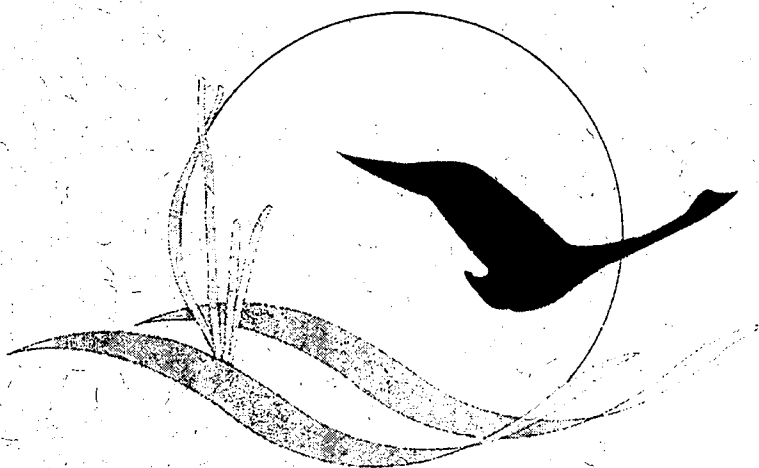


# Fall Line Loadings of Metals from the Potomac River Basin into Chesapeake Bay



**Chesapeake Bay Program**  
*A Watershed Partnership*

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2001

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## **Chesapeake Bay Program**

*A Watershed Partnership*

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**EPA CHESAPEAKE BAY PROGRAM  
TOXICS SUBCOMMITTEE FINAL REPORT**

TITLE: *Fall Line Loadings of Metals from the Potomac River Basin into Chesapeake Bay*

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DATES OF STUDY: 1996-2000

## ABSTRACT

The Potomac River and Estuary form the second largest tidal tributary of the Chesapeake Bay, which includes at its mid-portion the large urban and suburban Washington DC area. The Potomac River basin was sampled for trace metals near its fall line at Chain Bridge, Washington DC, from October 1996 through August 1997, to determine its contribution to the metal loading of Chesapeake Bay. To characterize the river loadings during various flow regimes, the river was sampled (1) routinely, at base-flow, on monthly to bi-monthly intervals, and (2) intensively during a spring-storm, high flow event. The upper Potomac watershed was sampled twice at nine stations within the headwaters of the basin. In Washington DC, Rock Creek tributary was sampled on a monthly or bi-monthly interval during base-flow conditions. For comparison, the Potomac Estuary was sampled once each during the winter and summer of 1997.

The field sampling, preparation and analysis of the trace metals used ultra-clean sampling methods. The samples were analyzed for both dissolved ( $<0.45 \mu$ ) and particulate fractions for Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se (dissolved only), and Zn. The data are computed and compiled for (1) dissolved/particulate concentration distribution, (2) loadings using USGS discharge data, and (3) basin yields on an area specific basis for each watershed. The concentrations are compared to similar results from other Potomac and Chesapeake Bay tributary studies.

The concentrations and corresponding loads of trace metals at the fall line of the Potomac River are dominated under average flow conditions by the particulate fraction, unlike most of its upper tributaries, including Rock Creek. The metals which exhibited a significant (if minor) dissolved component at base flow include As, Cd, Cu, Hg, Ni and Zn. However, on an annual basis and dominated by storm flow, only As, Cd and Cu show any significant dissolved fraction. This particulate dominance at the fall line is unlike other tributaries within either the Potomac or Chesapeake basins, including the Potomac estuarine portion and the dominant Susquehanna River. The dissolved concentrations are fairly consistent for the basin, with a minimum at the Cotoctin and Monacacy tributaries. This reflects the atmospheric and weathering inputs in the upper reaches, and equal input from urban runoff in the lower portions. As expected, these concentrations are lower than the urban Anacostia tributary, but consistent with the Susquehanna studied previously. Rock Creek has lower concentrations in spite of being located within the urban watershed. This could reflect its protected status as a national park with limited urban runoff. However, the dominant particulate burden at the Potomac fall-line shows considerable spatial and temporal variation. While there is significant variability for some metals such as Mn and Zn which is thought to be related to seasonal changes of vegetation within the watershed, there is considerable increases in the metalloids As and Hg during the summer that appear related to seasonal pollution activities within the basin. As a function of high discharge flow, the concentrations of many metals show a peak early in the discharge, followed by dissolved peaks either later in the hydrograph, or even at other seasonal times unrelated to discharge.

The trace metal concentrations in the Potomac sub-estuary are, unlike the Chain Bridge fall line, characterized by a larger dissolved fraction, going through a minimum in winter and generally increasing downstream during the summer. This appears to reflect the seasonal changes in discharge, phytoplankton blooms, and riparian zones within the estuary. While the concentrations are similar to that at the fall line, it is apparent that the estuarine portion is processing the dominant particulate load of the river into more dissolved components. For non-crustal elements this could mean either eutrophic or toxic effects for metals within the Potomac sub-estuary and larger dissolved contribution to the greater Chesapeake Bay.

## I. INTRODUCTION

The Chesapeake Bay is an expansive estuarine system with a series of sub-estuaries draining a large variety of lithologies and urban/industrial activities, including its largest sub-estuary, the Potomac. Here, the land use varies from forested mountains, through an agricultural plain, to the extended Washington DC urban corridor, and in the large sub-estuary of Chesapeake Bay. Throughout the Potomac watershed, there are vastly different lithologies ranging from low grade metamorphic green stones to well-weathered quartzite.

The central hypothesis of this study is that metal contaminant concentrations and resulting loads are a function of both direct atmospheric deposition into and indirect throughput from the tributary watershed. This includes (1) weathering within distinct geological provinces, (2) various rural, suburban and urban runoff sources within the tributary basin, and (3) final estuarine processing within the Potomac estuary before input to the main stem of the Chesapeake Bay. Such a study allows a better understanding of how different subunits in a drainage basin contribute or process these metal contaminant sources. The study also permits some resolution of the contaminant metal sources fluxing across the fall line into the receiving coastal water, and thus better management of contaminant abatement within the basin.

Annual estimates of contaminant loadings above the fall lines of the Susquehanna, Potomac, and James rivers, the Bay's three largest tributaries, have been reported for various years between 1990 and 1994 by the Chesapeake Bay Fall Line (Toxics Monitoring) Program (CBFLP).

The CBFLP program is designed to:

- 1) Identify types and quantities of priority contaminants in fluvial transport
- 2) Characterize such contaminant concentration with respect to water discharge
- 3) Estimate annual contaminant loads of the major tributary sources to the Bay

Estimates of river fall line metal loads have proven to be useful in determining the overall contribution of fluvial *versus* the atmospheric input fluxes of contaminants to Bay tidal waters.

However, questions related to variables such as land use, basin lithology, hydrology, and modes of transport from the watershed cannot be answered with the limited degree of temporal and spatial coverage provided through the conventional CBFLP approach. The sources and behavior of toxic metal substances in fluvial transport from stream headwaters to Chesapeake Bay have not been previously characterized *via* the CBFLP. Better resolution of contaminant metal sources and loading throughout the provinces of an entire basin would allow for a much better understanding of not just the fluxes, but also processes responsible for net metal inputs to the Bay. To this end, this project focused on metal sources, processing, and fate in the greater Potomac River Basin, including some estuarine portions.

## II. THE STUDY

### *A. Background*

With the growing realization that the ecosystems of the Chesapeake Bay are potentially affected by toxic chemical contaminants, the U.S. Environmental Protection Agency - Chesapeake Bay Program (USEPA-CBP) has committed itself to defining the magnitude, timing, and severity of contaminant loadings to the Bay. The USEPA-CBP has formulated a list of primary and secondary "Toxics of Concern" which include trace elements (metals) that present a potential risk to the main estuarine portion of the Bay. Inputs of these contaminants come from point and non-point sources (*e.g.*, atmospheric deposition, industrial emissions and effluents as well as urban runoff). Measurements made at the fall lines of major Chesapeake Bay tributaries have provided a combined estimate of loads from all these sources from the non-tidal portion of the watershed.

Thus, this study was developed to enhance the understanding of the nature and transport of potentially toxic metal contaminants through the Potomac River Basin to the Chesapeake Bay. The study produced a database of metal inputs from the second largest tributary of the Bay during periods of varying flow and season to produce load estimates for selected metal contaminants. It also studied on occasion the sources of metals within riverine basin, and contribution to and behavior within the estuarine portions of the Potomac.

To better define geologic and geochemical processes and other variables important in fluvial trace metal transport through the Potomac River Basin, it is necessary to have greater spatial coverage within specific basins than that employed in the 1994 CBFLP. Geochemical factors include:

- (1) the composition and concentrations of dissolved and suspended trace metal particulate material crossing the Potomac River fall line under both baseline and high flow periods,

and

- (2) the nature and composition of Potomac River surface runoff, particularly in urban areas, and upper reaches represented during base flow.

Contaminant trace metal concentrations and fluxes in the physiographic provinces of the Potomac River basin were proposed to provide information regarding the importance of sources in fluvial transport. Streams discharging into the Potomac River contain both agricultural and urban runoff and constitute the primary source of agrichemicals. Thus, the flux at the fall line represents the sum of the Blue Ridge and Piedmont provinces, along with a substantial urban and sub-urban contaminant flux from the Washington metropolitan region into the Potomac River. The Blue Ridge Province section of the River receives runoff arising from atmospheric deposition processes on land surfaces. In the absence of unique point sources, the origin of metal contaminants in mountain streams of this province arises primarily from the atmosphere (Church, et al., 1998; Scudlark, et al., 1999). As such, there are trace metal atmospheric deposition data from related EPA (*e.g.*, CBADS, AEOLOS) and MDPPRP (conducted at Bear Branch and Frostburg MD) studies in the Chesapeake Basin. However, there is limited information on the concentration and fate of metals once discharged into the Potomac sub-estuary for processing before eventual contribution to the main stem of Chesapeake Bay. These processes likely include phytoplankton blooms and tidal exchange with subtidal and intertidal salt marshes.

### ***B. Objectives***

Our overall objective was to determine how the concentration, distribution, and loads of trace metal contaminants change within the Potomac basin. The study was designed to help determine how the mode of trace metal loading is also likely to undergo dynamic changes during fluvial transport from watersheds into the river basin and ultimately across the fall line.

Our specific research objectives included the following:

- (1) Better define the concentrations of trace metal contaminants by fluvial transport crossing the Potomac River fall line but extending, on occasion, from the headwaters in Appalachian Mountains in West Virginia through to the fall line near Washington D.C. Upstream watershed sources were focused on two of the three physiographic regions of the river basin, the Blue Ridge and Piedmont provinces.
- (2) Characterize the relative loadings of trace metals to aid in determining the hydrologic pathways and basin yields at the physiographic level. It has been shown that groundwater sources in streams (*i.e.*, base flow) have relatively higher concentrations of some trace metals relative to surface runoff. Pinpointing the mechanisms by which these metal contaminants comprise fluvial transport can serve as specific tracers of the hydrologic cycle (*e.g.*, atmospheric runoff *versus* ground water inputs).

- (3) Determine the mode of transport *via* dissolved and particulate partitioning to better define the total concentrations of metals, fluvial loading, and modes of transport through each of the physiographic regions of the basin.

### ***C. Project/Task Description***

The approach to the project is described as follows:

(1) determine the ambient concentration, nature, and transport of selected metals for various flow conditions sampled routinely at the Potomac River fall line, and the urban Rock Creek tributary. These data were used for comparison to water-quality standards and in calculating load estimates,

(2) improve the metal load estimates to the Chesapeake Bay by including the annual metal loads from the second largest Bay tributary the Potomac River. Load estimates were improved by the use of ultra-clean sampling methods and more sensitive analytical techniques. In addition, the quantitative analysis of the particulate phase provided a more comprehensive load estimate, which should improve the mass balance of the Chesapeake Bay. In the past, trace elements were determined as the "total-recoverable" fraction of the sample, which was quantitatively defined and thus difficult to interpret, and

(3) additionally measure twice yearly, the same suite of metal contaminants from the Potomac River fall line at several headwater gaging stations and three major tributaries of the Potomac River, as well as the lower estuarine portions. Instantaneous contaminant loads and corresponding basin yields are calculated for each of the tributary sites. This should provide a more synoptic evaluation of non-point metal loads from the upper portion of the Potomac watershed. Results of this synoptic study also identified regions contributing disproportionately to the pollutant metal loading that may require further management.

## **III. SAMPLING DESIGN**

Base flow samples near the fall line were collected once per month in January, July, August, September, October, November and December, and twice per month in February, March, April, May, and June of 1997. Discrete storm flow samples were collected for one storm event; during both the rising and falling hydrograph, and during peak flow. Synoptic samples were collected near the fall line at the USGS gaging on Rock Creek starting in December, 1997. Two surveys of the tidal portion of the Potomac sub-estuary were taken at five sites along the salinity gradient in February and July of 1997.

### ***Sampling Sites (Figure 1)***

1) **The Potomac Watershed** was proposed for intensive study because (1) it contains contrasting sub-basin geologies and biogeochemistries, (2) it is the second largest fresh



water source to the Bay, (2) there are relatively high contaminant yields were identified in the previous 1994 CBFLP, and (4) varied land uses. The Potomac River basin drains a watershed of 11,560 mi<sup>2</sup> above Chain Bridge, Washington, D.C., has an average annual discharge of about 10,000 ft<sup>3</sup>/s, and is divided in land use between forested (56%), agricultural (38%), and urban (6%) areas. The Potomac Basin has an airshed characterized by both remote fossil fuel emissions and local non-industrial (*e.g.*, motor vehicle) emissions which funnel into a watershed with mountain forests, rural agricultural, suburban and urban run-off.

**2) Potomac River** was sampled near its fall line in Washington, D.C., (01646580) Arlington County, Virginia, latitude 38 55'46", longitude 77 07'02", hydrologic unit 02070010. This site was chosen at the fall line because it is before potential tidal influence, including downstream areas of the river which drain the D.C. metropolitan area with a contributing urban watershed. The river contributes approximately 16% of the total freshwater discharge into Chesapeake Bay. Discharge measurements are made one and one half miles upstream at the Little Falls Dam USGS gauging station (01646500), latitude 38 56'58", and longitude 77 07'40".

**3) Head Water and Tributary Survey** was conducted during two intensive phases during May and August 1997, throughout the upper reach of the river basin during a high base flow and low base flow period. The headwaters of the River were sampled synoptically at nine USGS gauging stations both at the primary tributaries and throughout the basin. The location of these nine stations above the fall line were chosen to be representative of the geographic and geologic provinces along the River. The goal was to understand sub-basin processes related to fluvial transport and ultimately water quality of the Bay.

The headwater and tributary survey was done twice during the sampling year. It included seven sites along the reach of the Potomac River from Kitzmiller, Maryland to Chain Bridge, as well as three tributaries of the Potomac River, Catoctin Creek, the Monacacy River and Rock Creek. The locations of the headwater sites are listed in Table 1a.

**4) Potomac Estuary Survey** was conducted twice during the winter (February) and summer (July) of 1997 at five locations along the salinity gradient from near its terminus at Piney Point up to confluence with the Anacostia River. Sampling included upper and lower waters in the stratified regions. The locations of the tidal Potomac sites are listed in Table 1b.

#### IV. METHODOLOGY

All samples were collected using ultra-clean techniques. The analytical methods and detection limits for the trace metal constituents are summarized in Table 2. Samples were analyzed for selected metals, both dissolved, and particulate phases, for all constituents (dissolved Se only).

### *A. Field Methods*

The sampling schedule for the study is outlined in Table 3. Trace metal samples were collected with a fixed volume Teflon® bailer. At the fall-line, samples were collected as a cross section to ensure that they would be representative of current river conditions. This was done by integrating three individual samples at the center of flow, or using a similarly appropriate grab sample integration at the basin stations. The unfiltered samples were stored on ice and returned to the laboratory for filtration the same day. Briefly, all sample handling and analysis was performed using ultra-clean trace metal procedures that included: sampling with pre-cleaned, non-contaminating sampling apparatus, manipulation with polyethylene gloved hands and multiple bagged sample storage. The samples were filtered through a pre-cleaned 0.45µm Nuclepore membrane filter which was retained for particulate analysis. A complete description of these methods was included in the QA/QC plan (Section C).

The Potomac River at the fall line was sampled from Chain Bridge, which is approximately 70 feet above the water surface. Samples were collected at three cross-sectional intervals including increments of equal flow using a Teflon® bailer. A 100-foot length Teflon®-coated cable wound on a cordwheel was used to lower and raise the bailer to and from the point of sample collection. At each section, as the sample was collected it was poured directly into a single holding container to integrate the sample (except for replicates) via a Teflon®-spout inserted into the bailer just before the moment of sample transfer. This process involved a minimum of two people, a designated “clean” person and a designated “dirty” person. The clean person, with a change of surgical gloves at each sample collection point along the cross-section, handled the bailer and nozzle only. The “dirty” person handled the hand reel, passed the bailer nozzle through its storage bag to the clean person, and uncovered the appropriate bottles for sample collection. Equipment blanks were performed quarterly prior to sample collection at the mid-point of the sample-collection using ultra-pure inorganic-free-water.

Trace metal samples were collected in pre-cleaned, tared low-density polyethylene (LDPE) bottles. Samples for Hg were collected in pre-cleaned Teflon®-bottles. The LDPE bottles were cleaned using a multi-step procedure involving three-day soaks in three different strengths of both HNO<sub>3</sub> and HCl, with several rinses of de-ionized (DI) water both during the transfers and at the end of the procedure. After cleaning, the bottles were allowed to dry under a class 1000 clean bench and weighed.

The sampling bottles were pre-treated at the site by rinsing the bottles three times with river water prior to sample collection. Sampling for the headwater survey followed similar protocols for ultra-clean sampling with the following modifications: At several upstream locations, the Potomac River is too shallow for the Teflon®-bailer to function properly. In these situations the River was sampled by submerged filling of a pre-cleaned and tared, LDPE bottle directly by gloved hand from the approximate center-of-flow of the River. Similarly, the estuarine samples were collected directly from a Zodiac rubber boat by gloved hand into the tidal flow.

After collection, the samples were kept on ice during transit to the University of Delaware. Upon return to the laboratory, they were immediately filtered through pre-cleaned, tared 0.4  $\mu\text{m}$  Nuclepore® filters using a peristaltic pump and a cleaned polycarbonate support apparatus. The filters were dried in a 40 C oven, allowed to cool in a desiccator, weighed and retained for particulate analysis. This and all future steps were done in a Class 1000 clean environment.

The dissolved portion was collected in pre-cleaned LDPE bottles and acidified with doubly-(quartz) distilled HCl to 0.4% volume/volume, as per our normal operating procedures. Once acidified, the samples were frozen in a laboratory freezer dedicated to trace metals storage.

### ***B. Trace Metal Analytical Methods***

Sample analysis for the dissolved portion was done by GFAAS (Graphite Furnace Atomic Absorption Spectrophotometry) for Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn, CVAAS (Cold Vapor Atomic Absorption Spectroscopy) for As and Se, or CFAAS (Cold Vapor Atomic Fluorescence Spectroscopy) for Hg. For saline samples in the tidal Potomac, a chelation/solvent extraction procedure (APDC/DDC into chloroform) was used to pre-concentrate the samples for GFAAS. The particulate phase was analyzed following a digestion and total dissolution with hot HCL:HNO<sub>3</sub>:HF in the proportions of 1:3:0.5 respectively (Church, et al., 1998). The digest was analyzed by ICP-OES (Inductively Coupled Plasma – Optical Emissions Spectroscopy), GFAAS for Cd and Pb, CVAAS for As and Se and CVAAS for Hg.

**1) Dissolved Metals.** The dissolved fraction of the samples was analyzed for Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn using a Perkin-Elmer 3300 Atomic Absorption Spectrophotometer equipped with a 600 HGA graphite furnace (GFAAS). This instrument is also equipped with a deuterium background correction and a L'vov platform was used to maximize temperature uniformity during the furnace cycle. Citric acid was used as a matrix modifier for Al and Fe to increase analytical sensitivity. The standard analyte injection was 60  $\mu\text{l}$  for all elements except for Zn (10  $\mu\text{l}$ ). Multiple injections were used for Ni and Pb increasing the volume of analyte to 120-180  $\mu\text{l}$ , thus, augmenting the sensitivity 2-3 times. For As and Se, the samples were converted to the hydrides with sodium borohydride, the hydrides purged and concentrated cryogenically on a chromatographic substrate, and determined by sweeping them into a quartz cuvette for AAS analysis. For Hg, the samples were reduced by stannous chloride, the resulting elemental Hg was purged and concentrated on two successive columns of gold coated sand, and then heating the columns to sweep the elemental Hg vapor into a quartz cell for determination by atomic fluorescence spectrometry.

**2) Particulate Metals.** The particulate fraction was operationally defined as that portion of the sample which was retained on the 0.4  $\mu\text{m}$  Nuclepore® filter. The particles were digested using a technique to completely breakdown the filter and sediment. Briefly, the technique involved a cold-soak overnight in concentrated HNO<sub>3</sub>, followed by successive heating

with concentrated HCl and HF. The samples were brought to volume with a saturated solution of boric acid and then analyzed.

Because of the higher concentrations of elements in the particulate phase, ICPOES analysis was employed for the same suite of elements as in the dissolved analysis. The samples were aspirated directly into the instrument without additional treatment.

For As and Se, aliquots of the digests were analyzed as for the dissolved fraction. For Hg, the samples were treated both filtered and unfiltered, with the difference attributed to particulate Hg which is still highly reactive under the analytical protocol.

### ***C. Quality Control and Assurance***

The quality assurance practices of field procedures included complete documentation of sampling quality assurance of field personnel. Two very important essential elements of our Laboratory QC were (1) conducting and evaluation of blanks, and (2) use of externally certified reference materials. These quality assurance and control procedures are detailed in the separate QA/QC document previously submitted.

**1) Sampling Blanks.** Most contamination associated with trace element analysis is associated with field collection. Thus, conducting and evaluating field blanks was considered to be the most important component to our quality assurance program. Two major types of blanks were evaluated: Field Blanks and Filter Blanks. The Field Blank is a collection bottle that is filled with DI water at the collection site, which is subsequently filtered and acidified along with the samples. Data from this blank is evaluated to determine the amount of contamination associated with field collection and subsequent processing, including filtering.

**2) Filter Blanks** Acid (10% HCl) cleaned Nuclepore® filters were used to filter the Field Blank consisting of an average sample volume of distilled water. The filter was dried, weighed, and processed in an identical manner to the particulate samples. This blank quantifies the amount of contamination from the filter and filtering process. In addition to these blanks several unused filters were also digested and analyzed to quantify the contaminate contribution from the filter itself.

**3) Reference Materials.** Externally certified reference materials were regularly analyzed to verify the accuracy of the methods. These reference materials were obtained from the National Research Council of Canada, and chosen because they are representative of the sample matrices encountered in this study. They were a natural river water (SLRS-3) and natural river sediment (BCSS-1) that have been certified for the metals analyzed for in this study. The results of the replicate analysis of the EPA standard for water are included as Table A-1 in the Appendix.

#### ***D. Blanks and Replicates***

The comparison of the average field blanks to average river concentrations of the Potomac at the fall line are presented in Figure 2. For all metals, the blanks are less than ten percent of the average sample concentration, except for Ni (25%).

Replicate analyses for (a) dissolved and (b) particulate trace metals in duplicate grab samples are listed in Table 4. They include three Potomac stream side samples just below the Chain Bridge and two other main stem sites (Paw-Paw and Cumberland) upstream during each of the two headwater surveys. The dissolved replicates range 10-20%, which from laboratory and field replicates reflects about half analytical uncertainty and half field variation. The particulate variation is greater, and in a few cases (Fe, Pb and Zn), as much as a factor of two at the fall line, but less upstream where the lower range of concentration is encountered.

### **V. RESULTS AND DISCUSSION**

The Potomac primary data sets for dissolved and particulate concentrations of metals are presented in the Appendix as Table A-2 and those for mercury in Table A-3. These primary-data spread-sheets are available in electronic form from the EPA-CBP office.

#### ***A. Potomac Fall Line Concentrations and Loads***

A summary of the total concentrations at the fall line for (a) Chain Bridge and (b) Rock Creek are presented in Table 5. As there was insufficient sample for analysis of particulate Se, only dissolved Se concentrations are presented. However, our previous fall line studies around Chesapeake Bay suggest particulate Se contributions to be small. Normally, all samples were taken as cross sectional integration, at which time a Center Of Flow (COF) sample was also taken at Chain Bridge. However, on the first sampling (23 October 1996), three grab samples from stream side just below the bridge (a, b, c), and the normal integration of the COF sample at three points on the bridge (X-sec) were also taken. These results suggest considerable spatial variability in the Potomac at this wide portion of the fall line. Alternatively, there may be some coarse particle fall-out during compositing containing much of the Al and some other trace elements. However this would be partly compensated if occurring in all samples taken from the same integrated volume and treated identically.

The percentage distribution between dissolved and particulate concentrations for base flow samples at the Potomac fall line is presented in Figure 3 a. It shows that the particulate concentration is totally dominant for crustal elements (Fe, Mn, and Cr), still more than eighty percent for the pollutant metals As, Cu, Ni and Zn, but only fifty percent for Cd, which agrees with the phase concentration measured in an earlier study at the fall line of the Delaware River (Church and Scudlark, 1998). However, for the annual period including all flows, the particulate burden is totally dominant (Fig. 3b). It is not known to what extent this is as much due to the high energy of flow for the restricted portion of the Potomac River at the fall-line. This is unlike

the Susquehanna in 1994 (Miller, et al., 1996) where most of the pollutant metals show about half dissolved distribution, maybe explained by a greater proportion of particle fall-out behind a higher density of larger dams. The Rock Creek tributary, downstream of the Potomac fall line, was sampled routinely and synchronous with the Chain Bridge fall line. Here, the annual average sample concentration (Fig. 3c) is particulate dominant for all but Mn and Ni, unlike the other upstream Potomac tributaries discussed in the next section. The range of dissolved and particulate concentrations for Chain Bridge at base flows is presented as a series of box plots in Figure 4. While the dissolved concentrations are reasonably consistent for all but Al and Cd, the particulate concentrations show appreciable temporal variation. This suggests that the process of particle formation varies throughout the year, depending probably on the seasonal changes in sources or biogeochemical processes (e.g. winter weathering vs. summer biota), as well as discharge.

The dissolved concentrations of the Potomac fall line are compared to three other Potomac basin systems studied by our group during recent years under previous programs. They include another Potomac sampling during a fall line tributary survey in 1994, the pristine Bear Branch watershed study (Church, et al., 1998), and the year long EPA-CPB Anacostia river study during 1994-5. The results (Fig. 5) show that during an earlier study on the Potomac with only two sample collections, the concentrations are fairly representative for the year. The exceptions are Cd, Pb and perhaps Zn which were actually lower previously for Cd and Zn, but higher for Pb. This is consistent with seasonal changes in presumably the soil biogeochemistry of the watershed responsible for predominant Cd transmission and Pb retention from our previous studies (Church and Scudlark, 1998; Church, et al., 1998). The Potomac dissolved concentrations are more than forested Bear Branch, except for Zn where greater foliage density contributes, and much less than the Anacostia where most of the pollutant metals are derived from local urban sources.

Total Hg shows fairly consistent concentrations throughout the year (Fig. 6), with some notable peaks in the winter and summer, which were unusually high. Whether this is typical of urban airsheds in late summer, or an aberrant sample cannot be ascertained without further sampling. However, the same peak was observed also in the Rock Creek tributary. The dissolved and particulate proportions of Hg are about equivalent.

The concentration results were translated into a total annual loading as follows. The volume weighed mean concentration (concentration times instantaneous discharge divided by daily discharge) of the daily loads for the sixteen sampling days was multiplied by the annual discharge as reported at the nearest gauging station (USGS Water Resources Data) during the Water Years 1996 and 1997. Annual dissolved and particulate loadings are summarized in Figure 7a, showing that the particulate load dominates the total load, which includes all flow conditions. The Potomac annual load is then compared to the corresponding loads of the Susquehanna River at the Conawingo Dam fall line during our previous CBP-MD DNR study in 1992-4 in Figure 7b. This comparison of the total loads for the two major watersheds of the Chesapeake confirms the dominance of the Susquehanna loading to the Bay. This is

commensurate with its higher flow and comparable total, if not particulate, concentration of the Susquehanna. This also reflects the equally polluted condition of both systems for non-crustal elements, which in the case of the Susquehanna includes a series of upstream urban sites, and acid mine drainage from the regional coal deposits. Also, for the Potomac, while there are some upstream coal deposits and low grade metamorphic terrain, the main urbanized portion is the urban/sub-urban corridor above Washington DC, and included at the fall line sampling station.

The annual loadings for the Rock Creek tributary are shown in Figure 7c and b. The Rock Creek, even as an urban tributary, shows rather uniform dissolved (Fig. 7c) and particulate (Fig. 7d) concentrations throughout the year. However, some maximum particulate concentrations for both crustal and pollutant metals occur during the late spring, a period presumably concurrent with local soil resuspension.

The dissolved and particulate As at the Potomac fall line shows unique seasonal behavior with a very pronounced peak during the late spring and summer. This is presumably related to the nutrient behavior of arsenate, which is known to resemble phosphate in its biogeochemistry. In fact, As is a contaminant of phosphate fertilizer application which probably also reaches the fall line late during the planting season, continuing to leach out, and like phosphate equilibrated with the soil as a result of agricultural and general plant growing activity upstream.

#### ***B. Potomac Head Water and Tributary Concentrations, Loads and Basin Yields***

The headwaters of the Potomac River were sampled twice (May and August 1997) in the head waters of both the north and south branches. Included were three successive locations downstream above Chain Bridge, plus two midstream tributaries, and Rock Creek downstream below the fall line. The dissolved and particulate concentrations at the upstream sites are summarized as totals in Table 7, along with the corresponding discharges and upstream watershed areas. The percentage dissolved and particulate distribution upstream at Cumberland (Fig. 8a), the northern mid-stream tributary Cotoctin (Fig. 8b), as well as the fall line (Fig. 8c) and the Rock Creek tributary (Fig. 8d) are displayed to show an increasing, if minor, particulate contribution downstream for most of the watershed. This means the predominant particulate burden for the Potomac, dominant in May, is contributed mainly (but not only) during periods of high flow and re-suspended yield within the lower urban watershed.

From the corresponding discharge and watershed area data in Table 7, the total instantaneous loads and basin yields were calculated and reported in Tables 8 and 9, respectively. The data are displayed in Figure 9 as a comparison of total metal concentrations during the (a) May and (b) June head waters surveys. Going downstream, there is rather constant As, increasing Cu, while Mn, Ni and Cd are maximum upstream at Cumberland and Kitzmiller. Some metals such as Ni and Mn have higher concentrations during May early in the growing season, while others such as As, Cd and Cu are higher in August later in the season. Presumably this reflects seasonal biogeochemical processes, as well as the relative natural and anthropogenic sources. When translated into a comparison of the instantaneous loads in Figure 10 for (a) May

and (b) August 1997, one observes a greater load in the northern branches, including Rock Creek, less in the northern tributaries, but a general decrease downstream until the major contribution before the urban DC corridor. Within the urban corridor, Rock Creek is presumably lower to hydrological protection from run-off as a National Park. Thus, both upstream and downstream sources appear comparable, and this is confirmed when calculated as basin yields in Figure 11 (a) May and (b) August, 1997.

### ***C. Potomac Fall Line Concentrations and Discharge***

The dissolved and particulate concentrations at the fall line are displayed in Figure 12, along with the discharge, for (a) crustal element Al, (b) metalloid As, and c) pollutant metals (represented by Zn). There are about 6-8 large discharge periods, primarily in the Fall, with the main one during the March 1997 high flow storm event. Only when the discharge is concentrated around December is there a large crustal particulate concentration from the accumulative flushing of the watershed. However, for the metalloid and pollutant type metals, there is a dissolved peak in the late spring not associated with discharge, presumably from the accumulative effects of the natural and agricultural growing season.

Special attention was focused on a high discharge event in early March 1997 when there was an intensive sampling over three successive days of high rain fall within the Potomac basin. Again the data are displayed for the three characteristic metals (Fig. 13). It is apparent that for Al, the leading hydrograph of discharge carries most of the particulate burden, followed by a minor dissolved pulse, whereas for As, the two are comparable and peak later in the discharge hydrograph. For Zn, the dissolved burden is sustained through the discharge hydrograph.

When displayed as a percentage, the particulate burden is totally dominant for all metals during the first high discharge day, with only some minor dissolved As and Cd proportions during the last two days (Fig. 14). On an annual basis, it is this high particulate burden which apparently dominates the metal loading of the Potomac river basin, most of which originates in its lower reaches. In this respect, contaminated ground water sources with particulate scavenging or contaminated soils themselves cannot be ruled out.

### ***D. Tidal Potomac Survey***

Below the fall line near Georgetown and Rock Creek, and just below the routine Chain Bridge sampling site, the Potomac River becomes tidal. The result is the greater Potomac Estuary which extends some hundred kilometers further downstream before confluence with the main stem of Chesapeake Bay near Piney Point. In fact, this portion of the Potomac comprises the largest sub-estuary of the Chesapeake. Through its gradient of salinity and turbidity along with intertidal wetlands, it is likely to process some portion of those trace elements gaged to cross the fall line during this study. The importance is that the trace element loading of the Potomac to Chesapeake Bay proper at the main stem, is in fact determined ultimately by the fate of these elements within the sub-estuary.



The same trace elements were sampled synoptically with this study as part of the EPA AEOLUS project, but reported here so as to compare to the concentrations upstream in the watershed. This occurred on two seasonal occasions during the winter (Feb.) and summer (July) of 1997. The five sampling sites ranged the full length of the estuary from the Anacostia river to Piney Point. The exact locations and coordinates are listed in Table 1b. The raw dissolved and particulate concentrations are listed in the appendix as Table A-5.

During February (Fig. 15), both the total (a) and particulate (b) concentrations of most metals generally go through a minimum near Alexandria and then increase down to Piney Point. This is most pronounced for the crustal elements Al and Fe, and Zn, and less so for the other pollutant elements. This may indicate the fact that Alexandria coincides with the major Blue Plains sewage plant for Washington DC. This plant presumably injects large quantities of dissolved organic matter and nutrients which may lead to phytoplankton blooms and particle distribution or removal. Alternatively, as one proceeds down the salinity gradient, the riparian marshes which normally act as a sink for particulates maybe undergoing ice rafted tidal resuspension during the winter. However, the dissolved concentrations (c), show little change, except for Cd which goes through the same minimum, and Cr, Cu and Ni which increase down estuary in more saline waters. This may reflect reflux to the tidal waters from the diagenetic alteration in the riparian salt marshes which are more abundant in this portion of the estuary.

During July (Fig. 16), the total (a) and particulate (b) concentrations for the crustal elements Al, Fe and Mn are quite uniform, while the pollutant trace elements Zn, Cd, Cr, Cu and Ni increase generally down estuary to Quantico (there were no Piney Point samples in July). Arsenic (not reported for February) was quite uniform, perhaps reflecting like phosphate a buffered nutrient. The dissolved concentrations © reflect the same pattern as the total. Again, this may reflect the diagenetic reflux from intertidal areas down estuary, which should reach a maximum during the warm summer months of sulfate reduction and burying organisms.

The percentage distribution of dissolved and particulate trace elements (Fig. 17) show the same pattern for three common sites, perhaps corresponding to the position of the turbidity maximum. At Reagan National Airport (a) the particulate concentration dominates for crustal Al, Fe and for Mn, Cr and Zn as well during July. At Quantico (b), the same general pattern applies for both months. At both locations, the other pollutant elements (Cd, Cu, Ni) are dominantly dissolved. Down estuary at Piney Point(c), the February particulate distribution is dominated by crustal Fe and Mn (Al not available) plus Zn.

The overall impression is that the while the concentrations within the tidal Potomac estuary are similar to those crossing the fall line at Chain Bridge, the redistribution from the particulate to dissolved phase for the pollutant elements is significantly different. While the reasons maybe several as noted above (estuarine blooms stimulated by sewage plants, riparian diagenesis, etc.), the importance is that more of the pollutant trace loading in the Potomac River may be available for estuarine biota downstream. Depending on the element, this could mean

either eutrophic and/or toxic effects in the estuarine portions of both the Potomac and a greater dissolved contribution to the lower Chesapeake Bay.

## VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

In summary; the results from this study of the Potomac river and estuary conclude:

- Upstream, trace element loadings are dominantly dissolved in primary watersheds and tributaries.
- Downstream the loadings are dominantly particulate at the fall-line, unlike most tributaries.
- Comparison of dissolved tributary concentrations indicate some downstream retention.
- Instantaneous loadings show both mid-stream weathering and downstream urban sources.
- Basin yields show both sources to be important, equal for crustal and urban for pollutant elements.
- Estuarine concentrations are comparable to that at the fall line, but dissolved processing from biota or marshes is evident.

These observations lead to the following recommendations for future Potomac studies:

- Dissolved upstream atmospheric and weathering sources are later converted into particulate loads.

**The recommendation** is for intra-watershed study of particulate processing.

- Particulate loads during high flow are theorized to include flushing of an historical legacy.

**The recommendation** is longer term monitoring as global warming escalate biogeochemical transformations within the watershed.

- High basin yields are unique to the downstream urbanized portions of the river above the fall line.

**The recommendation** is for detailed studies on urban runoff in the DC corridor.

- Dominant particulate loading during high flow leads to equivalent estuarine concentrations .

**The recommendation** is for estuarine studies on the tidal fate and cycling of metals.

## VII. ACKNOWLEDGMENTS

We wish to acknowledge Mrs. Marie Freeman for her assistance with the field sampling. We also would like to acknowledge the analytical assistance of Mrs. Weiqi Chen and Ms. K.C. Filippino. Mrs. Wendy Grot provided the clerical and Brian Norton the graphical assistance in preparing this report.

## VIII. REFERENCES

- Castro, M. S., J. R. Scudlark, T. M. Church and R. P. Mason , 2000. "Input-Output budgets of major ions, trace elements, and mercury for a forested watershed in Western Maryland". Maryland Power Plant Research Program Report, 72 pp.
- Church, T.M. and J.R. Scudlark. 1998. "Trace metals in estuaries: A Delaware Bay synthesis." (In:) *Metal Speciation and Contamination of Surface Water* (J. Baker, ed) Ann Arbor Press, Inc., Chapt. 1, pp. 1-20.
- Church, T.M., J.R. Scudlark, K.M. Conko, O.P. Bricker, K.C. Rice. 1998. "Transmission of Atmospherically-deposited trace elements through an undeveloped, forested Maryland Watershed" *Maryland Department of Natural Resources Chesapeake Bay Research and Monitoring Division, CB93-005-002*.
- USEPA. 1996. Chesapeake Bay Program, *Chesapeake Bay Fall Line Toxics Monitoring Program Final Report 1994*, CBP/TRS-144/96, 125 pp.
- Water Resources Data. Maryland and Delaware Water 1996 and 1997. Volume 1 *Surface-Water Data. U.S. Geological Survey Water Data Report MD-DE-96-1. 97-1*.

## IX. APPENDICES ( ATTACHED TABLES)

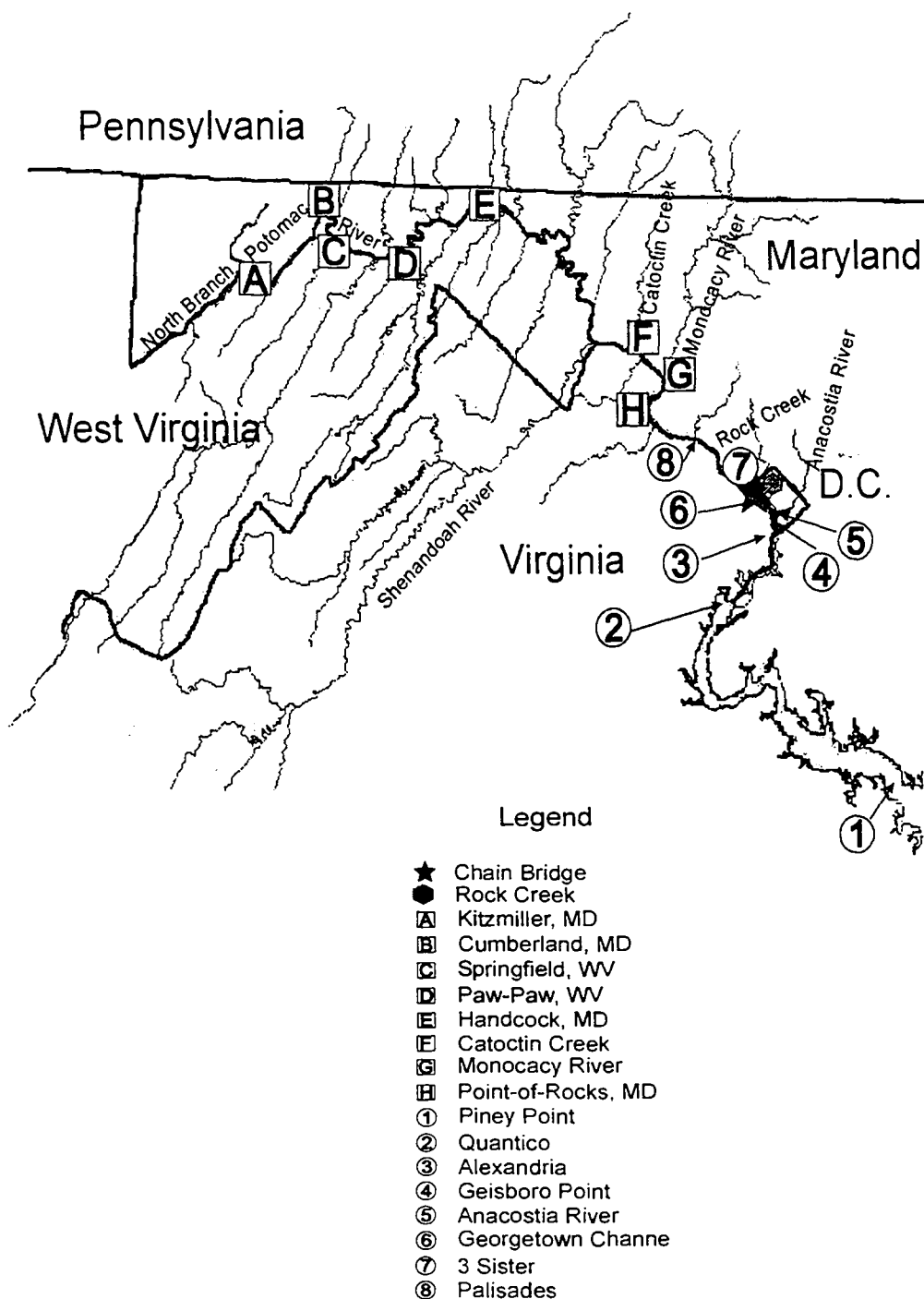


Figure 1 Sample locations in the Potomac River Watershed. The location symbols correspond to those listed in Table 2. The routine sampling occurred at Chain Bridge (ChB) near the fall line. Other stations were sampled twice during the early and late summer 1997. Going upstream, they represent three tributary (RkC, Mon, Cac), three mainstem (PoR, Hck, Paw), and three head waters on the north (Cmb, Spf) and south (Kzm) branches respectively.

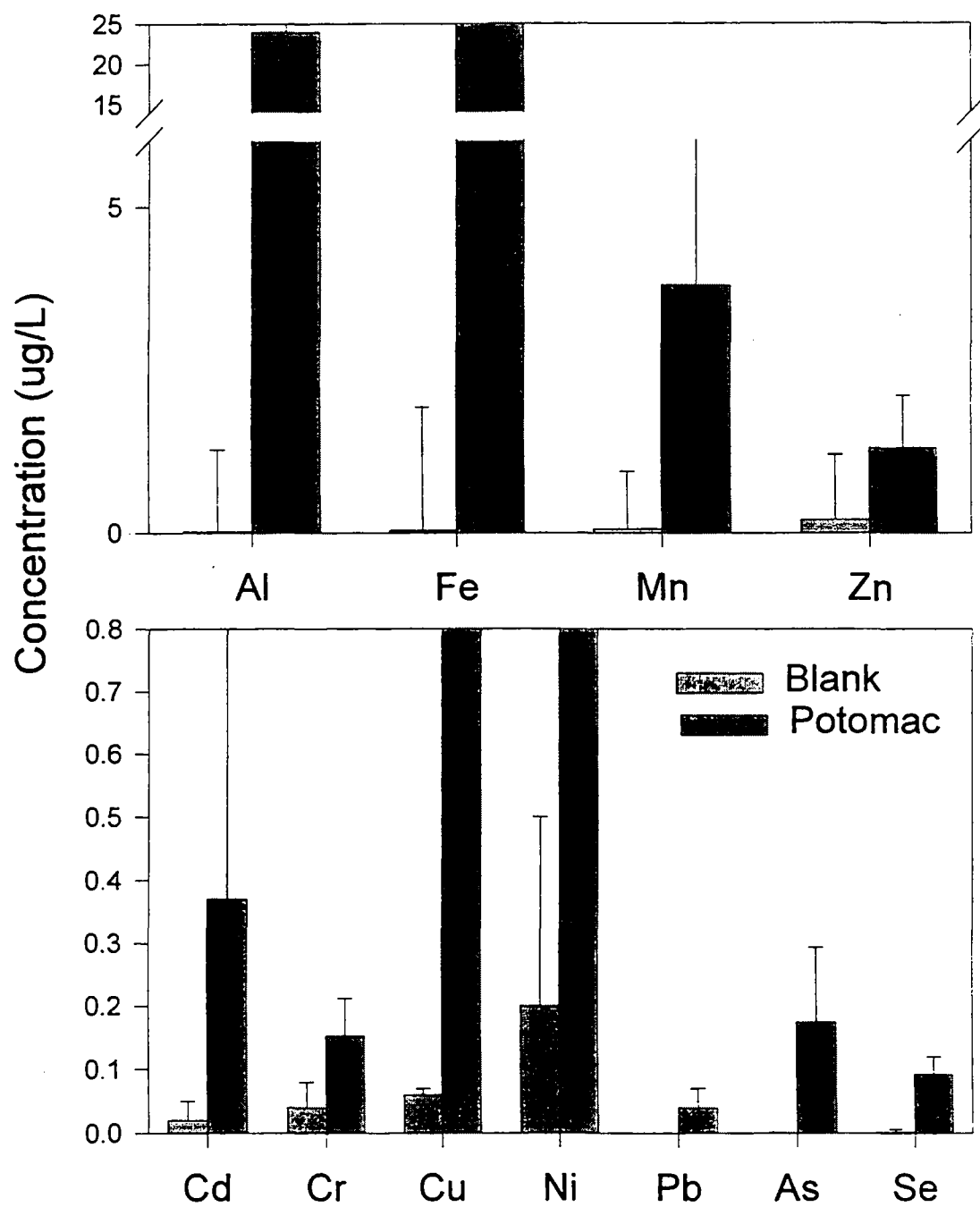


Figure 2 Comparison of average field blanks with average Potomac River concentrations. In most cases, the blank is a small percentage of the sample.

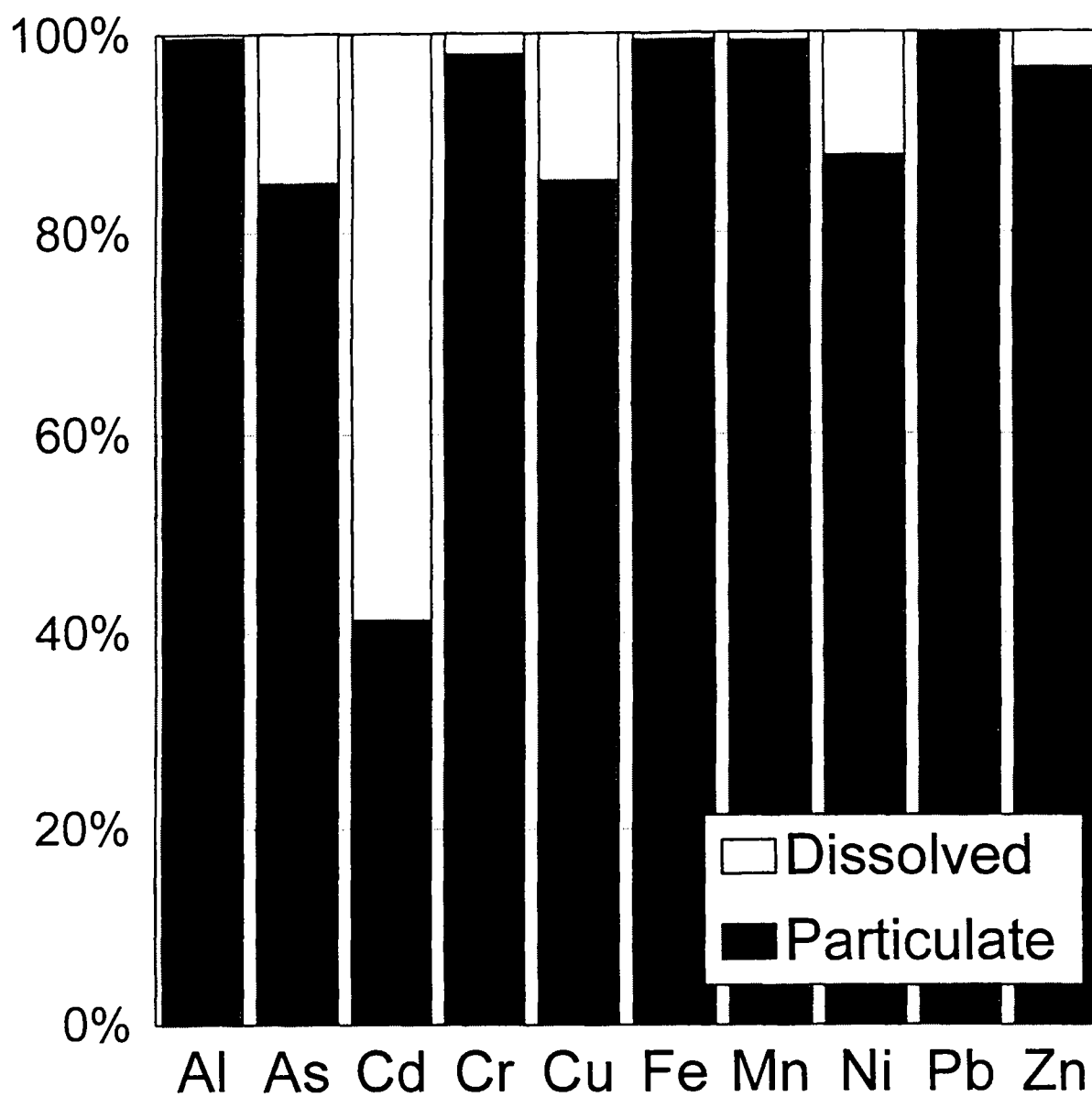


Figure 3a Percent dissolved and particulate distribution of average trace metal concentrations at the Potomac River fall line during base flow conditions.

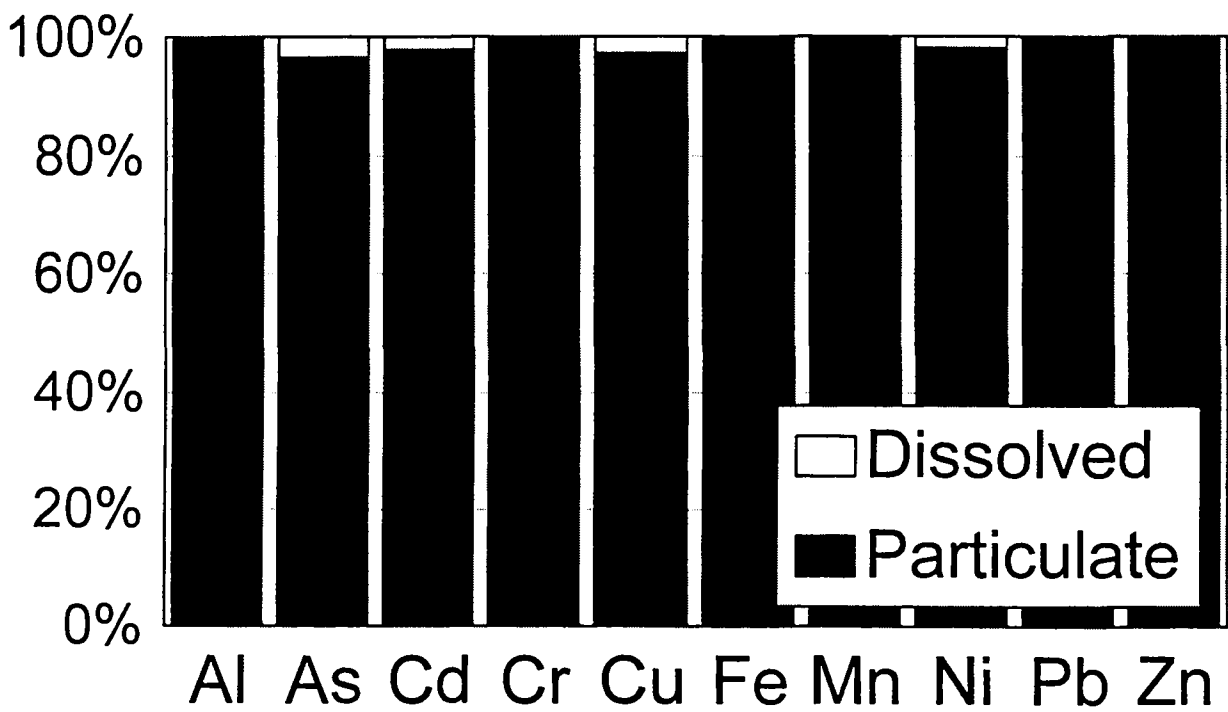


Figure 3b Percent dissolved and particulate distribution of average trace metal concentrations at the Potomac River fall line during all flow conditions.

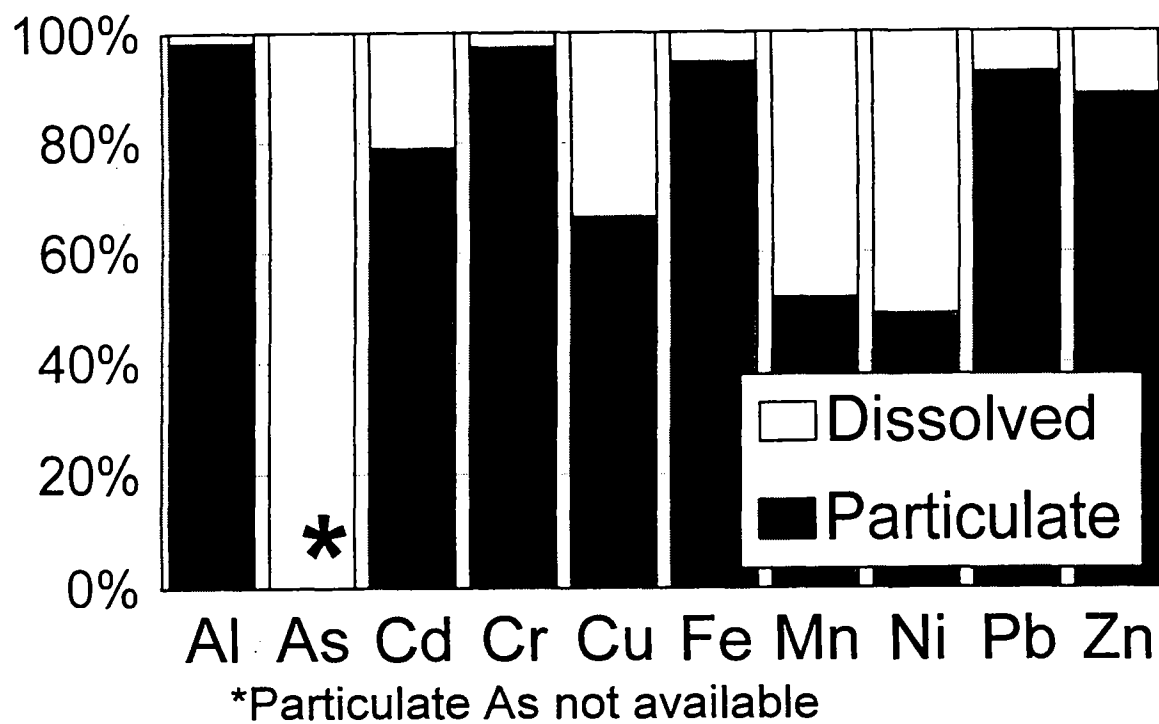


Figure 3c Percent dissolved and particulate distribution of average trace metal concentrations at the Rock Creek terminus during base flow conditions.



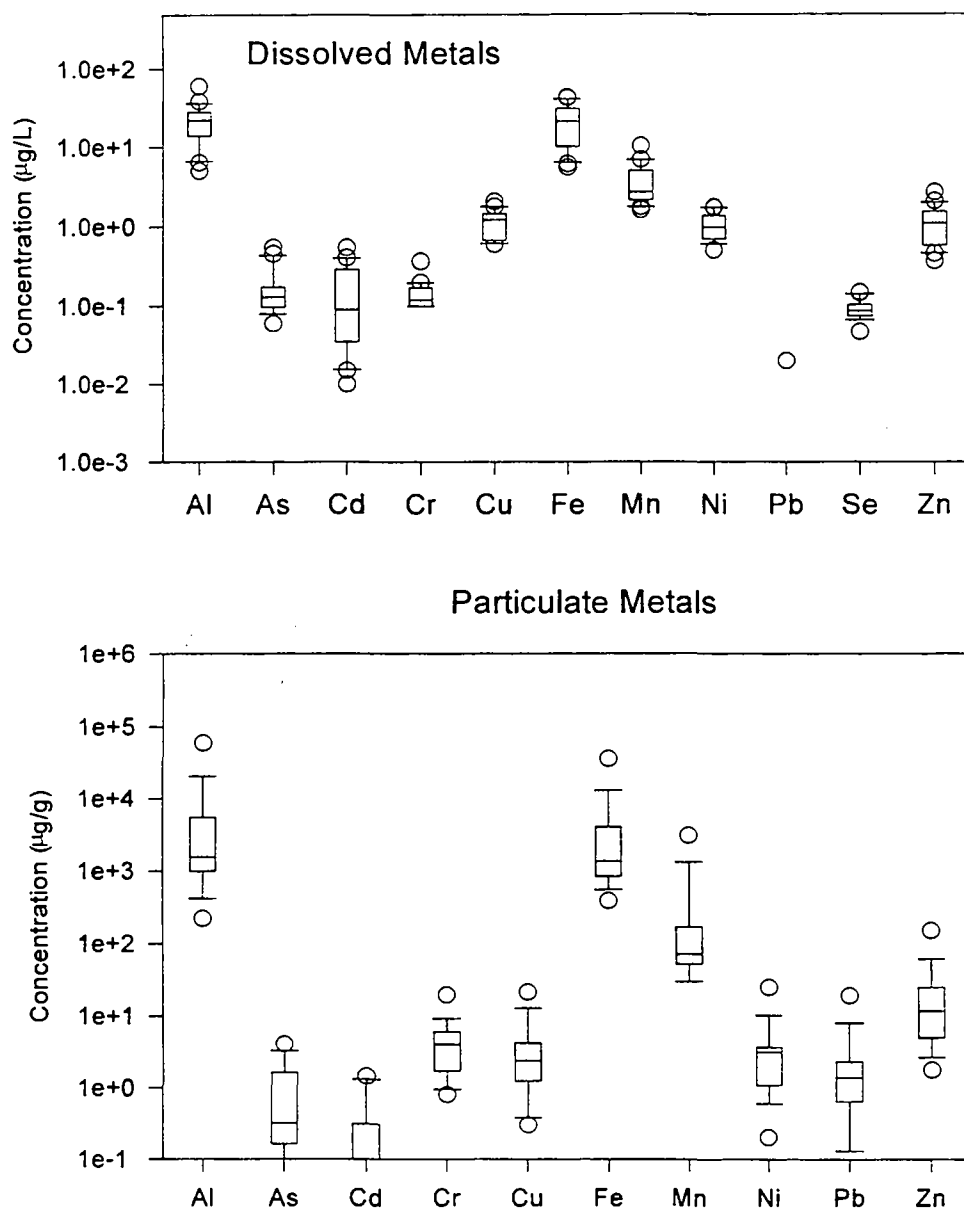


Figure 4 Variations in trace metal concentrations at the Potomac fall line during average base flow samples for dissolved and particulate samples. The box defines the median, 10th, 25th, 75th and 90th percentiles, and the circles the extremes of the entire sample distribution.

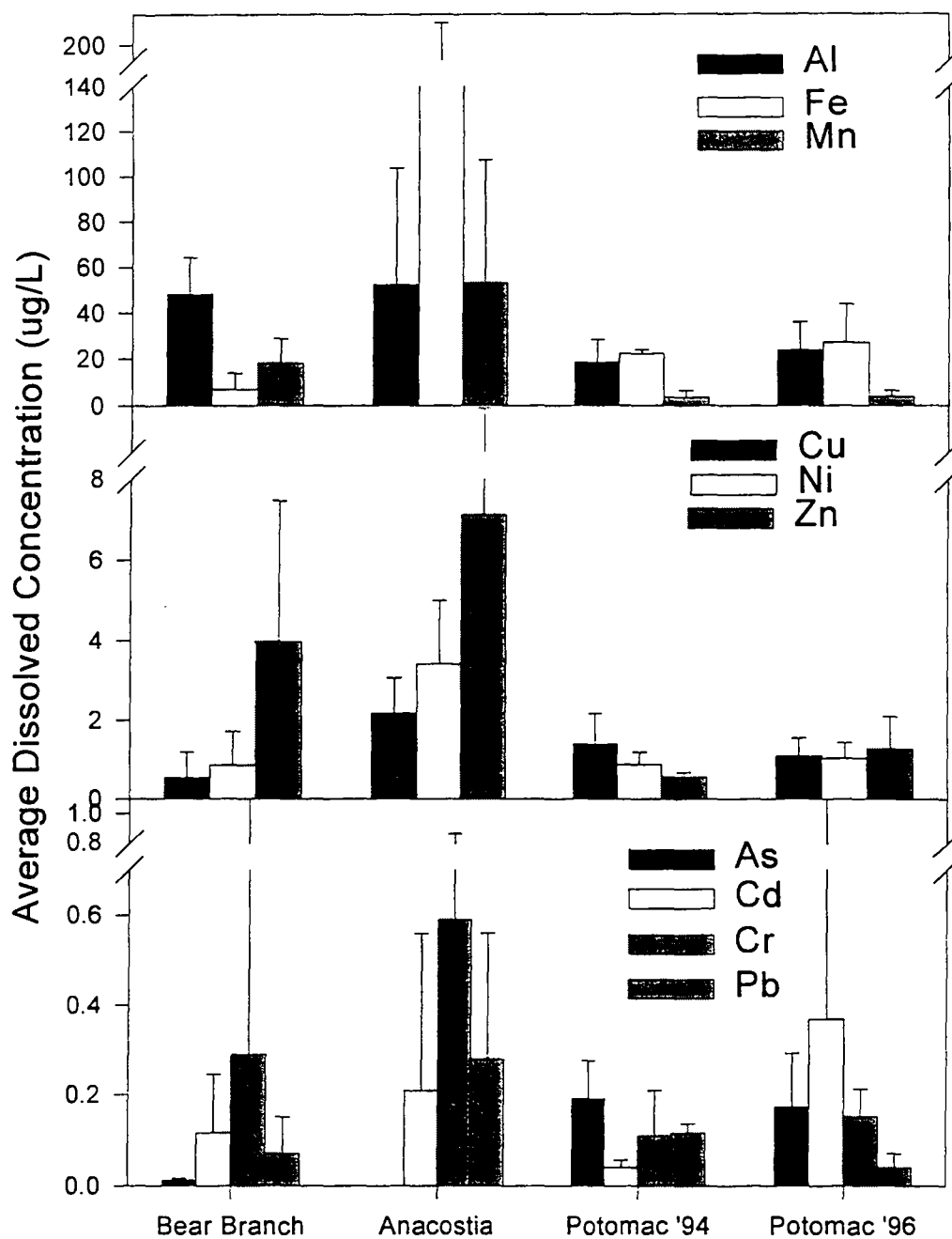


Figure 5 Comparison of average dissolved trace metal concentrations within the Potomac watershed from earlier studies. Included are the pristine Bear Branch on the Cactoctin tributary, the urban Anacostia tributary, and an earlier synoptic sampling around the Chesapeake (n=2) and that for this study (n=16) at the Potomac fall line.

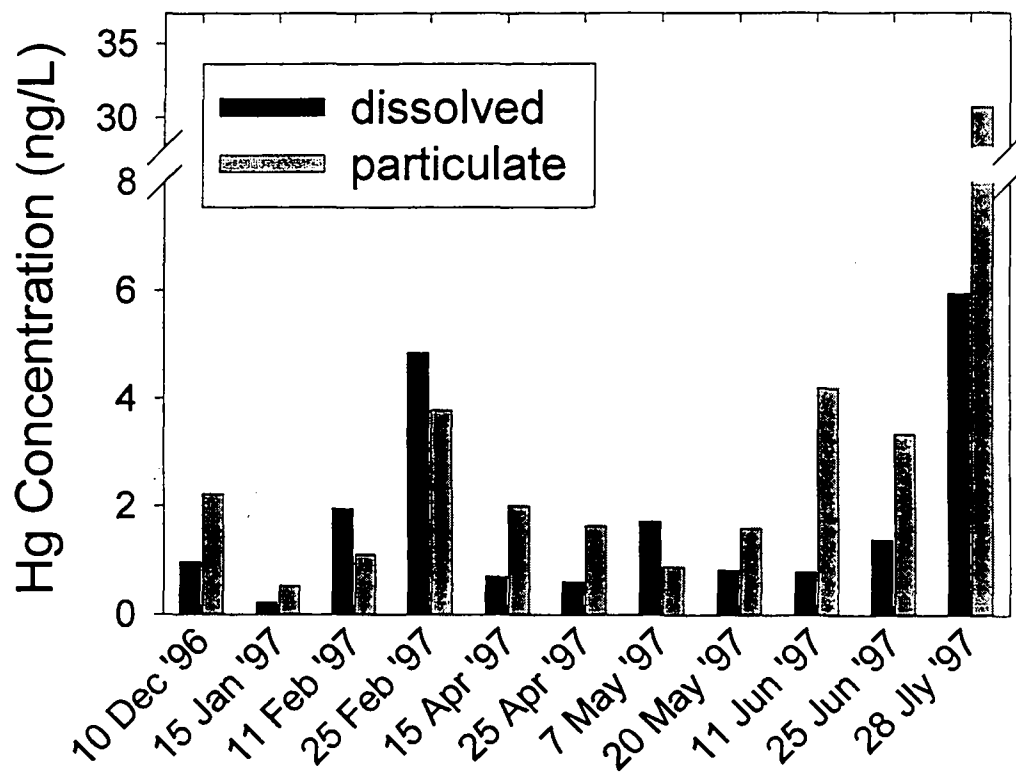


Figure 6 Total dissolved and particulate mercury concentrations (ng/l) at the Potomac fall line over time.

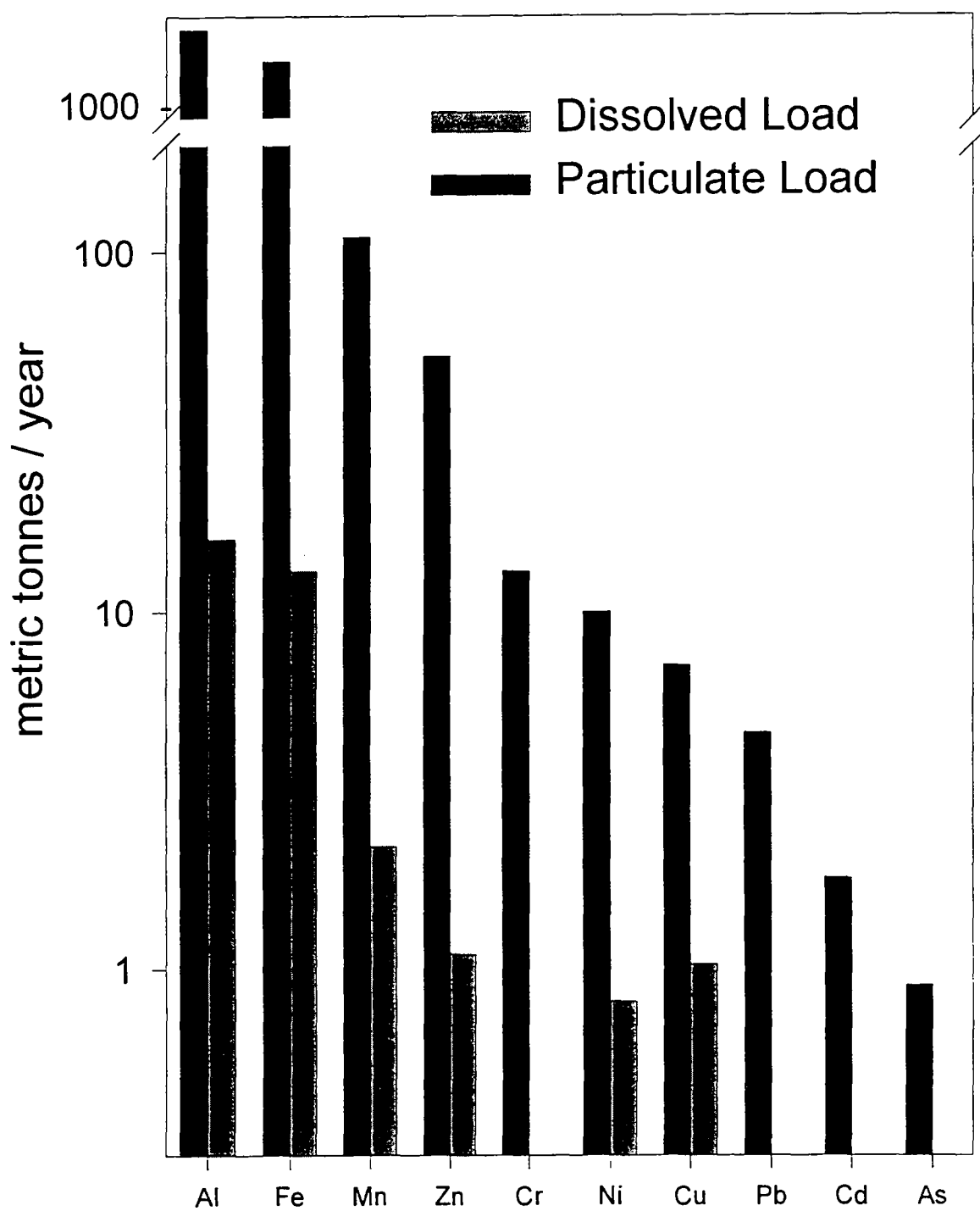


Figure 7a Trace metal loading at the Potomac fall line over all flow conditions.

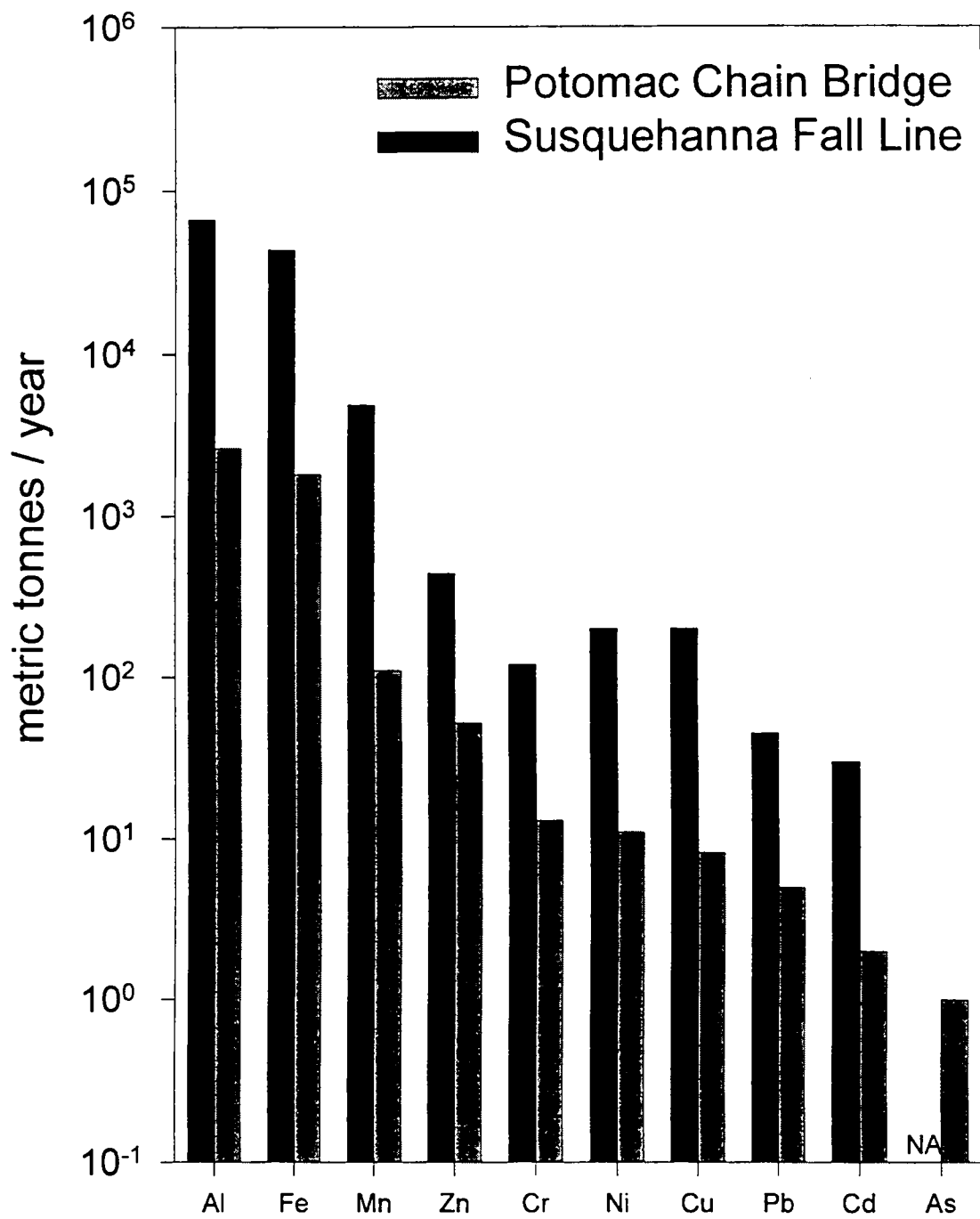


Figure 7b Comparison of the total trace metal loading at the Potomac and Susquehanna fall lines over all flow conditions. As for the flow, the Susquehanna dominates.

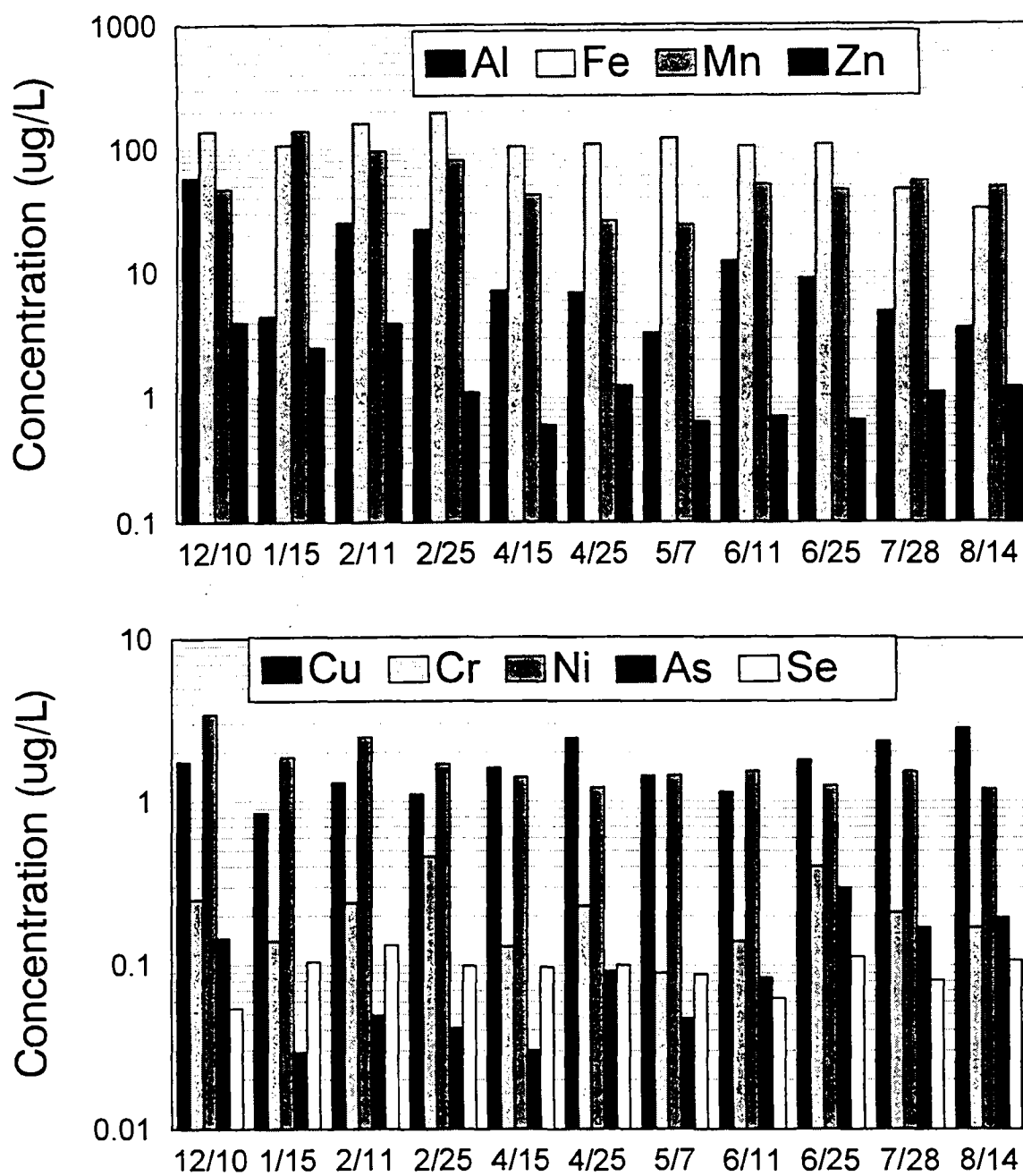


Figure 7c Comparison of the dissolved trace metal loading at the Rock Creek terminus for each sampling period.

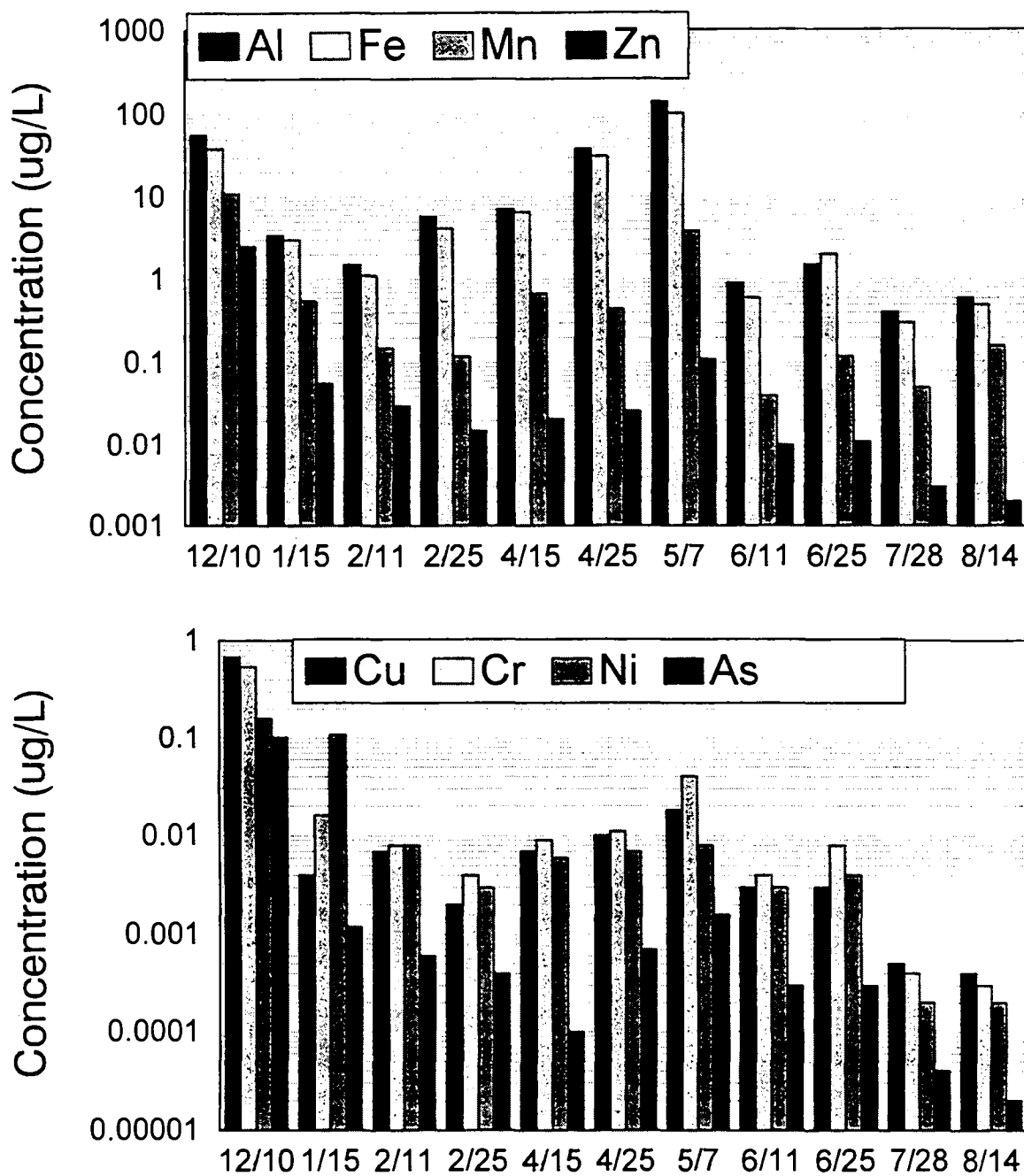


Figure 7d Comparison of the particulate trace metal loading at the Rock Creek terminus for each sampling period .

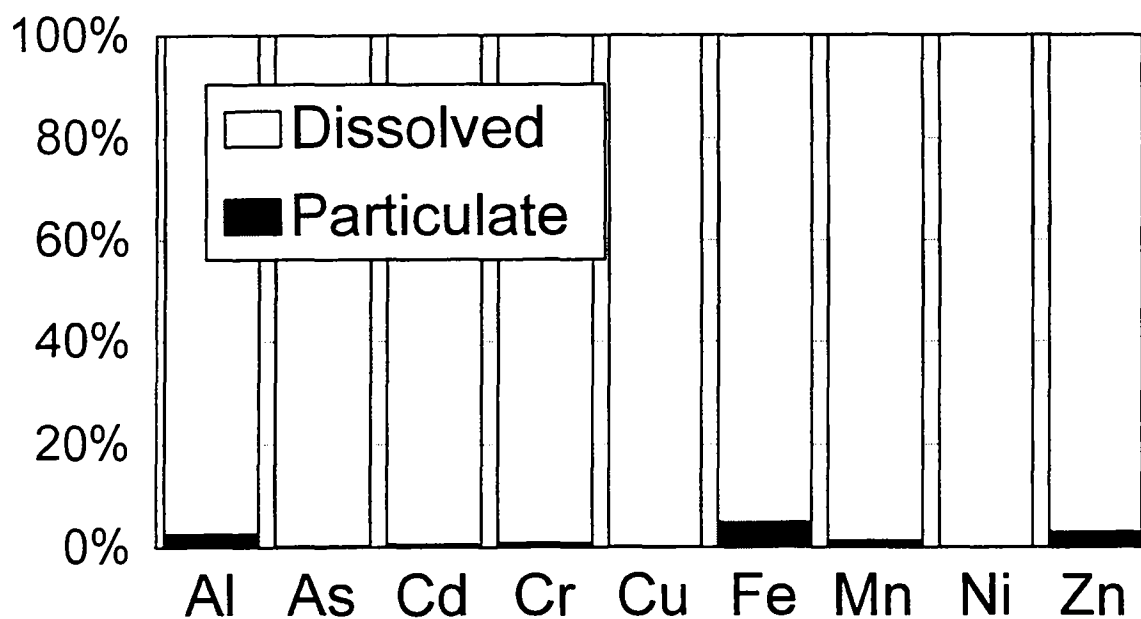
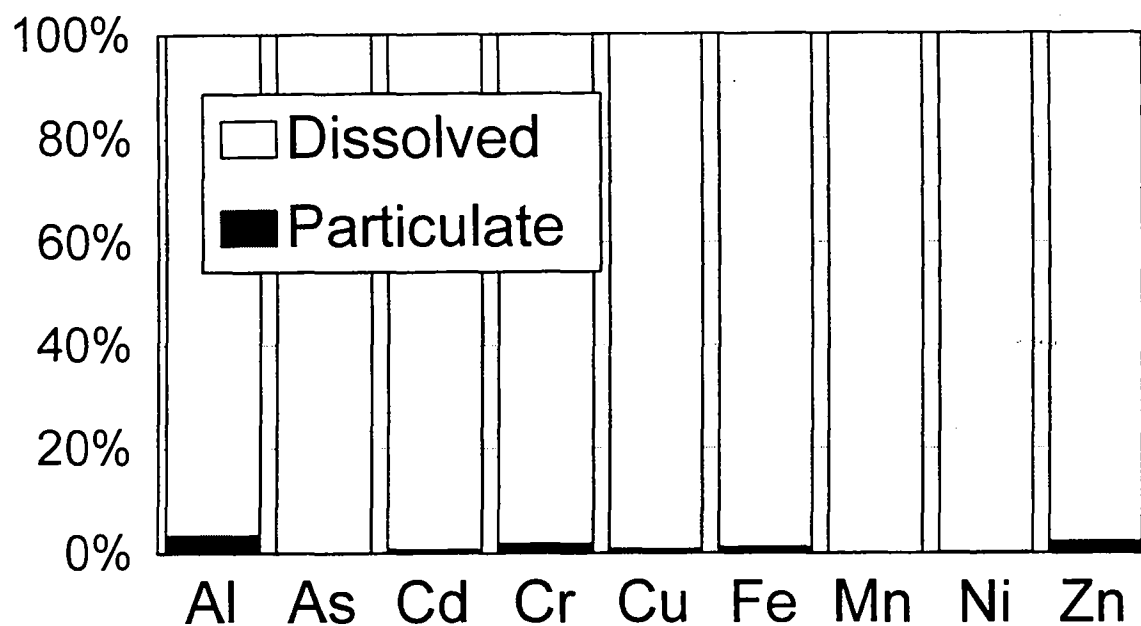


Figure 8a Percent dissolved and particulate trace metal concentrations an upper tributary of the Potomac. The sampling occurred during the early (May) and late (August) summer period. Cumberland, MD is on the north branch of the Potomac.



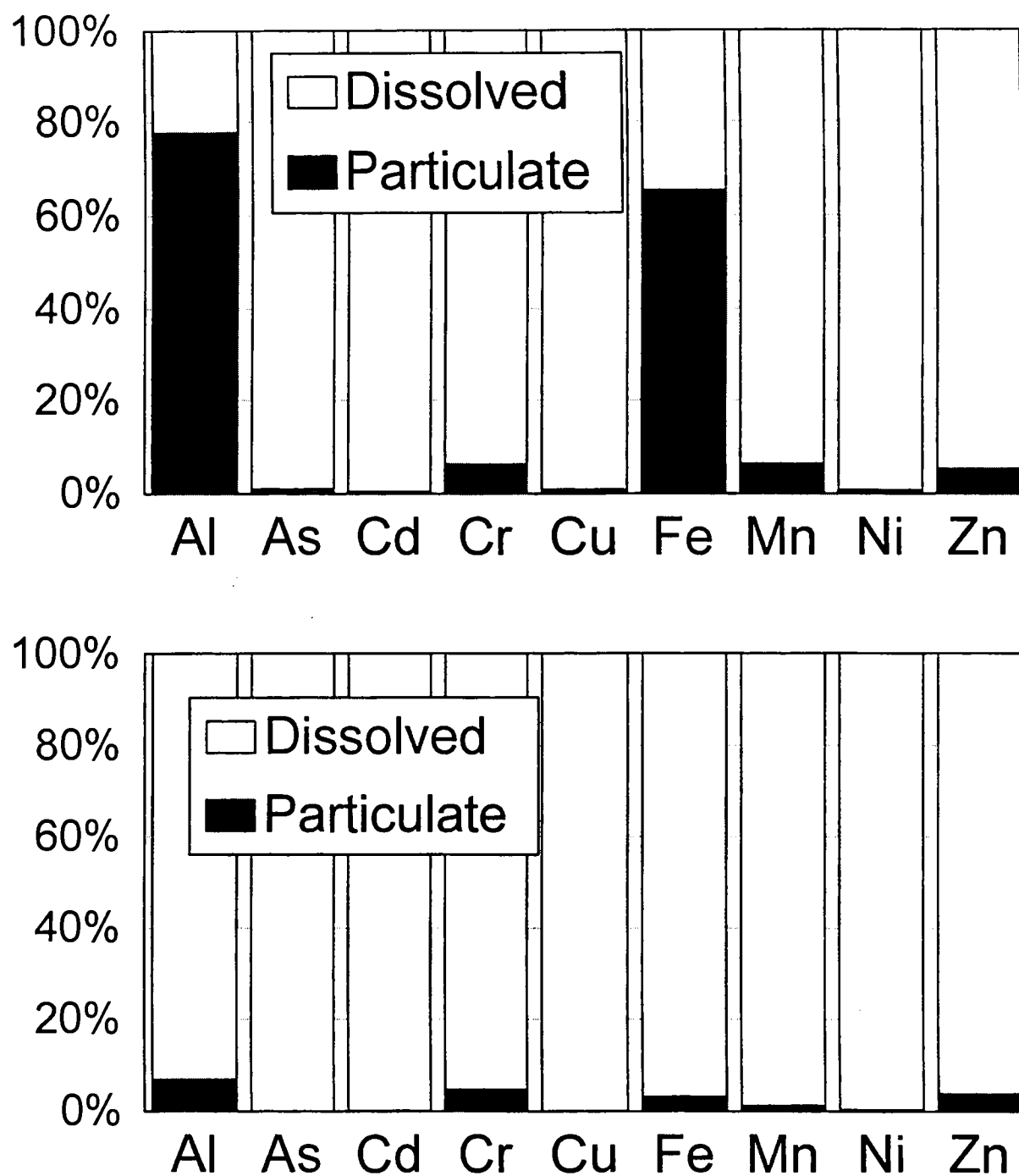


Figure 8b Percent dissolved and particulate trace metal concentrations a middle tributary of the Potomac. The sampling occurred during the early (May) and late (August) summer period. Cactoctin, MD is midway on the main stem of the Potomac.

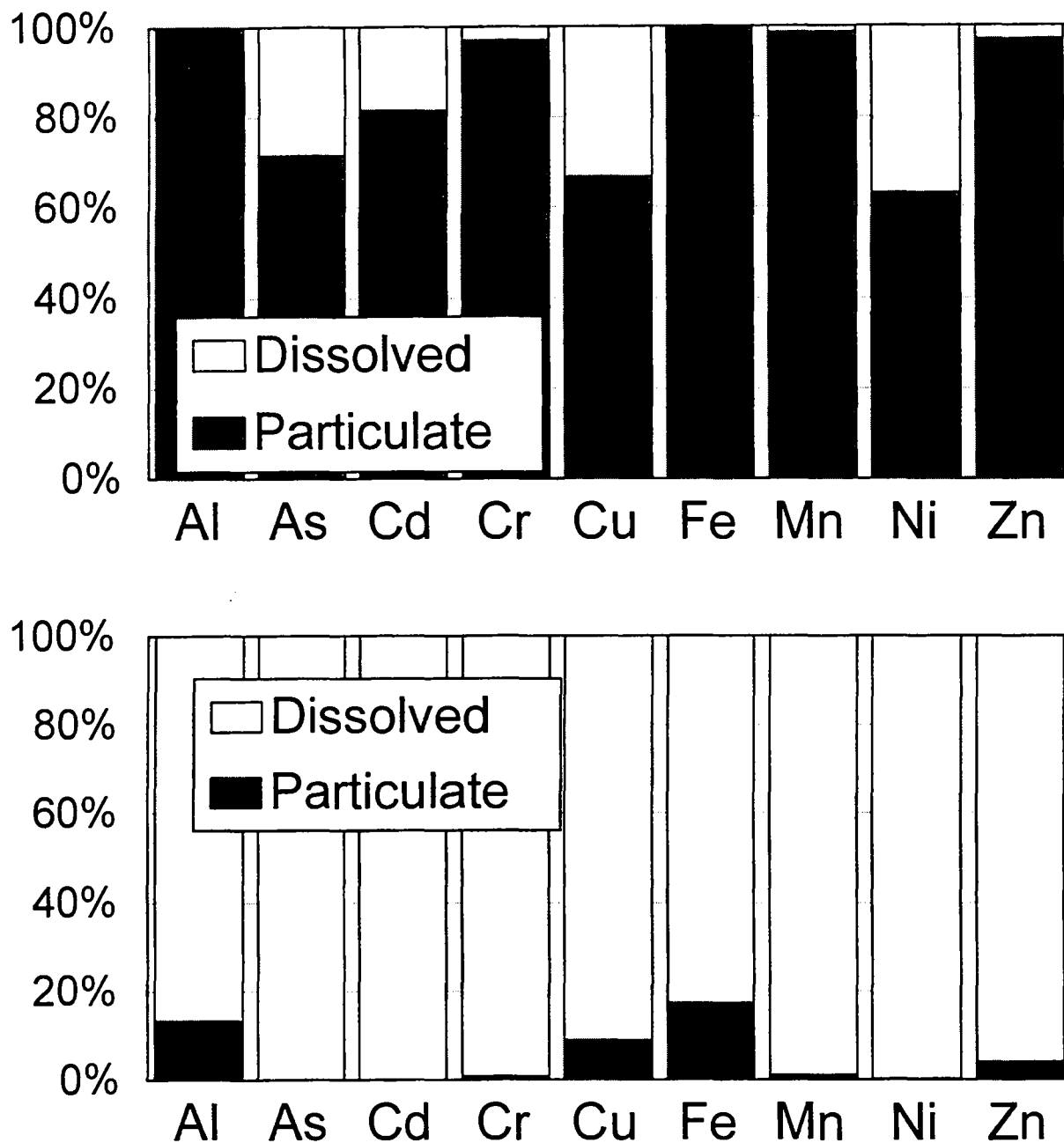


Figure 8c Percent dissolved and particulate trace metal concentrations downstream on the main stem of the Potomac. The sampling occurred during the early (May) and late (August) summer period. Chain Bridge DC is near the fall line.

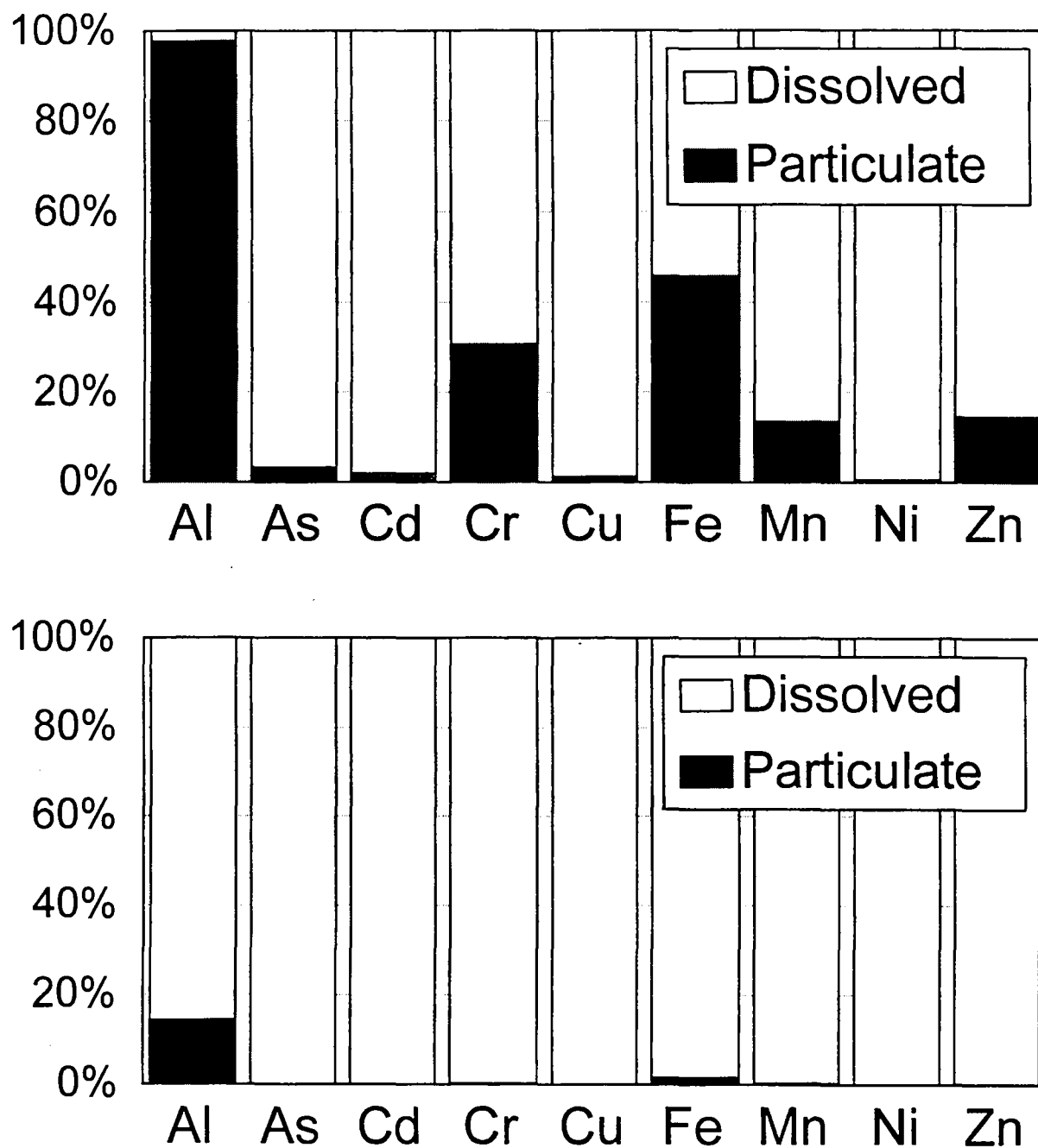


Figure 8d Percent dissolved and particulate trace metal concentrations for the terminus of Rock Creek, a lower tributary of the Potomac. The sampling occurred during the early (May) and late (August) summer period.

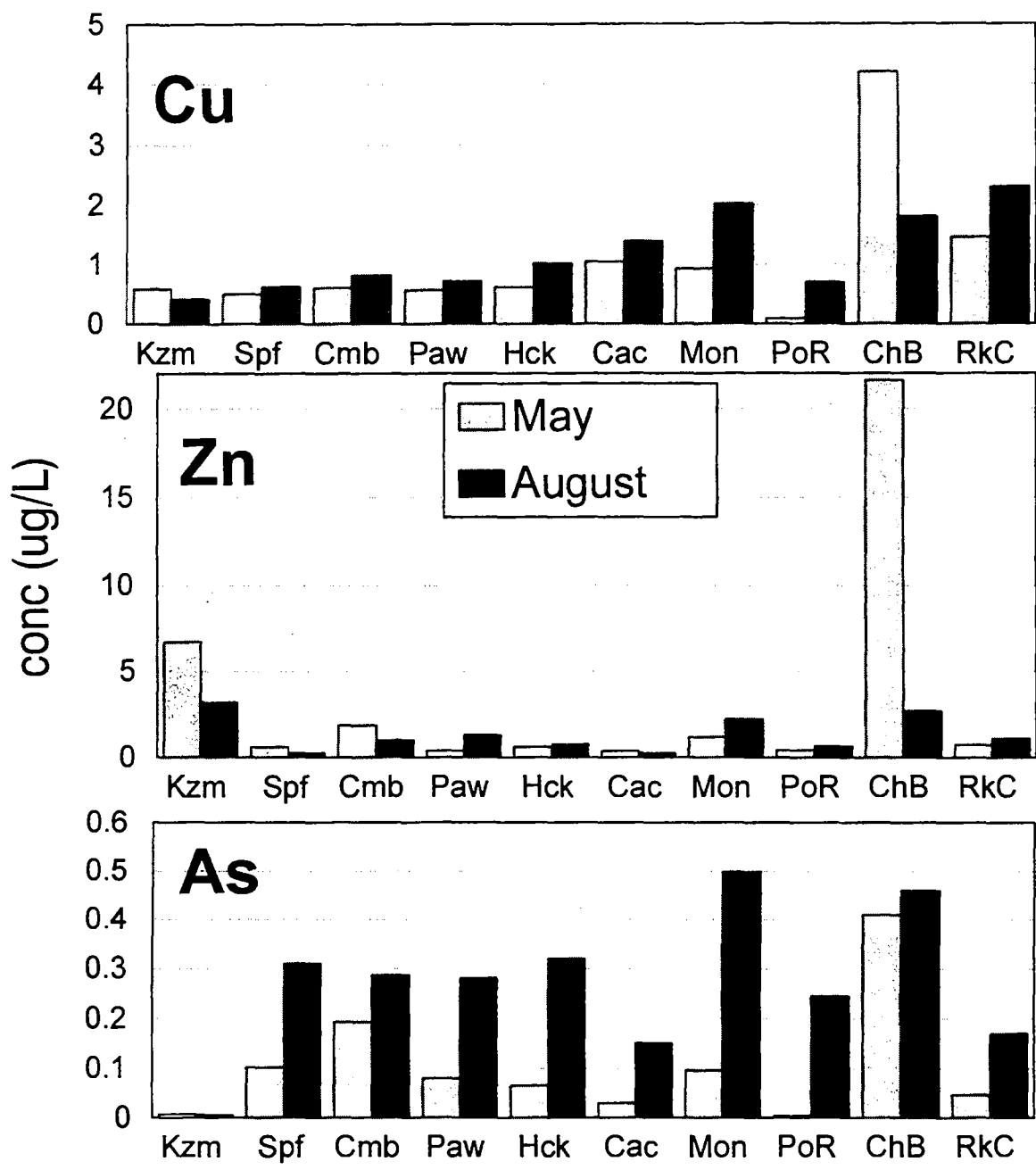


Figure 9a Total Cu, Zn, and As concentrations during early (May) and late (August) summer on the head waters and tributaries of the Potomac. The sites are generally upstream to downstream going from left to right.

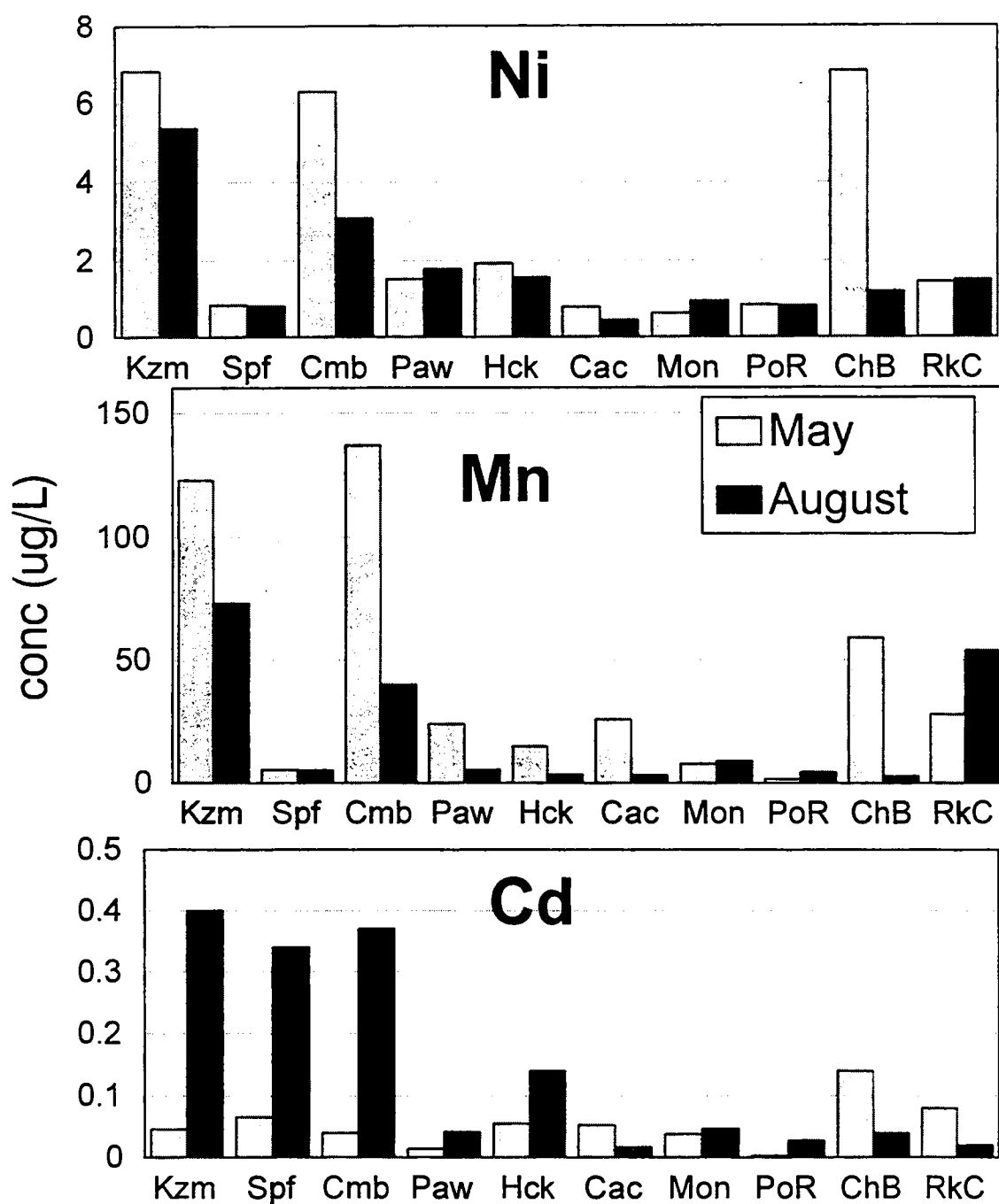


Figure 9b Total Ni, Mn, and Cd concentrations during early (May) and late (August) summer on the head waters and tributaries of the Potomac. The sites are generally upstream to downstream going from left to right.

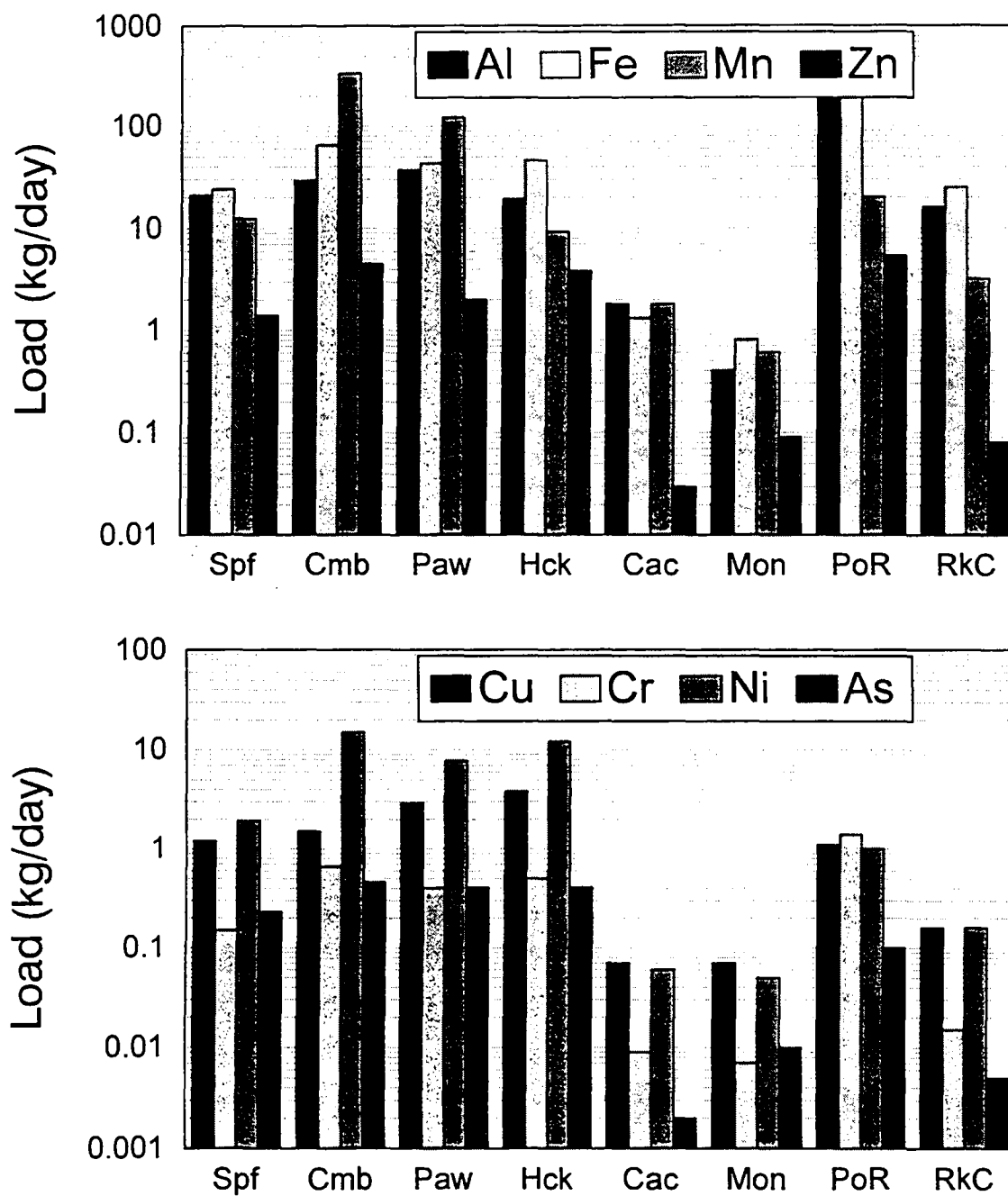


Figure 10a Instantaneous loads of trace metals during early (May) summer on the head waters and tributaries of the Potomac. The sites are generally upstream to downstream going from left to right.

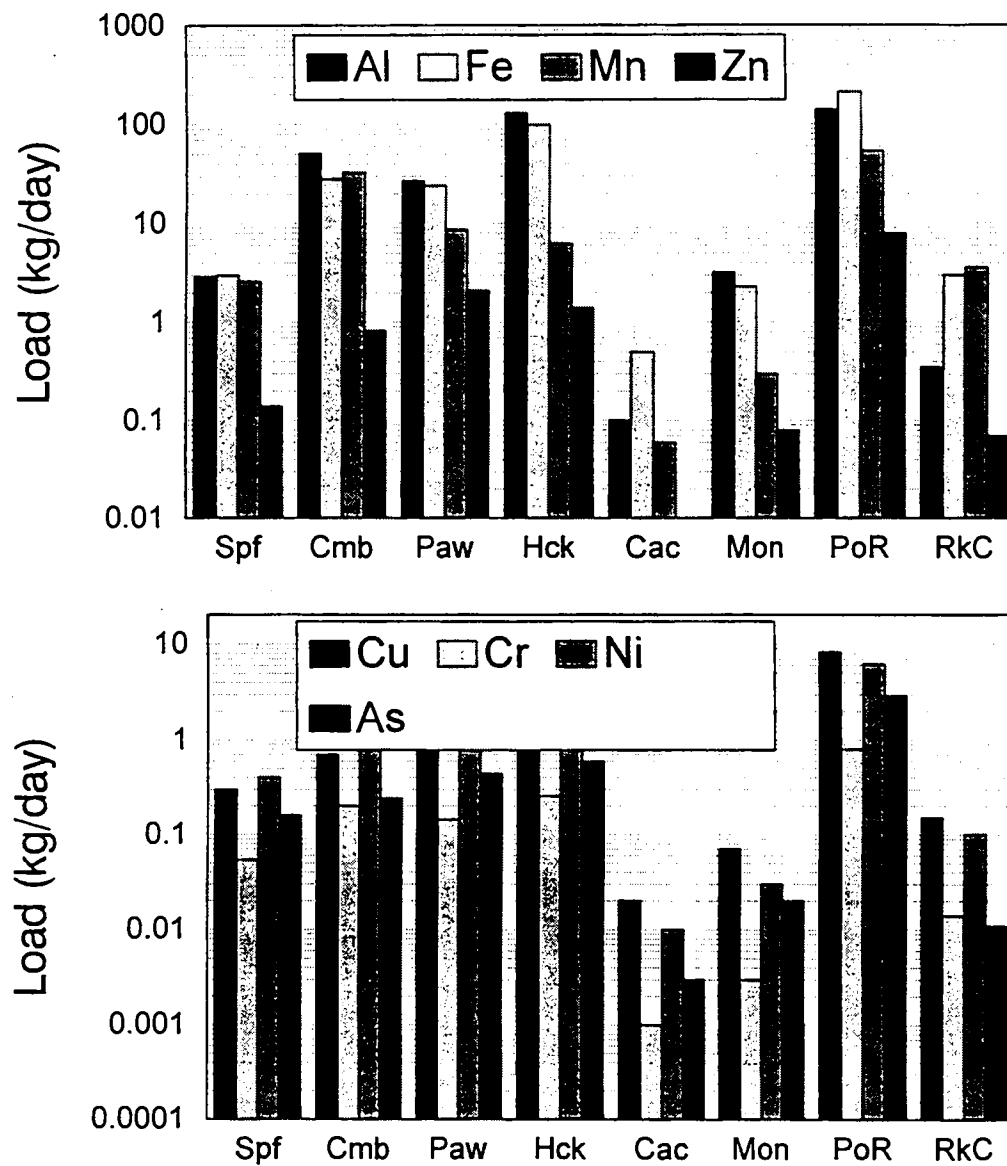


Figure 10b Instantaneous loads of trace metals during the late (August) summer on the head waters and tributaries of the Potomac. The sites are generally upstream to downstream going from left to right.

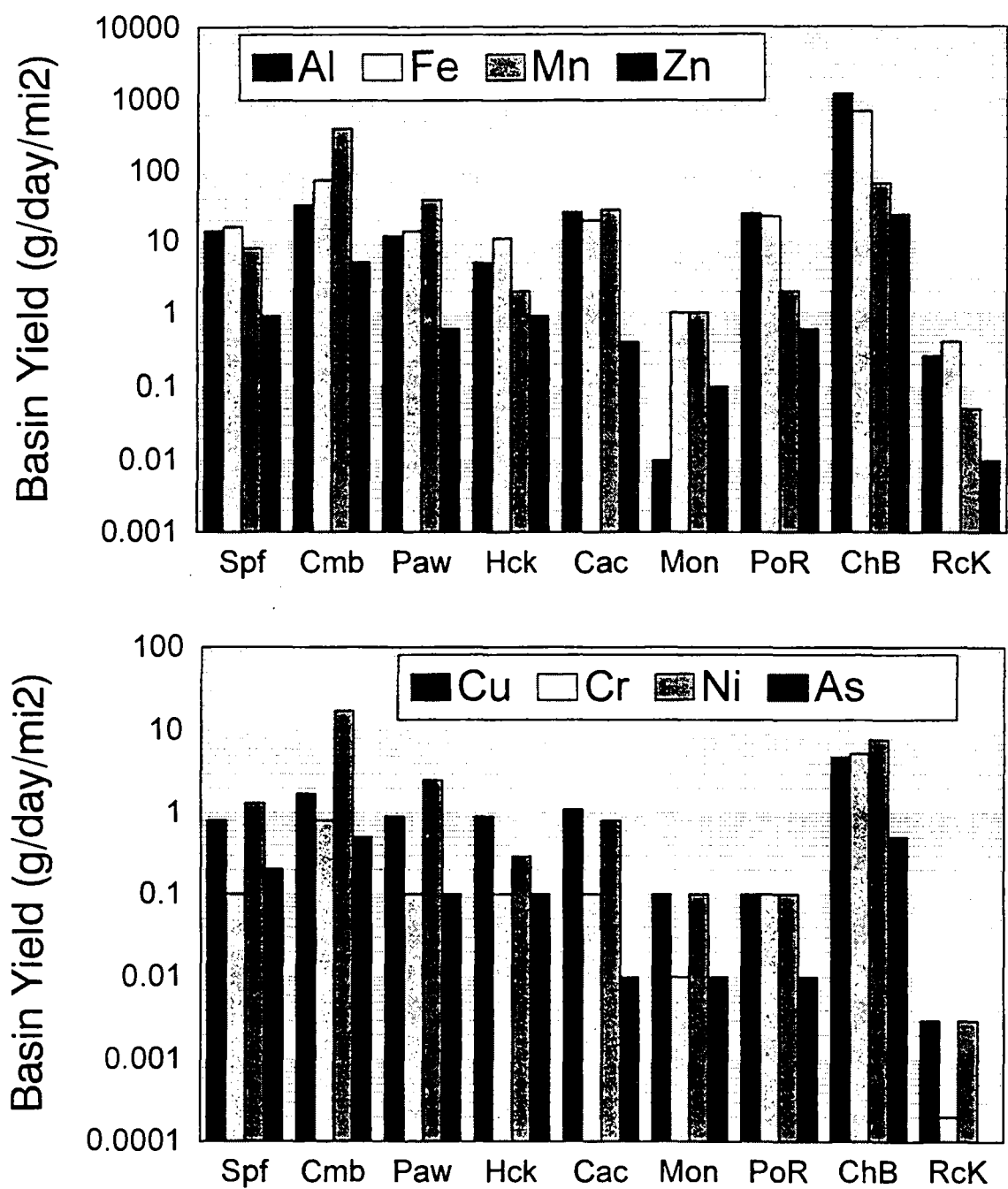


Figure 11a Basin yields of trace metals during early (May) summer on the head waters and tributaries of the Potomac. The sites are generally upstream to downstream going from left to right.



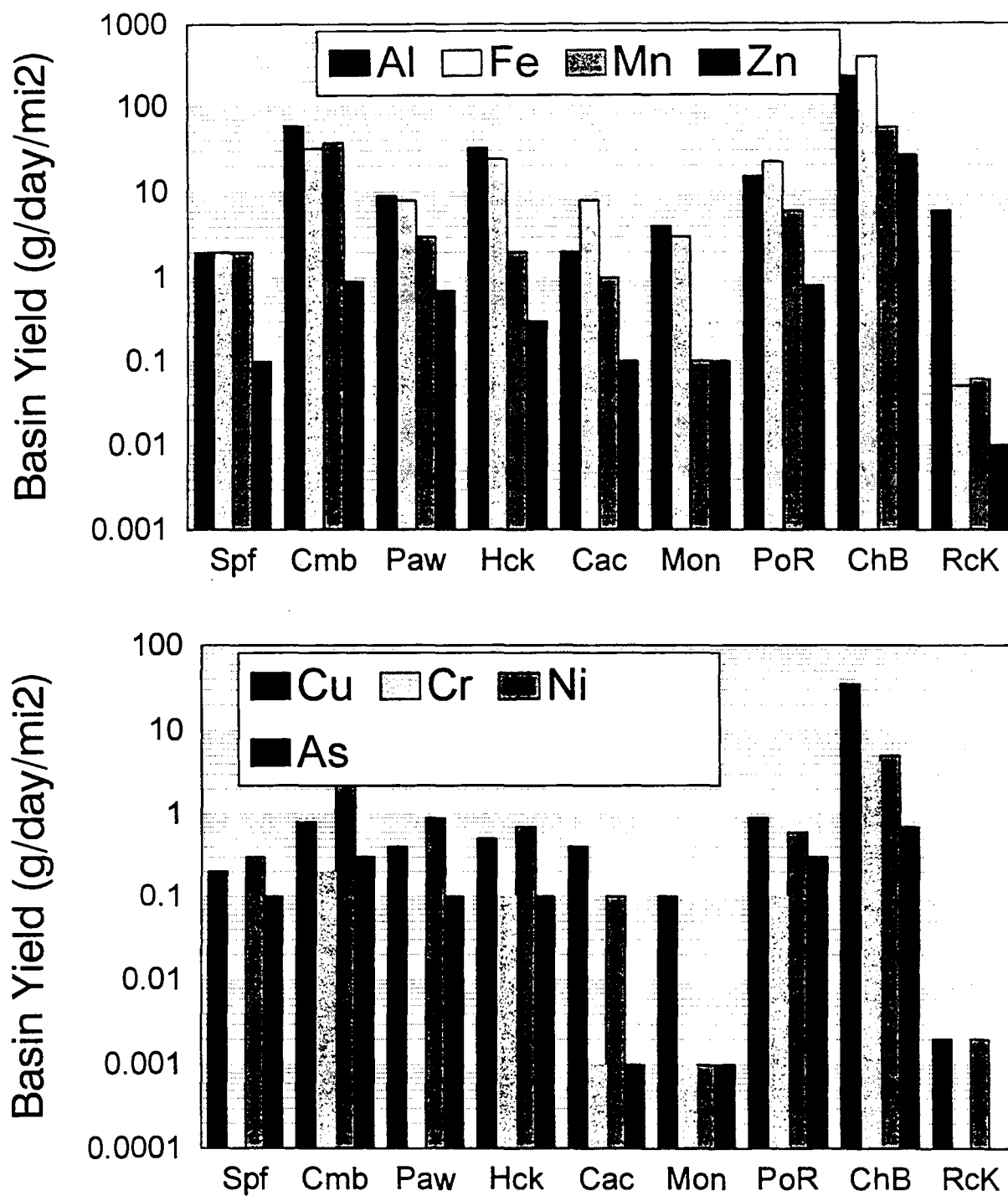


Figure 11b Basin yields of trace metals during the late (August) summer on the head waters and tributaries of the Potomac. The sites are generally upstream to downstream going from left to right.

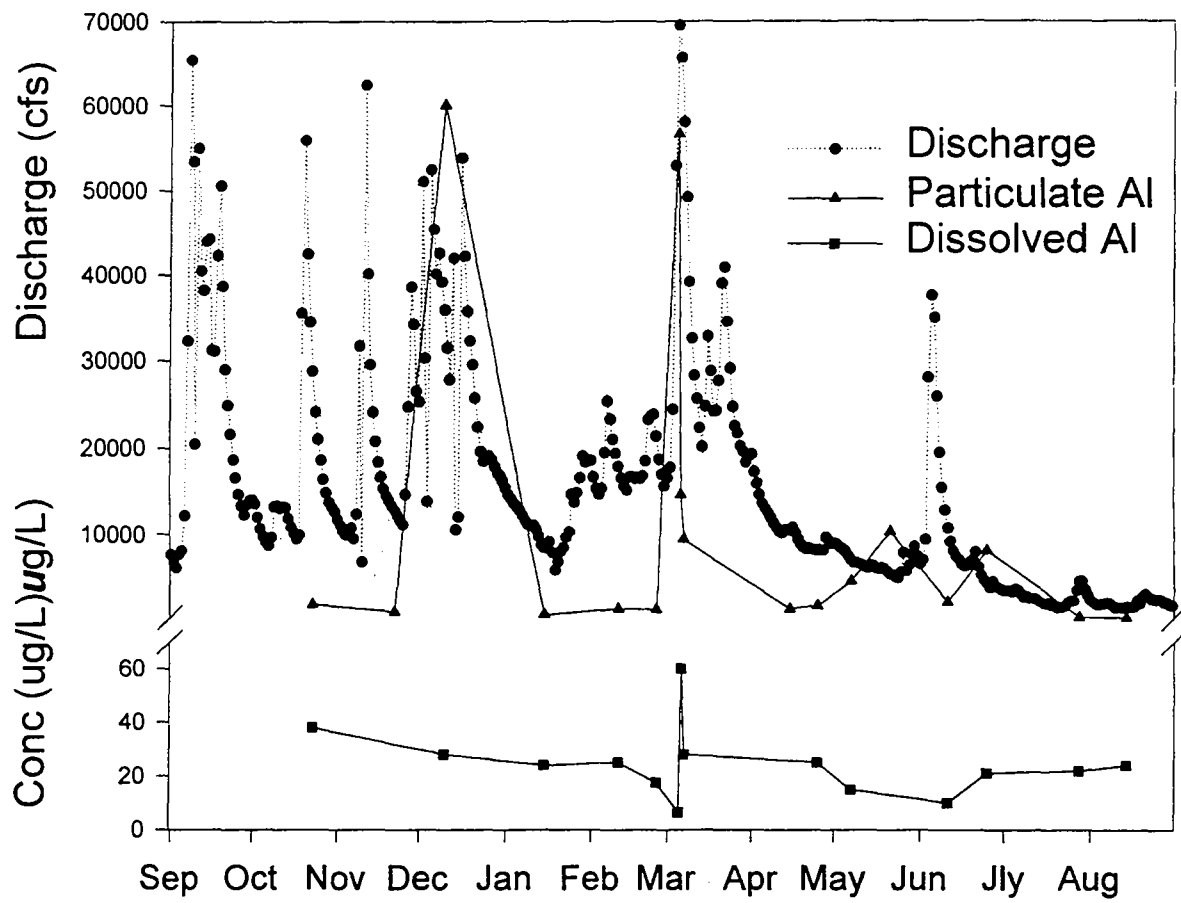


Figure 12a Concentrations of dissolved and particulate aluminum with annual discharge at the Potomac fall line.

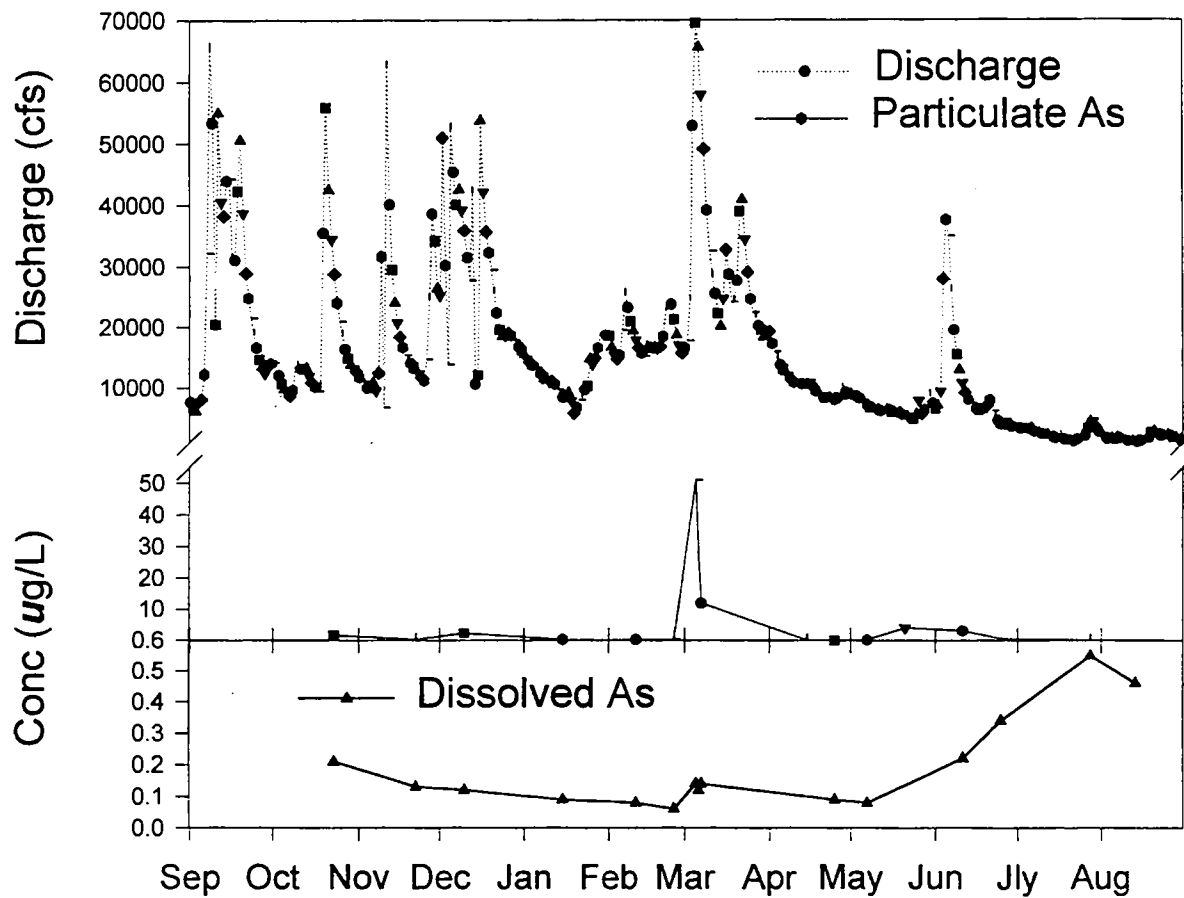


Figure 12b Concentrations of dissolved and particulate arsenic with annual discharge at the Potomac fall line.

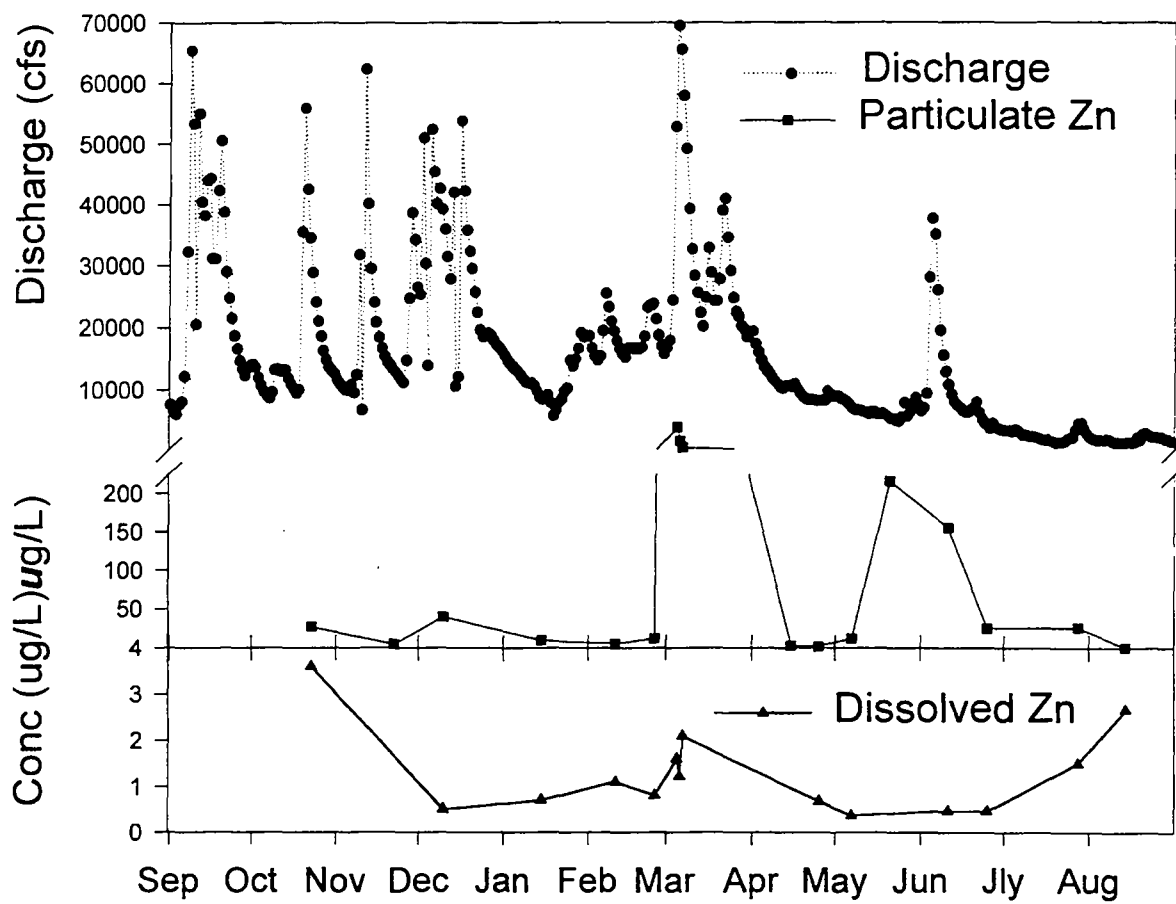


Figure 12c Concentrations of dissolved and particulate zinc with annual discharge at the Potomac fall line.

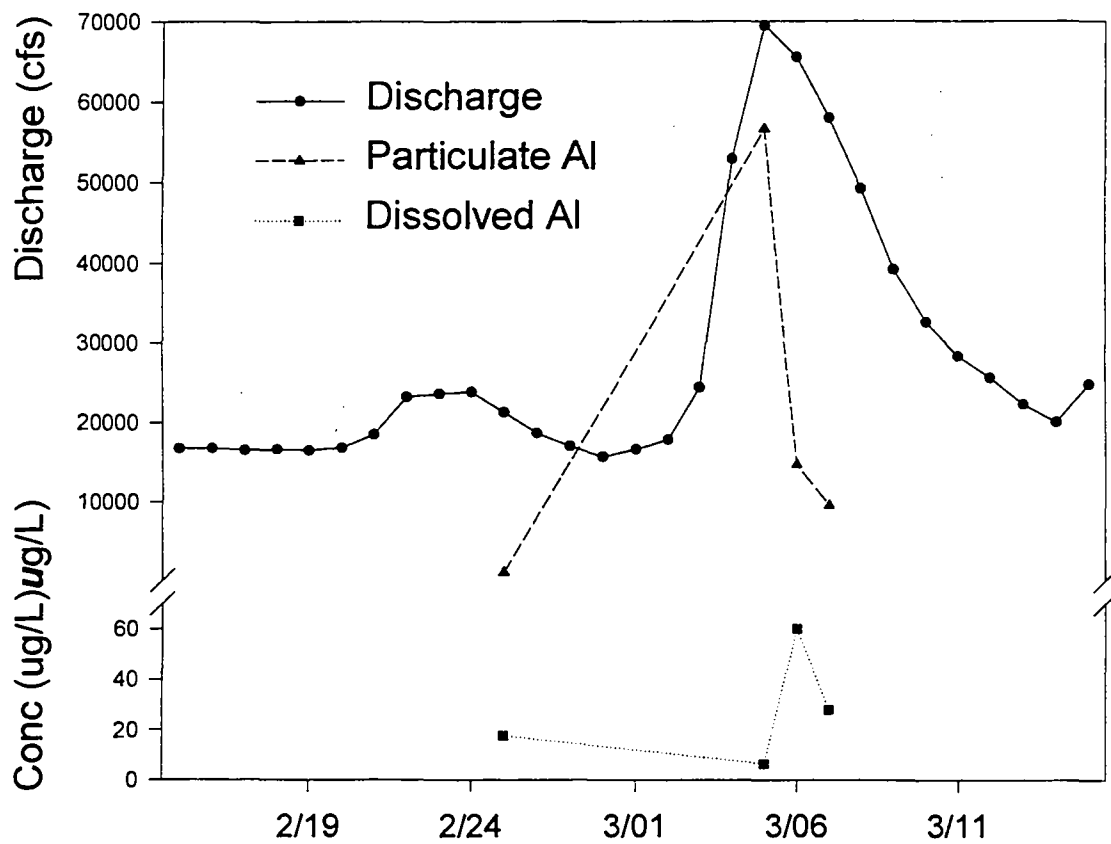


Figure 13a Concentrations of dissolved and particulate aluminum during peak discharge at the Potomac fall line.

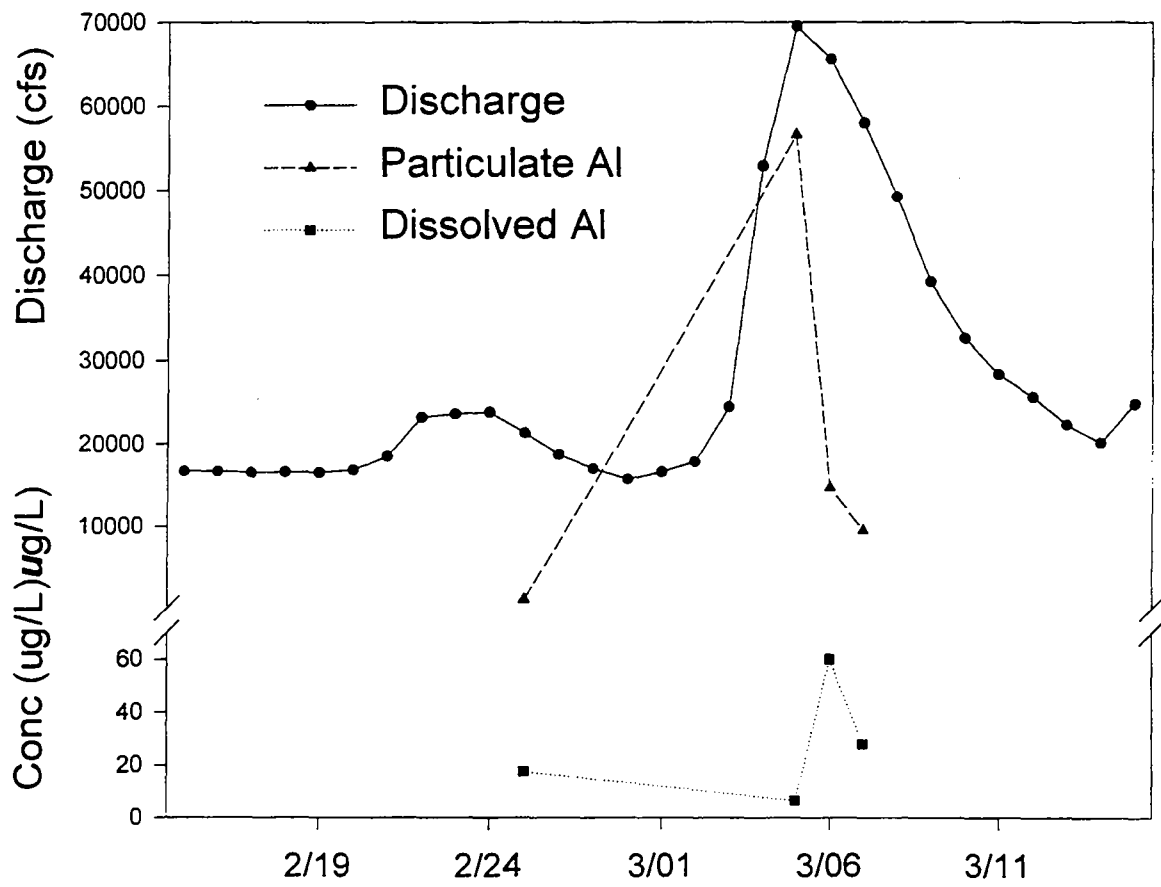


Figure 13b Concentrations of dissolved and particulate arsenic during peak discharge at the Potomac fall line.

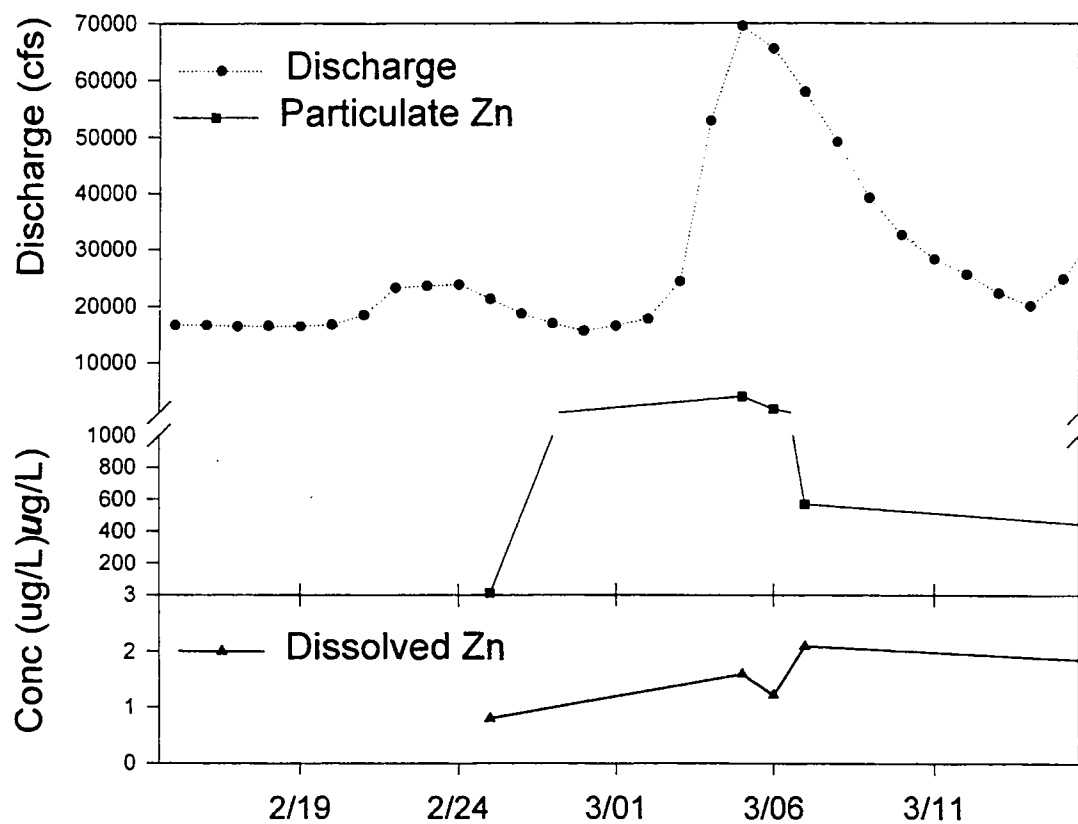


Figure 13c Concentrations of dissolved and particulate zinc during peak discharge at the Potomac fall line.



Figure 14 Percent dissolved and particulate trace metal distribution at the Potomac fall-line during the three days of peak flow corresponding to the storm intensive during Spring 1997.



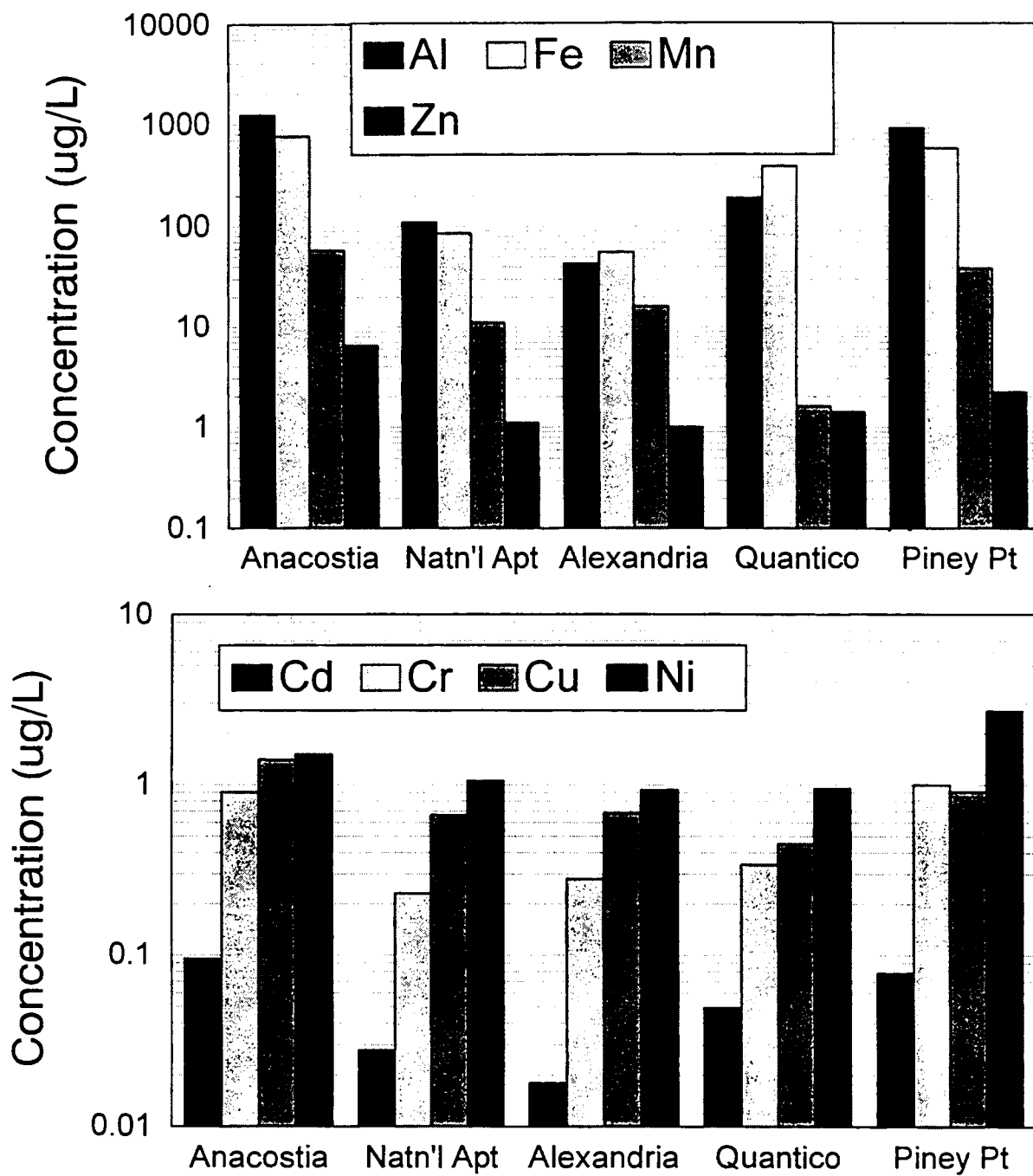


Figure 15a Comparison of total concentrations for tidal Potomac River during February 1997.

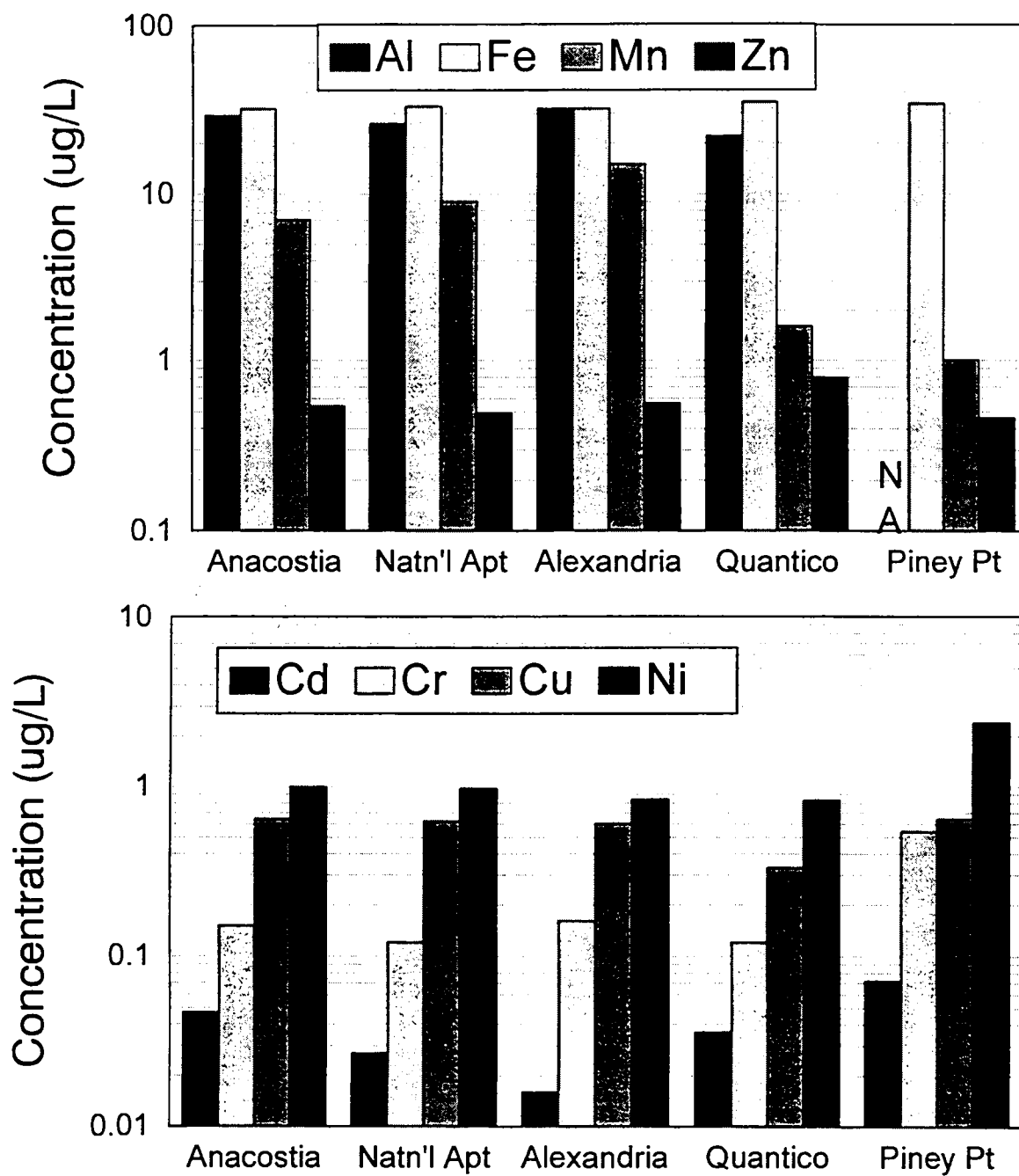


Figure 15b Comparison of dissolved concentrations for tidal Potomac river during February 1997.

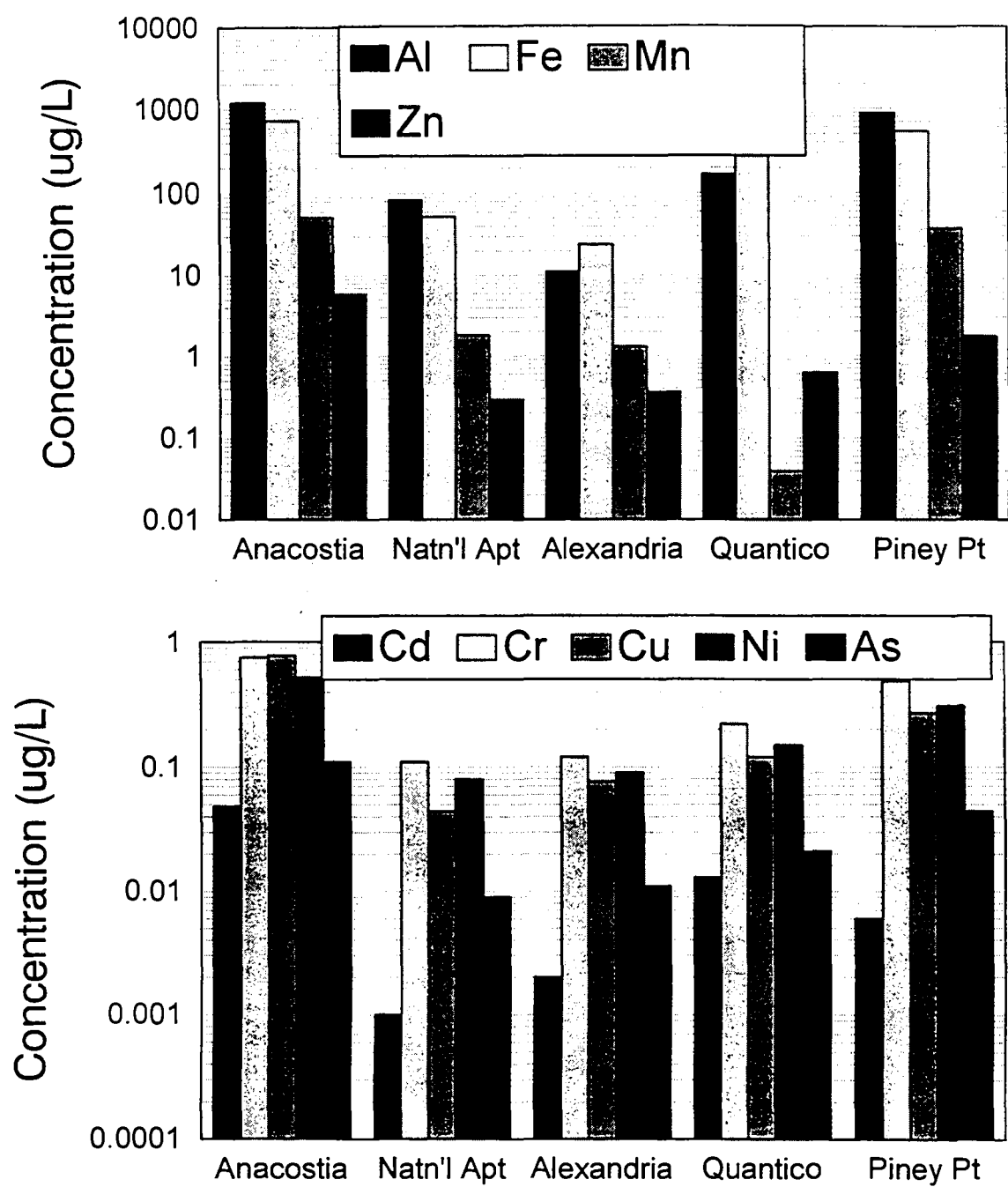


Figure 15c Comparison of particulate concentrations for tidal Potomac river during February 1997.

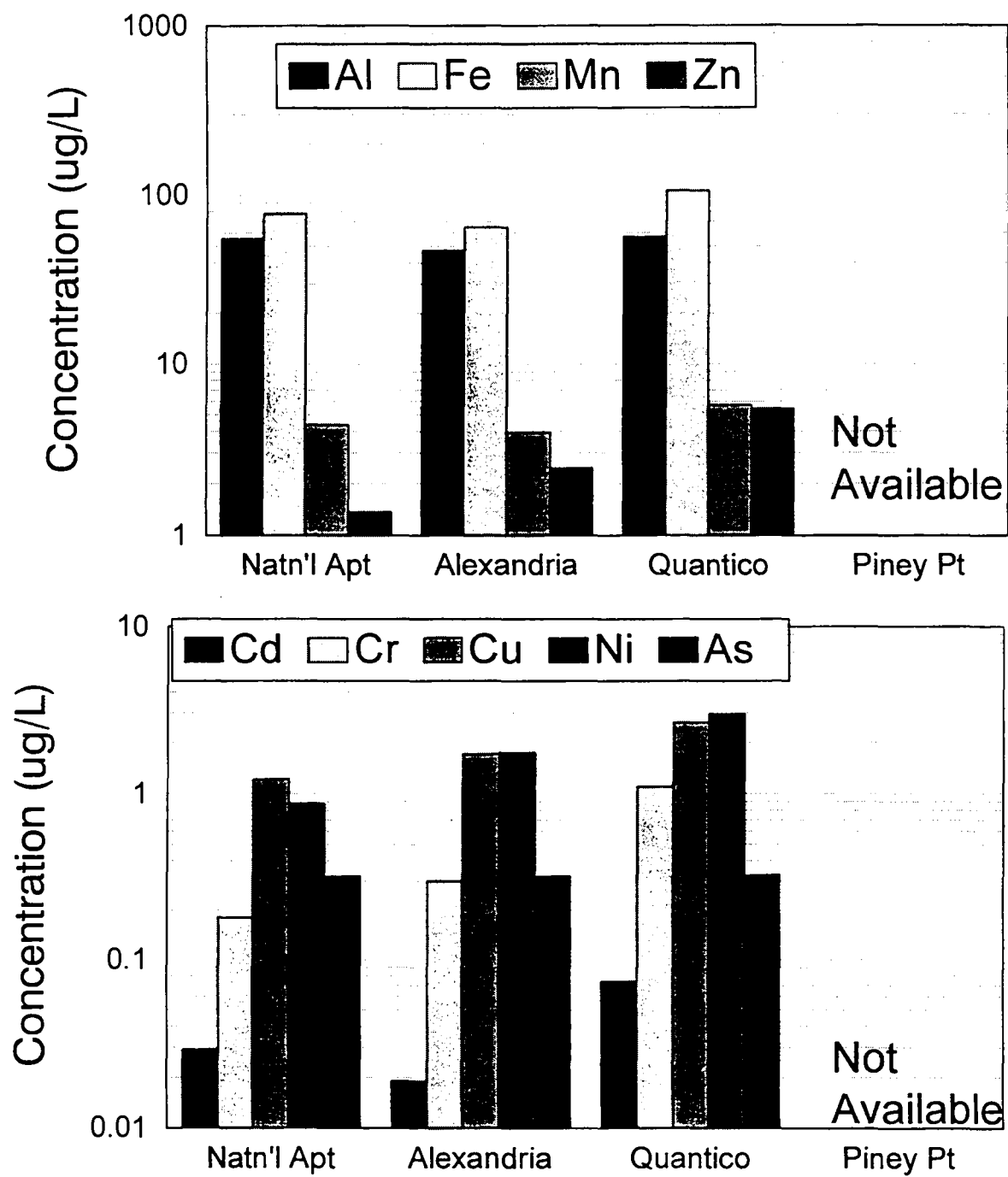


Figure 16a Comparison of total concentrations for tidal Potomac river during July 1997.

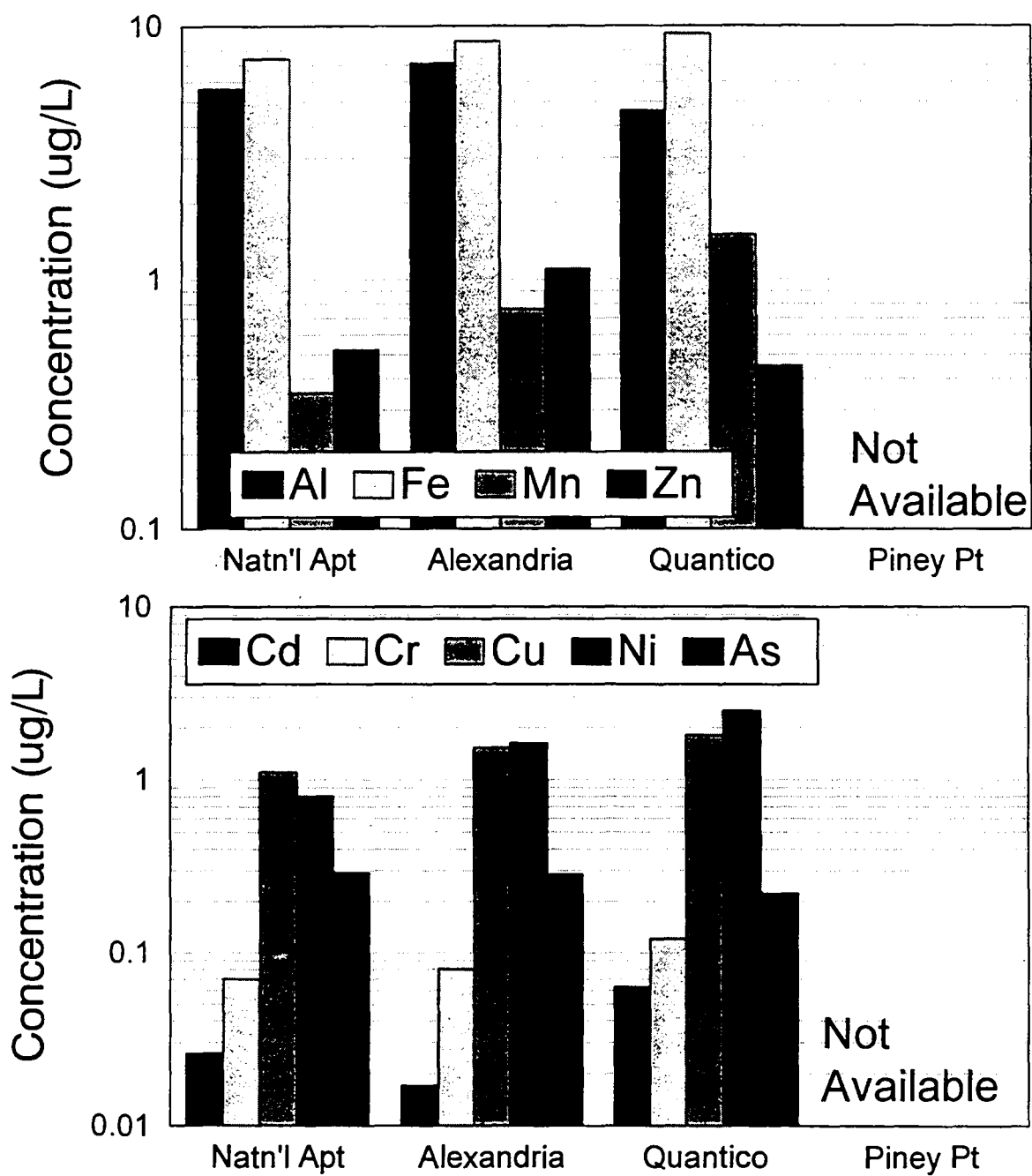


Figure 16b Comparison of dissolved concentrations for tidal Potomac river during July 1997.

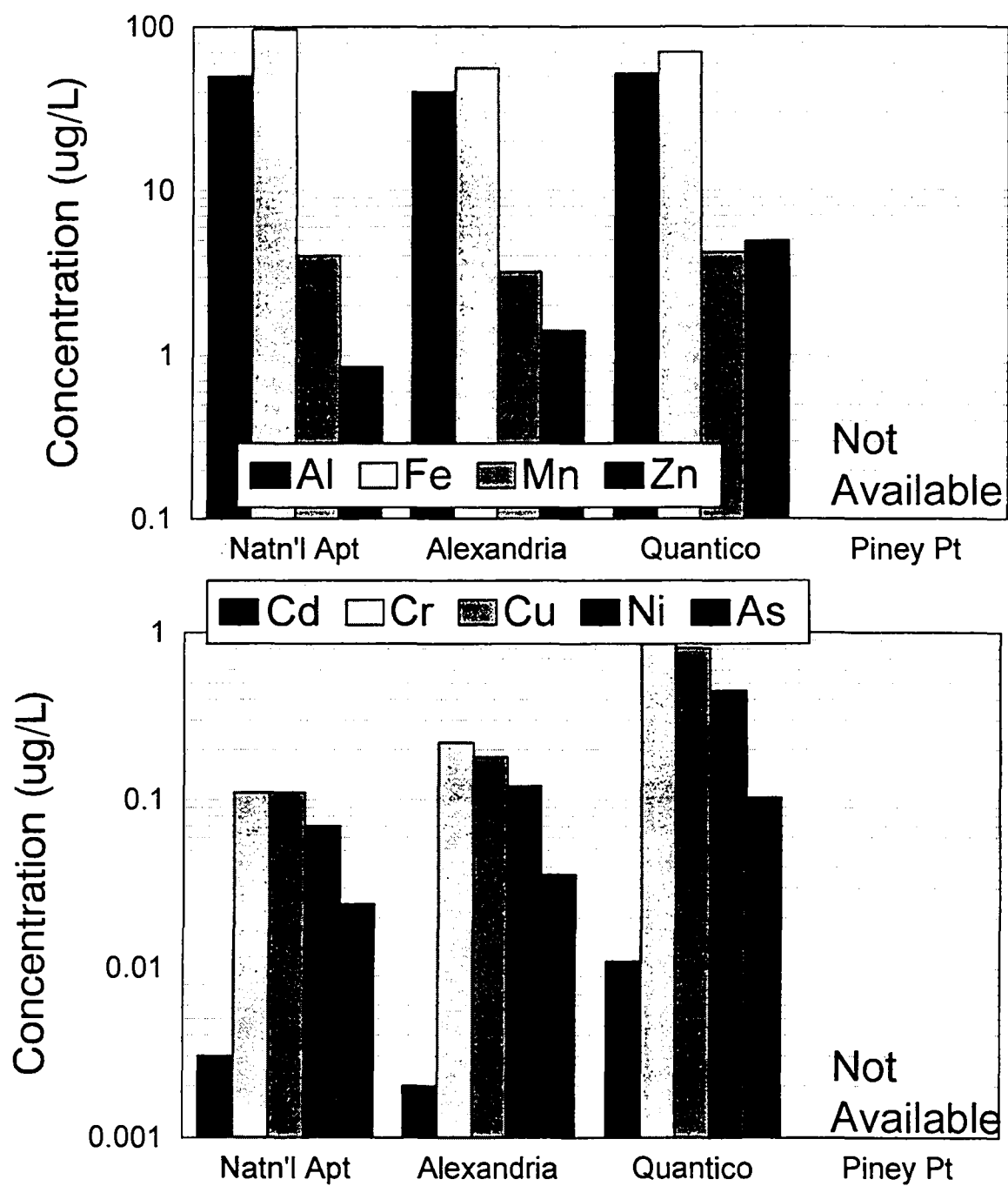


Figure 16c Comparison of particulate concentrations for tidal Potomac river during July 1997.

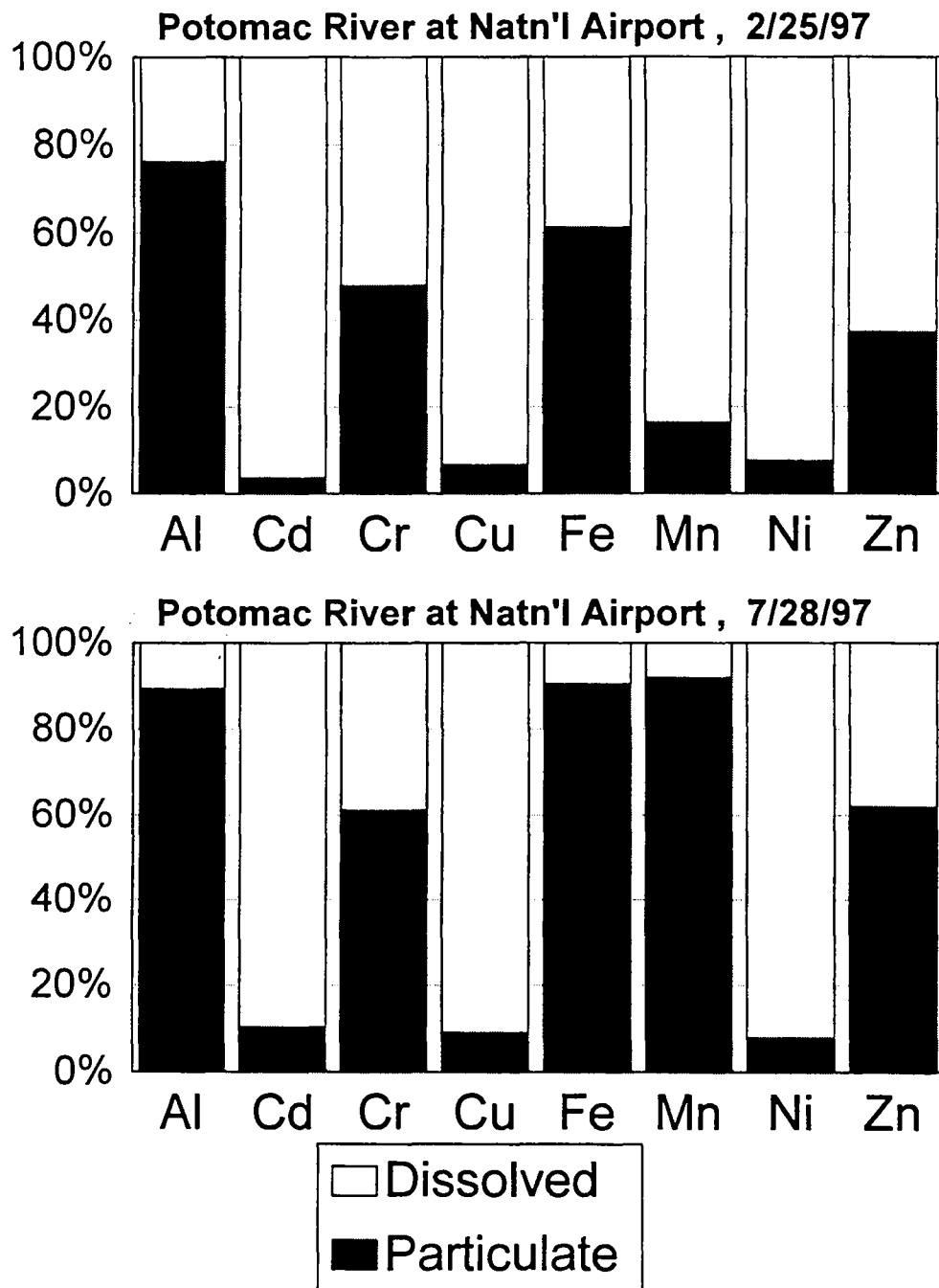


Figure 17a Percent average sample concentration in tidal Potomac river at National Airport during February and July 1997.

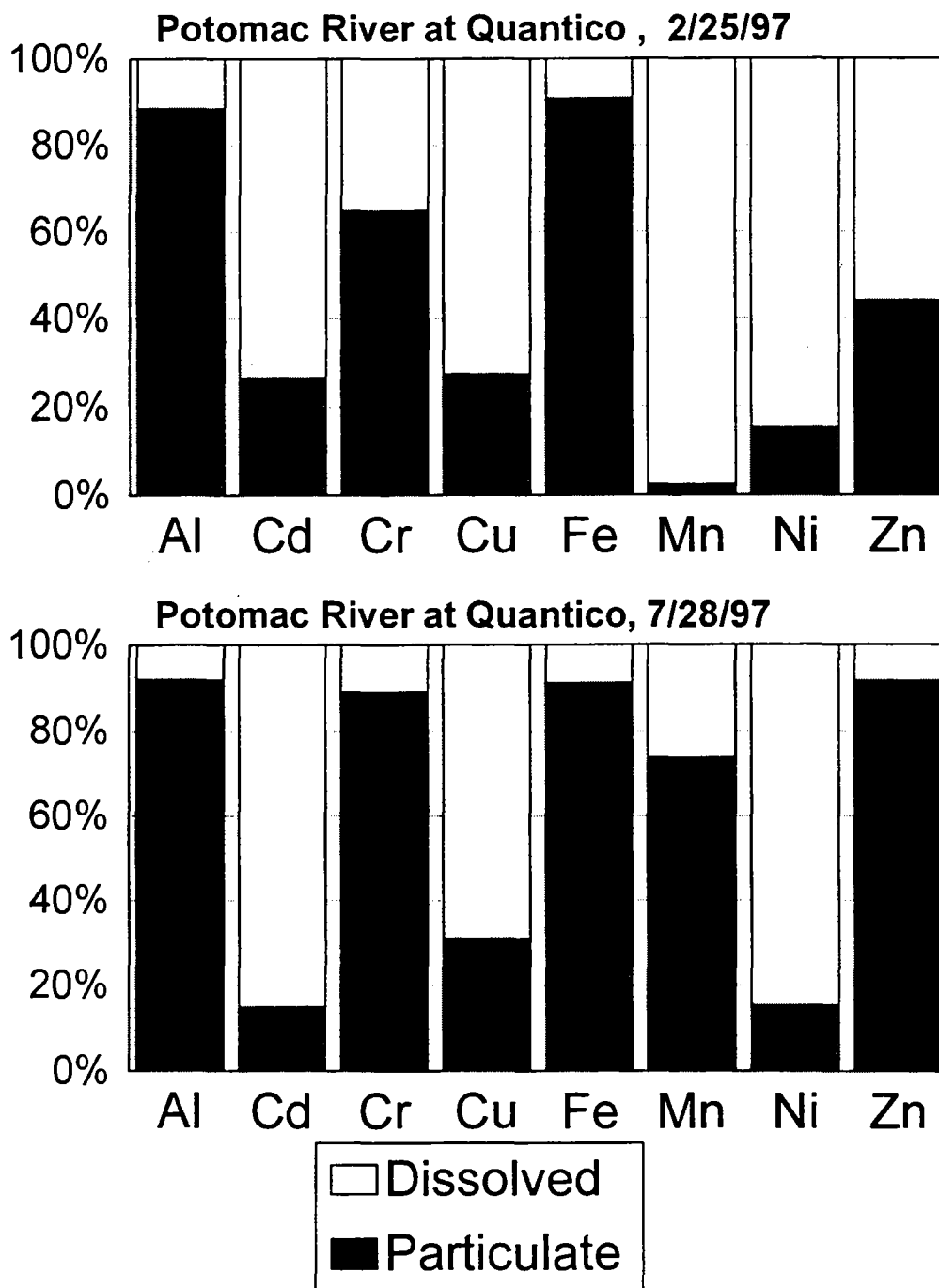


Figure 17b Percent average sample concentration in tidal Potomac river at Quantico during February and July 1997.



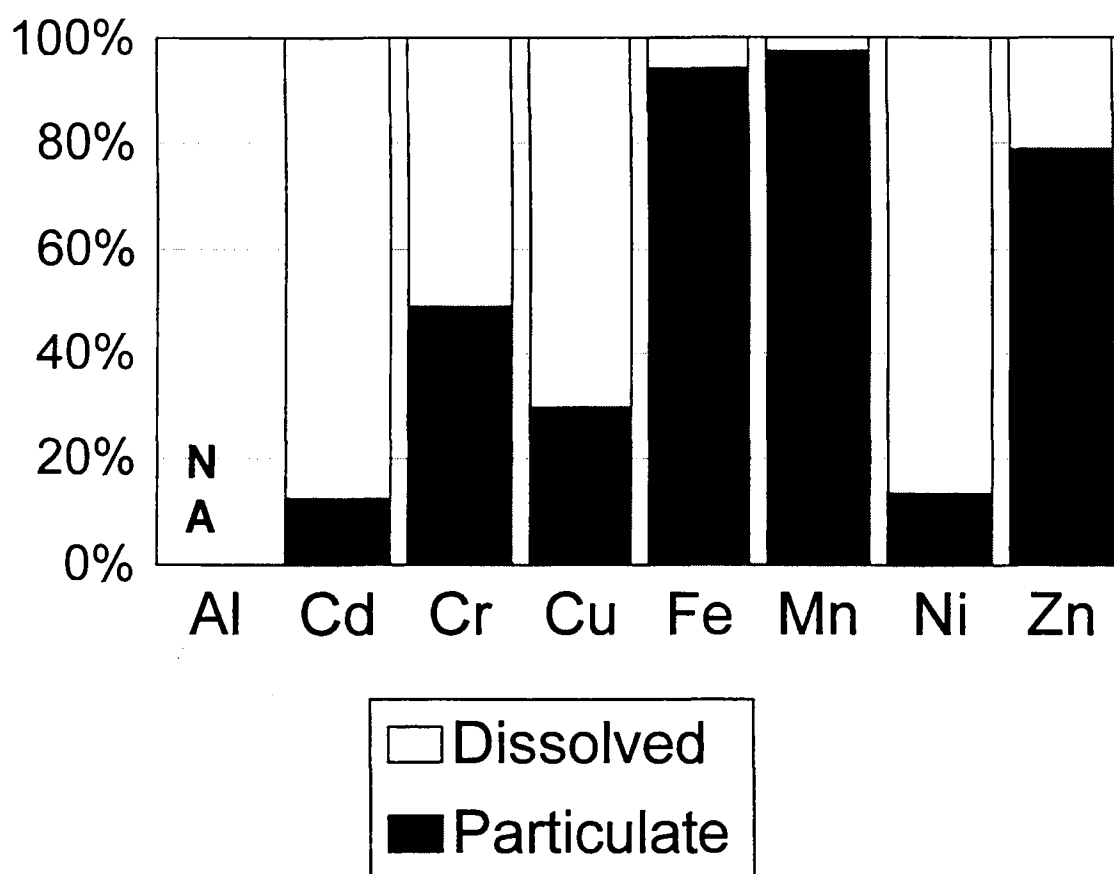


Figure 17c Percent average sample concentration in tidal Potomac river at Piney Point during February and July 1997.

Table 1a      Locations of sites included in the Headwater and Tributary Survey, noted as symbols in the Figures and USGS site identifications (numbers).

**Kzm - Kitzmiller, MD** (15955) north branch of the Potomac River. Samples were collected about 3/10 of a mile upstream from the gauging station on the left bank downstream from the bridge on State Highway 38.

**Cmb - Cumberland –Wiley Ford, MD** (1603) north branch of the Potomac River. Samples were collected from the bridge next to the gauging station at the approximate center-of-flow, on the downstream side of the Wiley-Ford Bridge 2.0 miles south of Cumberland.

**Spf - Springfield, WV** (16085) south branch of the Potomac River. Samples were collected 4/10 of a mile downstream from the bridge on State Highway 28, 2.0 miles east of Springfield.

**Paw - Paw-Paw, WV** (1610) main-stem of the Potomac River. Samples were collected about 250 feet upstream from the bridge on State Highway 51, 3.3 miles downstream from the Little Capon River.

**Hck - Hancock, MD** (1613) main-stem of the Potomac River. Samples were collected about 2/10 of a mile downstream from the bridge on highway 522, 1.2 miles upstream from Tonoloway Creek.

**Cac - Catoctin Creek** (1637) tributary of the Potomac River above the fall line. Samples were collected about 300 feet downstream from the bridge on State Route 17, 1.3 miles south of Middletown.

**Mon - Monacacy River** (1639) tributary of the Potomac River above the fall line. Samples were collected at Reich's Ford Bridge, 1.1 miles downstream from U.S. Route 40, 2.0 miles southeast of Frederick, MD.

**PoR - Point-of-Rocks, MD** (16385) main-stem of the Potomac River. Samples were collected on left bank at the downstream side of the bridge on U.S. Route 15.

**ChB - Chain Bridge, MD** (16465) routine fall line sampling site on the Potomac River. Samples were collected as integration of three samples near the center of flow

**RoC - Rock Creek, DC** (0164800) tributary of the Potomac River below the fall line. Samples were collected near the National Park headquarters.

Table 1b Tidal Potomac River sampling locations.

**Piney Pt**, at mouth of river into Chesapeake Bay. Samples collected near Piney Point, MD.

**Quantico**, samples collected near Quantico, Virginia ( $77^{\circ}16'$ ,  $38^{\circ}31'$ ).

**Alexandria**, samples taken near Alexandria, Virginia ( $77^{\circ}02'$ ,  $38^{\circ}46'$ ).

**National Airport**, samples taken near Regan National Airport, across the river from Geisboro Point, MD ( $77^{\circ}01'30''$   $38^{\circ}51'03''$ ).

**Anacostia**, samples were taken near the confluence of the Anacostia and Potomac Rivers ( $77^{\circ}01'01''$ ,  $38^{\circ}51'30''$ ).

Table 2 Trace elements, analytical techniques and detection limits (ug/l). Detection limits for particulate analyses (ug/l) are calculated assuming 0.1 mg dry weight particulate per 25 ml of sample.

Constituent	Method	Detection Limit
Al (Aluminum), particulate	AA,HGA	3.0
Al, dissolved	AA,HGA	0.12
As, (Arsenic), particulate	Hydride, AAS	0.1
As, dissolved	Hydride, AAS	0.007
Cd (Cadmium), particulate	AA,HGA	0.1
Cd, dissolved	AA,HGA	0.006
Cr (Chromium), particulate	AA,HGA	3.0
Cr, dissolved	AA,HGA	0.1
Cu (Copper), particulate	AA,HGA	3.0
Cu, dissolved	AA,HGA	0.12
Fe (Iron), particulate	AA,HGA	2.0
Fe, dissolved	AA,HGA	0.05
Hg (Mercury), particulate	CVAFS	0.05
Hg, dissolved	CVAFS	0.00002
Pb, (Lead), particulate	AA,HGA	3.0
Pb, dissolved	AA,HGA	0.12
Mn (Manganese), particulate	AA,HGA	3.0
Mn, dissolved	AA,HGA	0.10
Ni (Nickel), particulate	AA,HGA	3.0
Ni, dissolved	AA,HGA	0.12
Zn (Zinc), particulate	AA,HGA	3.0
Zn, dissolved	AA,HGA	0.14

Table 3      Project schedule.

Activity	Description and Dates
Fall 1996	Began Potomac River Basin sampling at the fall line
Spring 1997	First synoptic sampling of Potomac headwaters
Summer 1997	Second synoptic sampling of Potomac headwaters
Fall 1997	Completed sampling for Potomac River at the fall line
Spring 1998	Data submitted to CBP TLRI
April 1999	Preliminary report submitted for review
July 2000	Final report submitted to CBP

Table 4 Replicate analyses of (a) dissolved and (b) particulate trace metals in the Potomac River mainstem.

(a) Replicate analyses of dissolved trace metals in the Potomac River main stem												
		Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Se	Zn
Sample ID		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
10/23/96	Potomac A	30.6	0.154	0.180	0.13	1.00	63.8	2.85	0.98	<0.05	0.091	1.21
	Potomac B	28.3	0.163	0.027	0.18	0.81	53.4	2.42	0.96	<0.05	0.064	1.90
	Potomac C	24.0	0.130	ND	0.18	0.75	46.7	2.07	0.54	0.060	0.065	1.14
	Mean	27.7	0.149	0.069	0.16	0.85	54.6	2.45	0.83	ND	0.073	1.42
	Std Dev	2.73	0.014	ND	0.02	0.11	7.03	0.32	0.20	ND	0.012	0.34
01/15/97	Potomac A	27.8	0.104	0.100	0.20	0.62	34.2	10.3	0.84	<0.05	0.075	0.81
	Potomac B	20.2	0.081	ND	0.19	0.60	27.8	10.4	0.61	<0.05	0.103	0.62
	Mean	24.0	0.093	ND	0.20	0.61	31.0	10.3	0.73	0.000	0.089	0.72
03/05/97	Potomac A	5.06	0.135	0.548	0.10	1.45	6.06	3.15	1.7	<0.05	0.102	1.68
	Potomac B	6.43	0.158	0.275	0.10	1.39	5.53	2.73	1.4	<0.05	0.098	1.65
	Mean	5.75	0.147	0.412	0.10	1.42	5.80	2.94	1.6	ND	0.100	1.67
05/18/97	Paw-Paw A										0.089	ND
	Paw-Paw B	2.67	0.089	0.004	0.06	0.53	5.20	24.8	1.6	<0.05	0.058	0.42
	Paw-Paw C	4.00	0.071	0.023	0.09	0.61	4.87	22.7	1.5	<0.05	0.063	0.35
	Mean	3.34	0.080	0.014	0.08	0.57	5.04	23.7	1.5	ND	0.061	0.39
	Std Dev	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.014	ND
05/18/97	Springfield A	3.35	0.101	0.044	0.06	0.50	5.81	5.28	0.85	<0.05	0.063	0.69
	Springfield B	3.14	0.098	0.127	0.06	0.55	5.97	5.51	0.93	<0.05	0.044	0.72
	Springfield C	2.74	0.106	0.028	0.06	0.47	5.14	4.79	0.73	<0.05	0.054	0.40
	Mean	3.08	0.102	0.066	0.06	0.51	5.64	5.19	0.84	ND	0.054	0.60
	Std Dev	0.25	0.003	0.043	0.00	0.03	0.36	0.30	0.08	ND	0.008	0.14
ND = Not Determined												
(b) Replicate analyses of particulate trace metals in the Potomac River main stem												
		Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	
Sample ID		ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	
10/23/96	Potomac A	123	0.092	3.03	4.3	4.9	0.7	25.1	1.42	3	2.56	
10/23/96	Potomac B	122	0.086	2.45	3.3	3.9	5.5	18.9	1.08	7	3.50	
10/23/96	Potomac C	121	0.076	1.73	3.3	2.5	0.2	17.7	0.64	5	0.50	
	Mean	122	0.085	2.40	3.6	3.7	2.1	21	1.0	5.1	2.19	
	St Dev	0.8	0.007	0.53	0.5	1.0	2.4	3	0.3	1.3	1.25	
05/18/97	Paw Paw A	3.0	0.0003	0.0001	0.003	0.002	2.9	0.12	0.004	0.000	0.017	
05/18/97	Paw Paw B	ND	0.0004	0.0001	0.004	0.002	ND	ND	0.005	0.001	0.014	
05/18/97	Paw Paw C	5.1	0.0003	0.0001	0.002	0.002	4.1	0.17	0.001	0.001	0.012	
	Mean	2.7	0.0003	0.0001	0.003	0.002	2.3	0.10	0.003	0.001	0.014	
	St Dev	2.1	0	0	0.001	0.000	1.7	0.07	0.002	0	0.002	
	Cumberland A											
		* Sample was lost when bottle cracked.										
08/03/97	Cumberland B	1.5	0.0007	0.003	0.003	0.003	1.6	0.67	0.003	0.001	0.038	
08/03/97	Cumberland C	1.6	0.0002	0.001	0.002	0.001	1.7	0.24	0.001	0.000	0.012	
	Mean	1.5	0.0004	0.002	0.002	0.002	1.6	0.45	0.002	0.001	0.025	
	St. Dev	0.05	0.0002	0.001	0.001	0.001	0	0.22	0.001	0	0.013	
ND = Not Determined												

**Table 5 Total (dissolved plus particulate) metal concentrations at the Potomac River fall line for the sixteen routine samplings.**

Date		Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Se**	Zn
		(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
10/23/96	COF	1730	1.7	0.08	7.0	8.7	1300	800	2.0	4.4	0.09	28.0
10/23/96	grab a	560	0.80	0.10	2.7	4.1	520	2260	1.2	1.7	0.06	19.6
10/23/96	grab b	6620	1.2	0.09	4.1	4.1	3540	26	6.0	2.5	0.07	20.0
10/23/96	grab c	3500	1.6	0.27	5.0	5.3	2620	900	1.7	3.0	0.09	26.3
10/23/96	X sec	38	0.21	0.01	0.12	0.89	41	2	0.9	ND	0.10	3.7
11/22/96		780	0.44	0.06	1.8	1.3	600	240	1.1	0.71	0.07	4.6
12/10/96		60000	2.4	0.16	6.9	11	36000	3100	4.1	5.3	0.09	40.2
01/15/97		510	0.51	0.16	4.4	3.4	1280	93	4.7	1.4	0.18	10.7
02/11/97		1200	0.25	0.06	1.7	1.8	810	150	3.4	0.44	0.08	6.3
02/25/97		1070	0.38	0.46	3.4	3.2	2160	36	4.7	1.2	0.08	12.4
03/05/97		56600	51	23	1300	490	28200	6000	670	380	ND	3900
03/06/97		14700	28	320	340	150	15700	780	210	170	ND	1730
03/07/97		9500	12	1.31	130	55	4890	41	77	34	0.07	570
04/15/97		1160	0.08	0.44	1.0	0.40	870	30	1.1	0.14	ND	2.9
04/25/97		1570	0.10	0.34	0.92	1.2	1400	49	0.9	0.09	0.07	2.5
05/07/97		4550	0.28	0.32	6.1	3.6	3480	130	3.5	1.3	0.11	12.4
05/21/97		10400	4.1	1.45	47	42	5860	59	68	15	0.14	220
06/11/97		1980	3.3	1.30	20	22	1330	97	26	20	0.05	160
06/25/97		8180	0.91	0.12	6.6	5.3	7200	72	4.8	1.7	0.12	25.3
07/28/97		240	0.69	0.07	4.5	3.7	410	58	5.3	2.1	0.15	27.7
08/14/97		25	0.46	0.04	0.12	1.8	15	2.6	1.2	>0.05	0.15	2.7
	std	16544	12	68	281	106	9329	1419	146	86	0.05	883
ND= Not Determined												
*Missing the particulate data for this sample.							** Se is dissolved only -no particulate data					

**Table 6      Total (dissolved plus particulate) metal loading at the Potomac River fall line and downstream at Rock Creek.**

	<b>kg/Year</b>					
	<b>Dissolved</b>		<b>Particulate</b>		<b>Total</b>	
	<b>Potomac</b>	<b>Rock Creek</b>	<b>Potomac</b>	<b>Rock Creek</b>	<b>Potomac</b>	<b>Rock Creek</b>
<b>Al</b>	<b>16000</b>	<b>1300</b>	<b>2570000</b>	<b>2000</b>	<b>2600000</b>	<b>3300</b>
<b>As</b>	<b>220</b>	<b>NR</b>	<b>880</b>	<b>NR</b>	<b>1100</b>	<b>NR</b>
<b>Cd</b>	<b>70</b>	<b>10</b>	<b>1800</b>	<b>&lt;5</b>	<b>1800</b>	<b>10</b>
<b>Cr</b>	<b>120</b>	<b>10</b>	<b>13000</b>	<b>6</b>	<b>13000</b>	<b>20</b>
<b>Cu</b>	<b>1000</b>	<b>110</b>	<b>7100</b>	<b>7</b>	<b>8200</b>	<b>120</b>
<b>Fe</b>	<b>13000</b>	<b>9000</b>	<b>1750000</b>	<b>1400</b>	<b>1800000</b>	<b>10000</b>
<b>Mn</b>	<b>2200</b>	<b>4500</b>	<b>110000</b>	<b>160</b>	<b>110000</b>	<b>4700</b>
<b>Ni</b>	<b>810</b>	<b>140</b>	<b>10000</b>	<b>&lt;5</b>	<b>11000</b>	<b>140</b>
<b>Pb</b>	<b>&lt;5</b>	<b>&lt;5</b>	<b>5000</b>	<b>&lt;5</b>	<b>5000</b>	<b>&lt;5</b>
<b>Se</b>	<b>80</b>	<b>NR</b>	<b>NR</b>	<b>NR</b>	<b>80*</b>	<b>NR</b>
<b>Zn</b>	<b>1100</b>	<b>140</b>	<b>51000</b>	<b>30</b>	<b>52000</b>	<b>170</b>

**NR = Not Reported**

**\*Based on dissolved only**



**Table 7** Total (dissolved plus a particulate) metal concentrations at the head water and tributary sites on the Potomac River shown in Fig. 1, with the site symbols listed in Table 2.

	Date	Discharge	Watershed	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Se**	Zn
Locations*		cfs	sq miles	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Kitzmiller	05/18/97	NA	225	8.6	0.008	0.05	0.01	0.59	0.5	120	6.8	0.0004	0.17	6.7
Kitzmiller	08/03/97	NA	225	59	0.006	0.4	0.06	0.42	5.0	73	5.4	0.3	0.16	3.2
Springfield	05/18/97	938	1486	9.0	0.10	0.07	0.06	0.51	11	5.4	0.84	0.0007	0.05	0.61
Springfield	08/03/97	207	1486	5.7	0.31	0.3	0.11	0.63	5.9	5.2	0.82	0.004	0.06	0.28
Cumberland	05/18/97	976	875	12	0.19	0.04	0.27	0.61	27	140	6.3	0.002	0.19	1.9
Cumberland	08/03/97	336	875	62	0.29	0.4	0.24	0.82	34	40	3.1	0.09	ND	1.0
Paw Paw	05/18/97	2060	3109	7.3	0.080	0.01	0.08	0.57	8.5	24	1.5	0.001	0.06	0.40
Paw Paw	08/03/97	636	3109	17	0.28	0.04	0.09	0.72	16	5.5	1.8	0.0005	0.11	1.3
Hancock	05/18/97	2510	4073	3.0	0.066	0.06	0.08	0.62	7.5	1.5	1.9	0.0002	0.09	0.62
Hancock	08/03/97	747	4073	72	0.32	1.4	0.14	1.0	54	3.5	1.6	0.02	0.09	0.76
Catocin	05/21/97	29	67	25	0.030	0.05	0.13	1.0	19	26	0.79	0.002	0.08	0.38
Catocin	07/28/97	7	67	8.7	0.15	0.02	0.04	1.4	31	3.3	0.45	0.001	0.08	0.28
Monocacy	05/21/97	32	817	4.5	0.096	0.04	0.08	0.93	11	7.9	0.63	0.003	0.09	1.2
Monocacy	07/28/97	14	817	92	0.50	0.05	0.07	2.0	67	9.1	0.95	0.02	0.17	2.2
Point of Rocks	05/21/97	5030	9651	20	0.005	0.003	0.11	0.09	18	1.6	0.08	0.04	0.07	0.44
Point of Rocks	07/28/97	4850	9651	12	0.25	0.03	0.06	0.70	17	4.6	0.52	0.001	0.05	0.66
Chain Bridge	05/21/97	5360	11570	1040	0.41	0.14	4.7	4.2	590	59	6.8	1.5	0.14	22
Chain Bridge	07/28/97	4500	11570	240	0.69	0.07	4.5	3.7	410	58	5.3	2.1	0.15	28
*The site locations are listed on Table 2.													**Se is dissolved only	

**Table 8 Total (dissolved plus particulate) metal loadings at the head water and tributary sites on the Potomac River.**

Location	Date	Discharge cfs	Watershed sq miles	Al kg/day	As kg/day	Cd kg/day	Cr kg/day	Cu kg/day	Fe kg/day	Mn kg/day	Ni kg/day	Pb kg/day	Se* kg/day	Zn kg/day
Springfield	05/18/97	938	1486	21	0.23	0.15	0.15	1.2	24	12	1.9	0.002	0.12	1.4
Springfield	08/09/97	207	1486	2.9	0.16	0.17	0.054	0.3	3.0	2.6	0.4	0.002	0.03	0.14
Cumberland	05/18/97	976	875	29	0.46	0.1	0.66	1.5	65	340	15	0.005	0.44	4.5
Cumberland	08/09/97	336	875	51	0.24	0.3	0.20	0.7	28	33	2.5	0.08	< 0.001	0.83
Paw Paw	05/18/97	2060	3109	37	0.41	0.07	0.40	2.9	43	120	7.7	0.005	0.31	2.0
Paw Paw	08/09/97	636	3109	27	0.44	0.07	0.14	1.1	24	8.6	2.8	0.001	0.18	2.1
Hancock	05/18/97	2510	4073	19	0.41	0.34	0.50	3.8	46	9.2	12	0.001	0.53	3.8
Hancock	08/09/97	747	4073	130	0.59	2.6	0.25	1.9	99	6.3	2.9	0.04	0.16	1.4
Catocin	05/21/97	29	67	1.8	0.002	0.004	0.009	0.07	1.3	1.8	0.06	< 0.001	0.005	0.03
Catocin	07/28/97	7	67	0.1	0.003	< 0.001	0.001	0.02	0.5	0.06	0.01	< 0.001	0.001	<0.01
Monocacy	05/21/97	32	817	0.4	0.008	0.003	0.007	0.07	0.8	0.6	0.05	< 0.001	0.007	0.09
Monocacy	07/28/97	14	817	3.2	0.02	0.002	0.003	0.07	2.3	0.3	0.03	0.001	0.006	0.08
Point of Rocks	05/21/97	5030	9651	240	0.1	0.04	1.4	1.1	220	20	1.0	0.44	0.89	5.4
Point of Rocks	07/28/97	4850	9651	140	2.9	0.33	0.8	8.3	210	54	6.2	0.01	0.56	7.9
Chain Bridge	05/21/97	5360	11570	13600	5.4	1.8	62	55	7700	770	90	19	1.8	280
Chain Bridge	07/28/97	4500	11570	2600	7.6	0.8	49	40	4500	640	58	23	1.7	300
Rock Creek	05/07/97	46	62	16	NR	0.01	0.01	0.2	25	3.2	0.2	< 0.001	NR	0.07
Rock Creek	07/28/97	27	62	0.35	NR	< 0.001	0.01	0.15	3.0	3.6	0.1	< 0.001	NR	0.07

\*Se loads based on dissolved only

**Table 9 Total (dissolved plus particulate) metal basin yields at the head water and tributary sites on the Potomac River.**

Location	Date	Discharge cfs	Watershed sq miles	Al g/day/sq mi	As g/day/sq mi	Cd g/day/sq mi	Cr g/day/sq mi	Cu g/day/sq mi	Fe g/day/sq mi	Mn g/day/sq mi	Ni g/day/sq mi	Pb g/day/sq mi	Se* g/day/sq mi	Zn g/day/sq mi
Springfield	05/18/97	938	1486	14	0.16	0.10	0.10	0.79	16	8.3	1.3	0.001	0.08	0.95
Springfield	08/09/97	207	1486	19	0.1	0.12	0.04	0.21	2.0	1.8	0.28	0.001	0.02	0.10
Cumberland	05/18/97	976	875	33	0.53	0.11	0.75	1.7	74	340	17	0.06	0.51	5.1
Cumberland	08/09/97	336	875	58	0.27	0.35	0.23	0.77	32	37	2.9	0.09	< 0.001	0.95
Paw Paw	05/18/97	2060	3109	12	0.13	0.02	0.13	0.93	14	39	2.5	0.002	0.10	0.65
Paw Paw	08/09/97	636	3109	8.7	0.14	0.02	0.05	0.36	7.8	2.8	0.9	< 0.001	0.06	0.67
Hancock	05/18/97	2510	4073	4.6	0.10	0.08	0.12	0.94	11	2.2	2.9	< 0.001	0.13	0.93
Hancock	08/09/97	747	4073	32	0.14	0.64	0.06	0.46	24	1.6	0.71	0.01	0.04	0.34
Catocin	05/21/97	29	67	26	0.32	0.06	0.14	1.1	20	28	0.83	< 0.001	0.08	0.40
Catocin	07/28/97	7	67	22	0.39	< 0.001	0.01	0.36	7.8	0.84	0.12	< 0.001	0.02	<0.01
Monocacy	05/21/97	32	817	0.4	0.01	0.004	0.008	0.09	1.0	0.76	0.06	< 0.001	0.008	0.11
Monocacy	07/28/97	14	817	3.9	0.02	0.002	0.003	0.09	2.8	0.38	0.04	0.001	0.007	0.09
Point of Rocks	05/21/97	5030	9651	25	0.01	0.004	0.14	0.12	23	2.1	0.1	0.05	0.09	0.56
Point of Rocks	07/28/97	4850	9651	14	0.30	0.03	0.08	0.87	22	5.6	0.64	0.001	0.06	0.82
Chain Bridge	05/21/97	5360	11570	1200	0.46	0.16	5.3	4.8	660	66	7.7	1.7	0.06	24
Chain Bridge	07/28/97	4500	11570	22	0.66	0.07	4.3	3.5	390	55	5.0	2.0	0.14	26
Rock Creek	05/07/97	46	62	260	NR	< 0.001	< 0.001	0.003	0.40	0.05	0.003	< 0.001	NR	0.01
Rock Creek	07/28/97	27	62	6.0	NR	< 0.001	< 0.001	0.002	0.05	0.06	0.002	< 0.001	NR	0.01

**Table A-1 Comparison of trace metal concentrations with EPA standard reference materials; (1) natural river water standard water SLRS-3; (2) natural river sediment standard (BCSS-1).**

	<i>Al</i>	<i>Cd</i>	<i>Fe</i>	<i>Cr</i>	<i>Cu</i>	<i>Ni</i>	<i>Mn</i>	<i>Zn</i>	<i>Pb</i>
<i>EPA Std.</i>	<b>14.5</b>	<b>0.725</b>	<b>2.90</b>	<b>2.90</b>	<b>2.90</b>	<b>2.90</b>	<b>2.90</b>	<b>2.90</b>	<b>2.90</b>
<i>Lab</i>	<b>14.5</b>	<b>0.773</b>	<b>3.06</b>	<b>3.11</b>	<b>2.82</b>	<b>3.00</b>	<b>2.77</b>	<b>2.81</b>	<b>2.95</b>
	<b>14.3</b>	<b>0.729</b>	<b>3.23</b>	<b>3.00</b>	<b>2.78</b>	<b>2.90</b>	<b>3.04</b>	<b>2.88</b>	<b>2.82</b>
	<b>14.9</b>	<b>0.732</b>	<b>3.37</b>	<b>2.82</b>	<b>3.23</b>	<b>3.22</b>	<b>2.92</b>	<b>2.94</b>	<b>2.84</b>
	<b>15.1</b>	<b>0.741</b>	<b>3.00</b>	<b>3.02</b>	<b>2.95</b>	<b>3.00</b>	<b>2.95</b>	<b>2.90</b>	<b>2.96</b>
<i>Average</i>	<b>14.7</b>	<b>0.744</b>	<b>3.20</b>	<b>3.00</b>	<b>2.90</b>	<b>3.00</b>	<b>2.90</b>	<b>2.90</b>	<b>2.90</b>
<i>S.D.</i>	<b>0.4</b>	<b>0.02</b>	<b>0.20</b>	<b>0.10</b>	<b>0.20</b>	<b>0.14</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>

**Table A-2 Primary metal concentration data for (a) dissolved and (b) particulate fractions at the Potomac River fall line samples.**

(a) Dissolved Concentrations											
Date	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Se	Zn
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
10/23/96	38	0.21	0.014	0.12	0.89	41	2.2	0.90	0.02	0.099	3.6
11/22/96	ND	0.13	ND	ND	ND	ND	ND	ND	ND	0.067	ND
12/10/96	28	0.12	0.011	0.15	0.64	21	6.5	0.70	<0.01	0.088	0.47
01/15/97	24	0.09	0.100	0.20	0.61	30	10	0.70	<0.01	0.080	0.70
02/11/97	25	0.08	0.044	0.17	0.69	30	7.0	1.2	<0.01	0.077	1.1
02/25/97	18	0.06	0.340	0.13	0.62	21	5.5	1.0	<0.01	0.076	0.80
03/05/97	6.5	0.14	0.350	0.10	1.4	6.0	3.0	1.7	<0.01	0.10	1.6
03/06/97	60	0.12	0.410	0.10	1.5	43	2.1	0.51	<0.01	0.082	1.2
03/07/97	28	0.14	0.300	0.12	1.8	22	2.4	1.4	<0.01	0.074	2.1
04/25/97	25	0.09	0.268	0.12	0.94	36	4.5	0.74	<0.01	0.067	0.68
05/07/97	15	0.08	0.058	0.18	1.2	18	1.8	1.3	0.02	0.11	0.37
06/11/97	10	0.22	0.077	0.10	0.83	10	1.9	0.61	<0.01	0.047	0.47
06/25/97	21	0.34	0.027	0.13	1.4	10	1.6	1.0	<0.01	0.12	0.46
07/28/97	22	0.55	0.015	0.40	2.1	17	3.1	1.8	<0.01	0.15	1.5
08/14/97	24	0.46	0.042	0.12	1.8	14	2.2	1.2	<0.01	0.15	2.7

(b) Particulate Concentrations											
Date	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Se	Zn
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
10/23/96c-o-f	1700	1.6	0.080	6.8	7.7	1260	800	1.3	4.4	ND	27
10/23/96grab c	3500	1.4	0.092	4.9	4.3	2560	890	0.7	3.0	ND	25
10/23/96grab b	6600	1.1	0.086	3.9	3.3	3500	24	5.5	2.4	ND	19
10/23/96grab a	530	0.64	0.076	2.5	3.3	470	2260	0.2	1.7	ND	18
11/22/96	780	0.31	0.057	1.8	1.3	600	240	1.1	0.71	ND	4.6
12/10/96	60000	2.3	0.15	6.7	10.8	35900	3090	3.4	5.3	ND	40
01/15/97	470	0.32	0.057	4.0	2.2	1220	72	3.2	1.4	ND	9.3
02/11/97	1200	0.17	0.017	1.5	1.1	780	140	2.2	0.44	ND	5.2
02/25/97	1100	0.32	0.12	3.3	2.6	2140	30	3.7	1.2	ND	12
03/05/97	56600	51	23	1300	490	28200	6000	670	380	ND	3920
03/06/97	14700	28	320	340	150	15700	780	210	160	ND	1730
03/07/97	9500	12	1.0	130	53	4870	38	76	34	ND	570
04/15/97	1200	0.08	0.44	1.0	0.4	870	30	1.1	0.14	ND	2.9
04/25/97	1500	0.01	0.073	0.8	0.3	1360	45	0.2	0.09	ND	1.8
05/07/97	4540	0.20	0.26	5.9	2.4	3470	131	2.2	1.3	ND	12
05/21/97	10400	4.1	1.5	47	42	2560	59	68	15	ND	220
06/11/97	1950	3.1	1.3	20	21	1320	95	25	20	ND	150
06/25/97	8160	0.57	0.094	6.5	3.9	7220	70	3.8	1.4	ND	25
07/29/97	220	0.14	0.057	4.1	1.6	390	55	3.5	2.1	ND	26
08/14/97	9.20	0.20	0.040	0.10	1.0	6.9	4.4	0.70	0.60	ND	4.0

ND = Not Determined

**Table A-3 Primary mercury concentrations (ng/l) for dissolved, particulate and total fractions at the Potomac River fall line.**

<b>Date</b>	<b>Dissolved</b>	<b>Particulate</b>	<b>Total</b>
12/10/96	0.97	2.22	3.19
1/15/97	0.22	0.53	0.75
2/11/97	1.95	1.11	3.05
2/25/97	4.85	3.78	8.63
4/15/97	0.71	2.01	2.72
4/25/97	0.61	1.64	2.25
5/7/97	1.72	0.89	2.61
5/20/97	0.83	1.60	2.43
6/11/97	0.80	4.20	5.00
6/25/97	1.39	3.34	4.73
7/28/97	5.95	30.73	36.70

**Table A-4 Primary metal concentrations for (a) dissolved and (b) particulate fractions at Rock Creek.**

**(a) Dissolved Metal Concentrations**

Date	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
12/10/96	58	0.024	0.25	1.7	140	47	3.4	<0.01	3.9
1/15/97	4.5	0.032	0.14	0.85	110	140	1.9	<0.01	2.5
2/11/97	25	0.062	0.24	1.3	160	95	2.5	<0.01	3.9
2/25/97	22	0.066	0.16	1.1	190	80	1.7	<0.01	1.1
4/15/97	7.2	0.729	0.13	1.6	100	42	1.4	<0.01	0.61
4/25/97	6.9	0.15	0.23	2.4	110	27	1.2	0.09	1.3
5/7/97	3.3	0.078	0.09	1.4	120	25	1.4	<0.01	0.6
6/11/97	12	0.026	0.14	1.1	100	51	1.5	<0.01	0.7
6/25/97	9	0.032	0.4	1.8	110	46	1.2	<0.01	0.66
7/28/97	4.9	0.022	0.21	2.3	46	54	1.5	<0.01	1.1
8/14/97	3.6	0.029	0.17	2.8	32	48	1.2	<0.01	1.2

**(b) Particulate Concentrations**

**Particulate Metal Concentrations**

Date	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
12/10/96	56	0.01	0.54	0.69	38	11	0.16	0.30	2.5
01/15/97	3.4	<0.01	0.02	<0.01	2.7	0.55	0.11	0.01	0.06
02/11/97	1.5	<0.01	0.01	0.01	1.1	0.15	0.01	<0.01	0.03
02/25/97	5.7	<0.01	<0.01	<0.01	4.1	0.12	<0.01	<0.01	0.02
04/15/97	7.1	<0.01	0.01	0.01	6.5	0.67	0.01	<0.01	0.02
04/25/97	38	<0.01	0.01	0.01	31	0.44	0.01	<0.01	0.03
05/07/97	140	<0.01	0.04	0.02	102	3.8	0.01	0.01	0.11
06/11/97	0.90	<0.01	<0.01	<0.01	0.60	0.04	<0.01	<0.01	0.01
06/25/97	1.5	<0.01	0.01	<0.01	2.0	0.12	<0.01	<0.01	0.01
07/28/97	0.40	<0.01	<0.01	<0.01	0.30	0.05	<0.01	<0.01	<0.01
08/14/97	0.60	<0.01	<0.01	<0.01	0.50	0.16	<0.01	<0.01	<0.01

**Table A-5 Primary metal concentrations for (a) dissolved and (b) particulate fractions during transect at the Potomac Estuary.**

A. Dissolved Concentrations												
Date	Location	Station ID	Al (ug/L)	As (ug/L)	Cd (ug/L)	Cr (ug/L)	Cu (ug/L)	Fe (ug/L)	Mn (ug/L)	Ni (ug/L)	Pb (ug/L)	Zn (ug/L)
02/25/97	Piney Pt	stn 1	N/A	N/A	0.07	0.5	0.64	34	1.0	2	1>	0.46
02/25/97	Quantico	stn 2	22	N/A	0.04	0.1	0.33	35	1.6	0.8	1>	0.79
02/25/97	Alexandria	stn 3	32	N/A	0.02	0.2	0.60	32	15	0.8	1>	0.56
02/25/97	Natn'l Airt	stn 4	26	N/A	0.03	0.1	0.62	33	9.2	1	1>	0.49
02/25/97	Anacostia	stn 5	29	N/A	0.05	0.2	0.64	32	6.9	1	1>	0.54
07/28/97	Piney Pt	stn 1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07/28/97	Quantico	stn 2	4.6	0.22	0.06	0.1	1.8	9.3	1.5	2	1>	0.45
07/28/97	Alexandria	stn 3	7.1	0.28	0.02	0.1	1.5	8.7	0.8	2	1>	1.1
07/28/97	Natn'l Airt	stn 4	5.6	0.29	0.03	0.1	1.1	7.4	0.4	0.8	1>	0.52
B. Particulate Concentrations												
Date	Location	Station ID	Al (ug/L)	As (ug/L)	Cd (ug/L)	Cr (ug/L)	Cu (ug/L)	Fe (ug/L)	Mn (ug/L)	Ni (ug/L)	Pb (ug/L)	Zn (ug/L)
02/25/97	Piney Pt	stn 1	880	0.044	0.01	0.48	0.27	540	37	0.31	0.26	1.7
02/25/97	Quantico	stn 2	170	0.021	0.01	0.22	0.12	350	0.04	0.15	0.10	0.62
02/25/97	Alexandria	stn 3	11	0.011	0.002	0.12	0.076	24	1.3	0.09	0.05	0.36
02/25/97	Natn'l Airt	stn 4	83	0.009	0.001	0.11	0.044	52	1.8	0.08	0.03	0.29
02/25/97	Anacostia	stn 5	1200	0.11	0.05	0.75	0.78	730	51	0.52	0.75	5.9
07/28/97	Piney Pt	stn 1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07/28/97	Quantico	stn 2	52	0.10	0.01	0.96	0.81	96	4.2	0.45	0.47	4.9
07/28/97	Alexandria	stn 3	40	0.036	0.002	0.22	0.18	56	3.2	0.12	0.10	1.4
07/28/97	Natn'l Airt	stn 4	50	0.024	0.003	0.11	0.11	70	4.0	0.07	0.08	0.85
Dissolved												
09/09/95	Natn'l Airport	stn 4	14.36		0.127		1.78	4.66	5.968	0.9	0	1.19
09/09/95	Georgetown	stn 5	80.76		0.119	0.53	1.68	8.13	0.925	0.97	0	0.56
09/09/95	3-Sisters	stn 6	83.67		0.082	0.29	1.55	8.39	1.107	0.78	0	1.14
09/09/95	Palisades	stn 7	83.1		0.091		1.67	9.84	1.436	0.71	0	0.43
Particulate												
05-Oct-95	piney pt	stn 1	133	0.219	0.371	4.4	2.3	200	1.89	2.02	1.56	25.8
05-Oct-95	quantico	stn 2	244	0.005	0.115	1	0.45	166	5.73	0.54	0.003	0.21



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