Chemical Contaminant Loads in Urban Stormwater Runoff from the Chesapeake Bay Basin

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Executive Summary

Effective point source controls have reduced the overall chemical contaminant loads to the Chesapeake Bay and its tributaries. However, nonpoint sources such as stormwater runoff may now be the most significant source of chemical contaminants to many waterbodies in the Chesapeake Bay basin, particularly in urban areas. Runoff that flows over roads, buildings and other urban surfaces can become polluted with a variety of chemical contaminants, including metals and organic chemicals, whose sources range automobile use to pesticide application. Once in surface waters, these contaminants may impact the living resources in the Chesapeake Bay basin.

This report presents improved estimates of annual chemical contaminant loads in stormwater from urban lands in the Chesapeake Bay basin. The Chesapeake Bay Program's well-supported and calibrated Chesapeake Bay Watershed Model was selected from several evaluated alternatives as the source for average annual runoff estimates. Typical concentrations (or Event Mean Concentrations - EMCs) for selected contaminants were developed using NPDES stormwater monitoring data collected by 20 urban jurisdictions in the basin. The load estimates were then calculated by multiplying the average annual runoff volumes and the basinwide EMCs.

Examination of the combined NPDES stormwater monitoring database showed 39 chemicals were detected in 374 samples from 115 watersheds, eighteen of which have been identified as being of some level of concern across the basin by the Chesapeake Bay Program's Toxics Subcommittee. The chemicals detected most frequently and at the highest concentrations were metals (zinc, copper, lead) and, to a lesser extent, organic chemicals (oil and grease, PAHs). Correspondingly, the highest load estimates were also for these contaminants. These results are consistent with previous local and national stormwater monitoring data, and with what is known about the typical sources of contaminants in urban areas.

Further improvements to urban stormwater estimates will require both better runoff volume estimates and more accurate EMC values that are specific to a particular geographic region, or even each land use within that region. It is also important to develop a better understanding of how the contaminants entering the bay and its tributaries in urban stormwater will ultimately affect the bay's living resources. In the meantime, these load estimates provide a starting point for determining which chemicals should be targeted for general source reduction activities.

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Introduction

Over the past 25 years, chemical contaminant loads to the Chesapeake Bay and its tributaries have been reduced by placing limits on releases from industrial discharges and other point sources. As a result, stormwater runoff is now thought to be the most significant source of chemical contaminants to many waterbodies in the Chesapeake Bay basin, particularly in urban areas. Precipitation in urban areas falls through polluted air and washes over roads, buildings, parking areas and other features of the urban landscape. When runoff forms, it can transport a variety of chemical contaminants to sewers and streams and potentially to the Chesapeake Bay. The contaminants commonly include metals and organic chemicals used in everything from automobile brake pad linings to pesticides (Table 1). Once in surface waters, these contaminants may impact the living resources in the Chesapeake Bay basin.

A number of techniques have been developed to estimate annual pollutant loads from urban runoff (Horner et al., 1994). A hydrologic model is typically used to estimate the average annual runoff volume from the urban area, and stormwater monitoring data is used to develop a series of "event mean concentrations" (EMCs) for each chemical whose load is being determined. If one assumes that the EMCs reflect the average concentrations of the chemicals in all runoff produced by an urban area, the estimated average annual chemical contaminant loads can be calculated by multiplying the runoff volume and the EMC concentration.

This report presents improved estimates of annual chemical contaminant loads in stormwater from urban lands in the Chesapeake Bay basin. A previous study (CBP, 1994; Olsenholler, 1991) provided useful, first-cut estimates of these loads, but they were based on simplified estimates of runoff volumes and on chemical concentrations obtained from limited sampling at sites across the nation. The load estimates presented here were calculated with the same modeled runoff estimates that are being used by the Chesapeake Bay Program partners to make nutrient management decisions in the Chesapeake Bay basin, and with EMCs developed from recent stormwater monitoring data that were collected from urban areas within the basin. Combined with load estimates from other sources in the watershed, these improved stormwater loads will lead to increased understanding of chemical contaminant sources, transport, and fate in the Chesapeake Bay basin (Velinsky, 1996) and will help focus management efforts that seek to protect the health of the basin's ecosystem, including it's human population.

Background

Methods for Calculating Average Annual Runoff Estimates

A previous estimate of chemical contaminant loads to the Chesapeake Bay calculated the average annual runoff from urban areas in the basin using the Simple Method (CBP, 1994; Olsenholler, 1991). The Simple Method employs an established regression relationship between

Table 1. Potential Sources for Common Pollutants in Urban Stormwater

Chemical	Some Potential Urban Sources
Aluminum	natural sources, coal combustion
Antimony	gasoline, paints, plastics
Arsenic	fossil fuel combustion, smelting, pesticides
Berylium	fossil fuel combustion
Cadmium	automobile tires and brakes, sludge and other fertilizers, pesticides
Chromium	metal corrosion, engine part wear, dyes, paints, fertilizers, pesticides
Copper	automobile tires and brakes, building material corrosion, engine part wear, pesticides
Iron	natural sources, automobile corrosion, coke and coal combustion, landfill leachate
Lead	some gasolines, automobile tires, paints
Manganese	automobile tires and brakes, paints, dyes, fertilizers
Mercury	coal combustion, paints, dental wastes
Nickel	metal corrosion, engine part wear
Selenium	coal combustion
Silver	pesticides, dental and medical wastes, coal combustion
Thallium	dyes, pigments
Zinc	automobile tires and brakes, metal corrosion
Polychlorinated Biphenyls	electrical transformers, landfills, lubricants, hydraulic fluids
Polycyclic Aromatic Hydrocarbons (e.g., naphthalene, benzo(a)pyrene)	organic material combustion, automobile seepage, creosote-treated wood
Halogenated Aliphatics (e.g., chlorinated methanes, ethanes, ethylenes, propanes and propenes)	industrial solvents, aerosols
Benzenes, chlorinated benzenes, and toluenes	fuel spills and combustion, pesticides, solvents, asphalt
Phenols	resins, dyes, preservatives, pesticides
Phthalate Esthers	plastics, landfills, incinerators
Pesticides (e.g., chlordane, DDTs, acrolein)	land and water application, organic combustion

Adapted from Makepeace, et al., 1995.

the amount of impervious surface in a watershed and the volume of stormwater runoff produced. This model assumes that 90% of the precipitation in a year falls as part of runoff-producing events (Horner et al., 1994; Schueler, 1987).

In preparation for calculating the improved estimates of contaminant loads reported here, the Simple Method and three additional mathematical models of greater complexity were evaluated, based on their theoretical appropriateness and ease of implementation (Mandel et al., 1997). Two of the evaluated models predict runoff based on soil cover and moisture conditions (curve number method). The third model, the HSPF Chesapeake Bay Watershed Model, simulates runoff based on land use properties such as imperviousness and detention and infiltration capacities. The evaluation concluded that runoff estimates from the Simple Method were easy to obtain and based on reasonably sound, if oversimplified, theory. The curve number models were found to be less appropriate for calculating runoff from urban lands because they were designed primarily to predict runoff from agricultural lands. These models also require additional land use and soils data that is not readily available baywide, making them more difficult or impossible to implement throughout the Chesapeake Bay basin. The estimates from the Chesapeake Bay Watershed Model were theoretically sound, readily available and consistent with estimates used for other Bay Program efforts (Mandel et al., 1997).

Data Sources for Calculating EMC Values

An event mean concentration (EMC) is the flow-weighted average concentration of a chemical in stormwater runoff over the course of a typical rain event. In general, developing EMC values is problematic since suitable rain events are difficult to predict and monitor. At minimum, the rain events must be of sufficient size to produce runoff. To allow for contaminant build-up on the land in the monitored basin, it is also better to sample rain events that follow several days of dry weather. Lastly, to adequately sample fast-moving stormwater in urban areas, sampling must commence soon after the rainfall begins, requiring rapid mobilization of monitoring personnel and equipment.

Large monitoring studies. Because of the inherent difficulties in monitoring stormwater, few large studies of stormwater flowing from numerous basins have been undertaken. The best known large-scale study was the US EPA-led Nationwide Urban Runoff Program or NURP (Athayde et al., 1983), conducted in the early 1980s. NURP produced EMCs for conventional pollutants and selected metals based on monitoring of 2300 storm events at 81 sites in 22 cities. In addition, NURP's Priority Pollutant Monitoring Project measured an extended suite of contaminants in 121 runoff samples collected from 61 basins with predominately commercial or residential land uses (Cole et al., 1983). The analysis of the NURP data did not reveal significant differences between the concentrations of contaminants in stormwater from different-sized storms, various locations around the country, or different predominant land uses (Athayde et al., 1983).

Since 1992, another round of extensive stormwater monitoring has been conducted throughout the country by urban jurisdictions (either counties or cities). Those jurisdictions with municipal separate storm sewer systems that currently serve or are expected to serve more than 100,000 people were required to monitor stormwater discharges in support of their applications for National Pollutant Discharge Elimination System (NPDES) permits (US EPA, 1993). In brief, county and municipal governments were required to monitor separate storm sewer discharges from 5-10 representative land uses in their jurisdiction during three representative storms each. Two types of samples were collected from each storm: grab samples were collected during the initial 30 minutes of the storm, and flow-weighted composite samples were collected during the first three hours of the storm. The grab samples were analyzed for volatile organic compounds, oil and grease, total phenols, cyanide and conventional pollutants. The composite samples were analyzed for the remaining priority pollutants. All analyses were to measure "total" concentrations of each analyte using standard EPA-approved analytical methods (US EPA, 1993).

The data from this monitoring were to be used by the jurisdictions to develop EMC values for representative land uses. The EMCs could then be applied to modeled runoff volume data to estimate stormwater contaminant loads from all lands served by their separate sewer systems. A review of permit applications for this study revealed that few of the jurisdictions conducting monitoring in the Chesapeake Bay basin were able to derive EMCs from their limited local monitoring data alone. As a result, many of them used NURP data to derive the EMCs they used for their loading estimates.

Other monitoring studies. EMCs for particular contaminants have also been developed from smaller studies of single watersheds or land uses in the Chesapeake Bay basin and elsewhere (Shepp, 1996; Makepeace et al., 1995; Schueler, 1994; Schueler and Shepp, 1993; Olsenholler, 1991). These studies have documented that some land uses tend to contribute large amounts of certain chemicals to stormwater, such as hydrocarbons from parking lots, roads and other areas of high automobile use. Areal loading rates for several metals have also been estimated for different land uses, but the uncertainty in these estimates is high (Horner et.al., 1994).

EMC values from the previous Chesapeake Bay urban loads estimate. A previous estimate of chemical contaminant loads to the Chesapeake Bay in urban stormwater runoff (Olsenholler, 1991) used EMC estimates that were derived from the limited data of the NURP Priority Pollutant Monitoring Project, the limited dataset collected as part of the broader NURP study. The NURP Priority Pollutant Monitoring Project estimated EMC values by calculating geometric mean concentrations for the 8 metals and 2 organic compounds that were detected in greater than 20% of the samples nationwide (the geometric mean was selected over the arithmetic mean because it provides a better estimate of central tendency for log-normally distributed data such as the NURP data). "Low" EMC values were calculated by substituting one-tenth the detection limit value (because geometric means cannot be calculated from datasets containing zero values) for below detection limit results, and "high" EMC values were calculated by substituting the detection limit value for below detection limit results. The final EMC values used to calculate the previous load estimates were selected as the midpoint between the lower and upper EMC values reported by the NURP study.

To supplement this data, Olsenholler (1991) also derived EMC values for 5 additional metals using the arithmetic mean concentrations from samples collected for Washington, DC component of the NURP Priority Pollutant Monitoring Study (MWCOG, 1983). Lastly, because only a few organic compounds were detected in the NURP studies frequently enough to support calculation of EMCs, Olsenholler (1991) selected EMCs for 5 phenolic compounds, 13 PAHs, and "total hydrocarbons" from studies of smaller urban watersheds.

Methods

Calculating Average Annual Runoff Estimates

Based on the review of runoff calculation methods discussed above (Mandel, et al., 1997), the Chesapeake Bay Watershed Model was selected as the source for average annual runoff estimates. This model improves upon the method used in the previous estimate of urban stormwater loads (Olsenholler, 1991) because it uses a well-accepted, supported and calibrated modeling framework to simulate conditions in the entire Chesapeake Bay basin. The same runoff estimates are used by the Chesapeake Bay Program to calculate nutrient loads from various land uses in the basin. The Chesapeake Bay Watershed Model, therefore, provides readily accessible, theoretically sound, and consistent runoff values for calculating chemical contaminant loads in stormwater (Mandel et al., 1997).

The Chesapeake Bay Watershed Model estimates runoff for 87 discrete modeling segments in the Bay basin (Figure 1), based on land use classifications developed from US EPA's 1990 Environmental Monitoring and Assessment (EMAP) and USGS's Geographic Information Retrieval and Analysis System (GIRAS) land use data (Gutierrez-Magness et al., 1997). Runoff from pervious and impervious urban land in each segment is modeled separately by associating each urban land use class with a percent imperviousness value and lumping the impervious and pervious areas together in proportion to their size.

Annual runoff values for urban land in each segment were provided by the Chesapeake Bay Program based on rainfall data for the years 1984-1991. The variability in the runoff due to annual differences in rainfall amounts was estimated by calculating 95% confidence intervals around the mean annual runoff estimates during this period.

It is important to note that the runoff estimates calculated by the Chesapeake Bay Watershed Model represent the volume of stormwater runoff produced in a given watershed segment that reaches any receiving water such as a stream, river, lake, or the Bay. It is unlikely that all of this runoff actually reaches the mainstem of the Chesapeake Bay. In addition, runoff amounts were

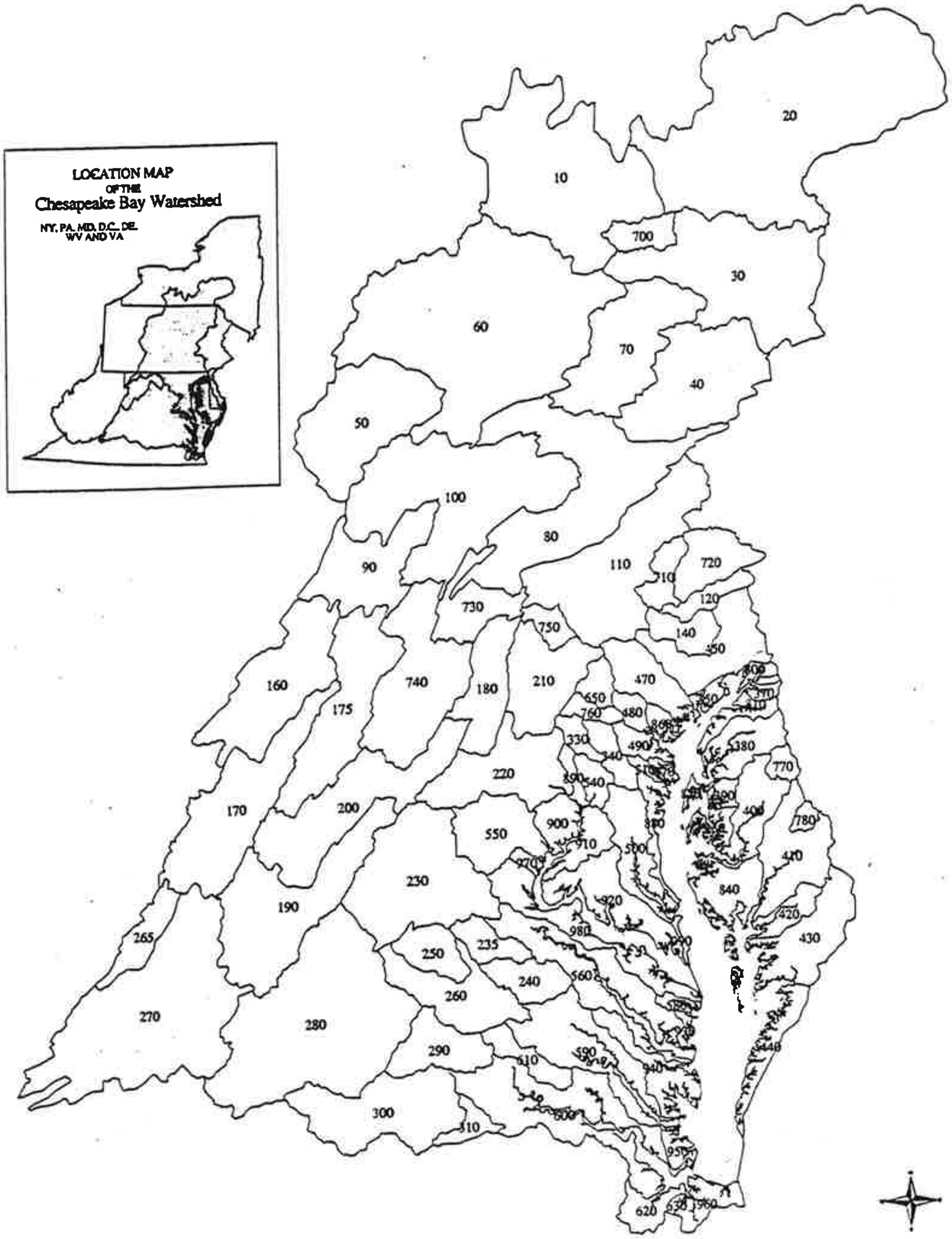

Figure 1. Chesapeake Bay Watershed Model segments. Adapted from Gutierrez-Magness et al. (1997).

not adjusted for best management practices designed to alter the delivery of stormwater or reduce sediment loads, although close calibration of the modeled runoff volumes to measured stream flows will account for some of this error.

Calculating EMC Values

Unlike the previous urban stormwater load estimates (Olsenholler, 1991), the EMC values used in this study were calculated from monitoring data collected by jurisdictions in the Chesapeake Bay basin. No other sources of EMC values were used to supplement those derived from the NPDES stormwater data. Although other EMC values are available in the literature, the NPDES stormwater data is recent and was collected with relatively consistent methods at sites only within the Bay basin. The data represents full priority pollutant analyses from several rain events at over a hundred monitored basins in the watershed, compared to the limited one sample per site scans from around the country represented by the NURP Priority Pollutant Project data (Cole et al., 1983) used in the previous estimate (Olsenholler, 1991).

The available NPDES stormwater monitoring data in the Chesapeake Bay basin was obtained directly from local governments, the Maryland Department of the Environment and the Virginia Department of Environmental Quality. To monitor the required number of storms in each basin, the jurisdictions conducted sampling was between 1992 and 1995. All of the data were placed into a single database for analysis, without regard to the date. When available, method detection limit values were included in database for those analyses reported as below the detection limit.

Land use differences. In preparation for calculating EMC values, the NPDES stormwater monitoring data were examined graphically to investigate potential differences between contaminant concentrations in runoff from the different land uses. Each monitored watershed was assigned to one of six general land use types (Industrial, Commercial, High Density Residential, Medium Density Residential, Low Density Residential, and Other) based on the predominant land use reported by the jurisdictions. The land use category "Other" was used to consolidate those watersheds whose land use is partly urban, yet predominantly either agricultural or park land. These general land use classes were used because there was no consistency between how the various jurisdictions classify their land use or how the classifications they use relate to imperviousness.

Land use differences were investigated for those chemicals detected in three or more samples using a specialized statistical package for water quality analysis (Aroner, 1995) that generates box plots showing the median and 25th and 75th percentile concentrations, as well as 95% confidence intervals around the median. If the confidence intervals for two land uses do not overlap, the median concentrations are likely to be significantly different. For this analysis, all below detection limit results were excluded from the dataset (i.e., the plots were developed from the *above detection limit* values only). Retaining the below detection limit results by assigning them a value such as zero or the detection limit value would have minimized the differences between medians for different land uses and the variability around those medians, since most of the samples would then have had the same value. Conducting the analysis in this manner would have likely masked any differences in the medians for values that were above the detection limit.

Basinwide EMCs. Based on the results of the land use analysis (presented below), all NPDES stormwater monitoring data from all sites across the Chesapeake Bay basin were analyzed together. EMC values developed from this database represent the typical chemical concentrations expected in urban stormwater runoff throughout the basin, even though not all contaminants were detected at all sites. EMCs were calculated for all chemicals detected in at least three samples, except those chemicals that were detected in only one jurisdiction and those suspected to be laboratory contaminants, based on quality control data.

EMC values were calculated from the geometric means of the available concentration data from all of the monitored sites. The geometric mean was chosen over the arithmetic mean because the data approximate a log-normal distribution, similar to the findings in other studies (Horner et al., 1994; Athayde et al., 1983). Because the analysis results were often below the detection limit for a given chemical, the exact EMCs could not be calculated directly from the data. For below detection limit results, the actual concentration of a given chemical could be anything from zero to the detection limit value. Adapting the method used by Olsenholler (1991) and Cole et al. (1983) and described above, lower and upper geometric means were calculated by substituting one-tenth the average available detection limit or the average available detection limit, respectively, for the below detection limit results. The average detection limit was used instead of the actual detection limit values because these were not available for all of the individual analyses. One-tenth the average detection limit was selected instead of zero for the lower geometric mean because geometric means cannot be calculated from datasets with zero values. The EMC value used to calculate the load estimates was then calculated as the midpoint between the lower and upper geometric means.

A general estimate of the uncertainty in the EMC values was developed by examining the variability in the concentration data for each chemical. Approximate 95% confidence intervals around the upper and lower geometric means were calculated. The average size of the confidence interval in either direction was then calculated to provide a rough estimate of the variability around the EMCs.

Calculating Chemical Contaminant Load Estimates

Chemical contaminant load estimates were calculated by multiplying the average annual runoff volume from urban land for each model segment of the Chesapeake Bay Model by the EMC concentrations developed from the NPDES stormwater monitoring database. Although not all contaminants were detected at all sites, it was assumed that the EMC values developed from the basinwide data represent the typical occurrence and concentrations of stormwater contaminants throughout the Chesapeake Bay basin and the same EMCs were applied uniformly to all model segments. An order of magnitude estimate of the uncertainty in the loads was estimated from the combined uncertainties in the runoff and EMC calculations.

Results and Discussion

Average Annual Runoff Estimates

Table 2 presents the average annual runoff estimates from urban lands for each Chesapeake Bay Program Watershed model segment. The complete runoff data for pervious and impervious urban lands in each segment during each year modeled is presented in Tables A-1 through A-3 (Appendix A).

Event Mean Concentrations

Overview. Data for 20 of the 23 jurisdictions (counties or cities) in the Chesapeake Bay basin that were required to collect stormwater monitoring data were assembled into a single database. The three jurisdictions whose data were omitted (Frederick and Washington counties in Maryland and Prince William county in Virginia) had either not yet submitted their data to the states, or the data submitted did not meet quality control standards. Nearly all of the 115 watersheds monitored in these jurisdictions were sampled on three occasions (others were sampled from one to six times) for a total of 374 samples. Table 3 lists the jurisdictions and the predominant land uses in the monitored watersheds. Watersheds draining predominately commercial land uses were most common, followed by those with predominantly medium and low density residential land uses.

Table 4 lists the 39 chemicals that were above method detection limits in at least one sample, the percent of samples in which they were above detection limits, and the number of jurisdictions and watersheds where they were detected. Eighteen of these 39 chemicals have been identified as being of some level of concern across the basin by the Chesapeake Bay Program's Toxics Subcommittee (CBP, 1997), yet only twelve of the 39 were detected in greater than 10% of the samples. The chemicals detected most frequently were zinc, copper, lead and other metals, similar to what was found in the NURP study (Athayde et al., 1983). Other than oil and grease, the organic compounds were infrequently detected. Quality control data for methylene chloride and bis (2-ethylhexyl) phthalate, common laboratory contaminants, indicate that their source is likely to have been sample contamination.

Land Use Differences. Figures 2-21 present box plots comparing chemical concentrations in stormwater from sites draining areas with different predominant land uses. The plots were

Table 2. Average Annual Precipitation Runoff From All Urban Land in the ChesapeakeBay Basin, 1984-1991

Modeling Segment	Urban Land (acres)	Annual Average Runoff (inches)	Modeling Segment	Urban Land (acres)	Annual Average Runoff (inches)
10	91238	13.6	470	40965	12.7
20	144710	17.7	480	56152	15.1
30	124801	16.3	490	59752	14.6
40	69450	18.9	500	75666	8.7
50	24246	19.9	510	13581	11.9
60	49185	15.7	540	79372	14.5
70	27785	16.1	550	103022	11.5
80	66499	16.3	560	36136	12.2
90	11182	13.4	580	2234	8.1
100	46912	13.0	590	33906	13.1
110	121532	15.8	600	187311	15.2
120	6039	16.0	610	51224	14.1
140	2423	17.6	620	26324	15.1
160	34196	19.6	630	11817	16.5
170	14921	15.4	700	4968	14.1
175	10617	15.7	710	13423	15.8
180	27996	14.9	720	51168	18.0
190	95703	12.1	730	19326	17.0
200	60177	8.9	740	42220	14.4
210	32413	13.8	750	6571	15.4
220	119735	13.6	760	7559	14.1
230	51509	14.9	770	1915	6.2
235	4054	11.7	780	2003	8.6
240	6314	12.6	800	4513	12.5
250	6441	17.1	810	2735	13.6
260	16297	16.9	820	6543	15.3
265	2582	12.7	830	12606	14.3
270	65583	14.1	840	5878	12.8
280	127491	15.5	850	16159	10.4
290	27756	14.3	860	50002	17.7
300	24182	11.0	870	14251	12.0
310	1809	12.4	880	32489	11.9
330	6384	11.1	890	42565	17.1
340	51995	14.0	900	115723	13.7
370	530	11.4	910	68150	11.5
380	6465	10.1	920	53981	8.6
390	3139	11.5	930	1575	8.6
400	12400	11.7	940	11004	13.6
410	19980	12.5	950	33362	19.1
420	18081	12.2	960	110296	18.4
430	14202	9.2	970	6983	12.6
440	11784	10.9	980	37146	10.7
450	38671	12.0	990	5478	10.4

Source: Chesapeake Bay Program Modeling Subcommittee

Table 3. Jurisdictions in the Chesapeake Bay Basin With Available NPDES Stormwater Data and Land Uses Sampled

Jurisdiction	Number of Stations Sampled By Predominant Land Use in Watershed[1]					
	Industrial[2]	Commercial	High Density Residential	Medium Density Residential	Low Density Residential	Other[3]
Anne Arundel County	1	2			2	
Baltimore City	1		1	1		
Baltimore County	1	2		1		1
Carroll County		2		1	1	1
Charles County	1	1	1	1		
Chesapeake, VA	1	2		1	3	
Chesterfield County	1			2	1	1
District of Columbia	1	1		3		1
Fairfax County	1	2		3		3
Hampton, VA		3	2		2	
Harford County	1	2		2		
Henrico County	2	2		2		
Howard County	2	1	1	1		
Montgomery County	1	2		1	1	
Newport News, VA	1	3	1	1	4	
Norfolk, VA		5	1		3	
Portsmouth,VA		2		1	2	
Prince Georges County	1	2		2		
Virginia Beach, VA	2	1		2	3	1
Total	18	35	7	25	22	8

[1] General predominant land use category, as reported by the jurisdictions.

[2] This category includes watersheds with predominantly industrial or light industrial/commercial land use.

[3] This category includes watersheds with some urban but predominantly agricultural or park land uses.

Table 4. Chemicals Above Detection Level (ADL) in Chesapeake Bay Basin NPDES Stormwater Sampling Data

Chemical	Total Samples	Total Samples ADL	Percent ADL	Juridistions ADL	Watersheds ADL
Oil and Grease	350	150	42.9%	18	83
Cyanide	339	24	7.1%	8	17
Total Phenols	337	82	24.3%	12	44
Acrolein	341	1	0.3%	1	1
Chloroform	358	8	2.2%	3	6
Ethylbenzene	358	1	0.3%	1	1
Methylene Chloride[1]	357	96	26.9%	11	46
Toluene	358	4	1.1%	1	4
Phenol	356	3	0.8%	2	3
Acenaphthene[2]	357	1	0.3%	1	1
Anthracene	358	2	0.6%	1	2
Benzo(a)anthracene[2,3]	358	4	1.1%	3	4
Benzo(a)pyrene[2,3]	358	3	0.8%	2	3
3,4-benzofluoranthene	345	6	1.7%	4	5
Benzo(ghi)perylene[2]	358	2	0.6%	1	2
Benzo(k)fluroanthene	358	3	0.8%	2	3
Bis(2-chloroethoxy)methane	358	3	0.8%	2	3
Bis(2-ethylhexyl)phthalate[1]	358	54	15.1%	11	36
Chrysene[2,3]	358	3	0.8%	2	2
1,4-dichlorobenzene	362	21	5.8%	2	14
Di-n-octyl phthalate	358	1	0.3%	1	1
Fluoranthene[3,4]	357	16	4.5%	12	8
Fluorene[2]	358	3	0.8%	3	3
Indeno(1,2,-cd)pyrene[2]	358	1	0.3%	1	1
Phenanthrene[4]	353	11	3.1%	6	9
Pyrene[2]	358	16	4.5%	6	12
Antimony	337	22	6.5%	7	15
Arsenic[2,5]	357	119	33.3%	15	62
Berylium	337	36	10.7%	9	27
Cadmium[2,3]	361	124	34.3%	15	64
Chromium[2,3]	341	184	54.0%	17	87
Copper[3,4]	361	318	88.1%	19	112
Lead[3,4]	361	241	66.8%	17	97
Mercury[2,3]	338	18	5.3%	9	16
Nickel[2]	356	142	39.9%	15	60
Selenium	353	25	7.1%	7	17
Silver	337	18	5.3%	9	16
Thallium	337	5	1.5%	4	5
Zinc[2,5]	361	351	97.2%	20	119

[1] Common laboratory contaminant, suspect data.

[2] Draft Revised Chemicals of Potential Concern List

[3] 1990 Toxics of Concern List

[4] Draft Revised Toxics of Concern List

[5] 1990 Chemicals of Potential Concern List

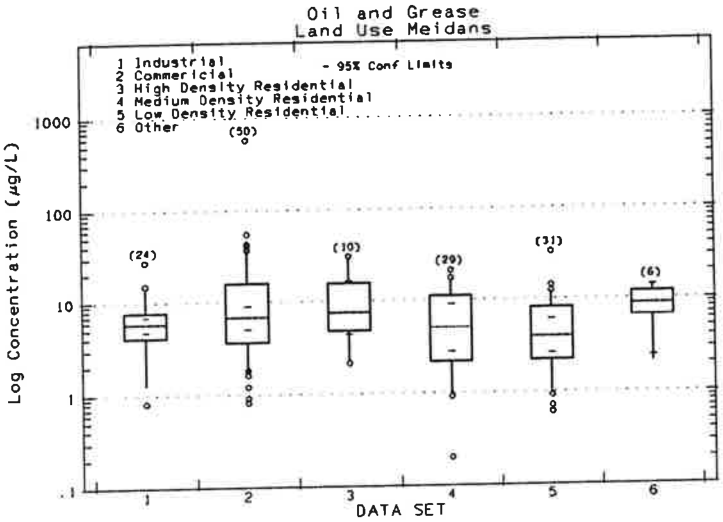

Figure 2. Land use medians for above detection level values (ADL) of oil and grease in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 16%, 2) 33.3%, 3) 6.7%, 4) 19.3%, 5) 20.7%, 6) 4%. See text for additional information.

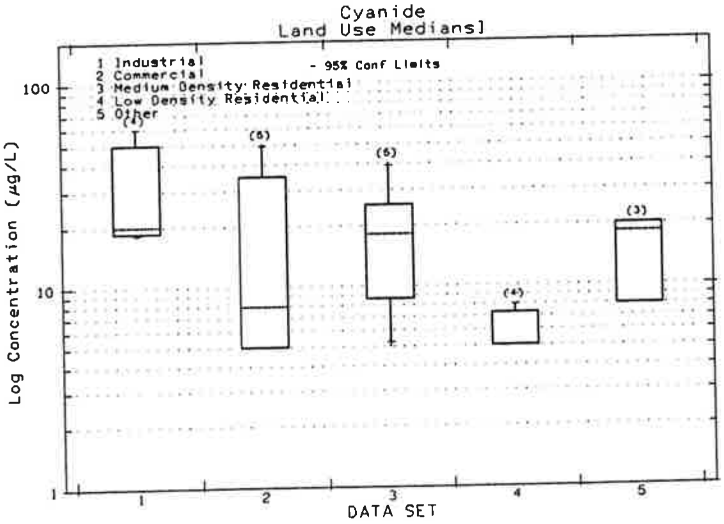

Figure 3. Land use medians for above detection level values (ADL) of cyanide in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 16.7%, 2) 25%, 3) 25%, 4) 16.7%, 5) 12.5%, and one value from high density residential. See text for additional information.

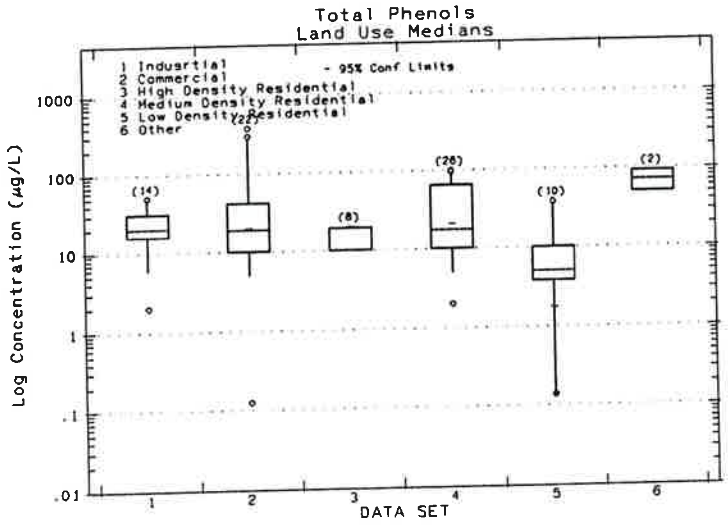

Figure 4. Land use medians for above detection level values (ADL) of total phenolic compounds in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 9.3%, 2) 26.8%, 3) 9.8%, 4) 31.7%, 5) 12.2%, 6) 2.4%. See text for additional information.

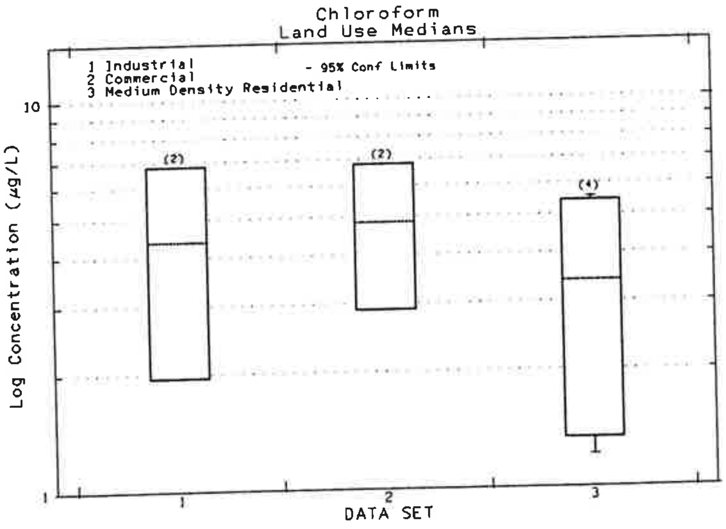

Figure 5. Land use medians for above detection level values (ADL) of chloroform in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 25%, 2) 25%, 3) 50%. See text for additional information.

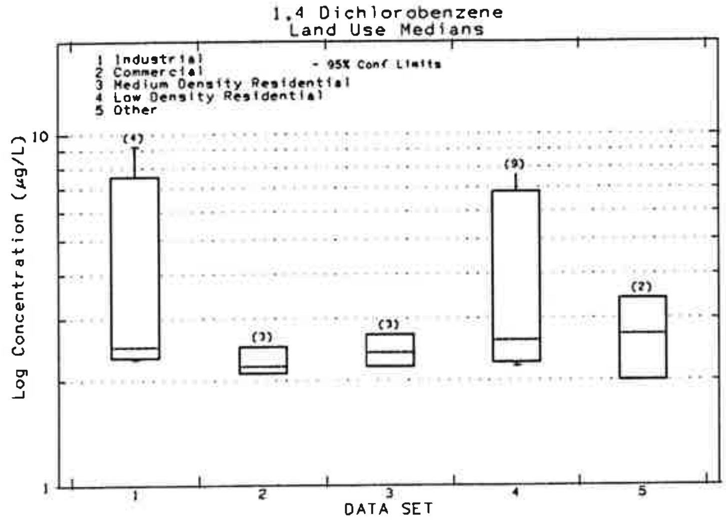

Figure 6. Land use medians for above detection level values (ADL) of 1,4-dichlorobenzene in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 19%, 2) 14.3%, 3) 42.9%, 4)9.5%. See text for additional information.

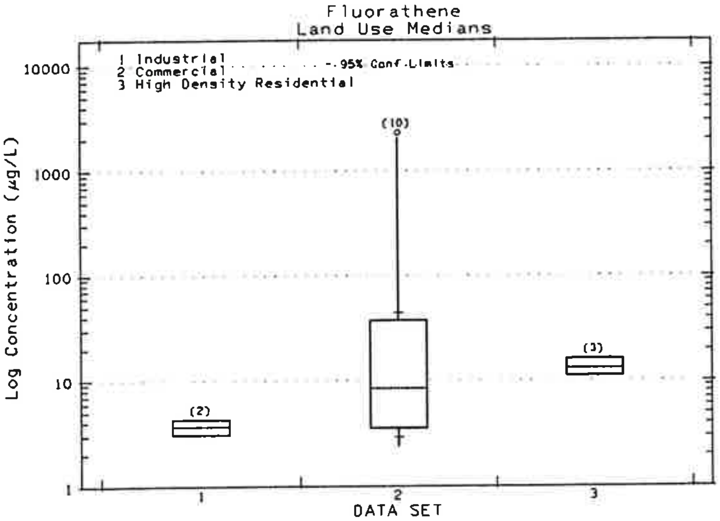

Figure 7. Land use medians for above detection level values (ADL) of fluoranthene in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 1.3%, 2) 62.5%, 3) 18.8%, and on value from low density residential. See text for additional information.

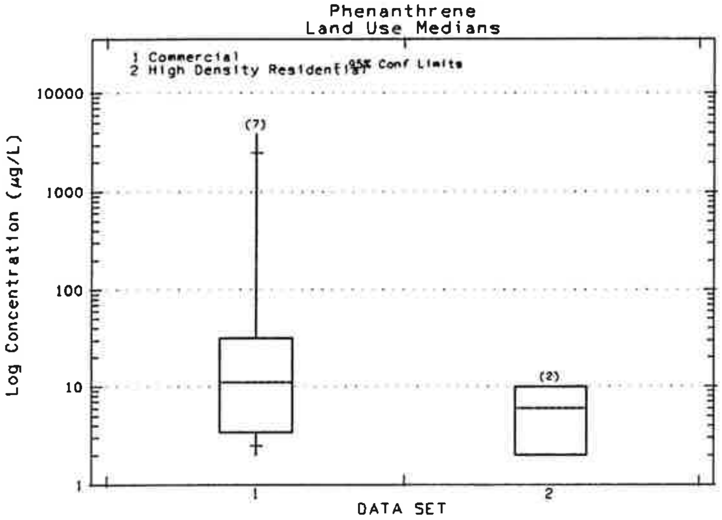

Figure 8. **Land use medians for above detection level values (ADL) of phenanthrene in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 63.6%, 2) 18.2% and on value each from industrial and low density residential. See text for additional information.**

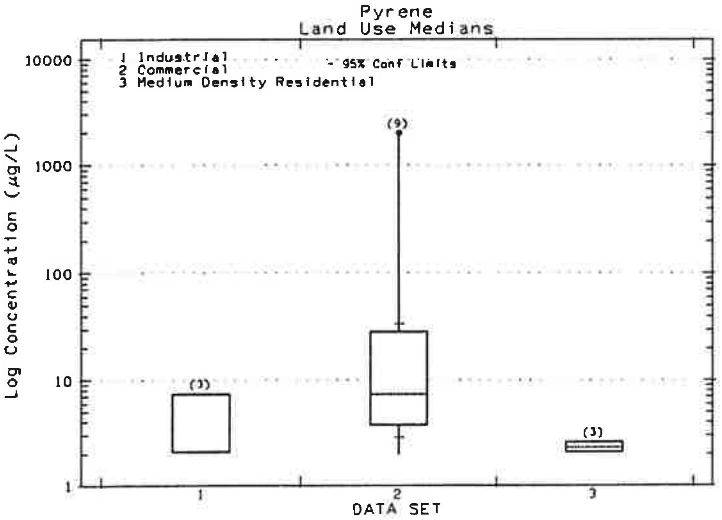

Figure 9. **Land use medians for above detection level values (ADL) of pyrene in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 18.8%, 2) 56.2%, 3) 18.8%and one value from low density residential. See text for additional information.**

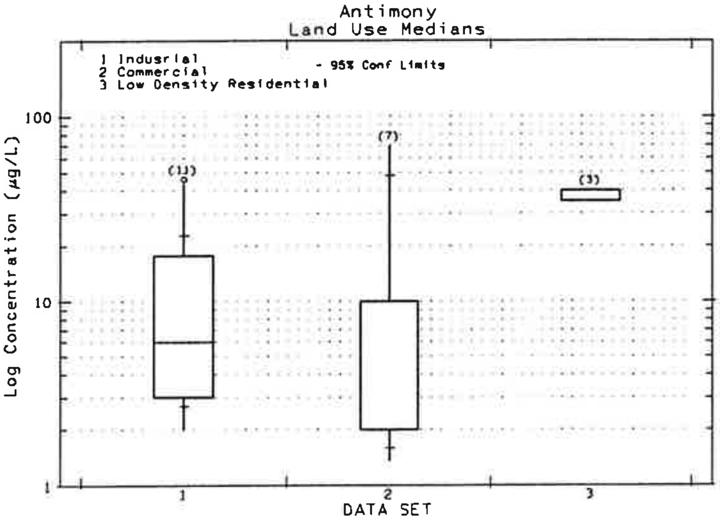

Figure 10. Land use medians for above detection level values (ADL) of antimony in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 50%, 2) 31.8%, 3) 13.6% and one value from "other." See text for additional information.

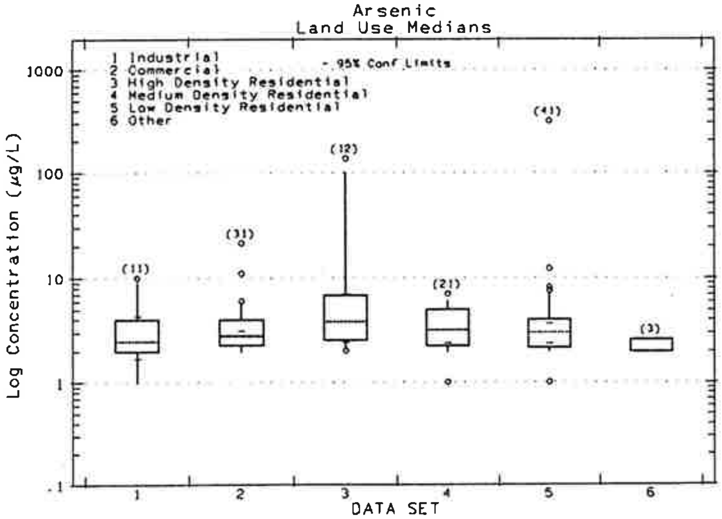

Figure 11. Land use medians for above detection level values (ADL) of arsenic in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 9.2%, 2) 26%, 3) 10.1%, 4) 17.6%, 5) 34.4%, 6) 2.5%. See text for additional information.

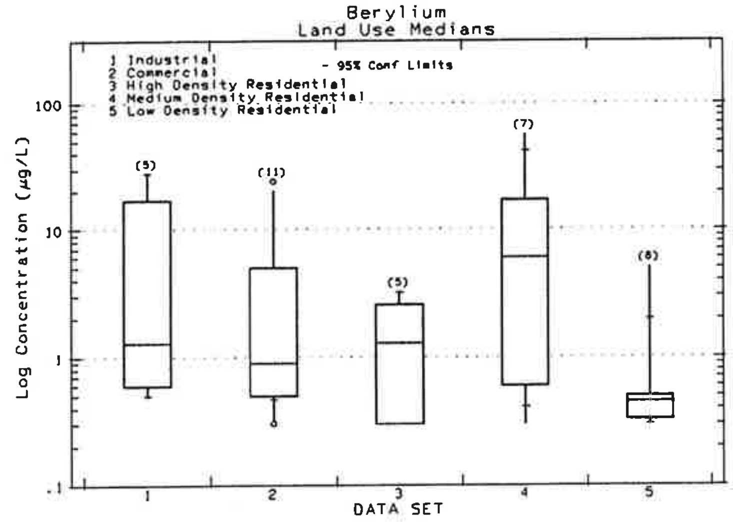

Figure 12. Land use medians for above detection level values (ADL) of beryllium in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 13.9%, 2) 30.6%, 3) 13.9%, 4) 19.4%, 5) 22.2%. See text for additional information.

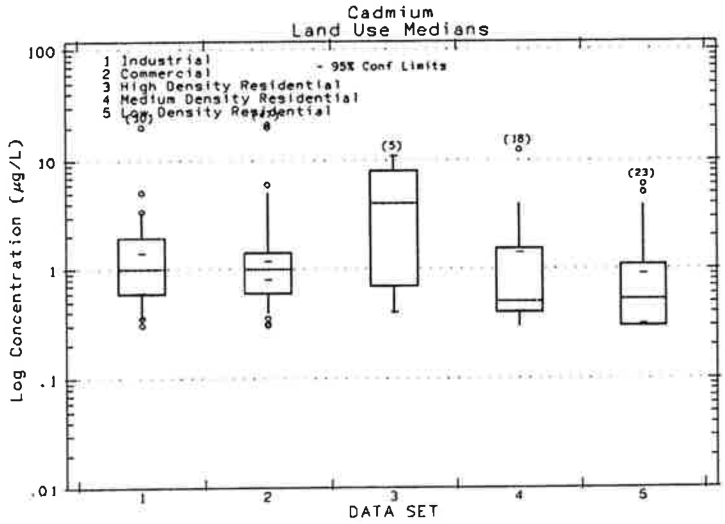

Figure 13. Land use medians for above detection level values (ADL) of cadmium in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 24.2%, 2) 37.9%, 3) 4%, 4) 14.5%, 5) 18.6%. See text for additional information.

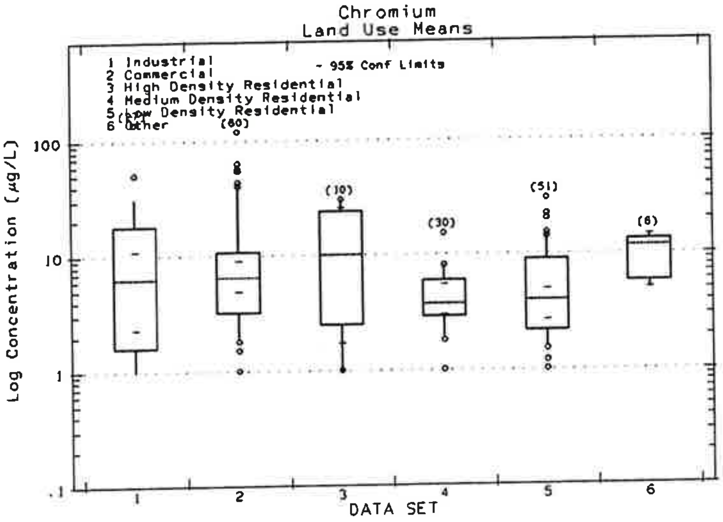

Figure 14. Land use medians for above detection level values (ADL) of chromium in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 14.7%, 2) 32.6%, 3) 5.4%, 4) 16.3%, 5) 27.7%, 6) 3.3%. See text for additional information.

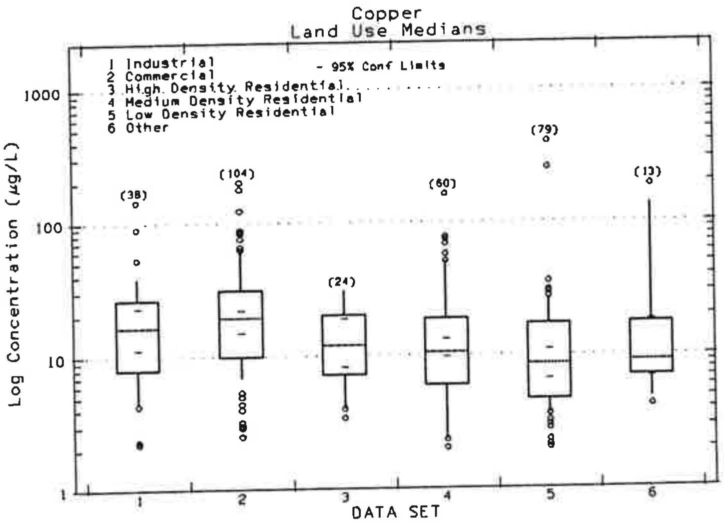

Figure 15. Land use medians for above detection level values (ADL) of copper in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 12%, 2) 32.7%, 3) 7.6%, 4) 18.9%, 5) 24.8%, 6) 4.1%. See text for additional information.

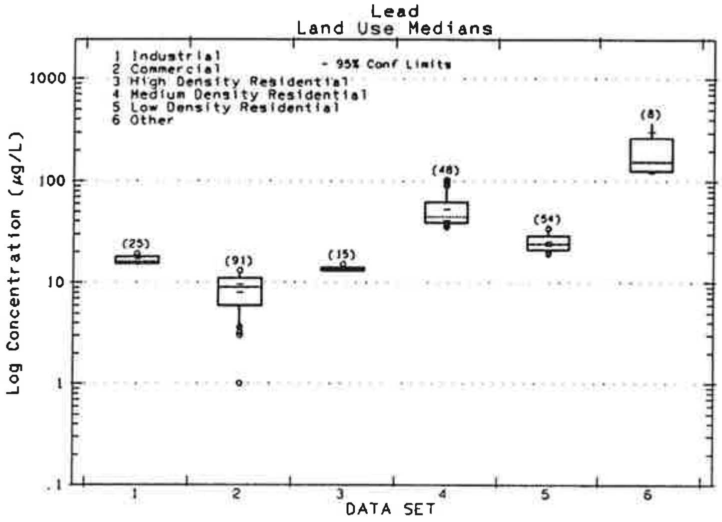

Figure 16. Land use medians for above detection level values (ADL) of lead in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 10.4%, 2) 37.8%, 3) 6.2%, 4) 19.9%, 5) 7.8%, 6) 3.3%. See text for additional information.

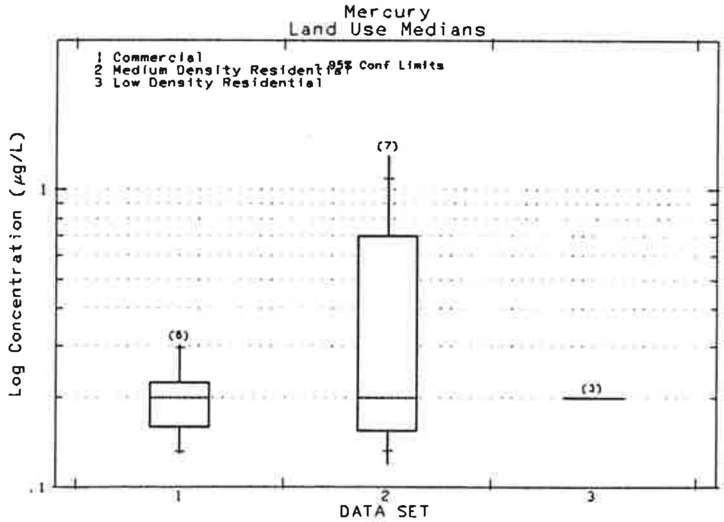

Figure 17. Land use medians for above detection level values (ADL) of mercury in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 33.%, 2) 38.9%, 3) 16.7% and one value each from industrial and "other." See text for additional information.

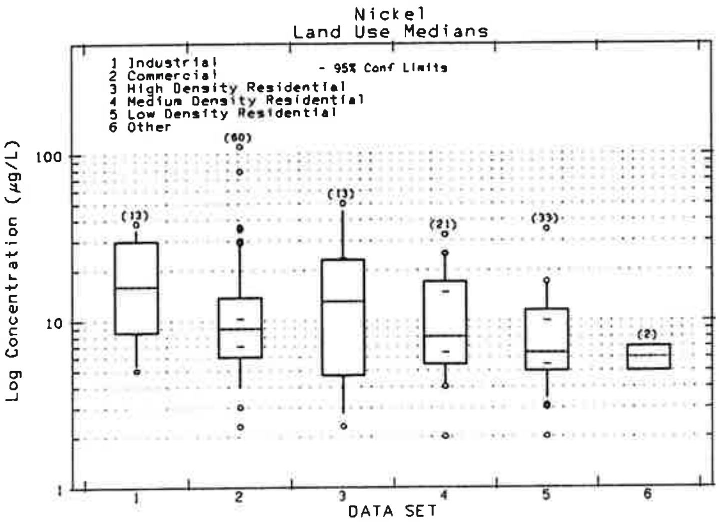

Figure 18. Land use medians for above detection level values (ADL) of nickel in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 9.1%, 2) 42.2%, 3) 9.2%, 4) 14.8%, 5) 23.2%, 6) 1.4%. See text for additional information.

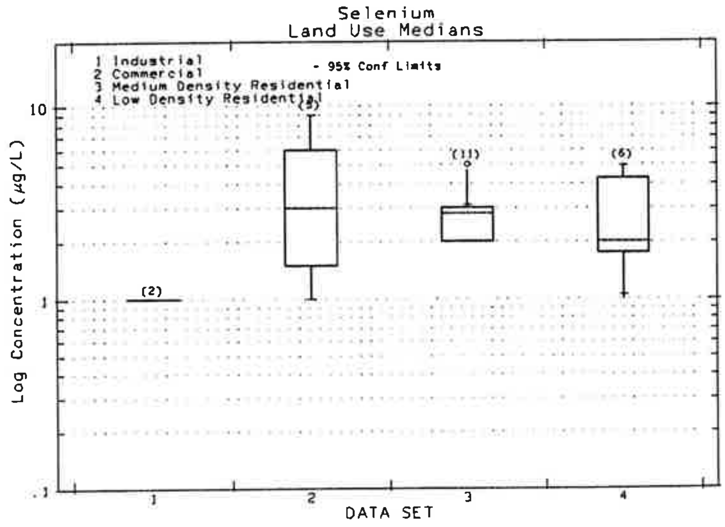

Figure 19. Land use medians for above detection level values (ADL) of selenium in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 8%, 2) 20%, 3) 44%, 4) 24% and one value from "other.". See text for additional information.

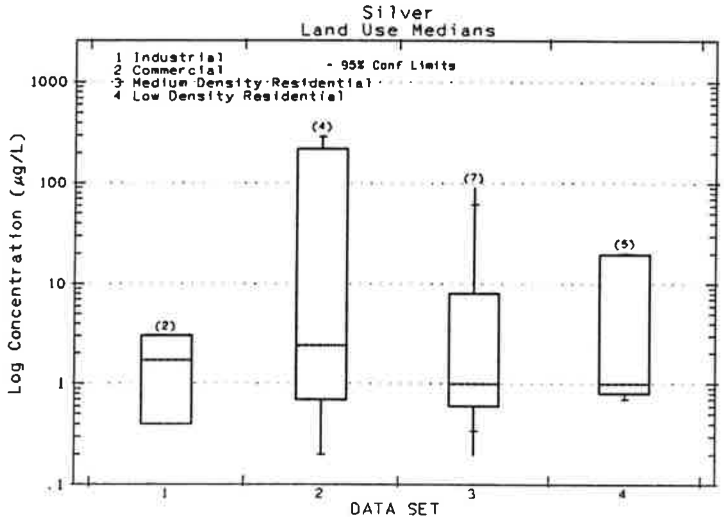

Figure 20. Land use medians for above detection level values (ADL) of silver in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 11.1%, 2) 22.2%, 3) 38.9%, 4) 27.8%. See text for additional information.

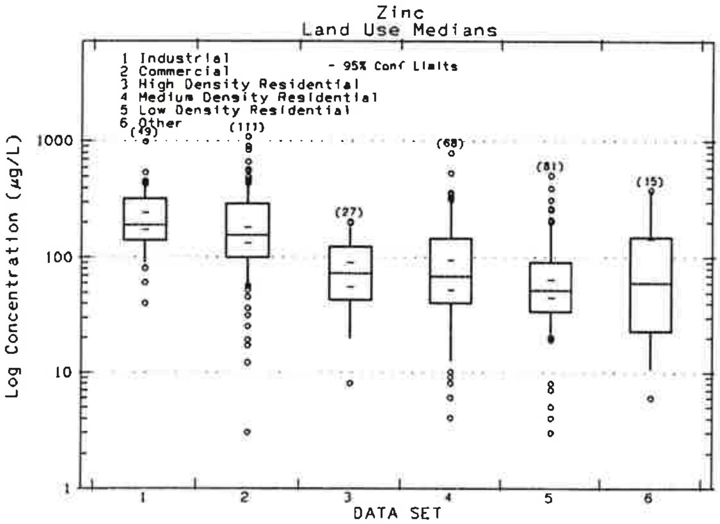

Figure 21. Land use medians for above detection level values (ADL) of zinc in NPDES stormwater monitoring data from the Chesapeake Bay basin. Percent of total ADL values from each land use category: 1) 14%, 2) 31.6%, 3) 7.7%, 4) 19.4%, 5) 23.1%, 6) 4.3%. See text for additional information.

developed from the *above detection limit values only* for the 20 chemicals that were detected in more than one sample and from more than one land use category. They show the number of samples, median concentrations, quartile ranges, and 95% confidence intervals around the medians. If the 95% confidence intervals for different land uses do not overlap, it is likely that the difference between the medians is statistically significant.

Few significant differences or consistent trends were observed by this analysis. The only general trend was that the watersheds in the residential land use categories tended to exhibit lower median concentrations for some chemicals (cyanide, total phenols, pyrene, copper, and zinc) compared to those from at least one of the other land use categories. However, the opposite appeared to be the case for some other chemicals (fluoranthene, antimony, and lead). Overall, the commercial land use category had the highest average percentage of above detection limit values for all chemicals (49%), followed by the three residential categories (HDR: 11%, MDR: 26%, LDR: 22%) and the industrial and "other" land use categories (19% and 9%, respectively).

As noted above, using only the above detection level data in the land use analysis had the effect of maximizing the differences between medians for different land uses, compared to conducting the same analysis on datasets with a value such as zero substituted for below detection limit results. Since few significant differences were discovered even under conditions where the differences were maximized, using the complete dataset (with below detection limit results) would not unlikely have altered the general conclusions.

The lack of definitively large or consistent differences in detected chemical concentrations from the different land use categories supports combining the data from all land uses to calculate general EMC values. Additional analysis of the NPDES stormwater database assembled for this report using more detailed land use or percent imperviousness classifications may reveal significant relationships and trends that were not observed here. Lastly, although it was deemed appropriate for this basinwide study, lumping data from several land uses may not be warranted for studies of smaller watersheds.

EMC values. Table 5 lists a series of descriptive statistics for the 29 chemicals that were detected in more than three samples and in more than one jurisdiction (excluding suspected laboratory contaminants). Lower and upper geometric means, calculated by substituting one-tenth the average detection limit or the full average detection limit for below detection limit results, respectively, are presented, as are the EMC values (the midpoints between the lower and upper geometric means). The geometric means for above the detection limit values only (all below detection limit results excluded) are also presented for comparison. The EMC values were lower than the geometric means for above detection limit data in all but four cases where the chemicals had high average detection limits.

Table 6 lists the EMC values from Table 5 alongside those used in a previous estimate of chemical contaminant loads in stormwater to the Chesapeake Bay (Olsenholler, 1991; described

Table 5. Descriptive Statistics and EMCs for Selected Chemicals Detected in Chesapeake Bay Basin NPDES Stormwater Sampling Data (µg/L)

Chemical	Min. Detected Value	Max. Detected Value	Geometric Mean of Detected Values	Average Available Detection Limit	Lower Geometric Mean	Upper Geometric Mean	EMC (Middle Geometric Mean)
Oil and Grease	200.00	570000.00	5650.00	4510.00	1330.00	4970.00	**3149.00**
Cyanide	5.00	60.0	13.56	12.75	1.51	12.80	**7.16**
Total Phenols	0.13	381.0	15.08	36.10	5.11	29.19	**17.15**
Chloroform	1.21	6.8	3.33	2.15	0.23	2.17	**1.20**
Phenol	2.00	9.2	5.53	3.38	0.35	3.39	**1.87**
Benzo(a)anthracene	2.60	760.0	21.52	3.67	0.38	3.74	**2.06**
Benzo(a)pyrene	2.60	510.0	27.09	3.22	0.33	3.27	**1.80**
3,4-benzofluoranthene	1.50	31.6	5.47	3.75	0.39	3.78	**2.09**
Benzo(k)fluroanthene	1.20	720.0	22.96	3.37	0.35	3.42	**1.89**
Bis(2-chloroethoxy)methane	3.70	32.3	15.69	3.89	0.40	3.94	**2.17**
Chrysene	1.60	820.0	28.15	3.21	0.33	3.27	**1.80**
1,4-dichlorobenzene	2.00	9.2	3.08	4.80	0.53	4.68	**2.61**
Fluoranthene	2.40	2290.0	12.30	4.13	0.48	4.34	**2.41**
Fluorene	1.00	1700.0	43.22	3.11	0.32	3.18	**1.75**
Phenanthrene	2.00	3840.0	11.05	5.87	0.64	5.98	**3.31**
Pyrene	2.00	1970.0	6.92	2.97	0.34	3.09	**1.72**
Antimony	1.00	69.0	7.46	33.44	3.52	30.32	**16.92**
Arsenic	1.00	310.0	3.38	3.03	0.68	3.14	**1.91**
Berylium	0.30	56.0	1.38	1.07	0.14	1.10	**0.62**
Cadmium	0.10	21.0	0.98	2.76	0.43	1.94	**1.18**
Chromium	1.00	140.0	5.53	7.63	2.22	6.41	**4.32**
Copper	2.00	396.0	13.25	10.95	9.85	12.96	**11.40**
Lead	1.00	368.0	17.92	27.15	9.57	20.58	**15.07**
Mercury	0.12	1.3	0.23	0.32	0.04	0.31	**0.17**
Nickel	2.00	110.0	9.46	16.27	3.28	13.10	**8.19**
Selenium	1.00	9.0	2.29	24.73	2.46	20.89	**11.68**
Silver	0.20	290.0	2.62	4.31	0.47	4.20	**2.34**
Thallium	1.00	51.0	7.66	48.28	4.86	46.97	**25.92**
Zinc	3.00	1078.0	96.17	41.34	88.14	93.95	**91.04**

See text for description of how geometric means and EMCs were calculated.

Table 6. Comparison of EMC Values With Those From a Previous Estimate Contaminant Loads in the Chesapeake Bay Basin (µg/L)

Chemical	Current Study EMC	Previous Load Estimate EMC[1]
Oil and Grease	3149.04	
Cyanide	7.16	9.9
Total Phenols	17.15	
Chloroform	1.20	
Phenol	1.87	
Benzo(a)anthracene	2.06	0.087
Benzo(a)pyrene	1.80	0.098
3,4-benzofluoranthene	2.09	
Benzo(k)fluroanthene	1.89	
Bis(2-chloroethoxy)methane	2.17	
Chrysene	1.80	0.25
1,4-dichlorobenzene	2.61	
Fluoranthene	2.41	0.36
Fluorene	1.75	0.08
Phenanthrene	3.31	0.32
Pyrene	1.72	0.28
Antimony	16.92	2.5
Arsenic	1.91	4.4
Berylium	0.62	14.6
Cadmium	1.18	1.1
Chromium	4.32	6.3
Copper	11.40	17.6
Lead	15.07	3.8
Mercury	0.17	0.2
Nickel	8.19	12.5
Selenium	11.68	22.1
Silver	2.34	
Thallium	25.92	2.7
Zinc	91.04	96.8

[1] Values from CBP, 1994; Olsenholler, 1991

above). In general, the EMCs calculated for this report tended to be higher for organic compounds and slightly lower for metals. One notably large difference is in the EMC values for lead where the newly calculated EMC value is more than four times larger than the one used previously. The previous study reduced the value for lead developed from the NURP study, assuming that lead from gasoline sources has been reduced dramatically since the NURP data were collected. The more recent data indicate that this assumption may not have been warranted. The new EMC values should better reflect recent conditions within the Chesapeake Bay basin.

Chemical Contaminant Load Estimates

Tables 7a and 7b present average annual load estimates for chemical contaminants in stormwater runoff, calculated from Chesapeake Bay Watershed Model runoff volume estimates and basinwide EMC values developed from recent NPDES stormwater monitoring data collected throughout the Chesapeake Bay basin. These estimates represent loads in stormwater runoff reaching any receiving waters and have not been adjusted to reflect attenuation during transport to the mainstem Bay. The total loads are presented first, followed by loads for each major sub-basin. The loads are also further divided into above or below the "fall line" loads. The fall line marks the boundary of two physiographic provinces (roughly following the western edges of Richmond, VA, Washington, DC and Baltimore, MD), and generally indicates the upstream extent of tidal action in the Bay's tributaries.

Table 8 summarizes the current total load estimates for the entire Bay basin and, for selected chemicals, compares them to those from the previous estimate (CBP, 1994; Olsenholler, 1991). Because the models used in these studies tend to predict similar runoff volumes (Mandel et al., 1997), the two sets of load estimates compare as would be expected from the patterns in the EMC values discussed above. Namely, the loads for organic compounds presented here are generally higher than those from the previous study and the loads for metals are generally lower.

The load estimate for "oil and grease" is particularly high. "oil and grease" is a collective term used for a group of related petroleum hydrocarbons that are measured together. It includes several parameters whose loads were also calculated individually (e.g., PAHs such as fluorene and benzo(a)pyrene). The sources of these hydrocarbons include direct seepage from engines, other automobile-related activities, and general fossil fuel combustion. Also notable is the high estimated load for lead. The previous estimate of urban stormwater loads assumed that lead in stormwater would be reduced greatly from the early 1980s when the NURP data was collected, yet this does not appear to be the case.

Uncertainty in load estimates. The uncertainty in the load estimates presented here cannot be rigorously determined, but a global, *order of magnitude* estimate of the quantifiable uncertainty is presented below. Other, unquantifiable sources of error are also discussed.

Table 7a. Average Annual Chemical Contaminant Loads in Stormwater Runoff

AFL=Above Fall Line, BFL=Below Fall Line

All values in Kilograms, except Oil and Grease in 1000s of Kg.

Chemical	Chesapeake Bay Total			Susquehanna	Western Shore MD			Eastern Shore MD	Patuxent			Potomac		
	AFL	BFL	Total	Total (All AFL)	AFL	BFL	Total	Total (All AFL)	AFL	BFL	Total	AFL	BFL	Total
Oil and Grease	8,437	6,772	15,210	4,519	34	1,297	1,332	581	259	232	491	2,039	2,065	4,104
Cyanide	3,209	2,576	5,785	1,719	13	493	507	221	99	88	187	776	785	1,561
Total Phenols	19,172	15,389	34,561	10,268	78	2,948	3,026	1,320	589	527	1,115	4,634	4,692	9,326
Chloroform	45,952	36,885	82,836	24,610	187	7,066	7,253	3,164	1,411	1,262	2,673	11,106	11,245	22,351
Phenol	5,009	4,021	9,030	2,683	20	770	791	345	154	138	291	1,211	1,226	2,437
Benzo(a)anthracene	5,522	4,432	9,954	2,957	23	849	872	380	170	152	321	1,335	1,351	2,686
Benzo(a)pyrene	4,833	3,879	8,713	2,588	20	743	763	333	148	133	281	1,168	1,183	2,351
3,4-benzofluoranthene	5,590	4,487	10,077	2,994	23	860	882	385	172	154	325	1,351	1,368	2,719
Benzo(k)fluroanthene	5,051	4,054	9,105	2,705	21	777	797	348	155	139	294	1,221	1,236	2,457
Bis(2-chloroethoxy)methane	5,815	4,667	10,482	3,114	24	894	918	400	179	160	338	1,405	1,423	2,828
Chrysene	4,824	3,872	8,696	2,583	20	742	761	332	148	133	281	1,166	1,180	2,346
1,4-dichlorobenzene	6,985	5,606	12,591	3,741	28	1,074	1,102	481	214	192	406	1,688	1,709	3,397
Fluoranthene	6,453	5,180	11,634	3,456	26	992	1,019	444	198	177	375	1,560	1,579	3,139
Fluorene	4,687	3,762	8,450	2,510	19	721	740	323	144	129	273	1,133	1,147	2,280
Phenanthrene	8,879	7,127	16,006	4,755	36	1,365	1,401	611	273	244	516	2,146	2,173	4,319
Pyrene	4,597	3,690	8,287	2,462	19	707	726	317	141	126	267	1,111	1,125	2,236
Antimony	45,336	36,390	81,726	24,280	185	6,971	7,156	3,122	1,392	1,245	2,637	10,957	11,095	22,052
Arsenic	5,120	4,109	9,229	2,742	21	787	808	353	157	141	298	1,237	1,253	2,490
Berylium	1,662	1,334	2,996	890	7	256	262	114	51	46	97	402	407	808
Cadmium	3,165	2,541	5,706	1,695	13	487	500	218	97	87	184	765	775	1,540
Chromium	11,563	9,282	20,845	6,193	47	1,778	1,825	796	355	318	673	2,795	2,830	5,624
Copper	30,549	24,521	55,069	16,361	125	4,697	4,822	2,104	938	839	1,777	7,383	7,476	14,859
Lead	40,386	32,417	72,803	21,630	165	6,210	6,375	2,781	1,240	1,109	2,349	9,761	9,883	19,644
Mercury	464	372	837	249	2	71	73	32	14	13	27	112	114	226
Nickel	21,953	17,621	39,574	11,757	90	3,376	3,465	1,512	674	603	1,277	5,306	5,372	10,678
Selenium	31,282	25,109	56,391	16,754	128	4,810	4,938	2,154	960	859	1,820	7,561	7,655	15,216
Silver	6,259	5,024	11,284	3,352	26	962	988	431	192	172	364	1,513	1,532	3,045
Thallium	69,442	55,739	125,181	37,191	283	10,678	10,961	4,782	2,132	1,908	4,039	16,784	16,994	33,777
Zinc	243,935	195,801	439,736	130,644	995	37,508	38,503	16,798	7,488	6,701	14,190	58,957	59,695	118,652

Table 7b. Average Annual Chemical Contaminant Loads in Stormwater Runoff

AFL=Above Fall Line, BFL=Below Fall Line

All values in Kilograms, except Oil and Grease in 1000s of Kg.

Chemical	Western Shore VA	Eastern Shore VA	Rappahannock			York			James		
	Total (All BFL)	Total (All BFL)	AFL	BFL	Total	AFL	BFL	Total	AFL	BFL	Total
Oil and Grease	922	42	249	143	392	166	144	310	1,171	1,348	2,518
Cyanide	351	16	95	54	149	63	55	118	445	513	958
Total Phenols	2,095	94	566	325	891	377	326	704	2,661	3,062	5,723
Chloroform	5,021	226	1,356	778	2,134	904	782	1,686	6,377	7,339	13,716
Phenol	547	25	148	85	233	99	85	184	695	800	1,495
Benzo(a)anthracene	603	27	163	94	256	109	94	203	766	882	1,648
Benzo(a)pyrene	528	24	143	82	224	95	82	177	671	772	1,443
3,4-benzofluoranthen	611	28	165	95	260	110	95	205	776	893	1,668
Benzo(k)fluroanthene	552	25	149	86	235	99	86	185	701	807	1,508
Bis(2-chloroethoxy)m	635	29	172	99	270	114	99	213	807	929	1,736
Chrysene	527	24	142	82	224	95	82	177	669	770	1,440
1,4-dichlorobenzene	763	34	206	118	324	137	119	256	969	1,116	2,085
Fluoranthene	705	32	190	109	300	127	110	237	896	1,031	1,926
Fluorene	512	23	138	79	218	92	80	172	650	749	1,399
Phenanthrene	970	44	262	150	412	175	151	326	1,232	1,418	2,650
Pyrene	502	23	136	78	214	90	78	169	638	734	1,372
Antimony	4,954	223	1,338	768	2,106	892	771	1,664	6,291	7,241	13,532
Arsenic	559	25	151	87	238	101	87	188	710	818	1,528
Berylium	182	8	49	28	77	33	28	61	231	265	496
Cadmium	346	16	93	54	147	62	54	116	439	506	945
Chromium	1,264	57	341	196	537	228	197	424	1,605	1,847	3,451
Copper	3,338	150	901	518	1,419	601	520	1,121	4,239	4,879	9,118
Lead	4,413	199	1,192	684	1,876	795	687	1,482	5,605	6,450	12,055
Mercury	51	2	14	8	22	9	8	17	64	74	139
Nickel	2,399	108	648	372	1,020	432	373	806	3,046	3,506	6,553
Selenium	3,418	154	923	530	1,453	616	532	1,148	4,341	4,996	9,337
Silver	684	31	185	106	291	123	106	230	869	1,000	1,868
Thallium	7,588	342	2,049	1,176	3,225	1,367	1,181	2,548	9,637	11,091	20,727
Zinc	26,656	1,201	7,198	4,132	11,330	4,801	4,150	8,951	33,852	38,959	72,811

Table 8. Comparison of Baywide Loads With Those From a Previous Estimate of Contaminant Loads in the Chesapeake Bay Basin

Chemical	Current Study Total Load (Kg/yr)	Previous Study Total Load[1] (Kg/yr)
Oil and Grease	15,209,876	
Cyanide	34,561	58,968
Total Phenols	82,836	
Chloroform	5,785	
Phenol	9,030	
Benzo(a)anthracene	9,954	168
Benzo(a)pyrene	8,713	181
3,4-benzofluoranthene	10,077	
Benzo(k)fluroanthene	9,105	
Bis(2-chloroethoxy)methane	10,482	
Chrysene	8,696	454
1,4-dichlorobenzene	12,591	
Fluoranthene	11,633	680
Fluorene	8,450	
Phenanthrene	16,006	
Pyrene	8,287	
Antimony	81,726	14,515
Arsenic	9,229	25,855
Berylium	2,996	86,184
Cadmium	5,706	6,350
Chromium	20,845	37,195
Copper	55,069	104,328
Lead	72,803	22,226
Mercury	837	1,179
Nickel	39,574	72,576
Selenium	56,391	131,544
Silver	11,284	
Thallium	125,181	15,876
Zinc	439,736	589,680

[1] Values from CBP, 1994; Olsenholler, 1991 converted from pounds.

Three main sources of quantifiable error have been identified: modeling error in the average annual runoff estimates, interannual variability in the those estimates, and variability in the measured chemical contaminant concentrations. A comparison of the basinwide urban land use data that is used in the Chesapeake Bay Watershed Model with more detailed county-level land use data suggested an order of magnitude estimate of about 10% error in the amount of urban land and the percentage of impervious surface within those urban areas (Mandel et al., 1997), both of which affect the average annual runoff estimates. There is some additional uncertainty associated with the average annual runoff estimates due to interannual variability in rainfall amounts. To develop an order of magnitude estimate of this uncertainty, 95% confidence intervals were calculated around the mean annual runoff estimates for each segment for each year from 1986-1993. The magnitudes of the confidence intervals in either direction, expressed as the percent of the mean, ranged from 9 to 26% and the average was 16%. Combining the ±10% estimate of modeling error due to land use with the ±16% error from the interannual runoff variability, the uncertainty in the calculated runoff values is likely to be about ±25%.

A similar approach was taken to determine order of magnitude estimates in the uncertainty of the EMC values. To assess the variability in the measured concentrations, 95% confidence intervals were determined around the geometric means of the *above detection limit* concentrations for each chemical. The magnitude of the confidence intervals in either direction, expressed as the percent of the mean, ranged from 10 to 3365%, and the average was about 354%. Several chemicals had very large confidence intervals due to high variability and low number of values. If the five chemicals from Table 4 above that were detected in fewer than five samples (acrolein, ethylbenzene, acenaphthene, di-n-octyl phthalate, indeno(1,2,-cd)pyrene) are removed from the preceding analysis, the average confidence interval drops to 54% of the mean. Note that if the complete dataset that was used to calculate the EMCs (i.e., with one-tenth the average detection level or the average detection level substituted for the "below detection level" results), the average size of the confidence interval drops to about 6% of the geometric mean. To be conservative, ±54% was selected as an order of magnitude estimate of the uncertainty in the EMC values.

Since the load estimates are calculated from the product of the runoff and EMC values, the combined quantifiable uncertainties suggest that the average annual loads presented here are between one-third and twice the true loads. This is not a true confidence interval around the load estimates, but merely an attempt to quantify some of the uncertainty.

In addition, there are several sources of uncertainty that cannot be quantified. To avoid misapplying data that are not characteristic to this region, EMCs and contaminant loads were not calculated for any chemicals that were not detected at sites *within the basin*. Several factors may have reduced the number of chemicals that were commonly detected by the NPDES stormwater monitoring, thereby also reducing the number of EMC values and loads that were calculated. The detection limits achieved by most of the laboratories are generally high for measuring ambient concentrations in stormwater. Also, as in all stormwater monitoring, it is difficult to capture the "first flush"portion of a storm, which may have more chemicals at higher concentrations. Conversely, applying EMC values developed from basinwide data to all urban land in the basin may have artificially created loads for contaminants in some areas where they are not actually present. Lastly, the loads may be overestimated because the calculations did not account for attenuation of contaminant concentrations during transport from waters that receive runoff to the main tributaries or the Bay.

In summary, the loads presented here are general, baywide estimates of loads to the Bay's hydrologic system. Although they are based on the best data available, it is possible that a smaller or larger number of chemicals may be entering receiving waters in runoff, especially from some localized areas. Determining the ultimate fate of these contaminants and their potential effects on living resources will require more complex modeling.

Conclusions and Recommendations

The load estimates for chemical contaminants in stormwater runoff from urban lands in the Chesapeake Bay watershed presented here reflect runoff estimates that are consistent with those used for other Bay Program efforts and stormwater monitoring data collected from urban areas within the basin. As such, they improve upon a previous load estimate that used other runoff values and contaminant concentrations that were measured at sites across the country.

It is important to remember that, since the same EMC values were applied to all urban land uses throughout the Chesapeake Bay basin, the differences in estimated loads from one part of the basin to another are due only to differences in the amount of urban land and the degree of imperviousness within it. The loads do not indicate which urban areas are likely to be contributing chemical contaminants out of proportion to their size. Also, users of this report may want to exercise caution when applying EMC values and load estimates for those chemicals that were detected in only a few samples.

The load estimates show that certain metals (arsenic, cadmium, copper, lead, nickel, and zinc) are commonly detected in urban stormwater in the Chesapeake Bay basin, confirming what was predicted from the local and national stormwater data (Olsenholler, 1991) and from what is known about the typical sources of metals in urban areas (Table 1; Makepeace et al., 1995). The general class of hydrocarbons measured as "oil and grease" was also commonly detected and may be of baywide concern as well.

Other metals and a number of organic compounds were detected less often and in fewer areas. These chemicals may be more localized problems or they may have not been effectively captured by the limited sampling in each watershed, given the high variability in rainfall amounts and antecedent conditions. Polycyclic Aromatic Hydrocarbons or PAHs (a subset of "oil and grease"), including 3,4-benzofluoranthene, fluoranthene, phenanthrene, and pyrene, were the most commonly detected organic compounds. Their sources are primarily seepage from automobiles and organic matter combustion. It is interesting to note that no pesticides or PCBs were found in Chesapeake Bay basin stormwater, even though these chemicals have been observed in other studies (Makepeace et al., 1995).

Further improvements to urban stormwater load estimates will require both better runoff volume estimates and more accurate EMC values that are specific to a particular geographic region, or even to each land use within that region. Runoff estimates could be improved somewhat by developing better urban land use data for the watershed model. Improved EMC values may be developed by expanding and further analyzing the combined dataset assembled for this study as additional NPDES stormwater monitoring data from urban areas is collected. The NPDES stormwater monitoring data will provide a more accurate picture of contaminants in stormwater if detection limits can be lowered by using refined sampling and analytical techniques.

It is difficult to predict how the contaminants entering the bay and its tributaries in urban stormwater will ultimately affect the bay's living resources. Further study of the specific sources of the chemicals commonly detected in NPDES stormwater monitoring, along with their transport and fate, may be warranted in certain urban areas. These estimates of contaminant loads in urban stormwater, when combined with similar estimates of loads from other sources, can be used to assess the relative importance of various sources of contaminants to the Bay system and focus management efforts appropriately.

If, as suspected, urban stormwater is found to be a significant contributor of chemical contaminants relative to other sources, these load estimates provide a starting point for determining which chemicals should be targeted for general source reduction activities such as pollution prevention or best management practices. The analysis of the NPDES stormwater data presented here, along with other information, may also help determine which areas of the basin are in need of further study. Intensive monitoring and modeling in a particular subwatershed may then provide enough information about chemical loads, transport, and fate to allow reduction targets to be set for that sub-watershed.

References

Aroner, E. 1995. *WQHYDRO - Water Quality/Hydrology/Graphics/Analysis System: User's Manual.* P.O. Box 18149, Portland, OR, 97218.

Athayde, D.E., P.E. Shelly, E.D. Driscoll, D. Gaboury and G.B. Boyd. 1983. *Results of the Nationwide Urban Runoff Program: Volume I - Final Report.* US EPA, Washington, DC.

Chesapeake Bay Program. 1994. *Chesapeake Bay Basin Toxics Loading and Release Inventory: Basinwide Toxics Reduction Strategy Commitment Report.* CBP/TRS 102/94. Chesapeake Bay Program, Annapolis, MD

Cole, R.H., R.E.Frederick, R.P. Healy, R.G. Rolan. 1983. *NURP Priority Pollutant Monitoring Project: Summary of Findings.* US EPA, Washington, DC.

Gutierrez-Magness, A.L., J.E. Hannawald, L.C. Linker and K.J. Hopkins. 1997. *Chesapeake Bay Watershed Model Application and Calculation of Nutrient and Sediment Loadings: Appendix E - Phase IV Watershed Land Use and Model Links to the Airshed and Estuarine Models.* EPA 903-r-97-019, CBP/TRS 180/9. Chesapeake Bay Program, Annapolis, MD.

Horner, R.R., J.J. Skupien, E.H. Livingston, and H.E. Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues.* Terrene Institute, Washington, DC.

Mandel, R., D. Caraco, and S. S. Schwartz. 1997. *An Evaluation of the Use of Runoff Models to Predict Average Annual Runoff From Urban Areas.* Interstate Commission on the Potomac River Basin Report # 97-7, Rockville, MD.

Makepeace, D.K., D.W. Smith, and S.J. Stanley. 1995. Urban Stormwater Quality: Summary of Contaminant Data. Critical Reviews in Environmental Science and Technology, 25(2):93-139.

Metropolitan Washington Council of Governments. 1983. Urban Runoff in the Washington Metropolitan Area: Final Report - Washington, DC Area Urban Runoff Project. MWCOG for Washington Metropolitan Water Resources Planning Board. Washington, DC.

Olsenholler, S.M. 1991. *Annual Loading Estimates of Urban Toxic Pollutants in the Chesapeake Bay Basin.* Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R. 1994. Hydrocarbon Hotspots in the Urban Landscape: Can They Be Controlled? Watershed Protection Techniques, 1(1): 3-5.

Schueler, T.R. and D. L. Shepp. 1993. The Quality of Trapped Sediments and Pool Water Within Oil Grit Separators in Suburban Maryland. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R. 1987. *Controlling Urban Runoff: A Practical Manaual for Planning and Designing BMPs.* Metropolitan Washington Council of Governments, Washington, DC.

Shepp, D.L. 1996. Petroleum Hydrocarbon Concentrations Observed in Runoff from Discrete, Urbanized Automotive-Intensive Land Uses. Presented at Water Environment Federation's *Watershed '96* Conference, Baltimore, MD. Metropolitan Washington Council of Governments, Washington, DC.

US Environmental Protection Agency. 1993. *NPDES Storm Water Sampling Manual.* US EPA, Office of Water. Washington, DC.

Velinsky, D.J. 1996. *A Chemical Mass Balance Framework for Chesapeake Bay.* Interstate Commission on the Potomac River Basin Report # 96-2, Rockville, MD.

Appendix

Table A-1. Annual Precipitation Runoff from Pervious Urban Land in the Chesapeake Bay Basin, 1984-1991 (inches)

Modeling Segment	Pervious Urban Land (acres)	1984	1985	1986	1987	1988	1989	1990	1991
10	59704	11.74	2.43	5.99	2.65	1.96	5.45	7.30	3.06
20	98467	12.18	5.14	11.56	6.80	6.15	8.23	14.56	6.84
30	84571	8.30	3.46	10.94	6.99	4.65	7.71	9.49	4.13
40	44958	9.68	4.65	10.00	8.33	6.86	9.26	9.97	5.50
50	16702	13.83	9.83	16.65	9.99	8.22	11.49	13.90	7.16
60	32977	12.46	5.29	7.90	6.21	4.56	7.05	8.93	3.93
70	18454	8.63	3.54	7.67	4.53	6.05	6.81	9.94	5.50
80	43055	11.95	3.99	7.13	4.70	4.74	8.14	10.51	3.55
90	8085	8.65	5.94	5.42	5.63	5.48	8.88	6.21	3.02
100	33610	7.89	5.54	5.66	3.91	3.73	8.33	5.60	3.65
110	77880	10.43	3.78	6.32	4.07	3.59	7.32	8.45	1.97
120	3834	9.53	3.99	4.57	5.74	5.66	7.14	5.70	1.99
140	1630	13.84	6.22	8.28	6.46	9.41	13.05	12.10	4.83
160	23010	17.94	16.16	10.25	10.42	10.48	17.22	14.75	6.53
170	9804	11.00	14.14	5.16	7.22	4.85	11.35	7.11	4.47
175	7082	13.69	9.91	6.38	8.61	7.36	10.97	8.84	5.33
180	17523	13.31	4.17	2.89	3.20	3.29	5.34	5.74	1.31
190	74007	10.63	8.63	1.66	6.77	1.28	7.53	7.14	4.19
200	47300	7.84	4.16	1.17	3.02	1.25	3.22	4.87	2.15
210	20860	10.69	2.74	3.05	1.84	2.51	3.41	1.70	1.38
220	78752	9.99	1.91	1.41	3.38	3.44	4.32	2.59	1.66
230	43333	19.02	14.24	6.17	15.28	5.46	11.04	11.23	5.44
235	3225	11.14	7.69	2.11	7.61	2.13	7.13	3.75	2.20
240	4851	11.30	7.69	2.11	7.61	2.13	7.13	3.75	2.20
250	5097	17.30	15.22	6.29	15.37	6.20	17.21	11.00	7.67
260	12949	16.51	15.12	6.25	15.25	6.18	17.08	11.01	7.65
265	1788	6.12	5.19	0.97	3.18	0.57	7.21	2.98	3.32
270	46629	6.92	7.43	1.70	7.86	0.69	8.67	5.04	3.56
280	93379	11.40	7.73	2.09	12.14	1.54	13.17	7.71	5.29
290	19353	8.06	6.82	1.66	6.55	1.24	6.38	3.26	3.53
300	17459	2.76	3.02	0.29	2.41	0.15	1.37	0.74	0.79
310	1230	2.76	2.93	0.27	2.32	0.13	1.27	0.71	0.74
330	4657	3.24	0.57	0.85	1.35	1.29	5.86	1.53	0.60
340	33023	2.65	0.31	0.64	0.88	0.97	5.07	1.03	0.41
370	396	4.15	1.37	2.64	2.30	2.84	6.21	2.56	1.02
380	5006	3.15	1.15	2.10	1.82	2.32	5.35	2.18	0.80
390	2501	7.67	4.21	3.30	1.92	2.61	11.86	4.94	2.72
400	9546	5.94	3.44	2.66	1.37	2.05	9.89	4.06	2.05
410	14879	6.09	3.44	2.68	1.36	2.05	9.78	3.97	2.04
420	12395	4.11	3.08	1.23	1.70	0.46	8.66	1.64	1.09
430	11402	5.63	3.69	1.70	2.11	0.76	9.64	1.92	1.45
440	9332	6.21	4.76	2.86	3.66	1.46	13.34	3.91	3.84
450	26431	3.48	0.98	2.11	1.59	1.94	3.70	1.67	0.42

Table A-1 (Cont.). Annual Precipitation Runoff from Pervious Urban Land in the Chesapeake Bay Basin, 1984-1991 (inches)

Modeling Segment	Pervious Urban Land (acres)	1984	1985	1986	1987	1988	1989	1990	1991
470	26408	1.90	1.61	1.37	1.34	0.60	3.17	1.30	0.68
480	31577	1.58	1.03	1.02	0.96	0.42	2.53	0.74	0.47
490	34471	1.54	1.00	1.00	0.93	0.41	2.47	0.71	0.45
500	59772	3.91	2.44	0.86	1.44	1.54	4.33	1.69	0.61
510	9178	2.56	1.53	1.62	1.66	0.78	3.95	1.36	0.82
540	47847	4.39	0.78	0.92	2.26	1.63	3.43	1.37	0.74
550	75282	6.79	1.76	1.71	4.09	2.71	5.73	2.81	1.23
560	27175	7.66	6.10	2.68	5.08	2.95	7.82	4.20	2.14
580	1962	8.38	5.94	2.16	4.41	2.61	6.94	3.42	1.33
590	23938	6.19	4.97	1.76	4.15	1.00	7.75	2.23	1.54
600	117230	5.25	4.09	1.29	3.48	0.69	6.62	1.65	1.15
610	34577	6.15	4.97	1.77	4.13	1.00	7.74	2.23	1.54
620	17318	4.96	3.43	0.24	4.20	0.64	6.39	4.38	3.82
630	7315	5.47	3.54	0.28	4.46	0.69	6.60	4.41	3.89
700	3108	9.68	1.51	6.98	3.62	2.37	5.60	7.29	2.51
710	8522	10.38	3.68	7.57	4.05	4.17	8.18	7.89	2.13
720	30972	9.92	4.97	9.31	4.40	4.84	8.35	5.88	1.57
730	12603	17.15	8.40	7.13	5.83	6.41	13.23	12.77	3.43
740	28241	14.37	7.22	4.15	6.67	5.42	7.83	7.40	2.17
750	4118	12.32	4.17	4.36	1.64	0.94	4.54	2.35	0.86
760	5199	8.21	3.20	4.39	4.93	2.77	10.20	5.01	3.34
770	1720	4.03	2.50	1.91	0.69	1.36	6.80	2.73	1.44
780	1623	2.44	1.89	1.44	0.40	0.94	4.73	1.66	0.77
800	3435	6.70	2.48	4.55	4.10	5.21	10.21	4.82	2.01
810	1989	6.70	2.48	4.55	4.10	5.21	10.21	4.82	2.01
820	4713	10.59	5.51	4.63	3.10	3.72	15.13	6.37	4.01
830	9486	10.59	5.51	4.63	3.10	3.72	15.13	6.37	4.01
840	4701	10.59	5.51	4.63	3.10	3.72	15.13	6.37	4.01
850	11697	3.27	0.65	1.90	1.26	1.58	3.13	1.12	0.37
860	24122	1.87	1.11	1.16	1.09	0.48	2.70	0.75	0.52
870	9417	1.87	1.11	1.16	1.09	0.48	2.70	0.75	0.52
880	22341	3.91	2.44	0.87	1.45	1.54	4.35	1.70	0.61
890	22597	5.41	1.27	1.26	3.17	2.22	4.69	2.21	0.98
900	74498	5.41	1.27	1.26	3.17	2.22	4.69	2.21	0.98
910	48581	4.90	2.93	1.18	1.93	1.97	5.37	2.20	0.81
920	43598	4.90	2.93	1.18	1.93	1.97	5.37	2.20	0.81
930	1325	5.83	4.77	2.05	3.87	2.21	5.99	3.26	1.51
940	7790	6.94	5.84	2.27	4.77	1.53	9.25	3.18	2.19
950	19470	8.01	5.76	0.82	6.69	2.27	11.10	7.02	6.33
960	61861	5.08	3.42	0.25	4.23	0.64	6.37	4.35	3.80
970	4731	5.41	1.27	1.26	3.17	2.22	4.69	2.21	0.98
980	29531	8.71	6.02	2.23	4.47	2.66	6.99	3.37	1.39
990	4033	3.91	2.44	0.86	1.44	1.54	4.33	1.69	0.61

Table A-2. Annual Precipitation Runoff From Impervious Urban Land in the Chesapeake Bay Basin, 1984-1991 (inches)

Modeling Segment	Impervious Urban Land (acres)	1984	1985	1986	1987	1988	1989	1990	1991
10	31534	40.34	23.19	32.90	28.04	24.01	30.60	37.37	22.56
20	46243	39.37	29.40	43.05	34.08	32.27	34.82	46.50	31.33
30	40230	38.74	32.08	43.52	35.56	30.84	35.22	44.16	27.29
40	24492	42.01	34.70	42.38	38.16	35.78	37.40	45.97	33.91
50	7544	42.82	37.04	44.84	36.48	33.74	37.56	46.43	31.77
60	16208	43.71	29.76	35.83	30.93	26.38	31.52	41.83	27.00
70	9331	39.77	29.53	39.62	30.80	31.60	33.21	44.66	30.23
80	23444	40.30	30.15	36.39	30.60	28.76	35.53	44.22	24.42
90	3097	39.04	32.91	28.87	29.69	29.48	38.97	36.05	23.21
100	13302	36.53	30.62	32.93	29.90	27.70	36.84	36.63	24.11
110	43652	38.32	31.32	36.42	30.17	28.92	38.55	40.65	25.19
120	2205	39.11	31.29	35.65	32.18	33.81	38.29	35.55	27.22
140	793	38.65	28.91	34.12	30.83	35.15	41.62	39.05	29.13
160	11186	39.28	37.57	29.83	31.95	29.67	38.16	36.44	23.51
170	5117	33.66	37.39	24.49	30.50	23.42	34.45	28.10	22.80
175	3535	34.86	31.87	24.80	30.98	26.74	32.07	30.67	22.08
180	10473	39.61	33.72	27.79	30.54	29.23	32.13	37.06	23.18
190	21696	38.30	37.93	23.92	36.85	24.80	37.59	35.62	29.30
200	12877	34.43	31.58	21.68	31.80	23.03	31.10	34.10	23.14
210	11553	41.38	34.14	30.28	31.13	27.42	33.36	36.41	27.31
220	40983	38.02	30.13	26.11	34.74	32.16	37.10	39.81	25.39
230	8176	41.04	38.06	29.08	42.01	28.65	37.87	41.10	28.96
235	829	39.98	39.82	28.10	42.37	28.90	43.50	35.78	29.77
240	1463	39.98	39.82	28.10	42.37	28.90	43.50	35.78	29.77
250	1344	40.36	40.18	28.49	42.80	29.35	44.01	36.23	30.13
260	3348	40.36	40.18	28.49	42.80	29.35	44.01	36.23	30.13
265	794	38.97	34.69	26.74	32.74	22.46	42.26	33.66	32.03
270	18954	39.36	39.16	28.23	39.54	26.34	44.91	37.08	31.70
280	34112	40.64	39.95	24.70	44.15	25.57	48.89	39.77	32.52
290	8403	40.49	40.54	28.38	40.51	30.36	43.80	33.88	33.54
300	6723	39.95	40.06	27.97	40.06	29.92	43.14	33.23	33.16
310	579	39.95	40.06	27.97	40.06	29.92	43.14	33.23	33.16
330	1727	36.34	32.68	30.55	34.87	34.91	49.13	39.66	28.59
340	18972	36.34	32.68	30.55	34.87	34.91	49.13	39.66	28.59
370	134	35.61	31.58	34.68	32.23	37.91	46.65	43.60	30.22
380	1459	35.61	31.58	34.68	32.23	37.91	46.65	43.60	30.22
390	638	38.41	33.23	32.47	32.01	31.26	55.12	40.38	37.42
400	2854	38.41	33.23	32.47	32.01	31.26	55.12	40.38	37.42
410	5101	38.41	33.23	32.47	32.01	31.26	55.12	40.38	37.42
420	5686	31.97	35.10	26.82	30.44	27.06	48.63	32.08	31.47
430	2800	31.97	35.10	26.82	30.44	27.06	48.63	32.08	31.47
440	2452	31.92	35.51	27.29	30.70	27.28	49.30	32.48	31.96
450	12240	37.70	28.18	32.71	29.83	34.26	40.27	36.92	28.16

Table A-2 (Cont.). Annual Precipitation Runoff From Impervious Urban Land in the Chesapeake Bay Basin, 1984-1991 (inches)

Modeling Segment	Impervious Urban Land (acres)	1984	1985	1986	1987	1988	1989	1990	1991
470	14557	33.32	32.28	31.09	32.24	28.97	43.18	37.75	25.23
480	24575	33.30	32.25	31.07	32.22	28.95	43.16	37.74	25.22
490	25281	33.30	32.25	31.07	32.22	28.95	43.16	37.74	25.22
500	15894	36.89	32.00	28.55	33.05	29.82	43.10	37.66	27.41
510	4403	33.30	32.25	31.07	32.22	28.95	43.16	37.74	25.22
540	31525	36.55	30.41	27.53	35.45	31.45	41.36	38.34	27.28
550	27740	36.55	30.41	27.53	35.45	31.45	41.36	38.34	27.28
560	8961	40.00	36.37	28.12	37.55	29.48	42.12	35.28	28.14
580	272	40.52	36.51	27.97	37.66	29.54	41.93	35.17	28.06
590	9968	39.42	40.31	29.70	34.56	30.46	46.51	32.99	30.88
600	70081	39.42	40.31	29.70	34.56	30.46	46.51	32.99	30.88
610	16647	39.42	40.31	29.70	34.56	30.46	46.51	32.99	30.88
620	9006	38.58	39.92	23.56	39.58	33.33	49.67	38.12	36.24
630	4502	38.58	39.92	23.56	39.58	33.33	49.67	38.12	36.24
700	1860	35.80	22.76	35.80	26.33	25.21	30.79	37.41	20.79
710	4901	36.77	30.06	37.25	28.47	29.25	37.88	38.93	24.11
720	20196	40.96	32.86	43.81	31.51	33.04	41.29	38.07	27.09
730	6723	36.60	30.68	28.91	29.64	28.04	36.73	38.00	24.07
740	13979	35.71	31.02	25.00	31.30	28.04	31.63	32.62	21.36
750	2453	44.53	37.91	36.04	30.21	27.35	36.92	38.70	25.79
760	2360	39.95	28.93	28.88	33.97	27.74	43.42	37.19	27.66
770	195	38.49	33.29	32.53	32.08	31.33	55.22	40.46	37.49
780	380	38.47	33.28	32.51	32.06	31.31	55.19	40.44	37.47
800	1078	35.59	31.56	34.67	32.22	37.90	46.63	43.58	30.20
810	746	35.59	31.56	34.67	32.22	37.90	46.63	43.58	30.20
820	1830	38.43	33.25	32.48	32.03	31.28	55.14	40.41	37.43
830	3120	38.41	33.23	32.47	32.01	31.26	55.12	40.38	37.42
840	1177	38.41	33.23	32.47	32.01	31.26	55.12	40.38	37.42
850	4462	37.68	28.15	32.69	29.81	34.25	40.25	36.89	28.14
860	25880	33.30	32.25	31.07	32.22	28.95	43.16	37.74	25.22
870	4834	33.30	32.25	31.07	32.22	28.95	43.16	37.74	25.22
880	10148	36.89	32.00	28.55	33.05	29.82	43.10	37.66	27.41
890	19968	36.55	30.41	27.53	35.45	31.45	41.36	38.34	27.28
900	41225	36.55	30.41	27.53	35.45	31.45	41.36	38.34	27.28
910	19569	36.89	32.00	28.55	33.05	29.82	43.10	37.66	27.41
920	10383	36.89	32.00	28.55	33.05	29.82	43.10	37.66	27.41
930	250	40.00	36.36	28.12	37.56	29.49	42.13	35.29	28.15
940	3214	39.60	40.50	29.88	34.72	30.62	46.77	33.19	31.05
950	13892	38.73	40.12	23.71	39.75	33.51	50.00	38.32	36.40
960	48435	38.58	39.92	23.56	39.58	33.33	49.67	38.12	36.24
970	2252	36.55	30.41	27.53	35.45	31.45	41.36	38.34	27.28
980	7615	40.52	36.51	27.97	37.66	29.54	41.93	35.17	28.06
990	1445	36.89	32.00	28.55	33.05	29.82	43.10	37.66	27.41

Table A-3. Annual Precipitation Runoff From All Urban Land in the Chesapeake Bay Basin, 1984-1991 (inches)

Modeling Segment	Urban Land (acres)	1984	1985	1986	1987	1988	1989	1990	1991
10	91238	21.62	9.61	15.29	11.43	9.58	14.14	17.69	9.80
20	144710	20.87	12.89	21.62	15.52	14.50	16.73	24.77	14.67
30	124801	18.11	12.69	21.44	16.20	13.09	16.58	20.67	11.60
40	69450	21.08	15.25	21.42	18.85	17.06	19.18	22.67	15.52
50	24246	22.85	18.30	25.42	18.23	16.16	19.60	24.02	14.82
60	49185	22.76	13.35	17.10	14.36	11.75	15.11	19.77	11.53
70	27785	19.09	12.27	18.40	13.35	14.63	15.68	21.60	13.81
80	66499	21.94	13.21	17.45	13.83	13.21	17.80	22.39	10.91
90	11182	17.07	13.41	11.91	12.29	12.13	17.21	14.47	8.61
100	46912	16.01	12.65	13.39	11.28	10.53	16.41	14.40	9.45
110	121532	20.45	13.67	17.13	13.44	12.69	18.54	20.02	10.31
120	6039	20.33	13.96	15.92	15.39	15.94	18.51	16.60	11.20
140	2423	21.96	13.65	16.74	14.44	17.83	22.40	20.92	12.78
160	34196	24.92	23.16	16.65	17.46	16.76	24.07	21.85	12.08
170	14921	18.77	22.11	11.79	15.20	11.22	19.27	14.31	10.76
175	10617	20.74	17.22	12.51	16.06	13.81	18.00	16.11	10.91
180	27996	23.15	15.22	12.20	13.43	12.99	15.36	17.46	9.49
190	95703	16.90	15.27	6.71	13.59	6.61	14.34	13.60	9.88
200	60177	13.53	10.03	5.56	9.18	5.91	9.19	11.12	6.64
210	32413	21.63	13.93	12.76	12.28	11.39	14.09	14.07	10.62
220	119735	19.58	11.57	9.86	14.11	13.27	15.54	15.33	9.78
230	51509	22.52	18.02	9.81	19.52	9.14	15.30	15.97	9.17
235	4054	17.04	14.26	7.42	14.72	7.60	14.57	10.30	7.84
240	6314	17.95	15.13	8.13	15.66	8.33	15.56	11.17	8.59
250	6441	22.11	20.43	10.92	21.09	11.03	22.80	16.26	12.36
260	16297	21.41	20.27	10.82	20.91	10.94	22.61	16.19	12.27
265	2582	16.22	14.26	8.89	12.27	7.30	17.99	12.41	12.15
270	65583	16.30	16.60	9.37	17.02	8.10	19.14	14.30	11.69
280	127491	19.22	16.35	8.14	20.70	7.97	22.73	16.29	12.58
290	27756	17.88	17.03	9.75	16.83	10.06	17.71	12.53	12.62
300	24182	13.10	13.32	7.99	12.88	8.43	12.98	9.77	9.79
310	1809	14.66	14.81	9.14	14.40	9.66	14.67	11.12	11.12
330	6384	12.19	9.26	8.88	10.42	10.38	17.57	11.84	8.17
340	51995	14.94	12.12	11.55	13.28	13.35	21.15	15.13	10.69
370	530	12.10	9.01	10.74	9.87	11.71	16.43	12.94	8.40
380	6465	10.48	8.02	9.45	8.68	10.35	14.67	11.53	7.44
390	3139	13.92	10.11	9.23	8.04	8.43	20.65	12.14	9.77
400	12400	13.41	10.30	9.52	8.42	8.77	20.30	12.42	10.19
410	19980	14.34	11.05	10.29	9.19	9.51	21.36	13.27	11.07
420	18081	12.87	13.15	9.28	10.74	8.83	21.23	11.21	10.64
430	14202	10.82	9.88	6.65	7.70	5.95	17.33	7.87	7.37
440	11784	11.56	11.16	7.94	9.29	6.83	20.82	9.85	9.69
450	38671	14.31	9.59	11.80	10.53	12.17	15.27	12.83	9.20

Table A-3 (Cont.). Annual Precipitation Runoff From All Urban Land in the Chesapeake Bay Basin, 1984-1991 (inches)

Modeling Segment	Urban Land (acres)	1984	1985	1986	1987	1988	1989	1990	1991
470	40965	13.07	12.51	11.93	12.32	10.68	17.39	14.25	9.40
480	56152	15.46	14.69	14.17	14.64	12.91	20.31	16.93	11.30
490	59752	14.98	14.22	13.72	14.17	12.49	19.69	16.38	10.93
500	75666	10.84	8.65	6.68	8.08	7.48	12.47	9.25	6.24
510	13581	12.53	11.49	11.17	11.57	9.91	16.66	13.15	8.73
540	79372	17.16	12.55	11.49	15.44	13.47	18.50	16.05	11.28
550	103022	14.80	9.47	8.66	12.53	10.45	15.32	12.38	8.24
560	36136	15.68	13.61	8.99	13.13	9.53	16.33	11.91	8.59
580	2234	12.29	9.66	5.30	8.46	5.89	11.20	7.29	4.58
590	33906	15.96	15.36	9.97	13.09	9.66	19.15	11.27	10.17
600	187311	18.03	17.64	11.92	15.11	11.83	21.54	13.38	12.27
610	51224	16.96	16.45	10.85	14.02	10.57	20.34	12.23	11.08
620	26324	16.46	15.91	8.22	16.30	11.82	21.20	15.92	14.91
630	11817	18.08	17.40	9.15	17.84	13.13	23.01	17.25	16.21
700	4968	19.46	9.47	17.77	12.12	10.92	15.03	18.57	9.35
710	13423	20.02	13.31	18.41	12.97	13.33	19.02	19.22	10.16
720	51168	22.17	15.98	22.93	15.10	15.97	21.35	18.59	11.64
730	19326	23.92	16.15	14.71	14.11	13.93	21.41	21.55	10.61
740	42220	21.44	15.10	11.05	14.82	12.91	15.71	15.75	8.52
750	6571	24.34	16.77	16.19	12.31	10.80	16.63	15.92	10.17
760	7559	18.12	11.23	12.04	14.00	10.57	20.57	15.06	10.93
770	1915	7.54	5.64	5.03	3.89	4.41	11.73	6.57	5.11
780	2003	9.28	7.85	7.33	6.41	6.70	14.30	9.02	7.73
800	4513	13.60	9.43	11.74	10.82	13.02	18.91	14.08	8.74
810	2735	14.58	10.41	12.77	11.77	14.13	20.14	15.39	9.70
820	6543	18.38	13.27	12.42	11.19	11.43	26.32	15.89	13.36
830	12606	17.48	12.37	11.52	10.26	10.54	25.03	14.79	12.28
840	5878	16.16	11.06	10.20	8.89	9.23	23.14	13.18	10.70
850	16159	12.77	8.24	10.40	9.14	10.60	13.38	11.00	8.04
860	50002	18.14	17.23	16.64	17.20	15.22	23.64	19.90	13.30
870	14251	12.53	11.67	11.31	11.65	10.14	16.42	13.30	8.90
880	32489	14.21	11.67	9.52	11.32	10.37	16.45	12.93	8.98
890	42565	20.02	14.94	13.58	18.31	15.93	21.89	19.16	13.32
900	115723	16.50	11.65	10.62	14.67	12.63	17.75	15.08	10.35
910	68150	14.09	11.28	9.04	10.87	9.97	16.20	12.38	8.45
920	53981	11.05	8.52	6.44	7.92	7.33	12.63	9.02	5.93
930	1575	11.25	9.78	6.19	9.22	6.54	11.73	8.34	5.74
940	11004	16.48	15.96	10.33	13.52	10.03	20.21	11.95	10.62
950	33362	20.80	20.07	10.35	20.46	15.28	27.30	20.05	18.85
960	110296	19.79	19.45	10.49	19.75	15.00	25.38	19.18	18.05
970	6983	15.45	10.67	9.73	13.58	11.65	16.52	13.86	9.46
980	37146	15.23	12.27	7.51	11.27	8.17	14.15	9.89	6.86
990	5478	12.61	10.24	8.16	9.78	9.00	14.56	11.18	7.68