | 1 | | 9670 | 9670 | 9670 |
| MWT5.0N | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.0S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.1C | 226 | 2 | 78 | 170 | 225 | 281 | 6520 | 2 | 2670 | 4630 | 6520 | 8410 |
| MWT5.1N | 188 | 1 | . | 188 | 188 | 188 | 4500 | 1 | . | 4500 | 4500 | 4500 |
| MWT5.1S | 133 | 1 | . | 133 | 133 | 133 | 3540 | 1 | . | 3540 | 3540 | 3540 |
| MWT5.2C | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.2N | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| MWT5.2S | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 175 | 1 | . | 175 | 175 | 175 | 2960 | 1 | . | 2960 | 2960 | 2960 |

# Figure 5.23 Naphthalene concentrations (ppb) in Back River and Baltimore Harbor Sediments
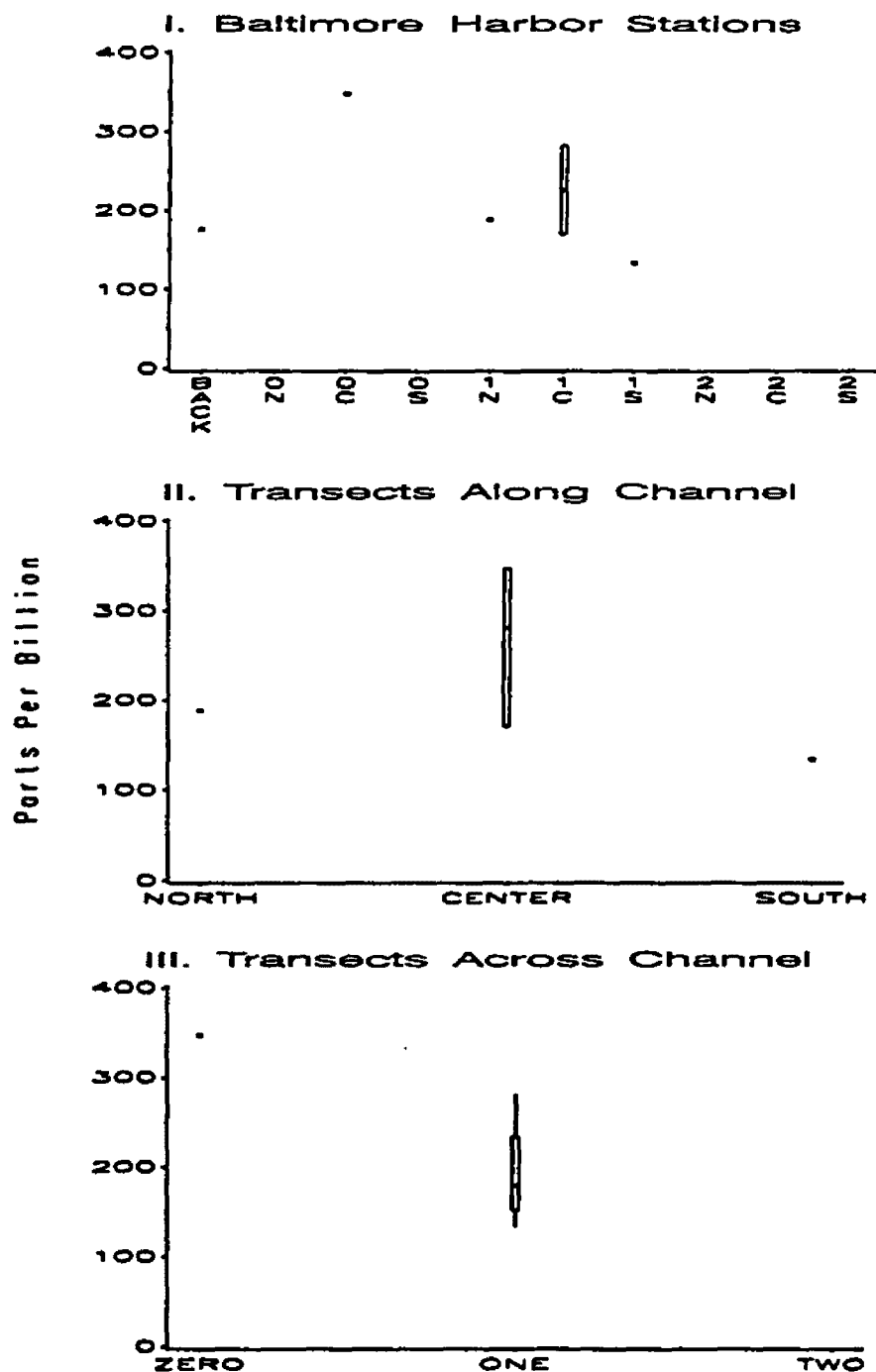
## I. Baltimore Harbor Stations

## II. Transects Along Channel

## III. Transects Across Channel
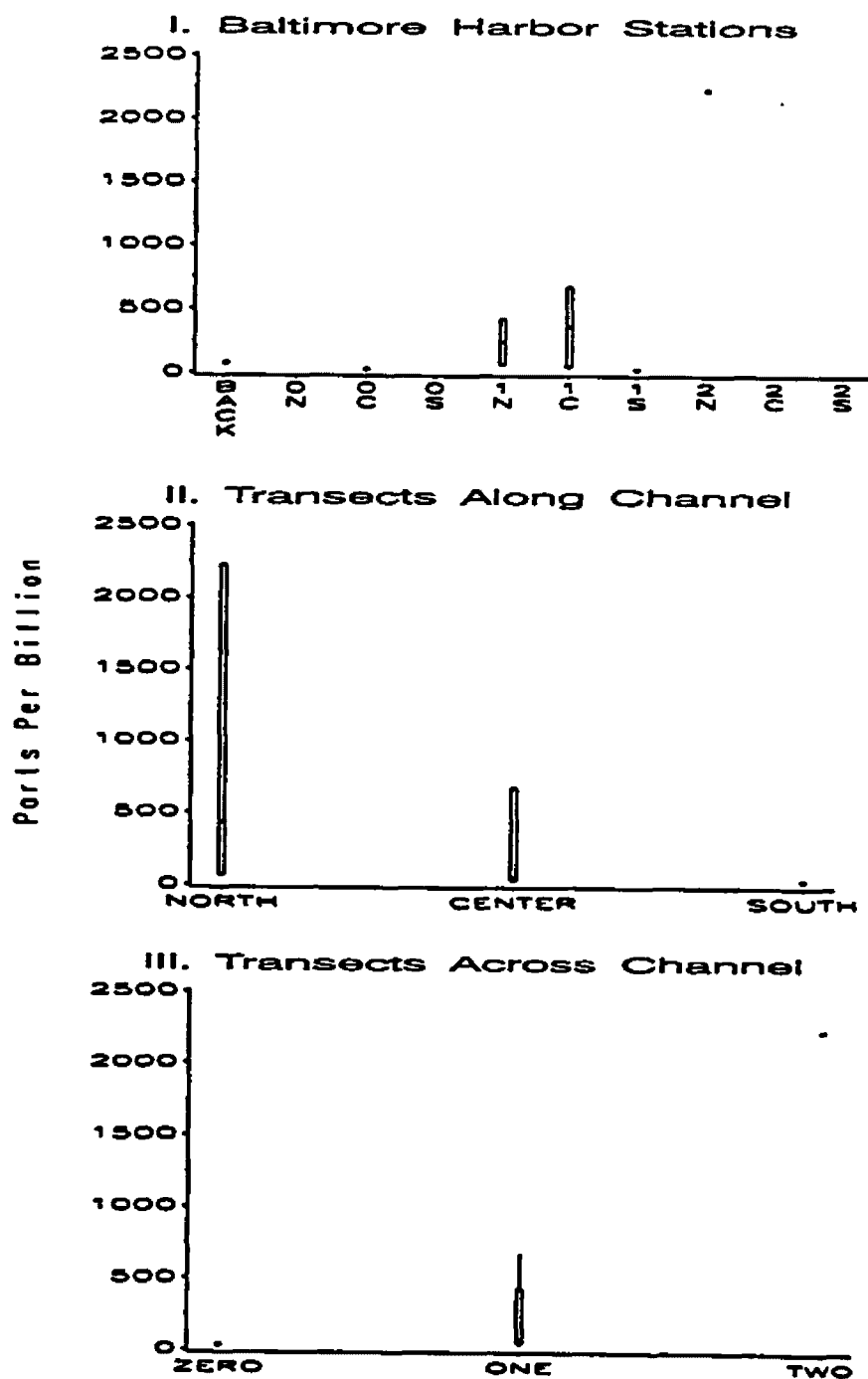
Figure 5.23 Naphthalene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment naphthalene concentrations are 130 ppb and 1100 ppb, respectively (MacDonald, 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

## Phenanthrene

The median sediment phenanthrene concentrations were 133 ppb and 315 ppb in Baltimore Harbor and Back River, respectively (Table 5.22). The region's maximum concentration of 315 ppb was found at the Back River station in 1987 (Table 5.22 and Figure 5.24).

All median sediment phenanthrene concentrations were below the NOEL concentration of 140 ppb. Toxic effects to aquatic biota due to the measured sediment concentrations of phenanthrene are not likely at any of the monitored stations in the Baltimore Harbor region.

Table 5.22 Summary statistics for phenanthrene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (zero, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH). A "." means the value(s) for that station is/are less than the detection limit.

| | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 130 | 5 | 44 | 81 | 133 | 199 | 3520 | 5 | 1220 | 2430 | 3230 | 5540 |
| | | | | | | | | | | | | |
| Center | 138 | 3 | 59 | 81 | 133 | 199 | 3860 | 3 | 1570 | 2430 | 3620 | 5540 |
| North | 135 | 1 | . | 135 | 135 | 135 | 3230 | 1 | . | 3230 | 3230 | 3230 |
| South | 104 | 1 | . | 104 | 104 | 104 | 2770 | 1 | . | 2770 | 2770 | 2770 |
| | | | | | | | | | | | | |
| Zero | 199 | 1 | . | 199 | 199 | 199 | 5540 | 1 | . | 5540 | 5540 | 5540 |
| One | 113 | 4 | 26 | 81 | 119 | 135 | 3010 | 4 | 520 | 2430 | 3000 | 3620 |
| Two | . | 0 | . | . | . | . | . | 0 | . | . | . | . |
| | | | | | | | | | | | | |
| MWT5.0C | 199 | 1 | . | 199 | 199 | 199 | 5540 | 1 | . | 5540 | 5540 | 5540 |
| MWT5.0N | . | 0 | . | . | . | . | . | 0 | | . | . | . |
| MWT5.0S | . | 0 | . | . | . | . | . | 0 | | . | . | . |
| | | | | | | | | | | | | |
| MWT5.1C | 107 | 2 | 37 | 81 | 107 | 133 | 3020 | 2 | 850 | 2430 | 3020 | 3620 |
| MWT5.1N | 135 | 1 | . | 135 | 135 | 135 | 3230 | 1 | | 3230 | 3230 | 3230 |
| MWT5.1S | 104 | 1 | . | 104 | 104 | 104 | 2770 | 1 | | 2770 | 2770 | 2770 |
| MWT5.2C | . | 0 | . | . | . | . | . | 0 | | . | . | . |
| MWT5.2N | . | 0 | . | . | . | . | . | 0 | | . | . | . |
| MWT5.2S | . | 0 | . | . | . | . | . | 0 | | . | . | . |
| | | | | | | | | | | | | |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 315 | 1 | . | 315 | 315 | 315 | 5330 | 1 | . | 5330 | 5330 | 5330 |

# Pyrene

The median sediment concentrations of pyrene were 678 ppb and 486 ppb in Baltimore Harbor and Back River, respectively (Table 5.23). The maximum sediment pyrene concentration, found at MWT5.2N in Baltimore Harbo in 1991, was 7007 ppb (Table 5.23 and Figure 5.25).

Median sediment pyrene concentrations in excess of the NOEL concentration of 290 ppb were observed at sever monitored stations in the region. One station in Baltimore Harbor (MWT5.2N) had a median concentration well above the PEL concentration of 1900 ppb. Toxic effects to aquatic biota due to the measured sediment concentrations of pyrene in the Baltimore Harbor region are likely only at one of the stations in Baltimore Harbor.

Table 5.23 Summary statistics for pyrene in Baltimore Harbor region sediments. Normalized concentrations are measured concentrations divided by the fraction total organic carbon in the sediment. Concentrations are in parts per billion. Statistics on data from the nine stations within the Baltimore Harbor were calculated with the stations aggregated in terms of the three arrays of stations which lie across the channel and parallel to the Key Bridge (z ro, one, and two transects). These stations were also aggregated based on whether they are north of the central dredged channel (NORTH), adjacent to the channel (CENTER), or south of the channel (SOUTH).

| Area | Measured | | | | | | Normalized | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | N | SD | Min | Median | Max | Mean | N | SD | Min | Median | Max |
| **Baltimore Harbor** | | | | | | | | | | | | |
| All | 1125 | 13 | 1808 | 177 | 678 | 7007 | 30660 | 13 | 55500 | 5300 | 15320 | 212320 |
| Center | 552 | 6 | 371 | 177 | 439 | 1093 | 13120 | 6 | 10090 | 5300 | 9090 | 32530 |
| North | 2365 | 4 | 3130 | 262 | 1095 | 7007 | 69090 | 4 | 96280 | 6270 | 28880 | 212320 |
| South | 617 | 3 | 350 | 241 | 678 | 933 | 14520 | 3 | 7490 | 6410 | 15950 | 21190 |
| Zero | 717 | 4 | 324 | 308 | 734 | 1093 | 19620 | 4 | 10090 | 8580 | 18670 | 32530 |
| One | 540 | 6 | 497 | 177 | 266 | 1400 | 11880 | 6 | 12080 | 5300 | 6880 | 36360 |
| Two | 2836 | 3 | 3616 | 570 | 933 | 7007 | 82950 | 3 | 112080 | 15320 | 21190 | 212320 |
| MWT5.0C | 700 | 2 | 555 | 308 | 700 | 1093 | 20560 | 2 | 16940 | 8580 | 20560 | 32530 |
| MWT5.0N | 790 | 1 | . | 790 | 790 | 790 | 21400 | 1 | . | 21400 | 21400 | 21400 |
| MWT5.0S | 678 | 1 | . | 678 | 678 | 678 | 15950 | 1 | . | 15950 | 15950 | 15950 |
| MWT5.1C | 446 | 3 | 389 | 177 | 270 | 892 | 7420 | 3 | 2150 | 5300 | 7360 | 9600 |
| MWT5.1N | 831 | 2 | 805 | 262 | 831 | 1400 | 21320 | 2 | 21280 | 6270 | 21320 | 36360 |
| MWT5.1S | 241 | 1 | . | 241 | 241 | 241 | 6410 | 1 | . | 6410 | 6410 | 6410 |
| MWT5.2C | 570 | 1 | . | 570 | 570 | 570 | 15320 | 1 | . | 15320 | 15320 | 15320 |
| MWT5.2N | 7007 | 1 | . | 7007 | 7007 | 7007 | 212320 | 1 | | 212320 | 212320 | 212320 |
| MWT5.2S | 933 | 1 | . | 933 | 933 | 933 | 21190 | 1 | . | 21190 | 21190 | 21190 |
| **Back River** | | | | | | | | | | | | |
| MWT4.1 | 486 | 2 | 41 | 457 | 486 | 515 | 8510 | 2 | 290 | 8300 | 8510 | 8710 |

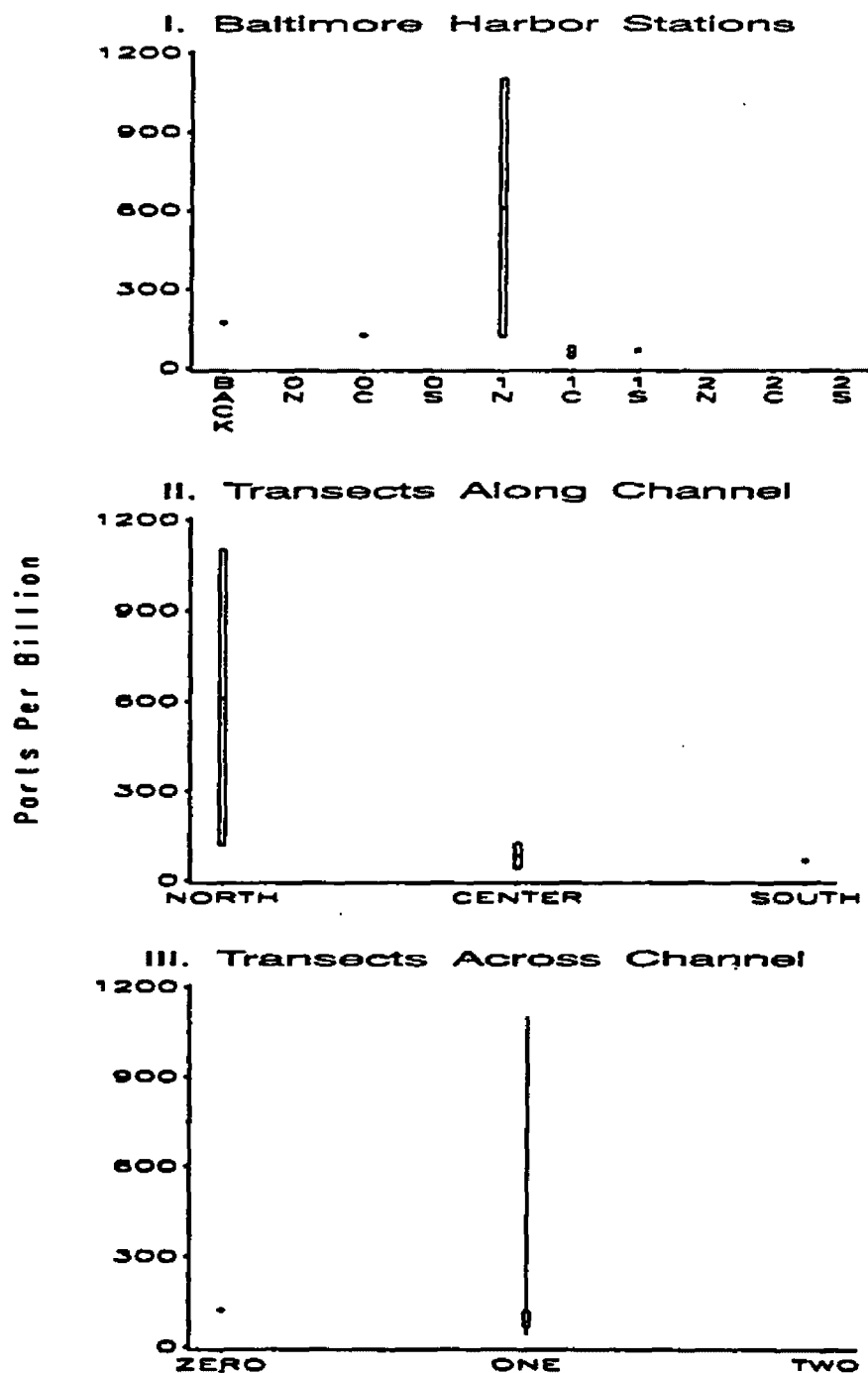# Figure 5.25 Pyrene concentrations (ppb)
# in Back River and Baltimore Harbor Sediments
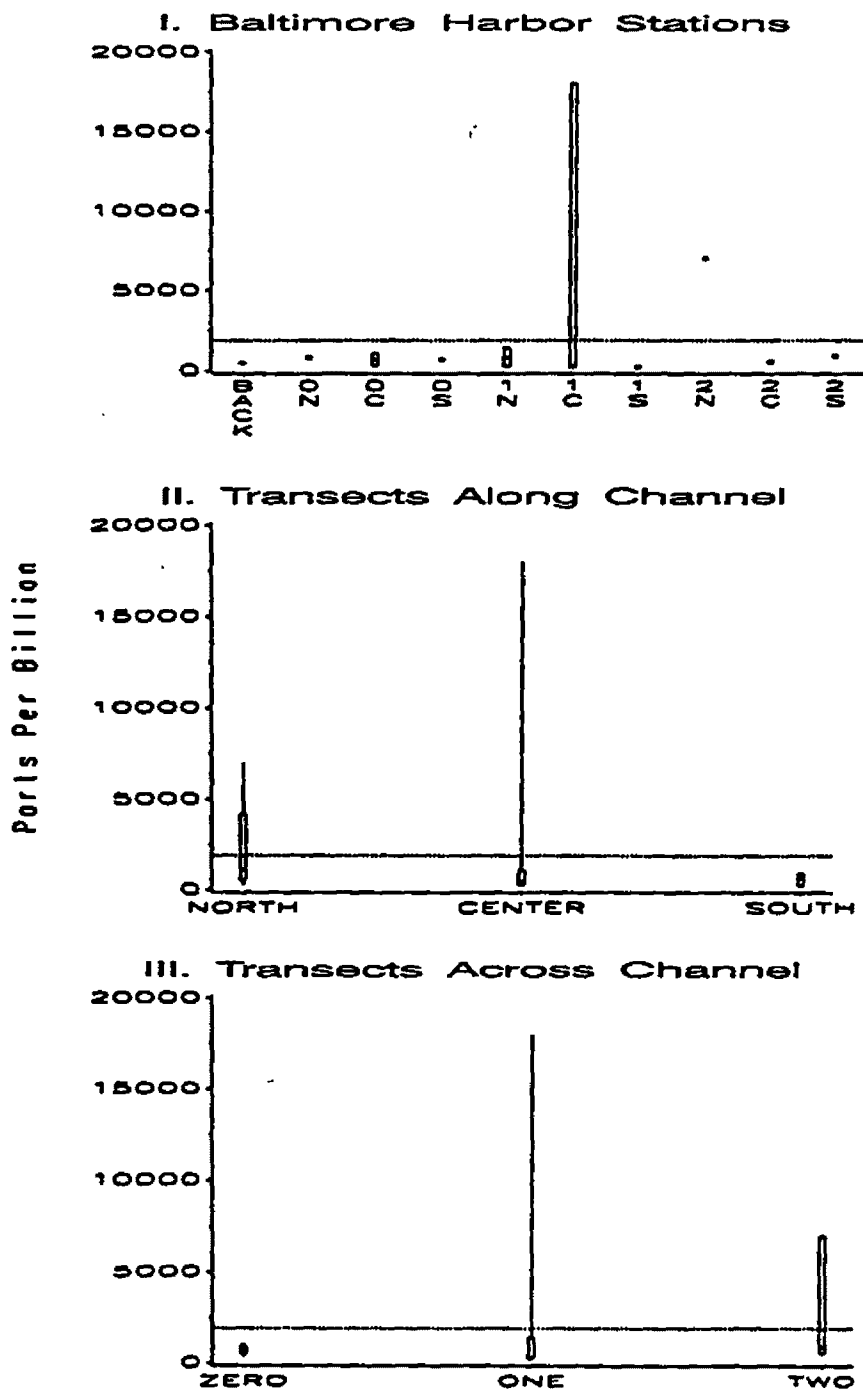


Figure 5.25 Pyrene concentrations in sediment in Baltimore Harbor and Back River. The box and whisker plots illustrate the median (central horizontal line), the quartiles (extent of the rectangle), and ranges (extent of vertical lines) of the data. If there are less than four values, the rectangle's bottom and top show the range. A dash indicates only a single value is available. The Baltimore Harbor stations in I. are aggregated by their location relative to the central dredged channel in II. and III. The NOEL and PEL values for sediment pyrene concentrations are 290 ppb and 1900 ppb, respectively (MacDonald, 1993). The PEL is represented in the graphs as a dotted line, if it is within the range of concentration values.

## Spatial Distribution of Chlorinated Hydrocarbons

A list of pesticides and PCBs analyzed for in the Baltimore Harbor and Back River sediments, the number of stations at which each compound was detected, and the range in measured concentrations found for each compound are shown in Table 5.24. Table 5.25 lists the compounds detected and the concentrations at whi :h th··· were found for each station. All data are from 1991.

### Pesticides: Alachlor, Chlordane, Heptachlor, Dieldrin, and DDT

The herbicide alachlor was found in the sediment at only one station. A concentration of 1.4 ppb was found ﹖t MWT5.1C in the Baltimore Harbor (Tables 5.24 and 5.25)

Chlordane, a Chesapeake Bay Program Toxic of Concern (Chesapeake Bay Program, 1991a), was one of th ﹖ most commonly detected pesticides in the Baltimore Harbor and Back River (Tables 5.24 and 5.25). The alpha foi m was found at seven locations and the gamma form at one location. The median concentrations for alpha- and ga. nma-chlordane at stations where these compounds were detected, was approximately 1.9 ppb for both compound :. Heptachlor was found at one Baltimore Harbor station at a concentration of 3.3 ppb (Tables 5.24 and 5.25). Concentrations of total chlordane (alpha plus gamma forms) measured in the Baltimore Harbor stations were mostly between the Long and Morgan (1990) ER-L and ER-M concentrations of 0.5 ppb and 6.0 ppb, respecti rely. The ER-M concentration for total chlordane was exceeded at two stations in the region—the Baltimore Harboi station, MWT5.0C, had a total chlordane concentration of about 6.9 ppb, while the Back River station had approximately 22.4 ppb. Toxic effects to aquatic biota due to the measured sediment concentrations of chlorc ane are not likely at the stations monitored in Baltimore Harbor region except for MWT5.0C and the station in the E ack River.

Dieldrin was found at four of the Baltimore Harbor stations at a range of measured concentrations from 5.7 to 6.1 ppb (Tables 5.24 and 5.25), well below the ER-M concentration of 20 ppb (Long and Morgan, 1990). The ER- ﹒ for dieldrin is 0.02 ppb (Long and Morgan, 1990). Due to the relatively small amount of data available, the degree of confidence in these ER-L and ER-M concentrations is low (Long and Morgan, 1990). Toxic effects to aquatic t iota due to the measured sediment concentrations of dieldrin are not likely at the stations monitored in Baltimore H; irbor or the Back River.

DDT decomposed during the analysis and could not be measured directly in the sediment samples, but the measured concentrations of DDD and DDE were converted into "DDT equivalents" for comparison with sedime nt guidelines relating to Total DDT. Total DDT was measured at three of the Baltimore Harbor stations, with a maximum concentration of 22.3 ppb total DDT (Tables 5.24 and 5.25), approximately an order of magnitude be low the MacDonald (1993) PEL concentration of 270 ppb. The two other stations with detectable levels of DDT hac concentrations slightly above the MacDonald (1993) NOEL concentration of 5.0 ppb for total DDT. Toxic effect ﹔ to aquatic biota due to the measured sediment concentrations of DDT are not likely at the stations monitored in th﹒﹒ Baltimore Harbor region.

## Triazines

Of the three triazine herbicides—atrazine, cyanazine, simazine—measured in sediment samples, only cyanazine was detected (Tables 5.24 and 5.25). It was found at two stations in the Baltimore Harbor and at the Back River station (Tables 5.24 and 5.25). The highest measured concentration was 11.4 ppb (Table 5.24 and Table 5.25). Sediment quality guidelines relating to cyanazine were not found in the literature.

## Hexachlorobenzene

Hexachlorobenzene is used in chemical manufacturing and as a fungicide (Windholz, et al., 1983). Hexachlorobenzene was found at seven of the nine stations in Baltimore Harbor, but was not detected at the Back River station (Tables 5.23 and 5.24). Measured concentrations varied from 2.4 ppb to 68.9 ppb (Table 5.25). Sediment quality guidelines relating to hexachlorobenzene were not found in the literature.

Table 5.24 Frequency of detection and range of observed concentrations for pesticides and PCBs analyzed in Baltimore Harbor sediments. The total number of stations was 10.

| Compound | Frequency | Minimum | Maximum |
|---|---|---|---|
| 2,2',3,5'-Tetrachlorobiphenyl | 0 | | |
| 2,2',4,5'-Tetrachlorobiphenyl | 0 | | |
| 2,3',5-Trichlorobiphenyl | 0 | | |
| 2,4',5-Trichlorobiphenyl | 0 | | |
| Alachlor | 1 | 1.4 | 1.4 |
| Alpha chlordane | 7 | 1.4 | 12.2 |
| Atrazine | 0 | | |
| Carbofuran | 0 | | |
| Chlorpyrifos | 0 | | |
| Cyanazine | 3 | 0.6 | 11.4 |
| DDD | * | * | * |
| DDE | * | * | * |
| DDT/DDT Equivalent | 3 | 9.1 | 22.3 |
| Dieldrin 4 | 5.7 | 6.1 | |
| Fenvalerate | 0 | | |
| Gamma chlordane | 1 | 10.2 | 10.2 |
| Heptachlor | 1 | 3.3 | 3.3 |
| Heptachlor epoxide | 0 | | |
| Hexachlorobenzene | 7 | 2.4 | 68.9 |
| Lindane | | 0 | |
| Metolachlor | 0 | | |
| Permethrin | 0 | | |
| Simazine | 0 | | |

* DDT decomposed during the sediment analysis and thus its breakdown products DDD and DDE cannot be reported separately.

Table 5.25 Pesticides and PCBs found at each sediment monitoring station in Baltimore Harbor and the Back River.

| Location | Compound | Concentration (ppb) |
|---|---|---|
| **ONE COMPOUND DETECTED = 1 station** | | |
| MWT5.0S | Hexachlorobenzene | 14.0 |
| | | |
| **TWO COMPOUNDS DETECTED = 3 stations** | | |
| MWT5.2C | Cyanazine | 11.4 |
| | Hexachlorobenzene | 10.9 |
| | | |
| MWT5.2S | Alpha chlordane | 1.4 |
| | Heptachlor | 3.3 |
| | | |
| MWT5.0N | Alpha chlordane | 1.5 |
| | Dieldrin | 5.9 |
| | | |
| **THREE COMPOUNDS DETECTED = 5 stations** | | |
| MWT5.1S | Alpha chlordane | 1.4 |
| | Dieldrin | 5.7 |
| | Hexachlorobenzene | 68.9 |
| | | |
| MWT5.1N | Alpha chlordane | 1.6 |
| | DDT Equivalent | 9.1 |
| | Hexachlorobenzene | 4.4 |
| | | |
| MWT5.2N | DDT Equivalent | 9.9 |
| | Dieldrin | 6.1 |
| | Hexachlorobenzene | 2.4 |
| | | |
| MWT5.0C | Alpha chlordane | 6.9 |
| | DDT Equivalent | 22.3 |
| | Hexachlorobenzene | 7.0 |
| | | |
| Back R. | Alpha chlordane | 12.2 |
| | Cyanazine | 7.6 |
| | Gamma chlordane | 10.2 |
| | | |
| **FIVE COMPOUNDS DETECTED = 1 station** | | |
| MWT5.1C | Alachlor | 1.4 |
| | Alpha chlordane | 1.9 |
| | Cyanazine | 0.6 |
| | Dieldrin | 5.7 |
| | Hexachlorobenzene | 22.8 |

## Summary of Sediment Organic Compounds in Baltimore Harbor and Back River

Based on the exceedences of the PELs, organic compounds generally pose less of a threat than metals, except possibly for station MWT5.2N. At that station the PELs for anthracene, benzo[a]anthracene, benzo[a]pyrene, dibenzo[a,h]anthracene, fluoranthene, and pyrene were exceeded. There is a lower level of risk at the other stations with the NOEL being exceeded at two to eight of the stations for the other compounds and the PEL was exceeded at two stations only for one compound. However, the data for organic compounds in Baltimore harbor are few, with no detectable concentrations at some stations for some compounds. In many cases, only a single measurement is available per station. Also, most areas of the Harbor are not monitored.

For the chlorinated compounds, available data indicate that several compounds are present at concentrations indicating possible impacts. Alpha chlordane and hexachlorobenzene were found most frequently.

# Elizabeth River

Recent data on sediment contaminant concentrations in the Elizabeth River are available from Phase I of the Elizabeth River Long-Term Monitoring Program (Virginia Water Control Board, 1991 and Greaves, 1990). As part of this program, the Applied Marine Research Laboratory at Old Dominion University conducted analyses of sediment metal concentrations and the Virginia Institute of Marine Science conducted analyses of sediment concentrations of organic compounds, including tributyltin. Data were also gathered on sediment toxicity, the concentrations of organic compounds in blue crab tissue, water column concentrations of inorganic and organic pollutants, and plankton and benthic communities.

In 1989, sediment samples were collected from four regions within the Elizabeth River and the Lafayette River, a tributary to the Elizabeth River (Figure 6.1). Three samples, one each from the central channel and either side of the channel, were collected at each site within the Southern Branch of the Elizabeth River. At all other sites, one sediment sample was collected.

Summary information on sediment contaminant concentrations obtained in this program is presented and briefly discussed below. Further information is available from Virginia Water Control Board (1991) and Greaves (1990).

## Trace Metals

Mean and maximum sediment concentrations of copper, lead, mercury, tributyltin and zinc were sometimes markedly higher in the Eastern Branch, Southern Branch, and Western Branch of the Elizabeth River than those found in the Lafayette River or the Main Branch of the Elizabeth River. The Western Branch had a sediment cadmium concentration over twice as great as at any other monitoring station, while the Southern Branch, Eastern Branch and Main Branch had intermediate sediment cadmium concentrations, and the Lafayette River had the lowest sediment cadmium concentrations (Table 6.1). The two stations in the Eastern Branch and the stations with the highest metal concentrations in the Southern Branch (SBE2 and SBE3) are all adjacent to or near large shipyards (Virginia Water Control Board, 1991).

Mean sediment metal concentrations above the appropriate NOEL concentrations, but below PEL concentrations were observed for chromium and zinc in all areas sampled (Table 6.1). Sediment metal concentrations exceeded the respective NOEL concentrations for cadmium, copper, and mercury in all areas except the Lafayette River, but no mean concentrations in excess of PEL values were observed. Sediment concentrations of zinc in excess of the PEL of 300 ppm were found in the Eastern Branch, Southern Branch, and Western Branches of the Elizabeth River. Mean lead concentrations in the sediment in the Eastern Branch were above the PEL of 160 ppm. Toxic effects to aquatic biota due the measured sediment concentrations of zinc and/or lead are likely in the Eastern Branch, Western Branch, and Southern Branch of the Elizabeth River, but are unlikely at the other sampled locations.

Insufficient data were judged to be available for development of sediment guidelines for tributyltin (Long and Morgan, 1990; MacDonald, 1993), but sediment concentrations as low as 10 ppm have been associated with high mortality of grass shrimp, a species generally considered insensitive to most toxic chemicals (MacDonald, 1993). Tributyltin concentrations in the sediments sampled in the Elizabeth River ranged from 0.04 ppm to 2.8 ppm. The major use of tributyltin (TBT), a Chesapeake Bay Toxic of Concern (Chesapeake Bay Program, 1991a), is as an additive to boat bottom paint to inhibit biofouling. The Federal Organotin Antifouling Paint Control Act of 1988 prohibits the use of TBT antifouling paints on all non-aluminum vessels under 82 feet and the sale, distribution, and use of existing stocks of tributyltin products is prohibited in the U.S. (Chesapeake Bay Program, 1991b).

# Anacostia River and the Potomac River Near Washington, D.C.

A comprehensive study of sediment contaminant concentrations in the Anacostia River and the upper Potomac River near Washington, D.C. was recently conducted by Velinsky *et al.* (1992) for the Interstate Commission on the Potomac River Basin. In this study, data were gathered on ambient sediment contaminant concentrations in the Anacostia River and upper Potomac River, as well as sediment contaminant concentrations in front of and within major storm and combined sewer outfalls discharging to these areas. Sediment toxicity tests and benthic community analyses were also conducted at a subset of stations at which sediment contaminants were analyzed.

Sediment samples not associated with stormwater or combined sewer outfalls were collected in 1991 from six stations in the Anacostia River and four stations in the upper Potomac River between Rock Creek and the Anacostia River (Figure 7.1). Summary statistics for sediment concentrations of selected sediment contaminants from these two areas are presented below and briefly discussed. For further information on these two areas, as well as data collected on sediments in the Tidal Basin, Washington Ship Channel, and Kingman Lake, see Velinsky *et al.*, 1992.

## Trace Metals

Sediment concentrations of trace metals were higher in the Anacostia River than in the upper Potomac River (Table 7.1). Within the Anacostia River, markedly higher sediment trace metal concentrations were observed at station AR-4, located just downstream of the Washington Navy Yard (Table 7.1 and Figure 7.1). Within the upper Potomac River, higher trace metal concentrations were consistently found at station PR-1 (Table 7.1), located below the mouth of Rock Creek, a tributary draining the northwest section of the District of Columbia (Velinsky *et al.*, 1992).

Sediment concentrations of lead, mercury, and zinc were above their respective NOEL concentrations at all stations in both the Anacostia River and upper Potomac River (Table 7.1 and MacDonald, 1993). Sediment trace metal concentrations above the NOEL concentration were observed at at least one station in the Anacostia River for copper and at at least one station in both the Anacostia River and upper Potomac River for chromium (Table 7.1, MacDonald, 1993). Sediment concentrations in excess of the appropriate PEL concentration were observed only in the Anacostia River for lead and zinc (Table 7.1, MacDonald, 1993). Toxicity to aquatic biota due to the measured sediment concentrations of lead and zinc would ordinarily be considered likely at a minority of the sampled locations in the Anacostia River; however, measurements of acid volatile sulfide in these areas indicate that these metals may not be in a form which is available to the biota and thus not likely to cause toxic effects (Velinsky *et al.*, 1992).

Table 6.1. Summary statistics for sediment trace metal concentrations in various portions of the Elizabeth River. Concentrations are in ppm dry weight.

| | Eastern Branch | Lafayette Branch | Main River | Southern Branch | Western Branch |
|---|---|---|---|---|---|
| **Cadmium** | | | | | |
| min. | 0.8 | 0.6 | 1.3 | 0.6 | 6.3 |
| mean | 1.2 | 0.6 | 1.6 | 1.4 | 6.3 |
| max. | 1.5 | 0.6 | 1.8 | 2.8 | 6.3 |
| **Chromium** | | | | | |
| min. | 38 | 50 | 32 | 28 | 54 |
| mean | 52 | 50 | 44 | 55 | 54 |
| max. | 65 | 50 | 56 | 76 | 54 |
| **Copper** | | | | | |
| min. | 150 | 23 | 22 | 28 | 70 |
| mean | 161 | 23 | 33 | 118 | 70 |
| max. | 172 | 23 | 39 | 229 | 70 |
| **Lead** | | | | | |
| min. | 169 | 41 | 34 | 38 | 129 |
| mean | 235 | 41 | 57 | 127 | 129 |
| max. | 300 | 41 | 82 | 186 | 129 |
| **Mercury** | | | | | |
| min. | 0.72 | 0.08 | 0.13 | 0.20 | 0.34 |
| mean | 0.99 | 0.08 | 0.16 | ≑ 0.52 | 0.34 |
| max. | 1.25 | 0.08 | 0.2 | 1.02 | 0.34 |
| **Nickel** | | | | | |
| min. | 17 | 21 | 13 | 11 | 18 |
| mean | 21 | 21 | 18 | 22 | 18 |
| max. | 24 | 21 | 23 | 29 | 18 |
| **Tributyltin** | | | | | |
| min | 0.220 | 0.150 | 0.032 | 0.043 | 0.190 |
| mean | 0.660 | 0.150 | 0.056 | 0.951 | 0.190 |
| max | 1.100 | 0.150 | 0.099 | 2.800 | 0.190 |
| **Zinc** | | | | | |
| min. | 467 | 102 | 116 | 86 | 666 |
| mean | 483 | 102 | 205 | 369 | 666 |
| max. | 499 | 102 | 267 | 624 | 666 |

**Polycyclic Aromatic Hydrocarbons and Polychlorinated Biphenyls**

Mean and maximum sediment concentrations of polycyclic aromatic compounds (PAHs) and total polychlorinated biphenyls (total PCBs) were much higher in the Eastern and Southern Branches of the Elizabeth River than in the other regions sampled. Sediment concentration of PAHs and total PCBs were higher in the Western Branch and Main Branch than at the Lafayette River station (Table 6.2).

Sediment concentrations of all of the PAH compounds included in Table 6.2 were above their respective NOEL concentrations in the Southern and Eastern Branches of the Elizabeth River. Mean sediment concentrations in excess of the appropriate NOEL concentration were also found in the Western Branch and Main Branch of the Elizabeth River for phenanthrene and total PCBs, and in the Main Branch for pyrene (Table 6.2). Sediment concentrations of total PCBs and all the PAH compounds listed in Table 6.2 except naphthalene exceeded their respective PEL concentration at one or more stations in both the Eastern Branch and Southern Branch of the Elizabeth River. Toxic effects to aquatic biota due to the measured sediment concentrations of total PCBs and several PAHs are likely only in the monitored locations in the Eastern Branch and Southern Branch of the Elizabeth River.

Table 6.2. Summary statistics for sediment concentrations of selected polycyclic aromatic compounds and total PCBs in various portions of the Elizabeth River. Concentrations are in ppb dry weight.

| | Eastern Branch | Lafayette River | Main Branch | Southern Branch | Western Branch |
|---|---|---|---|---|---|
| **Anthracene** | | | | | |
| min. | 310 | 9 | 20 | 161 | 43 |
| mean | 593 | 10 | 42 | 548 | 43 |
| max. | 877 | 11 | 55 | 2505 | 43 |
| **Benzo(a)anthracene** | | | | | |
| min. | 735 | 36 | 39 | 323 | 143 |
| mean | 1289 | 40 | 93 | 970 | 143 |
| max. | 1842 | 45 | 150 | 2029 | 143 |
| **Benzo(a)pyrene** | | | | | |
| min. | 906 | 34 | 38 | 637 | 161 |
| mean | 1415 | 35 | 99 | 1362 | 161 |
| max. | 1924 | 36 | 151 | 2519 | 161 |
| **Chrysene** | | | | | |
| min. | 1154 | 54 | 82 | 511 | 196 |
| mean | 1785 | 59 | 153 | 1822 | 196 |
| max. | 2417 | 63 | 224 | 3768 | 196 |
| **Fluoranthene** | | | | | |
| min. | 2401 | 92 | 114 | 823 | 375 |
| mean | 3876 | 103 | 279 | 2974 | 375 |
| max. | 5350 | 115 | 390 | 6029 | 375 |
| **Naphthalene** | | | | | |
| min. | 151 | 3 | 73 | 99 | 33 |
| mean | 300 | 5 | 80 | 240 | 33 |
| max. | 449 | 7 | 88 | 491 | 33 |
| **Phenanthrene** | | | | | |
| min. | 892 | 36 | 87 | 413 | 170 |
| mean | 484 | 38 | 151 | 838 | 170 |
| max. | 077 | 41 | 196 | 892 | 170 |
| **Pyrene** | | | | | |
| min. | 2577 | 91 | 120 | 1459 | 397 |
| mean | 4860 | 96 | 286 | 3426 | 397 |
| max. | 7143 | 102 | 457 | 8138 | 397 |
| **Total PCBs (ppb)** | | | | | |
| min. | 400 | 56 | 24 | 19 | 240 |
| mean | 530 | 74 | 72 | 538 | 240 |
| max. | 660 | 91 | 120 | 2400 | 240 |

Table 7.1.  Summary statistics for sediment trace metal concentrations in the Anacostia and upper Potomac Rivers.  Concentrations are in ppm dry weight.  Normalized values are measured concentrations divided by the fraction of the sediment consisting of silt and clay particles.

| | Measured values | | Normalized values | |
|---|---|---|---|---|
| | Anacostia River | Potomac River | Anacostia River | Potomac River |
| **Cadmium** | | | | |
| min. | 0.92 | 0.52 | 0.93 | 0.58 |
| mean | 1.87 | 0.66 | 2.00 | 0.77 |
| max. | 3.18 | 0.99 | 3.70 | 1.27 |
| **Chromium** | | | | |
| min. | 90.3 | 63.4 | 91.1 | 70.1 |
| mean | 116.3 | 73.8 | 123.8 | 85.8 |
| max. | 155.5 | 96.2 | 180.8 | 123.1 |
| **Copper** | | | | |
| min. | 63.8 | 34.2 | 64.4 | 39.4 |
| mean | 91.7 | 41.8 | 97.6 | 48.8 |
| max. | 126.9 | 59.7 | 147.5 | 76.4 |
| **Lead** | | | | |
| min. | 83.2 | 32.0 | 83.9 | 36.9 |
| mean | 177.7 | 58.2 | 193.0 | 69.8 |
| max. | 408.9 | 127.7 | 475.4 | 163.4 |
| **Mercury** | | | | |
| min. | 0.29 | 0.13 | 0.29 | 0.14 |
| mean | 0.49 | 0.25 | 0.53 | 0.30 |
| max. | 1.04 | 0.56 | 1.21 | 0.72 |
| **Zinc** | | | | |
| min. | 279 | 168 | 281 | 189 |
| mean | 387 | 223 | 412 | 262 |
| max. | 512 | 365 | 595 | 467 |

## Polycyclic Aromatic Hydrocarbons

Sediment concentrations of select polycyclic aromatic compounds were generally higher at the stations in the Anacostia River than at the stations in the upper Potomac River. However, station PR-1 in the upper Potomac River had the highest sediment concentrations among all stations for all of the select PAH compounds (Table 7.2). As with trace metals, within the Anacostia River, station AR-4 below the Washington Navy Yard had markedly higher sediment concentrations of selected PAH compounds compared to the other Anacostia River stations, and station PR-1 in the upper Potomac River downstream of Rock Creek had markedly higher sediment concentrations of selected PAHs than did other stations in the upper Potomac River (Table 8.2 and Velinsky et al., 1992).

Sediment PAH concentrations above the appropriate NOEL concentration were observed in both the Anacostia and upper Potomac rivers for all of the compounds listed in Table 7.2. Sediment concentrations above the appropriate PEL concentration were only found at station PR-1 in the upper Potomac River for phenanthrene and pyrene. Toxic effects to aquatic biota due to the measured sediment concentrations of PAHs are likely among the sampled areas of the upper Potomac and Anacostia rivers only at station PR-1 below Rock Creek in the upper Potomac River.

## Pesticides and other Chlorinated Organic Compounds

Sediment concentrations of total chlordane, total PCBs, and, to a lesser extent, total PCBs were generally higher in the Anacostia River than in the upper Potomac River (Table 7.3). Sediment concentrations of all three of these contaminants exceeded their respective NOEL concentrations at all stations within both rivers. Sediment concentrations in excess of the respective PEL concentrations were found in the Anacostia River for total chlordane and total PCBs, but not for total DDT. Toxicity to aquatic biota due to the sediment concentrations of total chlordane and total PCBs are likely at some of the monitored locations in the Anacostia River, but are not likely at any of the monitored locations in the upper Potomac River.

Table 7.2. Summary statistics for sediment concentrations of selected polycyclic aromatic hydrocarbons in the Anacostia and upper Potomac Rivers. Concentrations are in ppb dry weight. Normalized values are measured concentrations divided by the fraction of total organic carbon in the sediment.

| | Measured values | | Normalized values | |
| --- | --- | --- | --- | --- |
| | Anacostia River | Potomac River | Anacostia River | Potomac River |
| **Anthracene** | | | | |
| min. | 35 | 28 | 971 | 683 |
| mean | 80 | 104 | 2201 | 2812 |
| max. | 138 | 322 | 3677 | 8337 |
| **Benzo(a)anthracene** | | | | |
| min. | 169 | 106 | 4742 | 2715 |
| mean | 397 | 323 | 10764 | 8753 |
| max. | 607 | 933 | 15490 | 24161 |
| **Benzo(a)pyrene** | | | | |
| min. | 212 | 124 | 5949 | 3165 |
| mean | 431 | 345 | 11799 | 9338 |
| max. | 586 | 970 | 16860 | 25132 |
| **Chrysene** | | | | |
| min. | 253 | 135 | 7074 | 4327 |
| mean | 595 | 426 | 16279 | 11451 |
| max. | 817 | 1183 | 23652 | 30642 |
| **Fluoranthene** | | | | |
| min. | 482 | 372 | 13509 | 8982 |
| mean | 1265 | 975 | 34790 | 26534 |
| max. | 1867 | 2781 | 54301 | 72054 |
| **Naphthalene** | | | | |
| min. | 30 | 27 | 748 | 650 |
| mean | 58 | 162 | 1594 | 4304 |
| max. | 130 | 554 | 3477 | 14346 |
| **Phenanthrene** | | | | |
| min. | 189 | 184 | 5295 | 4587 |
| mean | 545 | 630 | 14965 | 16940 |
| max. | 1040 | 1959 | 27741 | 50757 |
| **Pyrene** | | | | |
| min. | 478 | 312 | 13397 | 7958 |
| mean | 1166 | 875 | 32203 | 23757 |
| max. | 1811 | 2533 | 49998 | 65617 |

Table 7.3. Summary statistics for sediment concentrations of selected organochlorine compounds in the Anacostia and upper Potomac Rivers. Concentrations are in ppb dry weight. Normalized values are measured concentrations divided by the fraction of total organic carbon in the sediment.

| | MEASURED | | NORMALIZED | |
|---|---|---|---|---|
| | Anacostia | Potomac | Anacostia | Potomac |
| **Total Chlordane** | | | | |
| min. | 28 | 5 | 774 | 134 |
| mean | 87 | 16 | 2361 | 439 |
| max. | 139 | 42 | 3741 | 1077 |
| **Total DDT** | | | | |
| min. | 29 | 7 | 803 | 177 |
| mean | 71 | 33 | 1877 | 889 |
| max. | 124 | 103 | 2879 | 2674 |
| **Total PCBs** | | | | |
| min. | 218 | 68 | 6118 | 1870 |
| mean | 820 | 123 | 21304 | 3402 |
| max. | 2203 | 265 | 51242 | 6855 |

# Interpretation of Trace Metal Concentrations in Chesapeake Bay Sediments

## Introduction

Trace metals are a natural component of sediment. However, natural concentrations among different sediments vary by as much as a factor of 100 (Windom et al., 1989) making it difficult to determine how much of a measured concentration is natural and how much is due to anthropogenic input. There are two major sources of natural variation. The first is the origin of the sediment. For example, if a sediment is eroded from a source rich in zinc, then it will also have relatively high levels of that metal. The second source of variation is the concentration of trace metals in fine-grained material. Thus, sediments with a greater proportion of fine-grained materials , generally have higher concentrations of trace metals than areas where coarse-grained materials, such as sands, predominate. This is believed to occur because fine particles have a greater surface area per unit mass than large particles and consequently adsorb more metals than the same mass of larger particles. Larger particles adsorb only small quantities of metals and thus act to dilute the metal concentration of sediments (Horowitz, 1985).

One approach to separating natural from anthropogenic variation in sediment trace element concentrations is to "normalize" trace metal concentrations to another element, such as aluminum or iron. The normalizing element is selected so that trace metal:normalizing element ratios are relatively constant in uncontaminated areas. This may occur because the normalizing element is present in very high concentrations relative to trace metals and/or because the sediment concentration of the normalizing element is not affected by human activities. Among the elements that have been used to normalize sediment trace metal concentrations are lithium (Loring, 1990 and 1991), rubidium (Grant and Middleton, 1990), iron (Trefey, et al., 1976; Sinex and Helz, 1981; Helz et al., 1983; Rule, 1988; Sinex and Wright, 1988), and aluminum (Windom et al., 1989; Environmental Protection Agency, 1991). Sediment samples with an ususually high trace metal:normalizing element ratio are said to be "enriched" with this trace metal, presumably due to anthropogenic inputs.

Often, the determination of what constitutes enrichment is based on the average trace metal:normalizing element ratio in the earth's crust (Rule, 1988; Sinex and Wright, 1988). However, assuming an average crustal composition may not be appropriate for a relatively limited geographic area such as the Chesapeake Bay, since local geology may result in different trace metal:normalizing element ratios than those obtained from average crustal composition. An alternative is to develop a more site-specific ratio by using trace metal:normalizing element ratios from sediments from areas within the region that are relatively unaffected by anthropogenic inputs of trace metals (Windom et al., 1989). This method has the disadvantage of requiring the identification of areas believed to be relatively uncontaminated with trace metals, which may introduce an element of subjectivity into the analysis.

The use of trace metal:normalizing element ratios for interpreting the trace metal concentrations discussed in this report is hampered by several factors. The first is that an analytical method which completely dissolves the sediment sample, i.e. a "total concentration" of metals should be used in this type of analysis (Windom et al., 1989). However, the majority of the data discussed in this report were obtained using a less rigorous technique for extracting the metals from the sediment, i.e., "total recoverable" concentrations, which does not completely dissolve the sediment matrix. There are advantages and disadvantages to both methods of determining sediment metal concentrations; however, data obtained from the two methods may not be directly comparable.

The second factor complicating the analysis is that areas in the study region that would a priori be assumed to have very low levels of trace metal contamination because they are in more pristine areas and not influenced by currents from populated areas, e.g., the Southeastern Rivers and Bays region in Maryland, also differ from other areas of Chesapeake Bay in other ways. Sediments on the lower eastern shore of

Chesapeake Bay are generally coarser than those located elsewhere in the Bay, and thus would be expected to have lower trace metal concentrations than other areas in the Bay for that reason alone. However, dividing sediment trace metal concentrations by the concentration of a normalizing element generally accounts for much of the variability in trace metal concentrations which can be accounted for by variations in grain size (Luoma, 1990).

In addition, the presumably less contaminated sediments on the lower eastern shore may have a different geological origin than sediments on the western shore. The sediments along the eastern flank of the Bay are thought to have been transported from the south, while sediments from the western flank of the Bay are believed to be derived from the Susquehanna River (Helz and Valette-Silver, 1992). Finally, the trace metal:normalizing element ratios obtained from reference areas may be based on data with a smaller range in normalizing element concentrations than that found in the data as a whole, thus requiring the assumption that the trace metal:normalizing element ratios are the same at higher concentrations of the normalizing element (Schropp and Windom, 1988).

## Methods

The majority of areas in the Chesapeake Bay have data available on sediment trace metal concentrations measured by the "total recoverable" method. These include the mainstem Bay, its tidal tributaries in Maryland, and the Elizabeth River. A "total recoverable" method of metals analysis was also applied to sediment samples from the James River analyzed by the Virginia Department of Environmental Quality. However, data on the major metals typically used as normalizing elements were not available for these samples, and thus these data were not included in the analyses. Because of the use of the "total" method of sediment trace metal concentrations in data from the Anacostia River and Potomac Rivers near D.C. (Velinsky *et al.*, 1992) and the EMAP program in the Virginia tributaries, these data were also excluded from the analysis. Thus, all data used in the analysis were obtained with the same analytical method.

The assumption inherent in using trace metal:normalizing element ratios to identify areas impacted by anthropogenic inputs of trace metals is that in uncontaminated areas, the trace metal:normalizing element ratio will be relatively constant, and thus the majority of the variation in trace metals concentrations will be accounted for by variations in sediment concentrations of the normalizing element. To select the normalizing element, a correlation analysis was performed to determine the strength of the relationship between the concentrations of the various trace metals and the two major metals, iron and aluminum, which could potentially be used as normalizing elements. Data on the percentages of total organic carbon and silt and clay in the sediment were also included in this correlation analysis, since variation in these sediment characteristics have been found to be significantly correlated with the concentration of some trace metals (Windom *et al.*, 1989; Horowitz *et al.*, 1989; Luoma, 1990). Data from stations known to be influenced by point sources of trace metals were excluded from this correlation analysis.

The results of the correlation analysis showed that of the two major metals most commonly used for normalization of sediment trace metal concentrations, the concentrations of five of the eight trace metals were more strongly correlated with iron concentrations than with aluminum concentrations (Table 8.1). For all trace metals, correlation coefficients with iron concentrations were highly significant, and ranged from 0.214 in the case of lead to 0.774 for chromium.

Mercury and arsenic both had slightly higher correlation coefficients with aluminum than with iron. For mercury, the correlation coefficients with iron and aluminum were very close, with correlation coefficients of 0.484 and 0.508 for iron and aluminum, respectively. For arsenic, the correlation coefficient with aluminum (0.650) was somewhat higher than that for iron (0.515) (Table 8.1). For consistency, and for the reasons discussed below, iron was used as the normalizing element for all trace metals.

Iron is a reasonable candidate to use in normalizing trace metal concentrations in Chesapeake Bay sediments, since anthropogenic inputs of iron are small relative to natural sources (Tippie, 1984). Helz *et*

*al.* (1983) found that despite large inputs of iron to Baltimore Harbor in the past, the ratio of aluminum to iron in Harbor sediments was not anomalous, suggesting that the relatively high iron concentrations found in Baltimore Harbor are probably a consequence of the predominance of fine-grained sediments in the area, rather than past anthropogenic inputs. Several studies of trace metal enrichment of Chesapeake Bay sediment which used sediment metal concentration data obtained from a "total recoverable" type of analysis have used iron as the normalizing element (*e.g.*, Sinex and Wright, 1988; Rule, 1988).

The higher correlations of sediment trace metals with iron as compared to aluminum may be partially due to the type of extraction used in measuring the metal concentrations. The "total recoverable" method used in this study would have measured primarily metals associated with the surface of sediments, and iron oxides are one of the principal binding sites for metals on the surfaces of oxic sediments (Luoma, 1990). A relatively large proportion of trace metals associated with aluminum, in contrast, are located in the matrix of the sediment, and thus are not released unless a complete dissolution of the sediment is used to extract the metals. Use of aluminum as a normalizing element for trace metal concentrations is not recommended unless a "total metal" extraction technique is used (Schropp and Windom, 1988). Quality assurance and quality control data (Appendix C) indicate that the difference in metal concentrations obtained from the total metal technique versus that obtained from the total recoverable metal technique was much greater for aluminum than it was for iron and the trace metals measured.

To identify trace metal:iron ratios which are high enough to indicate enrichment (i.e., possible anthropogenic trace metal contamination), the average trace metal:iron ratio for each metal at each station was compared to a threshold value. For each trace metal, the threshold was the approximate upper 95% confidence limit of the Baywide mean trace metal:iron ratio for that trace metal (the mean ratio plus two standard errors of the mean ratio). The Back River, Elizabeth, Magothy, Severn, and Sassafras Rivers, Baltimore Harbor, and mainstem segments 1 and 2 were excluded from the calculations of threshold values because these stations were thought to be more heavily affected by anthropogenic trace metal contamination. Regions with trace metal:iron ratios above the threshold are listed in Table 8.2. These procedures for identifying stations enriched with trace metals were used by Morse *et al.* (1993) in the Galveston Bay area.

In addition, enrichment factors relative to the earth's crust were calculated for each trace metal at each station by dividing the observed average trace metal:iron ratio by the trace metal:iron ratio in the average composition of the earth's crust. Sinex and Wright (1988) suggested that enrichment factors greater than two are probably indicative of elevated levels of trace metals, although they presented no support for this statement. Table 8.3 lists average enrichment factors in each region relative to crustal composition.

## Results and Discussion

Table 8.2 presents, for each trace metal, a list of the regions which were identified as enriched with that metal by the threshold criteria discussed above. Back River was is enriched with all trace metals except arsenic; Baltimore Harbor sediments are enriched with all of the listed metals except cadmium and nickel. There are no arsenic data for the Elizabeth River, but that area is enriched with all of the other metals except nickel. Other regions are enriched with varying combinations of metals. Copper is found to be enriched in 14 of the 23 listed areas; zinc in 13; and lead, mercury, and nickel in nine each.

Comparison of the trace metal:iron ratios with that expected based on average crustal composition (Taylor, 1964) rather than Chesapeake Bay ratios present a different picture using double the crustal ratio as the threshold for enrichment (Sinex and Wright, 1988) (Table 8.3). All stations were enriched for arsenic and most for cadmium, as opposed to 5 of 23 regions for both metals using the Chesapeake Bay ratios and indicated thresholds. Crustal ratios indicate a low frequency of enrichment for chromium, copper, lead, and mercury whereas Chesapeake Bay ratios indicate more frequent enrichment (between 9 and 14 of the 23 listed regions) for those metals. Crustal ratios indicated enrichment at 20 of 23 regions for nickel while Chesapeake Bay ratios indicated enrichment at 9 of 23. Zinc was enriched at 20 of 23 regions by crustal ratios and at 13 of 23 regions by Chesapeake Bay ratios.

This could indicate that arsenic, cadmium, nickel, and zinc may be somewhat elevated naturally in Chesapeake Bay area sediments, as well as enriched due to anthropogenic inputs in localized areas within the region. It might also be indicative of widespread contamination, suggesting that diffuse atmospheric sources are, or have been, a significant proportion of the total loadings for these metals. High arsenic:aluminum ratios relative to those based on average crustal composition have also been found in Florida estuarine sediments (Windom et al., 1989).

**Comparisons with Other Studies of Trace Metal Enrichment in Chesapeake Bay Sediments**

Sinex and Wright (1988) calculated enrichment factors relative to average crustal composition for Chesapeake Bay sediments. These authors used iron as the normalizing element and the same source of data for average crustal composition as was used in the analysis presented above. The sources of data for Baltimore Harbor sediment metal concentrations they cite are from 1981 and 1982, and thus most likely reflect measurements made in the late 1970s. The results of their analysis are similar to the results discussed above with respect to widespread enrichment of zinc in the Baltimore Harbor and upper and middle regions of the mainstem and marked chromium enrichment in Baltimore Harbor.

Sinex and Wright (1988) also found widespread enrichment of zinc relative to average crustal composition in mainstem Chesapeake Bay sediments, and suggested this was consistent with a large atmospheric source of zinc to the Bay. In the past, high concentrations of zinc were reported in rainwater from storms in the region (Environmental Protection Agency, 1982). Zinc has been found to be enriched relative to average crustal composition in the upper portion of cores from the mainstem, but not in the bottom portion, suggesting an increase in zinc loadings to the Bay in the past 100 years (Sinex and Wright, 1988). Thus, the available evidence suggests that a considerable portion of the zinc concentration in Chesapeake Bay sediments is probably due to anthropogenic inputs, at least in the urbanized areas showing the highest levels of enrichment with zinc.

However, the enrichment of lead in mainstem sediments found by Sinex and Wright is not evident in the current analysis. Sinex and Wright (1988) noted that atmospheric sources (presumably from the use of leaded gasoline) were an important source of lead to the mainstem. The decline in the use of leaded gasoline which occurred from 1979 to 1989 has been estimated to have reduced the concentration of lead in urban runoff by 95% (Olsenholler, 1985), and a similar decrease has probably occurred in direct atmospheric loadings of lead. Thus, the decline in enrichment in lead in mainstem sediments may reflect the switch to unleaded gasoline. Sinex and Wright (1988) also found enrichment of copper in the sediments in the upper portion of the mainstem and enrichment with zinc in lower mainstem sediments. Neither of these areas were identified as enriched with these elements in the analysis based on more recent data.

Velinsky, et al.(1992) found marked enrichment of cadmium and, to a lesser degree, lead, in the sediments from the lower Anacostia and upper Potomac rivers in the vicinity of Washington, D.C. The lower Anacostia River was more enriched with these two metals than the upper Potomac River. Copper and zinc showed more modest enrichment than cadmium and lead, and the levels of enrichment of these trace metals were similar for the two rivers. Enrichment factors for mercury varied considerably among the stations in the lower Anacostia and upper Potomac rivers. Mercury was not enriched at most of the stations sampled, but some stations in the lower Anacostia River (station AR-4 below the Washington Navy Yard) and upper Potomac River (station PR-1 below the confluence with Rock Creek) were enriched with mercury. Chromium was generally not enriched at the stations sampled in these two rivers.

Table 8.1. Correlation matrix for major and trace metal sediment concentrations, carbon and sediment characteristics from monitoring stations in Chesapeake Bay and its tidal tributaries. Data from Back, Elizabeth, Magothy, Severn, and Sassafras Rivers, Baltimore Harbor, and Mainstem Segments 2 and 3 were excluded in calculating correlations. (TOC = fraction total organic carbon in the sediment; GL62 = fraction silt and clay particles in the sediment).

| | TOC | GL62 | Fe | Al | As | Cd | Cr | Cu | Pb | Hg | Ni | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOC | 1.000 | 0.277 | 0.368 | 0.501 | 0.343 | 0.187 | 0.309 | 0.170 | 0.063 | -0.032 | 0.269 | 0.292 |
| GL82 | | 1.000 | 0.539 | 0.571 | 0.356 | 0.133 | 0.419 | 0.448 | 0.214 | 0.174 | 0.464 | 0.447 |
| Fe | | | 1.000 | 0.659 | 0.515 | 0.284 | 0.774 | 0.761 | 0.214 | 0.484 | 0.751 | 0.698 |
| Al | | | | 1.000 | 0.650 | 0.224 | 0.651 | 0.533 | 0.174 | 0.508 | 0.638 | 0.647 |
| As | | | | | 1.000 | 0.022 | 0.522 | 0.326 | 0.131 | 0.050 | 0.437 | 0.243 |
| Cd | | | | | | 1.000 | 0.272 | 0.217 | 0.234 | 0.083 | 0.270 | 0.351 |
| Cr | | | | | | | 1.000 | 0.692 | 0.195 | 0.222 | 0.704 | 0.580 |
| Cu | | | | | | | | 1.000 | 0.280 | 0.476 | 0.779 | 0.831 |
| Pb | | | | | | | | | 1.000 | 0.182 | 0.277 | 0.269 |
| Hg | | | | | | | | | | 1.000 | 0.432 | 0.323 |
| Ni | | | | | | | | | | | 1.000 | 0.731 |
| Zn | | | | | | | | | | | | 1.000 |

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Table 8.2. Sediment trace metal:iron ratios above threshold values for regions of the Chesapeake Bay mainstem and its tidal tributaries. Threshold values are the mean plus two standard errors of the ratios for all stations excluding Back, Elizabeth, Magothy, Severn, and Sassafras Rivers, Baltimore Harbor, and mainstem segments 2 and 3. Ratios are x 10,000. A "*" means the region's trace metal:iron ratio is below the threshold.

| Region | As | Cd | Cr | Cu | Pb | Hg | Ni | Zn |
|---|---|---|---|---|---|---|---|---|
| Ches. Bay Average Ratio | 6.841 | 0.252 | 15.791 | 7.742 | 11.849 | 0.032 | 9.511 | 49.313 |
| Ches. Bay Std. Error | 0.250 | 0.018 | 0.364 | 0.202 | 0.912 | 0.001 | 0.263 | 1.411 |
| Ches. Bay Threshold Value | 7.341 | 0.289 | 16.520 | 8.147 | 13.673 | 0.035 | 10.037 | 52.136 |
| Baltimore Harbor | | | | | | | | |
| Back River | 7.469 | | | | | | | |
| Northwest Rivers | | 0.964 | 52.867 | 20.190 | 20.816 | 0.072 | | 80.605 |
| Western Rivers | | | 65.821 | 45.537 | 46.319 | 0.112 | 26.991 | 163.104 |
| Patuxent River | | | 17.501 | 14.039 | 16.777 | 0.056 | 11.597 | 59.002 |
| Potomac River | | 0.337 | 21.671 | 12.758 | | 0.035 | | 63.474 |
| Elizabeth River (No data) | | | 18.571 | 10.187 | | | | |
| Northeast Rivers | 11.746 | 0.568 | 19.702 | 37.642 | | 0.048 | 11.403 | 54.984 |
| Chester and Choptank | 7.733 | | 29.259 | 14.127 | 48.299 | 0.188 | | 132.284 |
| Eastern Bays | 9.027 | | | | | 0.079 | | |
| S.E. Rivers and Bays | 7.881 | 0.381 | | 8.741 | 16.140 | | 15.135 | 64.796 |
| Segment 1 | | | | | | | | |
| Segment 2 | | | | | 14.038 | | 10.317 | |
| Segment 3 | | | | 9.727 | 25.773 | | | |
| Segment 4 | | | | 11.044 | | | 20.346 | 82.105 |
| Segment 5 | | | | 9.854 | 15.667 | | 16.875 | 80.094 |
| Segment 7 | | | | 9.670 | | | 12.340 | 86.339 |
| Segment 8 | | | | | | | 10.556 | 74.341 |
| Potomac River Mouth | | | | | | | | 55.669 |
| Rappahannock River Mouth | | 0.555 | | | | 0.054 | | |
| Mobjack Bay | | | | 10.538 | 13.902 | | | |
| York River Mouth | | | | | | | | 73.037 |
| James River Mouth | | | | 8.954 | | 0.073 | | |

Table 8.3. Average enrichment of trace metals relative to average crustal composition for various regions in Chesapeake Bay. Values are calculated by dividing the Chesapeake Bay trace metal: iron ratio in the sediment by the trace metal:iron ratio in average crustal composition. If the Chesapeake Bay ratio is more than twice the crustal ratio, the region may be considered enriched. Crustal compositions based on Taylor, 1984; ratios are x 10,000.

| Region | As | Cd | Cr | Cu | Pb | Hg | Ni | Zn |
|---|---|---|---|---|---|---|---|---|
| Baltimore Harbor | 12.283 | 5.257 | 2.976 | 2.091 | 0.947 | 0.686 | 7.212 | 6.521 |
| Back River | 8.503 | 27.144 | 3.698 | 4.661 | 2.086 | 2.029 | 11.173 | 13.154 |
| Northwest Rivers | 11.608 | 4.739 | 0.972 | 1.386 | 0.726 | 0.868 | 5.542 | 4.652 |
| Western Rivers | 8.865 | 5.446 | 1.220 | 1.287 | 0.533 | 0.682 | 3.481 | 5.042 |
| Patuxent River | 11.848 | 9.501 | 1.043 | 0.602 | 0.347 | 0.653' | 1.729 | 3.011 |
| Potomac River | 9.236 | 6.408 | 0.738 | 1.026 | 0.426 | 0.847 | 4.840 | 4.413 |
| Elizabeth River | No data | 23.634 | 1.080 | 3.337 | 2.292 | 0.571 | 18.361 | 11.697 |
| Northeast Rivers | 19.068 | 4.591 | 1.644 | 1.446 | 0.592 | 1.138 | 7.881 | 5.226 |
| Chester & Choptank | 12.575 | 4.986 | 0.844 | 0.572 | 0.661 | 0.698 | 2.950 | 3.332 |
| Eastern Bays | 14.729 | 6.388 | 0.900 | 0.877 | 0.416 | 0.766 | 2.574 | 3.718 |
| S.E. Rivers & Bays | 12.574 | 10.557 | 0.922 | 0.610 | 0.608 | 0.648 | 3.447 | 3.468 |
| Segment 1 | 3.323 | 5.847 | 0.575 | 0.996 | 1.161 | 1.530 | 2.029 | 6.621 |
| Segment 2 | 6.470 | 4.821 | 0.504" | 1.130 | 0.614 | 1.269 | 2.978 | 6.459 |
| Segment 3 | 8.195 | 4.013 | 0.687 | 1.009 | 0.706 | 0.928 | 2.431 | 6.963 |
| Segment 4 | 9.091 | 4.905 | 0.811 | 0.989 | 0.559 | 0.789 | 2.451 | 5.881 |
| Segment 5 | 5.546 | 3.674 | 0.693 | 0.620 | 0.402 | 0.555 | 1.846 | 4.140 |
| Segment 7 | 3.198 | 1.618' | 0.527 | 0.433 | 0.177 | 0.334 | 1.987 | 1.721 |
| Segment 8 | 6.189 | 0.176 | 0.186 | 0.134 | 0.149 | 0.141 | 5.375 | 1.361 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| nes River Mouth | 2.319 | 0.447 | 0.143 | 0.⌐37 | 0.114 | 0.107 | 7.302 | 1.408 |
| Mobjack Bay | 5.448 | 1.418 | 0.703 | 0.508 | 0.262 | 0.401 | 2.416 | 2.165 |
| Potomac River Mouth | 10.225 | 15.638 | 0.814 | 1.079 | 0.626 | 0.716 | 2.001 | 5.890 |
| Rappahannock River | 3.801 | 3.182 | 0.545 | 0.601 | 0.273 | 0.398 | 2.782 | 2.222 |
| York River Mouth | 4.845 | 3.166 | 0.716 | 0.916 | 0.314 | 0.414 | 3.101 | 2.782 |

# Discussion and Conclusions

**Baywide Spatial Patterns in Sediment Concentrations of Trace Metals**

The distribution of the various trace metals generally show similar spatial patterns within the Chesapeake Bay and its tidal tributaries. The areas discussed in this report can be placed into one of four broad groups with regard to median sediment trace metal concentrations. These groups are listed and discussed below in order of decreasing sediment trace metal concentrations.

1.  Baltimore Harbor and Back River, the Anacostia River, and the Eastern and Western Branches of the Elizabeth River

Baywide, the highest median sediment concentrations of all the monitored trace metals were found in one of these areas (Table 9.1). For cadmium, chromium, lead and zinc, the sediment concentrations in these areas were markedly higher than those found elsewhere in the Chesapeake Bay mainstem or tidal tributaries. All of these areas had median sediment concentrations of zinc which exceeded the Probable Effects Level (PEL) values. Concentrations of cadmium, chromium, and lead in Back River, chromium in Baltimore Harbor, and lead in the East Branch of the Elizabeth River xceeded the respective PELs.

Back River had the highest median sediment concentrations of cadmium, copper, nickel, and zinc. Baltimore Harbor had the highest median concentrations of chromium and arsenic, however, arsenic concentrations were not available for the Anacostia River or Elizabeth River. The highest sediment concentrations of mercury and lead were in the Eastern Branch of the Elizabeth River, while the highest sediment cadmium concentration was in the Western Branch of the Elizabeth River.

2.  Tidal tributaries in the Northwestern, Western, and Northeastern Rivers regions in Maryland, the upper Potomac River near Washington, D.C., and the Southern Branch of the Elizabeth River.

Sediment contaminant monitoring stations in these areas generally had median trace metal concentrations less than those found in the areas listed above, but higher than those observed at stations in other tidal tributaries and the mainstem Bay.

Within these areas, zinc was the only trace metal for which average sediment concentrations exceeded PEL values.

3.  Tidal tributaries on the lower western shore (Patuxent and Potomac) and upper eastern shore of Maryland (Chester and Choptank), the Main Branch of the Elizabeth River, and the stations in the upper, western and central portions of the mainstem midbay.

Monitoring areas in the Patuxent, Potomac, Chester, and Choptank Rivers in Maryland, the main branch of the Elizabeth River, and the western flank and central portion of the midbay had sediment trace metal concentrations in the third highest category Baywide. Median sediment trace metal concentrations at these stations were generally below those found in the more highly industrialized and/or urbanized areas in the categories above, but were somewhat higher than those found in less urbanized tributaries on the lower western and eastern shores and elsewhere in the mainstem. None of these areas had average sediment trace metal concentrations in excess of PEL values.

The lower estuarine portion of the James River has higher concentrations than the upper portion, and the lower areas and the Lafayetter River could be placed within this group.

4.  Tributaries on the lower eastern shore of Maryland, the Rappahannock and York rivers, the upper portions of the James River, and the stations on the eastern flank of the midbay and the extreme upper and lower portions of the mainstem Bay.

These stations generally had the lowest sediment trace metal concentrations found in the mainstem or tidal tributaries of the Chesapeake Bay (Table 9.1).

There were a few exceptions to the spatial distribution of trace metals in Chesapeake Bay sediments described above. The tidal fresh station of the Patuxent River and some stations from the Southeastern Rivers and Bays Region on Maryland's eastern shore had sediment cadmium concentrations which were considerably above those from stations located near more populated areas, such as those in the Potomac River and Northeast Rivers regions. Although the spatial distribution of sediment arsenic concentrations was similar to that of the other trace metals, the arsenic concentrations found in Baltimore Harbor, the Anacostia and Back Rivers were not as high relative to those found elsewhere in the Chesapeake Bay as was the case for most other trace metals.

In general, the above patterns still held when trace metal concentrations were normalized to take into account differences in the proportions of silt and clay, or iron, in the sediment. The one major exception to this pattern was the station at the mouth of the Susquehanna River, which had relatively high trace metal concentrations for an area with a low percentage of fine-grained sediments and relatively low iron concentrations. In general, however, the spatial patterns in sediment trace metal concentrations probably reflect, in at least a broad way, the spatial distribution of trace metal loadings to the Bay, and do not result primarily from differences in sediment grain-size distribution.

**Baywide Spatial Patterns in Sediment Concentrations of Polycyclic Aromatic Hydrocarbons**

The Baywide pattern in the sediment concentrations of polycyclic aromatic hydrocarbons (PAHs) differed from that exhibited by the trace metals. Three broad categories of sediment concentrations of these compounds are discussed below in order of decreasing concentrations.

1.      The Southern and Eastern Branches of the Elizabeth River.

These two tidal tributaries had median sediment concentrations of most PAHs which far exceeded those found elsewhere in the Chesapeake Bay and its tidal tributaries (Table 9.2). The sediment concentrations of phenanthrene, fluoranthene, pyrene, and chrysene exceeded the PEL concentrations in the east branch; only pyrene exceeded the PEL in the south branch.

2.      Baltimore Harbor, Back River, Anacostia River, Northwestern, Western, Northeastern, Upper PotomacRiver Regions, West and Main Branches of the Elizabeth River, and Chesapeake Bay segments 2 and 3.

These areas had median sediment concentrations of most PAHs less than those in the Southern and Eastern Branches of the Elizabeth River, but greater than the rest of the Chesapeake Bay tidal tributaries and mainstem Bay. Within the Baltimore Harbor, sediment concentrations of most PAHs were markedly higher at station MWT5.2N near Sparrows Point than at the other monitoring stations (Chapter 5). Within the Anacostia River, sediment concentrations of most PAHs were markedly higher at station AR-4 below the Washington Navy Yard compared to other stations in the river (Chapter 7). Sediment PAH concentrations in these areas did not exceed PEL concentrations.

3.      All other monitored areas.

Stations in these areas generally had sediment concentrations of PAHs which were generally lower than those observed elsewhere in the Chesapeake Bay mainstem and tidal tributaries.

Table 9.1: Median trace metal concentrations in Chesapeake Bay sediments. Units are ppm (µg/g), dry weight. Data sources: Maryland tributaries: the Maryland Dept. of the Environment (MDE) sediment contaminants monitoring program. Bay mainstem: joint MDE-EPA Chesapeake Bay Program - Va. Dept. of Environmental Quality sediment contaminant monitoring program. Anacostia River and Upper Potomac River: Velinsky *et al.*, 1992. James River: deFur *et al.*, 1987. Elizabeth and Lafayette rivers: Virginia Water Control Board, 1991. ND=No data.

| Region | Arsenic | Cadmium | Chromium | Copper | Lead | Mercury | Nickel | Zinc |
|---|---|---|---|---|---|---|---|---|
| Back River | 18.2 | 4.10 | 265 | 191 | 191 | 0.491 | 113 | 682 |
| Baltimore Harbor | 40.4 | 0.91 | 303 | 112 | 109 | 0.367 | 46 | 413 |
| Anacostia River | ND | 1.83 | 113 | 91 | 143 | 0.365 | ND | 384 |
| Elizabeth R. (E. Branch) | ND | 1.15 | 52 | 161 | 235 | 0.985 | 21 | 483 |
| Elizabeth R. (W. Branch) | ND | 6.30 | 54 | 70 | 129 | 0.340 | 18 | 666 |
| | | | | | | | | |
| Northwestern Rivers | 28.0 | 0.50 | 69 | 45 | 54 | 0.230 | 47 | 216 |
| Western Rivers | 27.6 | 0.80 | 103 | 51 | 58 | 0.160 | 45 | 289 |
| Northeastern Rivers | 27.9 | 0.54 | 64 | 42 | 44 | 0.171 | 41 | 192 |
| Upper Potomac River | ND | 0.57 | 68 | 37 | 36 | 0.150 | ND | 180 |
| Elizabeth R. (S. Branch) | ND | 1.35 | 57 | 113 | 110 | 0.510 | 24 | 326 |
| | | | | | | | | |
| Patuxent River | 26.9 | 1.50 | 68 | 23 | 29 | 0.058 | 35 | 146 |
| Potomac River | 20.0 | 0.71 | 45 | 36 | 33 | 0.150 | 38 | 192 |
| Chester & Choptank | 21.4 | 0.40 | 40 | 15 | 32 | 0.069 | 27 | 114 |
| Elizabeth R. (Main Br.) | ND | 1.55 | 43 | 39 | 55 | 0.150 | 19 | 232 |
| Ches. Bay Segment 2 | 9.2 | 0.65 | 27 | 35 | 48 | 0.135 | 53 | 230 |
| Ches. Bay Segment 3 | 10.0 | 0.50 | 38 | 34 | 51 | 0.100 | 46 | 242 |
| Ches. Bay Segment 4 | 9.6 | 0.50 | 36 | 29 | 35 | 0.080 | 27 | 172 |
| Ches. Bay Segment 5 | 8.5 | 0.58 | 36 | 19 | 29 | 0.050 | 25 | 123 |
| | | | | | | | | |
| James River | 9.0 | 2.00 | 20 | 19 | 22 | 0.160 | 15 | 103 |
| Eastern Bays | 18.2 | 0.49 | 36 | 17 | 21 | 0.050 | 24 | 101 |
| S.E. Rivers & Bays | 14.5 | 0.49 | 29 | 11 | 17 | 0.050 | 16 | 77 |
| Rappahannock River | ND | 0.33 | 63 | 32 | 20 | ND | 26 | 128 |
| York River | ND | 0.22 | 19 | 4 | 9 | ND | 6 | 38 |
| Lafayette River | ND | 0.60 | 50 | 23 | 41 | 0.080 | 21 | 102 |
| Ches. Bay Segment 1 | 0.7 | 0.18 | 23 | 5 | 15 | 0.050 | 12 | 43 |
| Ches. Bay Segment 7 | 3.1 | 0.16 | 19 | 8 | 12 | 0.072 | 9 | 42 |
| Ches. Bay Segment 8 | 5.7 | 0.20 | 14 | 5 | 15 | 0.093 | 8 | 39 |
| | | | | | | | | |
| Potomac River Mouth | 7.3 | 2.00 | 35 | 26 | 35 | 0.050 | 24 | 128 |
| Rapp. River Mouth | 7.7 | 0.36 | 41 | 20 | 24 | 0.100 | 22 | 102 |
| Mobjack Bay | 8.0 | 0.23 | 40 | 16 | 26 | 0.086 | 19 | 93 |
| York River Mouth | 7.7 | 0.30 | 44 | 22 | 27 | 0.090 | 21 | 101 |
| James River Mouth | 4.4 | 0.30 | 22 | 9 | 21 | 0.073 | 11 | 55 |

Table 9.2: Median concentrations of selected polycyclic aromatic hydrocarbons in Chesapeake Bay sediments. Units are ppb (ug/kg), dry weight. Data sources: Maryland tributaries: the Maryland Dept. of the Environment (MDE) sediment contaminants monitoring program. Bay mainstem: joint MDE-EPA Chesapeake Bay Program - Va. Dept. of Environmental Quality sediment contaminant monitoring program. Anacostia River and Upper Potomac River: Velinsky et al., 1992. Rappahannock, York, and James Rivers: EPA Chesapeake Bay Program - Virginia Department of Water Quality sediment contaminant monitoring program. Elizabeth and Lafayette rivers: Virginia Water Control Board, 1991.

| Region | Naphthalene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Benzo(a) anthracene | Chrysene | Benzo(a) pyrene |
|---|---|---|---|---|---|---|---|---|
| Elizabeth R.(E. Branch) | 300 | 1484 | 593 | 3876 | 4860 | 1289 | 1785 | 1415 |
| Elizabeth R.(S. Branch) | 186 | 694 | 342 | 2607 | 2985 | 870 | 1683 | 1246 |
| Baltimore Harbor | 188 | 133 | 170 | 814 | 678 | 271 | 200 | 527 |
| Back River | 175 | 315 | 82 | 465 | 486 | 229 | 374 | 153 |
| Anacostia River | 42 | 533 | 76 | 1362 | 1162 | 393 | 647 | 464 |
| Northwestern Rivers | 528 | 314 | 84 | 290 | 322 | 133 | 368 | 135 |
| Western Rivers | 134 | 305 | 83 | 348 | 306 | 97 | 154 | 91 |
| Ches. Bay Seg. 2 | 120 | 407 | 149 | 371 | 388 | 208 | 279 | 270 |
| Ches. Bay Seg. 3 | 74 | 305 | 57 | 337 | 373 | 113 | 182 | 130 |
| Northeastern Rivers | 149 | 193 | 73 | 241 | 298 | 120 | 169 | 137 |
| Elizabeth R.(W. Branch) | 33 | 170 | 43 | 375 | 397 | 143 | 196 | 161 |
| Elizabeth R. (Main Br.) | 78 | 172 | 52 | 333 | 282 | 91 | 152 | 106 |
| Upper Potomac River | 34 | 188 | 32 | 374 | 329 | 126 | 193 | 143 |
| Patuxent River | 11 | 27 | 10 | 64 | 68 | 28 | 55 | 34 |
| Potomac River | 18 | 56 | 31 | 105 | 150 | 75 | 109 | 70 |
| Chester & Choptank | 44 | 74 | 33 | 83 | 126 | 47 | 98 | 75 |
| Eastern Bays | 28 | 13 | 13 | 38 | 38 | 13 | 24 | 15 |
| S.E. Rivers & Bays | 5 | 8 | 16 | 20 | 18 | 11 | 18 | 12 |
| Rappahannock River | 2 | 24 | 5 | 63 | 61 | 24 | 40 | 33 |
| York River | 5 | 35 | 7 | 79 | 71 | 35 | 54 | 28 |
| James River | 7 | 50 | 16 | 100 | 113 | 47 | 76 | 69 |
| Lafayette River | 5 | 38 | 10 | 103 | 97 | 40 | 59 | 35 |
| Ches. Bay Seg. 1 | 22 | 46 | 11 | 44 | 60 | 12 | 19 | 9 |
| Ches. Bay Seg. 4 | 15 | 56 | 15 | 90 | 74 | 50 | 93 | 32 |
| Ches. Bay Seg. 5 | 5 | 35 | 7 | 31 | 57 | 12 | 26 | 21 |
| Ches. Bay Seg. 7 | 1 | 2 | 1 | 4 | 3 | 2 | 4 | 3 |
| Ches. Bay Seg. 8 | 2 | 7 | 1 | 9 | 7 | 3 | 6 | 3 |
| Potomac River Mouth | 13 | 54 | 14 | 88 | 72 | 28 | 51 | 37 |
| Rapp. River Mouth | 7 | 28 | 6 | 54 | 53 | 21 | 33 | 30 |
| Mobjack Bay | 3 | 33 | 2 | 51 | 47 | 21 | 34 | 32 |
| York River Mouth | 4 | 27 | 4 | 58 | 54 | 22 | 36 | 30 |
| James River Mouth | 5 | 24 | 1 | 53 | 52 | 20 | 33 | 21 |

## Potential Risk to Aquatic Biota Due to Sediment Contaminant Concentrations

To summarize the large amount of data on sediment contaminant concentrations in Chesapeake Bay and its tidal tributaries, a procedure was developed to rank stations or regions according to the likelihood that the concentrations of sediment contaminants at these locations would be associated with adverse effects to aquatic biota.

In the ranking procedure, all locations were initially assigned a score of one. For each location the average sediment concentration of each contaminant included in the ranking procedure (selected trace metals, polycyclic aromatic hydrocarbons, PCBs, and pesticides) was then compared to the appropriate Probable Effects Level (MacDonald, 1993). Two points were added to a location's score for each contaminant for which the average sediment concentration was above its PEL. One point was added to a station's score for each contaminant for which the average sediment score approached the PEL, i.e, was between 80 and 100 percent of the PEL. No points were added to a location's score for those contaminants for which the average sediment concentration did not exceed or approach the PEL, i.e, were less than 80 percent of the PEL. A location's scores for all contaminants (Table 9.3) were then added together to produce a single numerical score for that location. The higher a location's score, the higher its sediment contaminant concentrations relative to the concentrations which may be associated with adverse effects to aquatic organisms, and thus the higher the probability of sediment contamination at that location resulting in adverse effects to its aquatic biota.

The contaminants included in the ranking process are listed in Table 9.3. The criteria for inclusion of a sediment contaminant in the ranking process were the availability of sediment concentration data for all or most of the Chesapeake Bay and its tidal tributaries and the availability of relevant sediment quality guidelines. Data on sediment concentrations of nickel were not included in the analysis because current sediment quality guidelines are not predictive of an increasing incidence of toxic effects (Long et al., 1995). A special effort was made to include those contaminants on the Chesapeake Bay Toxics of Concern List (Chesapeake Bay Program, 1991a).

For the Maryland tidal tributary stations, data on sediment concentrations of both trace metal and organic chemical contaminants were available, and thus the ranking process was applied to these individual stations. Within the Virginia tidal tributaries and the mainstem of Chesapeake Bay, data on both trace metals and organic chemical contaminants were not available from all stations or were collected from different locations within these areas. Thus, within these areas, sediment contaminant data were aggregated by Chesapeake Bay Program segment, with the tributaries divided into tidal fresh, estuarine transition, and lower estuarine segments. In areas which have been sampled more intensively, such as the Anacostia River, the upper Potomac River in the vicinity of Washington, D.C., the Baltimore Harbor, and the various branches of the Elizabeth River, data from several stations were aggregated and a single score for each of these areas was obtained by applying the ranking procedure to these average sediment contaminant concentrations.

The data used in the ranking process were primarily from the Virginia and Maryland sediment contaminant monitoring programs, since these two programs utilized similar analytical methods and provided good spatial coverage of the area of interest. Data from Velinsky et al. (1992) were utilized for the Anacostia and the upper Potomac rivers near Washington, D.C. No data were available on sediment concentrations of arsenic in these two areas, so the average sediment arsenic concentration at the tidal fresh station in the Potomac River was used as proxy data for these two locations. There were no data on sediment concentrations of trace metals in the York and Rappahannock rivers from Virginia's sediment monitoring program, so in these two areas data from the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) were utilized in the ranking process. The EMAP data available for this report did not include arsenic and mercury concentrations, so average concentrations from the Virginia portion of the mainstem were utilized as proxy data for these areas.

Table 9.3. Contaminants included in the procedure used to rank locations within Chesapeake Bay and its tidal tributaries according to the potential risk of toxic effects to aquatic biota posed by sediment concentrations of contaminants. Contaminants marked with two asterisks are on the Chesapeake Bay Toxics of Concern List (Chesapeake Bay Program, 1991a); contaminants marked with a single asterisk are on the secondary list of compounds being evaluated for inclusion on the list of Chesapeake Bay Toxics of Concern (Chesapeake Bay Program, 1991b).

| TRACE METALS | POLYCYCLIC AROMATIC HYDROCARBONS | CHLORINATED ORGANIC COMPOUNDS |
|---|---|---|
| Arsenic* | Anthracene | Total PCBs (or sum of measured congeners) |
| Copper** | Benzo[a]anthracene** | Total DDT |
| Cadmium** | Benzo[a]pyrene** | Total chlordane |
| Chromium** | Chrysene** | |
| Lead** | Fluoranthene** | |
| Mercury** | Naphthalene** | |
| Zinc* | Phenanthrene | |
| | Pyrene | |

Data on trace metal concentrations from the EMAP study were also used in the ranking process for the James River, since these data were more recent than that from the Virginia Department of Environmental Quality (VADEQ) monitoring program. In addition, the EMAP stations were located randomly, whereas those sampled by VADEQ were intentionally located near wastewater outfalls. For these reasons, the data from the EMAP stations were thought to be more representative of sediment trace metal concentrations in most of the James River. Data on sediment arsenic concentrations were unavailable for the Elizabeth River, so the average arsenic concentration in the lower estuarine portion of the James River was used as proxy data.

The data on sediment trace metal concentrations used in the ranking process were obtained with a "total recoverable" extraction procedure in the Maryland tributaries and the mainstem Bay, while a more rigorous "total" extraction procedure was used to obtain the data from the James, York, Rappahannock and Anacostia Rivers, as well as the upper Potomac River in the vicinity of Washington, D.C. The "total recoverable" method of sediment trace metal analysis may underestimate sediment trace metal concentrations compared to what would be obtained using the more rigorous "total" method of trace metal analysis.

The current level of scientific understanding of the effects of sediment contaminants does not allow for consistently accurate predictions of the probability of adverse effects on aquatic biota based solely on information on the sediment concentrations of contaminants. Thus, this ranking procedure, like any other based on current knowledge, cannot be expected to provide an accurate estimate of the relative risk to aquatic biota due to sediment contamination in all instances. Some of the shortcomings of the ranking procedure are discussed below.

The ranking procedure does not take into account differences among locations in sediment characteristics such as the concentration of acid volatile sulfide (AVS) or total organic carbon (TOC) which may strongly influence sediment contaminant bioavailability and toxicity. Bulk sediment contaminant concentrations were used in the ranking process because the PEL concentrations to which the sediment concentrations were

compared are based on bulk sediment contaminant concentrations. In addition, data on AVS concentrations were not available from the Maryland Department of Environment's monitoring program in the Maryland tidal tributaries or the Virginia Department of Environmental Quality - EPA Chesapeake Bay Program sediment contaminant monitoring program in the Virginia tidal tributaries.

Comparison of sediment contaminant concentrations in Chesapeake Bay to PEL concentrations should, on average, make reasonable predictions of the probability of adverse biological effects, assuming the sediments are generally similar to the sediments used to derive the PEL values. With respect to sediment from any one location, however, sediment characteristics may result in the PEL providing an inaccurate prediction of the likelihood of impacts to aquatic biota.

Differences in the concentrations of other sediment contaminants may also affect the applicability of the PEL guideline to sediments at a given location. The ranking procedure implicitly assumes that sediment contaminants present in concentrations at or above the PEL concentrations have additive effects, an assumption with some support in the literature (Okamura and Aoyama, 1994). However, in some instances, groups of similar sediment contaminants have been found to interact in a synergistic manner (Enserink et al., 1991 and Okamura and Aoyama, 1994). Thus, it is possible that a suite of sediment contaminants, none of which are present at concentrations near or above its PEL concentration, may in concert adversely effect the biota. However, the relationship of interactions among multiple sediment contaminants to the overall degree of sediment toxicity has not progressed sufficiently for such interactions to be modeled and included in the ranking process.

Because of the limitations of the ranking process discussed above, the ranking must be viewed as only a rough estimate of the relative probability of sediment toxicity to aquatic biota at various locations in Chesapeake Bay. As additional information on sediment characteristics such as the concentrations of acid-volatile sulfide and total organic carbon, and the results of sediment bioassays, studies of benthic and fish tissue contaminant concentrations, and benthic community condition at each location become available, our estimates of the relative risk to aquatic biota from sediment contamination for various locations may be altered.

The distribution of location scores is positively skewed, with a few stations showing much higher scores than those of the majority of locations (Figure 9.1). This indicates that at most locations in the Chesapeake Bay and its tidal tributaries the biota are not likely to be impacted by sediment contaminant concentrations. However, there are some locations where, due to natural concentertating factors (the two mainstem Bay segments), or to historical industrial activity (Patapsco and Elizabeth Rivers), or urbanization (Anacostia River) where adverse impacts are more likely.

The eastern branch of the Elizabeth River had the highest score of all ranked locations, followed by Back River and the Southern Branch of the Elizabeth River. The Patapsco River (Baltimore Harbor), according to these scores, is impacted less than the three threatened sites. Anacostia River, and the western branch of the Elizabeth River are just a little better than the Patapsco. The high scores of the eastern and southern branches of the Elizabeth River were due to the much higher sediment concentrations of polycyclic aromatic hydrocarbons (PAHs) in these areas compared to Baltimore Harbor, Back River, Anacostia River, and the western branch of the Elizabeth River. Back River, for instance, had several trace metals in excess of their PEL, but no PAHs exceeded the relevant PEL. In contrast, the Elizabeth, Anacostia, and Baltimore Harbor had somewhat lower sediment trace metal concentrations than Back River, but higher sediment PAH concentrations.

The Magothy, and Severn rivers received the next highest scores, followed by Bay segments 2 and 3, the South Northeast, Sassafras, and Middle rivers. With the exception of the Sassafras River, sediment trace metal concentrations contributed more heavily to these areas' overall scores than did sediment concentrations of PAHs. Segment two in the upper Bay and segment three in the upper midbay had the highest overall rankings among locations in the mainstem of Chesapeake Bay. This was due to having concentrations of zinc at 80% of the PEL. Zinc tends to be high in many areas of the Bay. In addition, segments two and three are areas where organic carbon and fine sediment tend to accumulate, further

IX-7

In general, sediment contaminant concentrations above the PEL occurred more frequently for trace metals than for PAHs and in all but some of the most contaminated areas, trace metals appear to pose greater environmental risks to aquatic biota than do polycyclic aromatic hydrocarbons and other organic contaminants. There is less data available on sediment concentrations of chlorinated organic compounds such as pesticides and PCBs in Chesapeake Bay than there is regarding trace metals and PAHs. In addition, there are no sediment guidelines for many chlorinated organic compounds. However, where available, sediment concentrations of chlorinated organic compounds did not exceed their Probable Effects Levels in the vast majority of monitored areas of the Chesapeake Bay, and thus are not likely to exert negative impacts to aquatic biota.

In conclusion, comparison of sediment contaminant levels with available sediment quality guidelines indicate that the risk to aquatic biota from sediment contamination varies widely throughout the Chesapeake Bay and its tidal tributaries. A few restricted areas of the Bay which are heavily industrialized and/or urbanized, specifically the Baltimore Harbor, Back River, Anacostia River, and Elizabeth River, have sediment concentrations of several contaminants which are high enough to adversely impact aquatic organisms. Estimates of the relative risk to aquatic biota due to sediment contamination at these areas are much higher than for areas elsewhere in the Bay.

Areas in and near the heavily urbanized or rapidly growing areas in the northern and western shores of the Chesapeake Bay have the next highest estimates of risk to aquatic biota from sediment contamination. A relatively large area of the Bay has sediment concentrations of toxics that are not high enough to be considered likely to cause adverse biological effects to aquatic organisms.

# RISK TO AQUATIC BIOTA DUE TO SEDIMENT CONTAMINANT CONCENTRATIONS
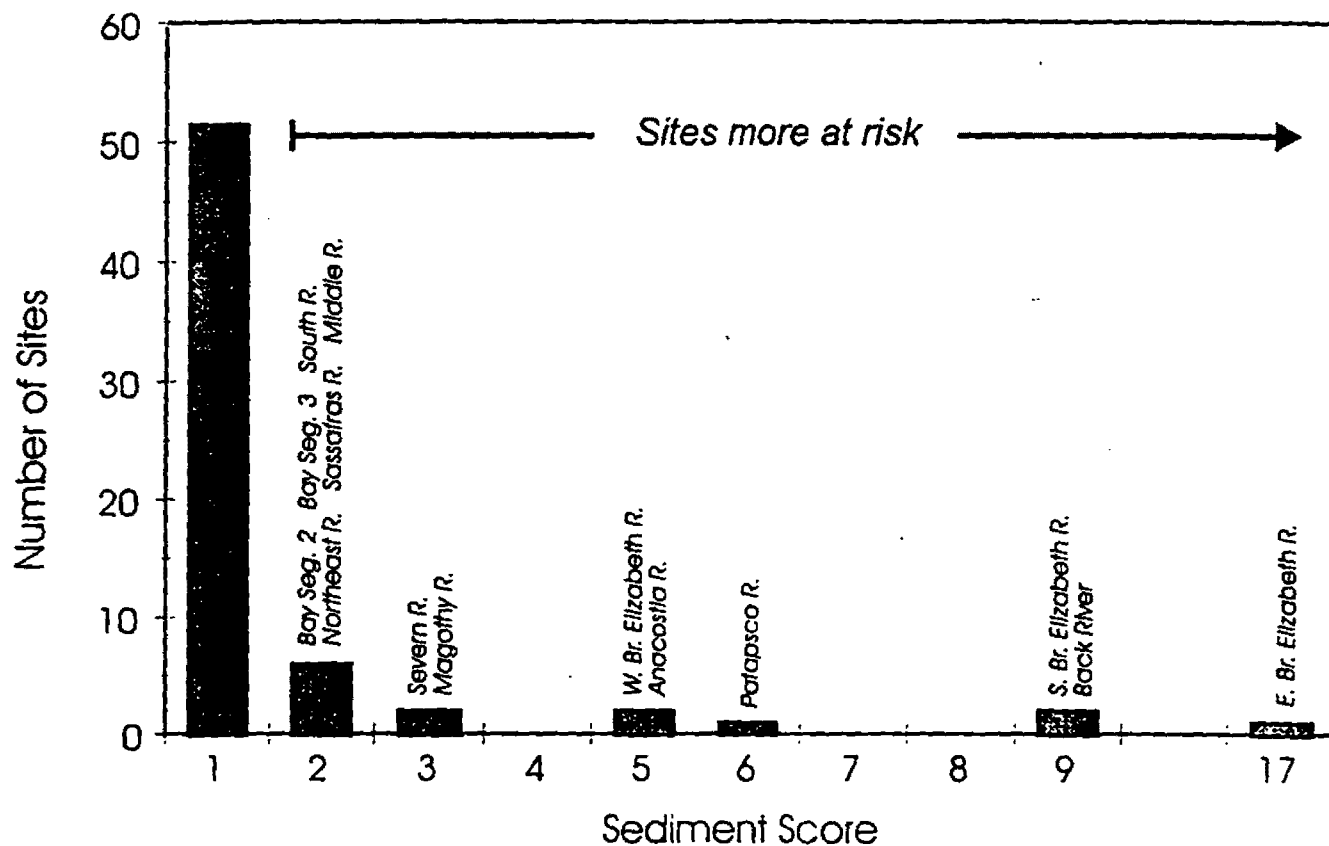


Figure 9.1 Distribution of scores of sites in the Chesapeake Bay based on the risk to aquatic biota due to sediment contaminant concentrations. Most sites have sediment contaminant concentrations well below the levels at which adverse effects to aquatic biota are likely to occur. However, a few sites have much higher levels of sediment contaminants which may represent a significant risk of adverse effects to aquatic biota.

Table 9.4. Substitutions for missing data to allow complete index values to be calculated (in addition to those mentioned in the text). Note that virtually all of the substituted values were well below the PEL and did <u>not</u> effect the score.

| Station | Proxy Station |
|---|---|
| <u>Naphthalene</u> | |
| Upper ChesterRiver | Lower Chester River |
| Upper Choptank River | Lower Choptank River |
| Bush River | Middle River |
| Gunpowder River | Middle River |
| Mattawoman Creek | Potomac Transition |
| South Tangier Sound | North Tangier Sound |
| Pocomoke River | Wicomico River |
| Upper Nanticoke River | Lower Nanticoke River |
| Manokin River | Wicomico River |
| Big Annemessex River | Wicomico River |
| <u>Phenanthrene</u> | |
| Upper ChesterRiver | Lower Chester River |
| Upper Choptank River | Lower Choptank River |
| James R. Transition | James River Tidal Fresh |
| Bush River | Middle River |
| Gunpowder River | Middle River |
| Mattawoman Creek | Potomac Transition |
| Upper Nanticoke River | Lower Nanticoke River |
| <u>Anthracene</u> | |
| Upper Choptank River | Lower Choptank River |
| Little Choptank River | Lower Choptank River |
| James River Transition | James River Tidal Fresh |
| Mattawoman Creek | Potomac Transition |
| North Tangier Sound | South Tangier Sound |
| Pocomoke Sound | Pocomoke River |
| Upper Nanticoke River | Lower Nanticoke River |
| Manokin River | Wicomico River |
| Big Annemessex River | Wicomico River |
| <u>Chrysene</u> | |
| Upper Chester River | Lower Chester River |
| Upper Choptank River | Lower Choptank River |
| Bush River | Middle River |
| Gunpowder River | Middle River |
| <u>Benzo(a)pyrene</u> | |
| Mattawoman Creek | Potomac Transition |
| North Tangier Sound | South Tangier Sound |
| Pocomoke River | Wicomico River |
| Upper Nanticoke River | Lower Nanticoke River |
| James River Transition | James River Tidal Fresh |

## Appendices

A. Chesapeake Bay sedimentation rates

B. Quality assurance/quality control data for the Virginia Institute of Marine Science Laboratory

C. Quality assurance/quality control data for sediment metals analysis at the Maryland Department of Health and Mental Hygiene

D. Quality assurance/quality control data for sediment total organic carbon measurements of the Chesapeake Biological Laboratory

E. Sediment grain size composition analysis methods

F. Quality assurance/quality control data for the Maryland Department of Agriculture

# Appendix A: Chesapeake Bay sedimentation rates

Below is a listing of selected sediment accumulation rates for various regions of Chesapeake Bay found in the literature. Where estimates of laboratory precision were available, the standard deviation of the estimate is expressed as mean ± standard deviation unless otherwise noted.

**Mainstem**

| Original Station | Approx MDE Equiv. | Sedimentation Rate (cm/yr) | Depth in Sediment (equiv. yrs.) | Year | Method | Corer | Author |
|---|---|---|---|---|---|---|---|
| Furnace B. | No. eq. | 0.96 | | | | | |
| UB-1 (Turkey Pt.) | ~MCB2.1 | 0.38* | 0-2 (80-78) | 1980 | Pollen | | Brush, 1989 |
| GS-2 | MCB2.2 | 0.06 | — | | Pollen | Grav. | Brush, 1990 |
| GS-3 | MCB3.1 | 0.12 | 0-2 (88-55) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-3 | MCB3.1 | 0.22 | 0-1 (88-80) | 1988 | Pollen | Grav. | Brush, 1990 |
| CHSP1416 | MCB3.3C | 3.* | 1-2 (80-75) | 1988 | Pollen | Grav. | Brush, 1990 |
| GIWXIII | MCB3.3C | 1.* | — | 1975 | Pb-210 | Box | Goldberg et al. 1973 |
| GIWXIV | MCB3.3C | 1.* | — | 1972 | Pb-210 | Grav. | Goldberg et al. 1973 |
| GS-4 | ~MCB3.3W | 0.13 | — | 1972 | Pb-210 | Grav. | Goldberg et al. 1973. |
| GS-4 | ~MCB3.3W | 0.72 | 0-1 (88-80) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-4A (Bloody Pt.) | ~MCB4.1C | 0.15 | 1-2 (80-79) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-4A (Bloody Pt.) | ~MCB4.1C | 0.54 | 0-1 (88-81) | 1988 | Pollen | Grav. | Brush, 1990 |
| R4-30 (Choptank) | ~MCB4.2W | 0.28 | 1-2 (81-79) | 1988 | Pollen | Grav. | Brush, 1990 |
| R4-45 (Choptank) | ~MCB4.2C | 0.26 | 0-3 (85-75) | 1985 | Pollen | Grav. | Brush, 1990 |
| 50-E | ~MCB4.2C | 0.21 | 0-10 (85-48) | 1985 | Pollen | — | Brush, 1990 |
| GS-8N (Trippe Bay) | MCB4.2E | 0.08 | 0-2 (85-76) | 1985 | Pollen | — | Brush, 1990 |
| GS-8N (Trippe Bay) | MCB4.2E | 0.10 | 0-1 (88-75) | 1988 | Pollen | Grav. | Brush, 1990 |
| Station C | ~MCB4.2E | 0.09-0.12 | 1-2 (75-65) | 1988 | Pollen | Grav. | Brush, 1990 |
| | | | — | | Pb-210 | Grav. | Schubel & Hirschberg, 1977 |
| GS-7 (Parker Cr.) | MCB4.3C | 0.12 | 0-1 (88-80) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-7 (Parker Cr.) | MCB4.3C | 0.12 | 1-2 (80-71) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-7A | MCB5.1 | 0.07 | 0-1 (88-74) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-7A | MCB5.1 | 0.06 | 1-2 (74-57) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-14 | MCB5.2 | 0.007 | 0-1 (88-45) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-14 | MCB5.2 | 0.005 | (1845-1645) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-17 | LE3.6 | >0.32 | post-European | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-18 Rapp. R. Spit | CB6.1 | 0.08 | 0-1 (88-75) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-18 Rapp. R. Spit | CB6.1 | 0.15 | 1-2 (75-69) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-18 Rapp. R. Spit | CB6.1 | 0.10 | post-European | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-21 York R. Spit | CB6.3 | 0.14 | 0-1 (88-81) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-21 York R. Spit | CB6.3 | 0.14 | 1-2 (81-74) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-21 York R. Spit | CB6.3 | 0.04 | post-European | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-22 Cape Charles | CB7 | 0.15 | 0-1 (88-81) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-22 Cape Charles | CB7 | 0.15 | 1-2 (81-75) | 1988 | Pollen | Grav. | Brush, 1990 |
| GS-22 Cape Charles | CB7 | 0.09 | post-European | 1988 | Pollen | Grav. | Brush, 1990 |

## Maryland Tributaries

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Back R. | MWT4.1 | 0.93[a] | (80-58) | 1980 | Pollen | | Brush, 1989 |
| Back R. | Above STP Brush, 1984b | 0.77±.08[a] | (74-30) | 1974 | Pollen | Piston c. | |
| Back R. | Mouth (MWT4.1) | 0.2[a] | (74-1780) | 1974 | Pollen | Piston c. | Brush, 1984b |
| Middle R. | Head of River Brush, 1984b | 0.15±0.2[a] | (74-1780) | 1974 | Pollen | Piston c. | |
| Magothy | Magothy | 0.23 | | | | | |
| Magothy | Magothy | 0.14 | | | | | |
| Nanticoke | Nanticoke | 0.20 | | | | | |
| Western Shore[1] | | 0.30[a] | (80-1700) | | | Pollen | Brush, 1984a |
| Upstream[2] | | 0.39±.03[a] | (80-1700) | Pollen | — | Brush, 1984a | |
| Midstream[2] | | 0.37±.03[a] | (80-1700) | Pollen | — | Brush, 1984a | |
| Downstream[2] | | 0.17±.02[a] | (80-1700) | Pollen | — | Brush, 1984a | |

## Potomac

| Original Station | MDE Equiv. | Approx. Sedimentation Rate (cm/yr) | Depth in Sediment (equiv. yrs.) | Year | Method | Corer | Author |
|---|---|---|---|---|---|---|---|
| 1 | MLE2.3 | 0.21±.02 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 1 | MLE2.3 | 0.17±.02 | 78-1878 | 1978 | Pb-210[b] | Divers | Brush et al. 1982 |
| 3 | MLE2.2 | 0.56±.05 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 3 | MLE2.2 | 0.70±.04 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |
| 4 | MLE2.2 | 0.56±.05 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 4 | MLE2.2 | 0.79±.09 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |
| 7 | XDA1177 | >0.81 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| | XDA1177 | 1.46±.06 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |
| 9 | XDA1177 | 0.48±.04 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 9 | XDA1177 | 0.67±.06 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |
| 10 | XDA1177 | 0.40±.03 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 10 | XDA1177 | 0.47±.04 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |
| 11 | XEA6596 | >0.72 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 11 | XEA6596 | 1.09±.14 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |
| 14 | XEA6596 | 0.22±.02 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 14 | XEA6596 | 0.43±.05 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |
| 15 | XEA6596 | 0.67±.06 | 78-1840 | 1978 | Pollen | Divers | Brush et al. 1982 |
| 15 | XEA6596 | 1.74±.12 | 78-1878 | 1978 | Pb-210 | Divers | Brush et al. 1982 |

## Virginia Tributaries

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| GS-23 Hog Is., James R. Brush, 1990 | LE5.2 | >0.30 | post-European | 1988 | Pollen | Grav. | |

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[a] average of several cores.

[b] for all Pb-210 values for Brush et al., 1982 the uncertainty is the uncertainty associated with individual activities; as the measured activity approaches background levels, the uncertainty increases.

[1] 39 cores in 10 western shore tributaries (Middle, Magothy, St. Mary's, Ware, Gunpowder, Back, Patapsco, Patuxent, and Potomac rivers, and Furnace Bay).

[2] based on samples for western shore.

## Appendix B: Quality assurance/quality control data for the Virginia Institute of Marine Science laboratory

The Virginia Institute of Marine Science (VIMS) laboratory performed analyses for sediment concentrations of mainstem metals and organic compounds, and organic compounds for Virginia tributaries. All data presented below is QA/QC information which covered their report of data from 1991 (Unger et al., 1992).

### I. Metals.

A. Comparison of mean VIMS analytical values to certified values of Standard Reference materials SRM 1646 (estuarine sediment).

n is the number of samples ( 1991) used to calculate the mean; CV is the NIST certified value; Range is the 95% tolerance range for the certified materials. Recovery is the percent of certified value recovered in analysis. All values rounded to the nearest tenth. Data from Unger et al. (1992).

Estuarine Sediment SRM 1646 (Al and Fe in % dry weight, all others in ppm)

| Metal | Mean | n | CV | Range | Recovery (%) |
|---|---|---|---|---|---|
| Al | 0.77 | 3 | 6.25 | .7-.89 | 12 |
| As | 9.7 | 3 | 11.6 | 9.5-10 | 84 |
| Cd | 0.30 | 3 | 0.36 | .233-.331 | 83 |
| Cr | 39 | 3 | 76 | 38.2-39 | 51 |
| Cu | 19 | 3 | 18.0 | 18.3 - 20.4 | 106 |
| Fe | 2.96 | 3 | 3.35 | 2.88 - 3.15 | 88 |
| Pb | 23.7 | 3 | 28.2 | 23.1 - 24.5 | 84 |
| Mn | 268 | 3 | 375.0 | 244.0 -288.0 | 71 |
| Ni | 26 | 3 | 32.0 | 20.7 - 31.6 | 81 |
| Zn | 118 | 3 | 138 | 110 -134 | 86 |

B. Percentage recovery from metal fortified sediment samples. Data from Unger et al., 1992.

| Metal | Mean Recovery | n | Range |
|---|---|---|---|
| Al | 95 | 2 | 91-98 |
| As | 90 | 2 | 86-94 |
| Cd | 92 | 2 | 85-100 |
| Cr | 115-124 | 2 | 120 |
| Cu | 102 | 2 | 96-108 |
| Fe | 89 | 2 | 85-94 |
| Pb | 97 | 2 | 91-103 |
| Mn | 107 | 2 | 106-108 |
| Ni | 101 | 2 | 99-103 |
| Zn | 110 | 2 | 109-110 |

## II. Acid-volatile sulfide

The method used to measure acid-volatile sulfide (AVS) in mainstem sediments in 1991 was tested using laboratory fortified blanks from freshly prepared sodium sulfide standard solutions over a range of expected sulfide concentrations. Results are presented below. Data are from Unger et al., 1992.

| Sample (mg sulfide) | Recovered (mg sulfide) | % Recovery |
|---|---|---|
| 0.497 | 0.512 | 103.2 |
| 0.499 | 0.485 | 97.2 |
| 0.933 | 0.946 | 95.2 |
| 10.15 | 9.991 | 98.4 |
| 9.923 | 9.375 | 94.5 |
| 99.23 | 94.16 | 94.9 |
| 100.1 | 94.58 | 94.5 |

| | |
|---|---|
| Mean Recovery , $\mu$ | 97.2 |
| Std. Dev, $\sigma$ | 3.6 |
| Control limit, $\mu \pm 3\sigma$ | 86.4-108 |

Recovery from sulfide fortified sediment samples. Data from Unger et al, 1992.

| Sample | % Recovery |
|---|---|
| CB5.4 | 88.7 |
| LE3.6 | 99.9 |
| WE4.1 | 89.2 |

The detection limits for AVS was 2 ppm.

## III. Polycyclic aromatic hydrocarbons

1. Analysis of Standard Reference Material 1941. Concentrations as ppb (ng/g dry weight) as determined by gas chromatography with a flame ionization detector. CV is NIST certified value. Measured value is the value determined by the VIMS laboratory. Data are from Unger et al., 1992.

| Compound | CV* | Measured |
|---|---|---|
| Phenanthrene | 597±4 | 643 |
| Anthracene | 202±6 | 237 |
| Fluoranthene | 1116±20 | 1366 |
| Pyrene | 1008±16 | 1426 |
| Benzo(a)anthracene | 538±12 | 422 |
| Chrysene | 577±12 | 431 |
| Benzo(a)pyrene | 566±12 | 431 |
| Perylene | 415±8 | 194 |
| Benzo(g,h,i)perylene | 478±14 | 339 |
| Indeno(g,h,i)perylene | 572±28 | 151 |

*Twelve samples analyzed in triplicate by NIST
Replicate analyses of two of the 1991 samples demonstrated good precision in measurement of individual PAHs.

## IV. PCBs

The following is a summary of information in Unger, *et al.* 1992, and more detailed information on analysis of the individual PCB congeners is available in that report.

Analysis of NIST Standard Sediment (SRM 1941)

| Sample | Congener Subtotal* | Total PCBs** |
|---|---|---|
| NIST reported value | 111.3 | 247 |
| VIMS measured vale | 143.9 | 320 |

\* total of the eight congeners used in estimating total PCBs

\*\* estimated total PCBs based on the assumption that the congener subtotal represent 44.9% of the total PCBs. This percentage is based on the average percentage in a mixture of Arochlors 1254 and 1260, which were thought to most closely match the mix of conngeners found in the sediment samples.

A recovery of 80.2% of estimated total PCBs was found for a spiked sand sample. Detection limits for individual PCB conceners were 0.01 µg/kg

## V. Other chlorinated hydrocarbons

Unger *et al.*, (1992) report that two of the mainstem samples were analyzed in duplicate, and that good agreement of results was observed between replicate samples.

**Appendix C: Quality assurance/quality control data for sediment metals analysis at the Maryland Department of Health and Mental Hygiene.**

The Maryland Department of Health and Mental Health and Mental Hygiene (DHMH) laboratory performed measurements of sediment metal concentrations for sediment samples from Maryland tributaries.

**I. Instrument detection levels for metals.**

| Element | GF AA[1] (ppm) | ICP[2] (ppm) | Cold Vapor (ppm) |
|---------|----------|-----------|------------------|
| Al | — | 0.05 | — |
| As | 0.001 | — | — |
| Cd | — | 0.01 | — |
| Cr | — | 0.01 | — |
| Cu | — | 0.01 | — |
| Fe | — | 0.01 | — |
| Hg | — | — | 0.05 |
| Mn | — | 0.01 | — |
| Ni | — | 0.01 | — |
| Pb | — | 0.10 | — |
| Zn | — | 0.01 | — |

[1] Graphite furnace atomic absorption
[2] Inductively coupled plasma

II. Comparison of mean DHMH analytical values to certified values of Standard Reference materials SRM 1645 (river sediment) and SRM 1646 (estuarine sediment). n is the number of samples (1987 to 1991) used to calculate the mean; CV is the NIST certified value; Range is the 95% tolerance range for the certified materials. Units are ppm (µg/g) dry weight.

| Metal | River Sediment SRM 1645 | | | | Estuarine Sediment SRM 1646 | | | |
|-------|------|---|-----|-------|------|---|-----|-------|
|       | Mean | n | CV | Range | Mean | n | CV | Range |
| As | 47.16 |   | 66[1] | N/A[1] | 12.1 | 5 | 11.6 | 10.3-12.9 |
| Cd | 9.1 | 5 | 10.2 | 8.7-11.7 | 0.383 |   | 0.36 | 0.29-0.43 |
| Cr | 2.8 | 6 | 3.0 | 2.7-3.2 | 55.6 | 5 | 76.0 | 73.0-79.0 |
| Cu | 101.6 | 6 | 109.0 | 90.0-128.0 | 16.6 | 5 | 18.0 | 15.0-21.0 |
| Fe | 10.8 | 3 | 11.3 | 10.1-12.5 | 3.1 | 4 | 3.4 | 3.3-3.5 |
| Pb | 659.6 | 5 | 714 | 686.0-742.0 | 25.1 | 4 | 28.2 | 26.4-30.0 |
| Mn | 711.3 | 5 | 785 | 688.0-882.0 | 316.0 | 4 | 375.0 | 355.0-395.0 |
| Hg | 0.753 | 2 | 1.1 | 0.6-1.6 | 0.066 | 3 | 0.063 | 0.051 0.075 |
| Ni | 43.6 | 4 | 45.6 | 42.9-48.7 | 28.9 | 5 | 32.0 | 29.0-35.0 |
| Zn | 1746.8 | 5 | 1720 | 1550-1890 | 134.6 | 4 | 138 | 132.0-144.0 |

| Metal | SRM 1648 | | | | SRM 2704 | | | |
|-------|------|---|-----|-------|------|---|-----|-------|
| As | 81.0 | 1 | 75 | 8 -82 |   |   |   |   |
| Cd | — |   |   |   |   |   |   |   |
| Cu | 584.0 | 1 | 609 | 582 -636 |   |   |   |   |
| Fe | 4.0 | 1 | 3.9 | 3.8-4.0 | 4.3 | 1 |   | 4.1 |
|    | 4.01-4.21 |   |   |   |   |   |   |   |
| Pb | 0.62 | 1 | 0.66 | 0.58 - 0.74 |   |   |   |   |

| | | | |
|-----|-------|---|-------|
| Mn  | 885.0 | 1 | 860   |
| Ni  | --    |   |       |
| Zn  | 0.457 | 1 | 0.476 |

[1]No certified value available. Arsenic concentration supplied as part of supplemental information.

III. Summary statistics for laboratory duplicates (1987-1991). N is the number of paired samples; Percent is the average percent of the mean represented by the standard deviation ($\sigma/\mu\times100$). The range indicates the highest and lowest analytical results to show the range of values for which the standard deviations were calculated.

| Metal | N | Percent | Minimum | Maximum |
|-------|-----|---------|---------|---------|
| Al | 11 | 2.7 | 11,166 | 41,042 |
| As | 12 | 5.2 | 6.4 | 64.7 |
| Cd | 11 | 9.9 | 0.5 | 3.34 |
| Cr | 20 | 4.0 | 18 | 558 |
| Cu | 21 | 3.8 | 7 | 198 |
| Fe | 18 | 2.8 | 15,520 | 67,026 |
| Hg | 5 | 4.7 | 0.009 | 0.283 |
| Mn | 22 | 1.7 | 228 | 2,669 |
| Ni | 22 | 7.1 | 10.1 | 59.8 |
| Pb | 17 | 9.7 | 5.2 | 204.7 |
| Zn | 22 | 2.2 | 52 | 683.5 |

**Appendix D: Quality Assurance/Quality Control data for sediment total organic carbon measurements of the Chesapeake Biological Laboratory.**

The Chesapeake Bay Biological Laboratory performed determinations of total sediment organic carbon content for sediment samples from Maryland tributaries.

The detection limit for percent sediment carbon was established as three times the standard deviation of seven repeated analyses. Inorganic carbon in Chesapeake Bay samples is insignificant and was ignored. Three samples were chosen for the determination, representing low, medium, and high ranges, as determined by the initial analyses.

Table 1: Samples chosen for determination of percent sediment carbon detection limits.

| Year | Station | Listed TOCS value |
|------|---------|-------------------|
| 1988 | MET7.1  | 0.67 |
| 1991 | XDE5339 | 3.47 |
| 1991 | MWT5.1C | 9.29 |

In addition, standard reference estuarine sediment supplied by the National Research Council of Canada (BCSS-1) was analyzed. The certified value for this material was 2.19 +/- 0.09%

Table 2: Results of replicate analyses for determination of percent sediment organic carbon detection limits.

| Replicate | MET7.1 | XCE5339 | MWT5.1C | BCSS-1 |
|-----------|--------|---------|---------|--------|
| 1 | 0.99 | 3.53 | 6.48 | 2.11 |
| 2 | 1.34 | 3.60 | 4.55 | 2.14 |
| 3 | 1.48 | 3.50 | 4.53 | 2.11 |
| 4 | 0.79 | 3.50 | 4.86 | 2.14 |
| 5 | 0.74 | 3.64 | 5.05 | 2.20 |
| 6 | 1.02 | 3.50 | 5.15 | 2.10 |
| 7 | 0.94 | 3.46 | 5.26 | 2.20 |
| Mean | 1.04 | 3.53 | 5.13 | 2.14 |
| Std. Dev. | 0.274 | 0.064 | 0.660 | 0.042 |
| MDL | 0.82 | 0.19 | 1.98 | 0.13 |

The method detection limit of the least variable Chesapeake Bay sample (XDE5339) is accepted as the general method detection limit for this test.

## Appendix E: Sediment grain size composition analysis methods

The method for the measurement of sediment grain size distribution generally followed those of Plumb (1981) as described briefly below.

Detergent (sodium hexametaphosphate) was added to sediment samples to prevent flocculation. Samples were wet sieved sequentially through 1000 µm and 62 µm screens. Each size fraction was dried at 50°C and weighed to determine the gravel (>1000 µm), sand (62-1000 µm), and mud (<62 µm) fractions. Results are expressed as percent of dry weight. Percent moisture is the difference between wet and dry weights after drying unmodified sediment at 50°C.

This method, without organic digestion, determines the "apparent" particle size, which is more repesentative of the sediment's actual exposed surface than is the particle size determined after organic digestion.

**Appendix F: Quality assurance/quality control data for the Maryland Department of Agriculture**

The Maryland Department of Agriculture performed the analysis of organic compounds in sediments samples from the Maryland tributaries in 1991. The following information is the quality assurance/quality control (QA/QC) data for the analyses of these 1991 samples. Quality control procedures consisted of spiked samples for PAHs and pesticides and spiked samples and analysis of NIST reference material 1939 for PCBs.

**I. List of Analytes**

<u>PAHs</u>
Anthracene
Acenaphthylene
Acenaphthene
2-Methylnaphthalene
Benzo(a)anthracene
Benzo(a)pyrene
Chrysene
Fluoranthene
3,4-Benzofluoranthene
Benzo(k)fluoranthene
Napthalene
Perylene
Benzo(ghi)perylene
Fluorene
Phenanthrene
Pyrene
Dibenzo(ah)anthracene
Indeno(1,2,3-cd)anthracene
Phenol

<u>PCBs</u>
Total PCBs

<u>Pesticides</u>
Alachlor
Aldrin
Atrazine (and other triazines, e.g., cyanazine, simazine)
Carbofuran
Chlordane (oxychlordane, heptachlor, heptachlor epoxide)
Chlorpyrifos (Dursban)
DDTs
Dieldrin
Heptachlor
Hexachlorobenzene
Lindane (alpha-BHC)
Metolachlor
Permethrin

## II. Polycyclic Aromatic Hydrocarbons

### A. Percentage recovery from spiked samples

| Compound | N | μ | σ |
|---|---|---|---|
| Phenanthrene | 5 | 70.6 | 15.7 |
| Anthracene | 5 | 70.2 | 3.3 |
| Benzo[a]anthracene | 5 | 88.1 | 10.2 |
| Benzo[a]pyrene | 5 | 77.2 | 18.1 |

N is the number of samples. Std. Dev. is the standard deviation of the percentage recovery for the spiked samples.

### B. Analysis of standard materials

No Analysis of NIST reference materials were performed for the PAHs.

## II. Pesticides and PCBs

### A. Percentage recoveries from spiked samples

| Compound | N | μ | σ |
|---|---|---|---|
| 2,3,5-Trichloro-<br>biphenyl | 4 | 73.6 | 18 |
| Heptachlor | 4 | 69.8 | 11.2 |
| Dieldrin | 5 | 84.1 | 5.7 |
| Cyanazine | 5 | 85.3 | 27.5 |
| Carbofuran | 5 | 91.8 | 19 |

### B. Analysis of NIST reference material for PCBs

| Compound | NIST Value<br>(μ ± σ) | Measured Value<br>(μ ± σ) |
|---|---|---|
| 2,3,5-Trichlorobiphenyl | 4.20 ± 0.29 ppm | 3.70 ± 0.29 |
| 2,2'3,5-Tetrachloro-<br>biphenyl | 1.07 ± 0.12 ppm | 1.07 ± 0.08 |

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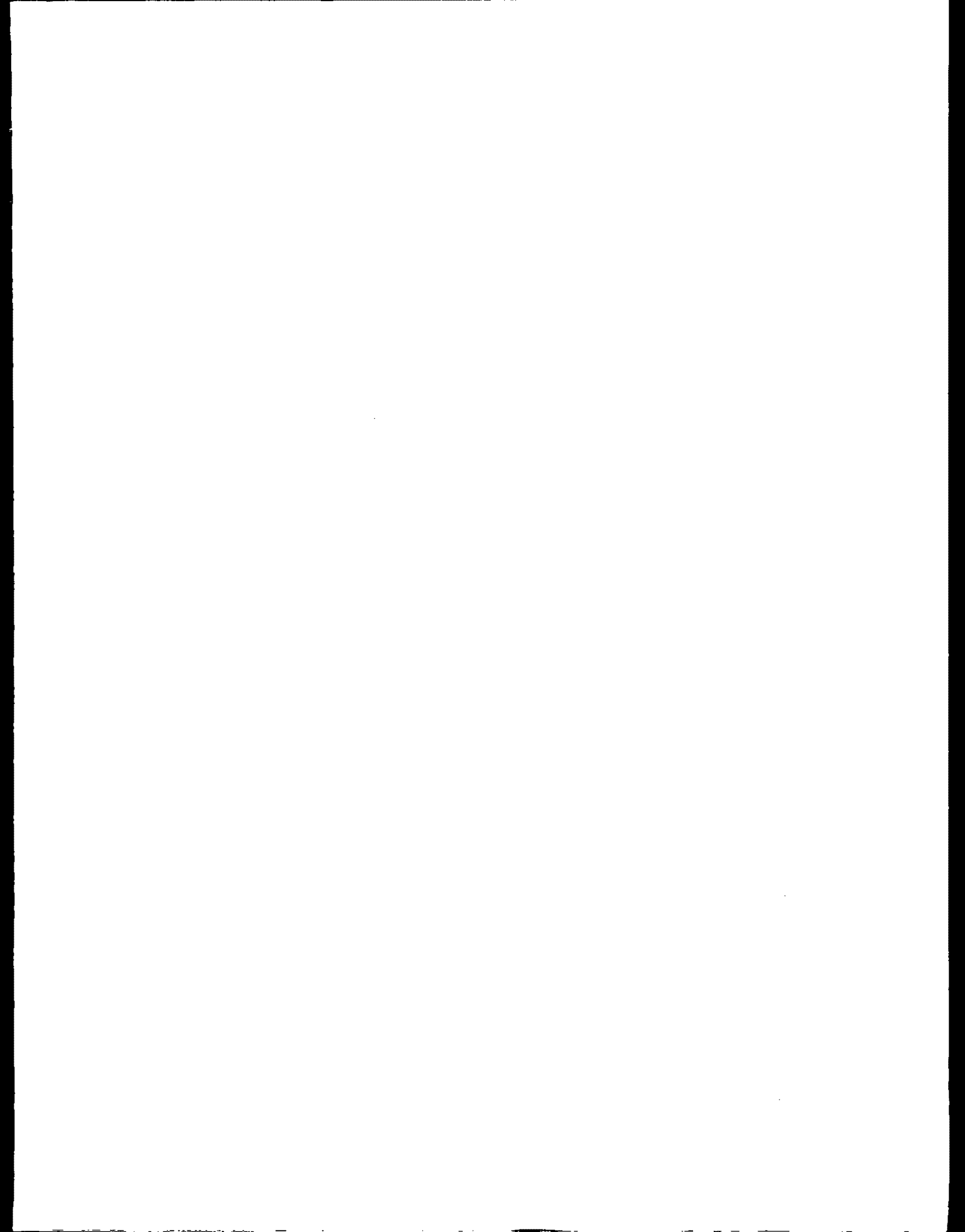
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