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Pesticides in Surface Water of the Mid-Atlantic Region

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Mid-Atlantic Integrated Assessment (MAIA) Region

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ABSTRACT

Water-quality data from 463 surface-water sites were compiled and analyzed to document the occurrence and distribution of pesticides in surface water of the Mid-Atlantic region as part of the Mid-Atlantic Integrated Assessment program of the U.S. Environmental Protection Agency. Those data collected by the U.S. Geological Survey from October 1973 through March 1997 were used in the analyses. Data are available for a large part of the Mid-Atlantic region, but large spatial gaps in the data do exist.

USGS data bases contained analyses of surface-water samples for 127 pesticide compounds, including 12 degradates, but only 16 of the compounds were commonly detected. Atrazine, metolachlor, simazine, prometon, alachlor, tebuthiuron, cyanazine, diazinon, carbaryl, chlorpyrifos, pendimethalin, 2,4-D, dieldrin, DCPA, metribuzin, and desethylatrazine (an atrazine degradate) were detected in more than 100 of the samples analyzed. At least one pesticide was detected in about 75 percent of the samples collected and at more than 90 percent of the sites sampled. Concentrations greater than the Federal Maximum Contaminant Level (MCL) for drinking water of 3 micrograms per liter (µg/L) for atrazine were found in 67 of 2,076 samples analyzed; concentrations greater than the MCL of 2µg/L for alachlor were found in 13 of 1,693 samples analyzed, and concentrations greater than the MCL of 4 µg/L for simazine were found in 17 of 1,995 samples analyzed. Concentrations of four pesticides were greater than Federal Health Advisory levels for drinking water, and concentrations of nine pesticides were greater than Federal Ambient Water-Quality Criteria for the Protection of Aquatic Organisms.

Streams draining basins with different land uses tend to have different pesticide detection frequencies and median concentrations. Median concentrations of herbicides tend to be highest in streams draining basins in which the major land use is agriculture, whereas median concentrations of insecticides tend to be highest in streams draining extensively urbanized basins. Concentrations of both herbicides and insecticides are usually highest during the spring and summer, although many pesticides are present at low concentrations in surface water throughout the year.

Pesticide concentrations vary greatly seasonally and over different hydrologic conditions, with overall variation sometimes exceeding four orders of magnitude. During periods of pesticide application (typically spring and summer), the occurrence of selected pesticides in some streams in the Mid-Atlantic region is related to streamflow. Correlations between concentrations of selected pesticides and streamflow are statistically significant during spring and summer for small (draining less than 55 square miles) streams. Concentrations of selected pesticides in small streams increase during high flows in the growing season, up to 30 times the concentrations present during low-flow conditions in the growing season. In small streams draining urban areas, concentrations of atrazine decrease during high-flow events but concentrations of the insecticides diazinon and chlorpyrifos increase. This may be due to the differences in the pesticides used in agricultural and urban areas and the amounts applied.

INTRODUCTION

The use of pesticides (such as herbicides, insecticides, and fungicides) increases crop yields and is beneficial in controlling weeds and nuisance organisms, but pesticides can adversely affect the environment (Larson and others, 1997a) and human health. Many pesticides are soluble in water and may enter a surface-water body in a dissolved state. Other pesticides bind to soil particles and can be transported to surface-water bodies through soil erosion. Pesticides bound to soil particles can remain suspended in the water column or can become entrained in the bed sediment. The transport of pesticides from their application areas by water is recognized as a source of contamination, and elevated levels of pesticides in surface water can render the water unfit for human consumption.

This report, prepared by the U.S. Geological Survey (USGS) in support of the U.S. Environmental Protection Agency's (USEPA) Mid-Atlantic Integrated

Assessment (MAIA) program, describes the occurrence and distribution of pesticides in surface water in the Mid-Atlantic region on the basis of data in USGS data bases. Temporal variability, and the variability due to different hydrologic conditions, also are discussed. The presence of pesticides and their measured concentrations are shown to vary spatially, seasonally, and due to fluctuating hydrologic conditions. Previously published water-quality data from a large area of the Mid-Atlantic region were compiled and analyzed to document the occurrence and distribution of selected pesticides in surface water of the area. No new water samples were collected for this study. Of the 115 pesticides and 12 pesticide degradates[1] for which data were compiled for this study, 16 compounds were selected for additional discussion. Atrazine, metolachlor, simazine, prometon, alachlor, tebuthiuron, cyanazine, diazinon, carbaryl, chlorpyrifos, pendimethalin, 2,4-D, dieldrin, DCPA, metribuzin, and desethylatrazine (an atrazine degradate) were selected because each of these compounds was detected in at least 100 samples. The occurrence of selected pesticides in surface water is compared to established Federal standards for drinking water and aquatic health and to possible explanatory variables such as seasonality and streamflow. Major spatial gaps in surface-water pesticide data collected by the USGS are identified, and limitations of currently available data for analyses of this type are discussed.

The USGS currently maintains a large data base on surface-water quality in the Mid-Atlantic region. Most of the data were collected as part of the National Water-Quality Assessment (NAWQA) program or of monitoring programs conducted by the USGS in cooperation with local, State, and other Federal agencies. Pesticide data for this report were compiled from the set of surface-water-quality data collected by or in cooperation with the USGS within the Mid-Atlantic region from October 1973 through March 1997.

[1]*Pesticide degradates include breakdown products of pesticide-active ingredients resulting from biological processes (metabolites) and chemical processes such as hydrolysis, photolysis, or photooxidation (U.S. Environmental Protection Agency, 1990). Other terms synonymous with degradate include "transformation product" and "daughter product."*

Figure 1. *Generalized land cover in the Mid-Atlantic region (Vogelmann and others, 1997).*

The Mid-Atlantic Integrated Assessment Program

The MAIA program is an integrated environmental assessment program being conducted by the USEPA, Region 3, and USEPA's Office of Research and Development, in partnership with other Federal and State agencies. Objectives of the MAIA program are to build partnerships and get all stakeholders involved in helping to: (1) identify questions needed for assessing major ecological resource areas such as ground water, surface water, forests, estuaries, wetlands, and landscapes; (2) characterize the health of each resource area, based upon exposure and effect information; (3) identify possible associations with stressors, including landscape attributes, that may explain impaired conditions for both specific resources and the overall ecosystem; (4) target geographic areas and critical resources for protection and restoration; and (5) monitor environmental management progress. MAIA will use this multidisciplinary approach to provide complete data for making informed management decisions based on good science, and serve as a demonstration of the integrated assessment framework for the Committee on Environmental and Natural Resources in the White House Office of Science and Technology.

The MAIA study area (fig. 1) includes Federal Region 3 (Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia) as well as adjacent parts of major river basins in New Jersey, New York, and North Carolina. The region includes the entire watersheds of Albemarle Sound, Chesapeake Bay, Delaware Bay, and

Pamlico Sound, as well as those of the Allegheny, Kanawha, and Monongahela Rivers, plus part of the Upper Tennessee River watershed. Land cover in the region for the period 1990 to 1994 was predominantly forested (69 percent), with smaller areas of row crops (16 percent), pasture or hay (9 percent), and urban development (3 percent; Vogelmann and others, 1997). Urban centers include Baltimore, Md., Philadelphia, Pa., Pittsburgh, Pa., Richmond, Va., and Washington, D.C.

Background

Nationwide, in most agricultural areas, the highest levels of pesticides in surface water occur as seasonal pulses lasting from a few weeks to several months, even though generally less than 2 percent of the amount applied to agricultural land each year typically reaches the streams (Larson and others, 1997a). Concentrations of pesticides in streams draining urban areas generally are lower than in agricultural areas, but seasonal pulses in streams draining urban areas last longer and are dominated more by insecticides (Larson and others, 1997a, b).

Approximately 1.1 billion pounds of synthetic organic pesticides are used annually in the United States to control a wide variety of organisms in both agricultural and nonagricultural settings. Agricultural uses of pesticides accounted for approximately 79 percent of the total pesticide use in 1995, up from 58 percent in 1966 (Asplin, 1994, 1997). Herbicide use, which has quadrupled from 1966 to 1991, now accounts for approximately 75 percent of the total agricultural use of pesticides (Larson and others, 1997a). Insecticide use has declined slightly over the same period, and the use of organochlorine insecticides, such as toxaphene and DDT, has largely been replaced by organophosphorus and carbamate compounds, such as chlorpyrifos and carbaryl. Fungicide use has increased slightly, but represents only 6 percent of the total agricultural pesticide use. Relatively small amounts of data are available to document non-agricultural uses of pesticides; however, insecticides account for approximately 30 percent of the total pesticide sales in the professional applicator market (lawn care, tree care, and treatment of structures) and 75 percent of total pesticide sales in the consumer market. A comparison of the top 50 agricultural pesticides and the top 50 urban-use pesticides show an overlap of only 20 percent (Larson and others, 1997a).

Within the Mid-Atlantic region, approximately 39 million pounds of pesticides are used annually in agricultural applications (Gianessi and Puffer, 1990; 1992a, b). Most of these pesticides are herbicides, with approximately 25 million pounds used annually; an additional 8.6 million pounds of insecticides and 5.1 million pounds of fungicides also are used in agricultural applications. Atrazine

is the most widely applied herbicide (table 1); chlorpyrifos and chlorothalonil are the most widely used insecticide and fungicide, respectively. In terms of pounds of active ingredients, more pesticides are applied to corn than are used in any other agricultural application.

Most of the pesticides currently registered for use in the United States, such as atrazine and metolachlor, have been designed to be more soluble in water than older pesticides, such as DDT and chlordane. Although this increase in solubility reduces the accumulation of these pesticides in the environment, it increases the possibility of a large volume of pesticides being transported to surface-water bodies by runoff from rainfall. Also, the solubility of these pesticides means that they can be transported to ground-water systems, to be later discharged to surface-water bodies as part of base flow.

Pesticides released into the environment can have adverse effects on ecological and human health. Many pesticides are known or suspected carcinogens and can be toxic to humans and aquatic species. Many of the known health effects, however, require exposure to concentrations higher than those typically found in the environment; the health effects of chronic, long-term exposure to low or trace concentrations of pesticides are generally unknown. Other concerns include synergistic effects of multiple pes-

Table 1. *Major agricultural pesticides used in the Mid-Atlantic region*

Type: F, fungicide; H, herbicide; I, insecticide *lbs/yr, pounds per year*
Crops: A, alfalfa, Ap, apples, C, corn, Cu, cucumbers, D, dry beans, G, grapes; H, hay, O, onions, P, pasture; Pe, peaches; Pn, peanuts; Po, potatoes, S, soybeans, T, tobacco, To, tomatoes, W, watermelons, Wh, wheat

PESTICIDE (TRADE NAMES[1])	TYPE	ESTIMATED ACTIVE INGREDIENT APPLIED[2] (lbs/yr)	ESTIMATED AREA TREATED[2] (acres)	MAJOR TARGET CROPS[2]
Atrazine (AAtrex, Gesaprim)	H	4,900,000	3,610,000	C
Metolachlor (Dual, Pennant)	H	4,270,000	2,500,000	C, S
Alachlor (Lasso, Alanox)	H	3,630,000	2,010,000	C, S, Pn
Chlorpyrifos (Dursban, Lorsban)	I	2,340,000	2,000,000	C, A, Pn, T
Glyphosate (Roundup, Rattler)	H	1,420,000	1,310,000	C, P, S
Chlorothalonil (Bravo, Daconil)	F	1,350,000	314,000	P, To, Cu
Butylate (Genate Plus, Sutan)	H	1,260,000	300,000	C
Mancozeb (Dithane DF, Nemispor)	F	1,180,000	247,000	Ap, Po, G, To, O, Cu, W
2,4-D (Weed-B-Gon, Chloroxone)	H	1,130,000	2,180,000	P, C, H, Wh
Cyanazine (Bladex, Fortrol)	H	1,090,000	716,000	C
EPTC (Eptam, Alirox)	H	1,070,000	257,000	C, A, Po, D
Carbofuran (Furadan, Curaterr)	I	992,000	923,000	C, A, S, T
Pendimethalin (Prowl, Stomp)	H	975,000	1,030,000	C, S, T
Captan (Clomitane, Captanex)	F	802,000	101,000	Ap, Pe
Simazine (Aquazine, Princep)	H	730,000	523,000	C, Ap, A, G
Paraquat (Cyclone, Total)	H	705,000	1,820,000	C, S, A
Linuron (Lorox, Linex)	H	485,000	795,000	S
Dimethoate (Cygon, Devigon)	I	485,000	928,000	A, S, Ap
Carbaryl (Sevin, Savit)	I	453,000	312,000	G, Pn, S, C, Ap, Wh
Dicamba (Banvel, Metambane)	H	410,000	1,290,000	P, C, H, Wh

[1]*Use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government*
[2]*From Gianessi and Puffer, 1990, 1992a,b.*

ticides as well as the processes of bioaccumulation, bioconcentration, and biomagnification, which entail the uptake and accumulation of chemical substances by organisms through the food chain.

Data Compilation and Analysis

Data to support a regional assessment of the spatial and temporal occurrence of selected pesticides in streams of the Mid-Atlantic region were compiled from the set of water-quality data collected in that area by the USGS or in cooperation with other agencies between October 1973 and March 1997; most of the data have been previously published. No additional water-quality data were collected as part of this study. Concentrations of pesticides or pesticide degradates have been measured in 2,545 different stream-water samples collected at varying frequencies at 463 sites. Most of these sites were sampled only once during the study period, but the Susquehanna River at Harrisburg, Pa., was sampled at least 181 times between 1973 and 1996. Of the 127 different pesticide compounds for which concentration data are available, only 11 were detected in more than half of the samples analyzed. Streamflow data were recorded during the collection of most samples. Streamflows were either measured directly or were estimated from water stage at USGS gaging stations. Drainage area and land-use data for watersheds were compiled, where available.

Problems in consistency and comparability arise when compiling data from multiple sources for regional synthesis. Water-quality data compiled for analyses cited in this report were collected at different times using various sampling designs and techniques, and thus do not represent a random, unbiased sampling of streams in the Mid-Atlantic region. Differences in analytical methods commonly yield different minimum reporting levels for the same compound (see discussion on Detection Levels and Data Censoring). Although sampling and analytical techniques have changed within the USGS since 1973, all available data were considered comparable. Unless otherwise indicated, measurements of "dissolved" and "total" concentrations of the same compound were considered comparable for the purpose of analyses for this report and all data cited are considered representative only of the time and location at which they were collected.

PESTICIDES IN SURFACE WATER IN THE MID-ATLANTIC REGION

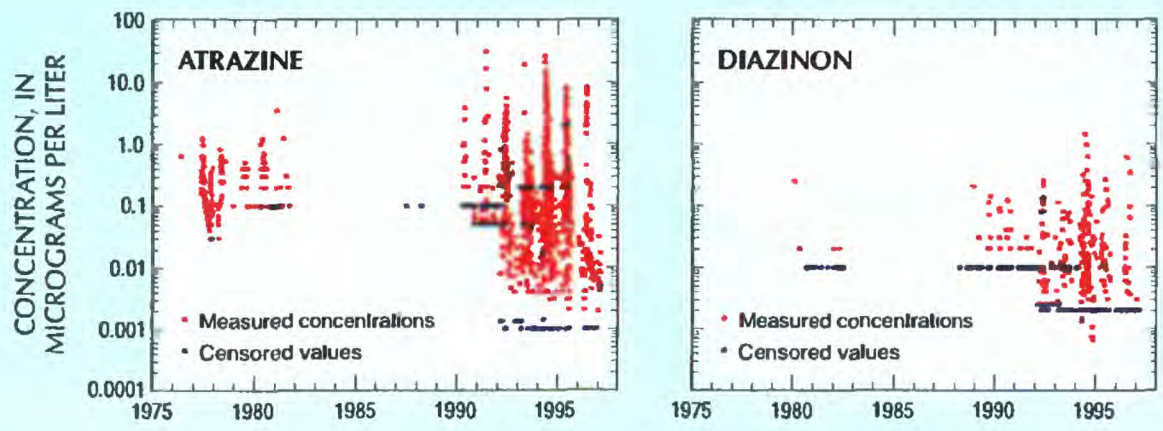
Regional data on surface-water quality are available for a large part of the Mid-Atlantic region, but large spatial gaps in the data do exist. Pesticide data were collected between 1987 and 1997 by the NAWQA program within six study units in the Mid-Atlantic region – the Albemarle-Pamlico Drainage, the Allegheny-Monongahela River Basins, the

Detection Levels and Data Censoring

Data censoring can significantly affect the level of information gained through interpretation of pesticide concentration data. An ideal analysis of water samples would reliably report the true concentration of every possible pesticide or metabolite present. This, however, is not feasible because of the large number of possible pesticides and metabolites, and limitations of analytical technology. Concentration data are censored when actual concentrations cannot be determined due to analytical or other limitations. Several common forms of censoring include: less than values; estimated values; and censoring due to sample interference. "Less than" values are reported when a pesticide compound either is not detected or is present at a level less than the method detection level (MDL), method reporting level (MRL), quantitation level (QL), or other lower-boundary detection level. Less than values do not indicate that the compound was not present, but only that it was not detected by that analysis. Estimated values are reported where the presence of the target compound is certain but the actual reported concentration is unreliable. Sample-matrix interferences can cause censoring to occur at different levels for individual samples.

Methods for laboratory analyses of pesticide concentrations in water samples have improved significantly over time. The newer methods offer much lower levels of quantification for a greater number of pesticides and metabolites. For example, in the 1990's, the USGS National Water Quality Laboratory (NWQL) developed and implemented two new techniques for the analysis of many different compounds at low quantification levels. These methods offer a total of 83 different target compounds, with quantification levels ranging from 0.001 to 0.05 micrograms per liter (µg/L). In the early 1990's, analysts at George Mason University implemented additional measures to lower detection levels for a large number of compounds to assist in quantifying the amounts of pesticides reaching Chesapeake Bay (U.S. Environmental Protection Agency, 1996b). For some pesticides, these detection levels were as low as 0.000005 µg/L. Improvements in lowering of detection levels can reveal a much clearer picture of the occurrence of pesticides in water. *Example data from improved laboratory analyses are shown here for atrazine, the most commonly detected herbicide in surface waters of the Mid-Atlantic region, and diazinon, the most commonly detected insecticide.* In the late 1970's the detection level for most analyses for atrazine ranged from 0.03 to 0.1 µg/L. In the 1990's, the predominant analytical method for atrazine lowered the detection level to 0.001 µg/L, about 1 percent of the previous level. Samples analyzed since the method change show that about 47 percent of the measured concentrations would have been undetected at the 0.1 µg/L level. Diazinon analyses show a similar change associated with lowering detection levels from 0.01 to 0.002 µg/L, in that 42 percent of the measured concentrations would have gone undetected. In addition, analyses at George Mason University showed 7 of 84 samples with detectable concentrations of diazinon less than the 0.002 µg/L level. Improved detection levels for these and other compounds have shown that some infrequently-detected compounds may be present in surface water at lower-than-detectable levels.

Interpretation of pesticide data with multiple censoring levels is difficult and, in some cases, can lead to spurious conclusions. In this report, summary statistics for each compound are calculated using all analytical data, regardless of detection levels. More detailed analyses comparing site-to-site variability, and variations with streamflow conditions were done using data analyzed with similar censoring levels.



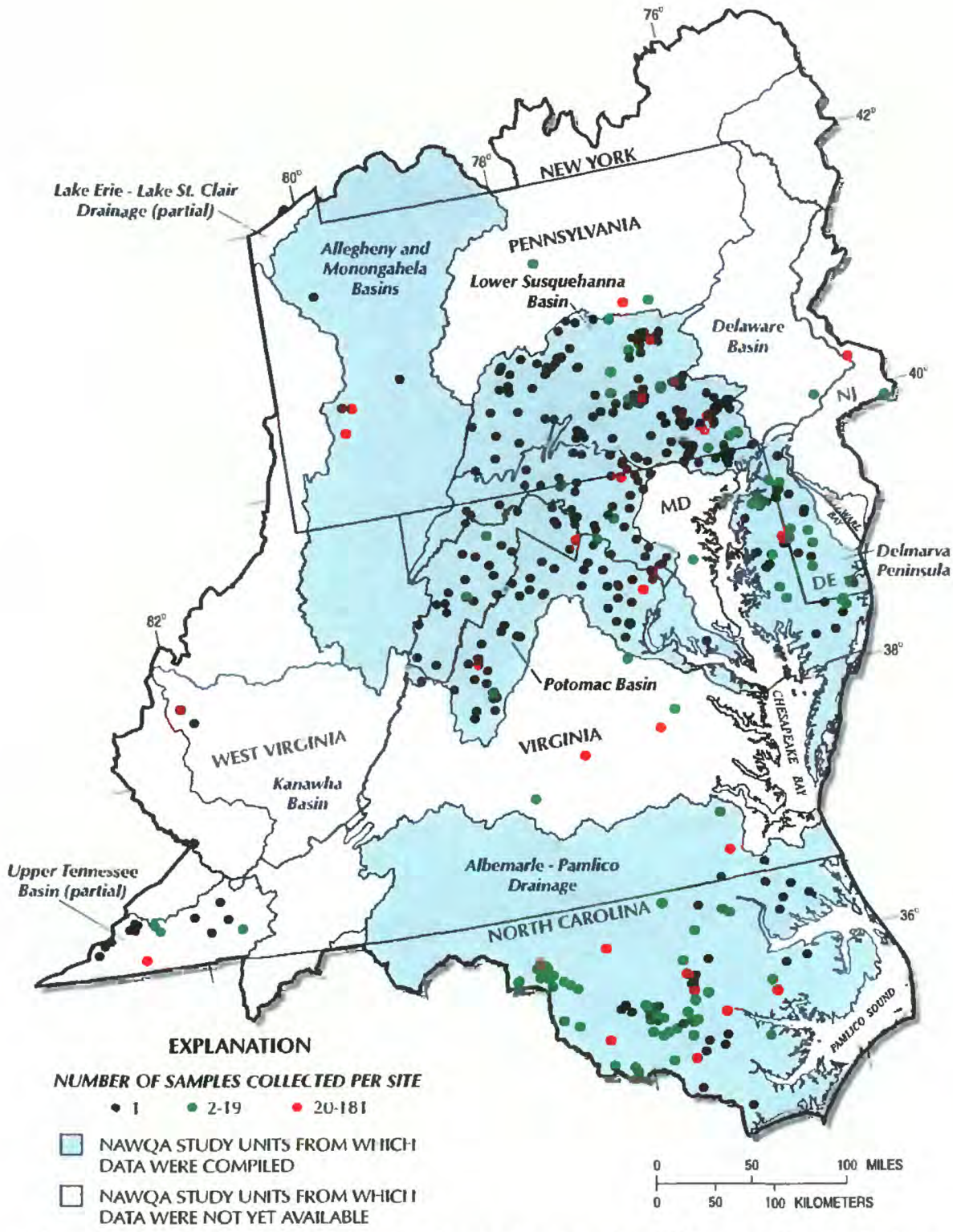


Figure 2. *Map of the Mid-Atlantic region showing location of available regional pesticide data and the number of samples collected at each site.*

Table 2. *U.S. Geological Survey projects from which regional surface-water pesticide data were compiled for this report*

PROJECT	NUMBER OF SURFACE-WATER SITES COMPILED	NUMBER OF SAMPLES COLLECTED
National Water-Quality Assessment (NAWQA) Program:		
Albemarle-Pamlico Drainage	61	256
Allegheny-Monongahela River Basins	5	7
Delmarva Peninsula	46	143
Lower Susquehanna River Basin	182	761
Potomac River Basin	117	293
Upper Tennessee River Basin	15	70
National Stream Quality Accounting Network (NASQAN) and state networks:		
Maryland	3	187
New Jersey	2	42
North Carolina	3	49
Pennsylvania	7	257
Virginia	4	123
West Virginia	3	31
Cooperative Programs:		
Army Stormwater Runoff, WVA	2	2
Chesapeake Toxics Fall Line Monitoring	10	84
Triangle Area Water Supply, NC	20	240
Totals:	463[1]	2,545

[1]*From each study, only those sites used in this report, some sites were sampled for multiple studies*

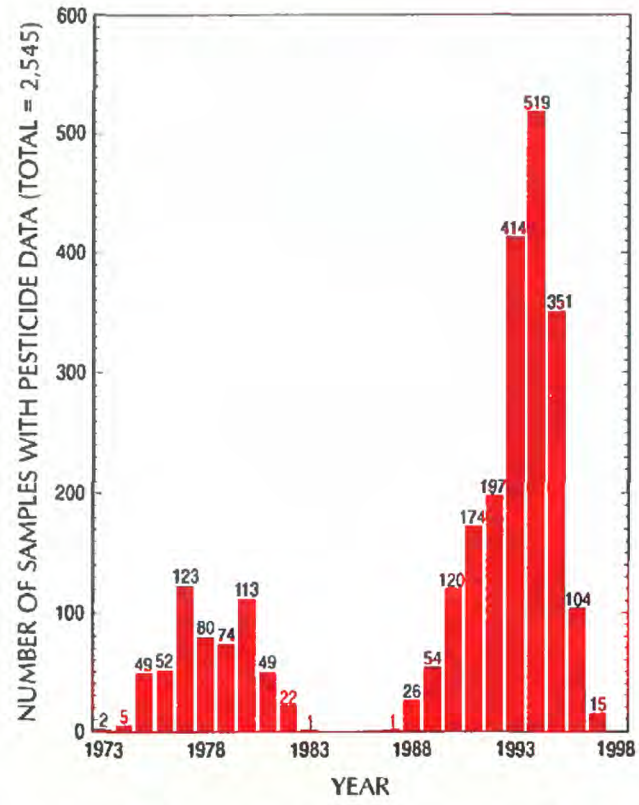


Figure 3. *Number of pesticide samples collected yearly from streams in the Mid-Atlantic region, 1973-97.*

Delmarva Peninsula, the Lower Susquehanna River Basin, the Potomac River Basin, and the Upper Tennessee River Basin (fig. 2; table 2). Future sampling is planned by the NAWQA program in these areas as well as in the Delaware and Kanawha River Basins (Gilliom and others, 1995). Additional pesticide data used in analyses for this report were collected as part of a USGS national water-quality network (Alexander and others, 1996), regional studies (U.S. Environmental Protection Agency, 1994a; 1996b) and several other studies (Childress and Treece, 1996; R.D. Evaldi, U.S. Geological Survey, written commun., 1996). Large spatial gaps in pesticide data compiled for this report include much of Pennsylvania and West Virginia, central and southern Virginia, western New Jersey, and southern New York (fig. 2); similar spatial gaps in ground-water pesticide data were noted in Ator and Ferrari (1997). A large part of the available data was collected during two periods, between 1975 and 1982 and between 1988 and 1996 (fig. 3).

Occurrence of pesticides

Pesticides and degradates are present in surface water throughout the sampled areas of the Mid-Atlantic region. Pesticides were detected in at least one sample at 422 of 463 surface-water sites in the Mid-Atlantic region (91 percent of sites). Of 2,545 surface-water samples for

which pesticide analyses were compiled for this report, 1,900 samples (75 percent) contained detectable concentrations of at least 1 compound, and 236 samples (9 percent) contained detectable levels of 10 or more compounds. Of 127 pesticide and degradates for which samples have been analyzed, 89 compounds were detected in at least 1 sample (table 3), and 16 compounds were detected in more than 100 samples (table 4). Atrazine, an herbicide, was detected in the greatest number of samples (1,489) at the most number of sites (348; fig. 4). Diazinon was the most commonly detected insecticide, with detections in 300 samples at 76 sites (fig. 5). Atrazine was detected throughout most of the sampled areas of the Mid-Atlantic region, whereas diazinon was generally found in urban areas.

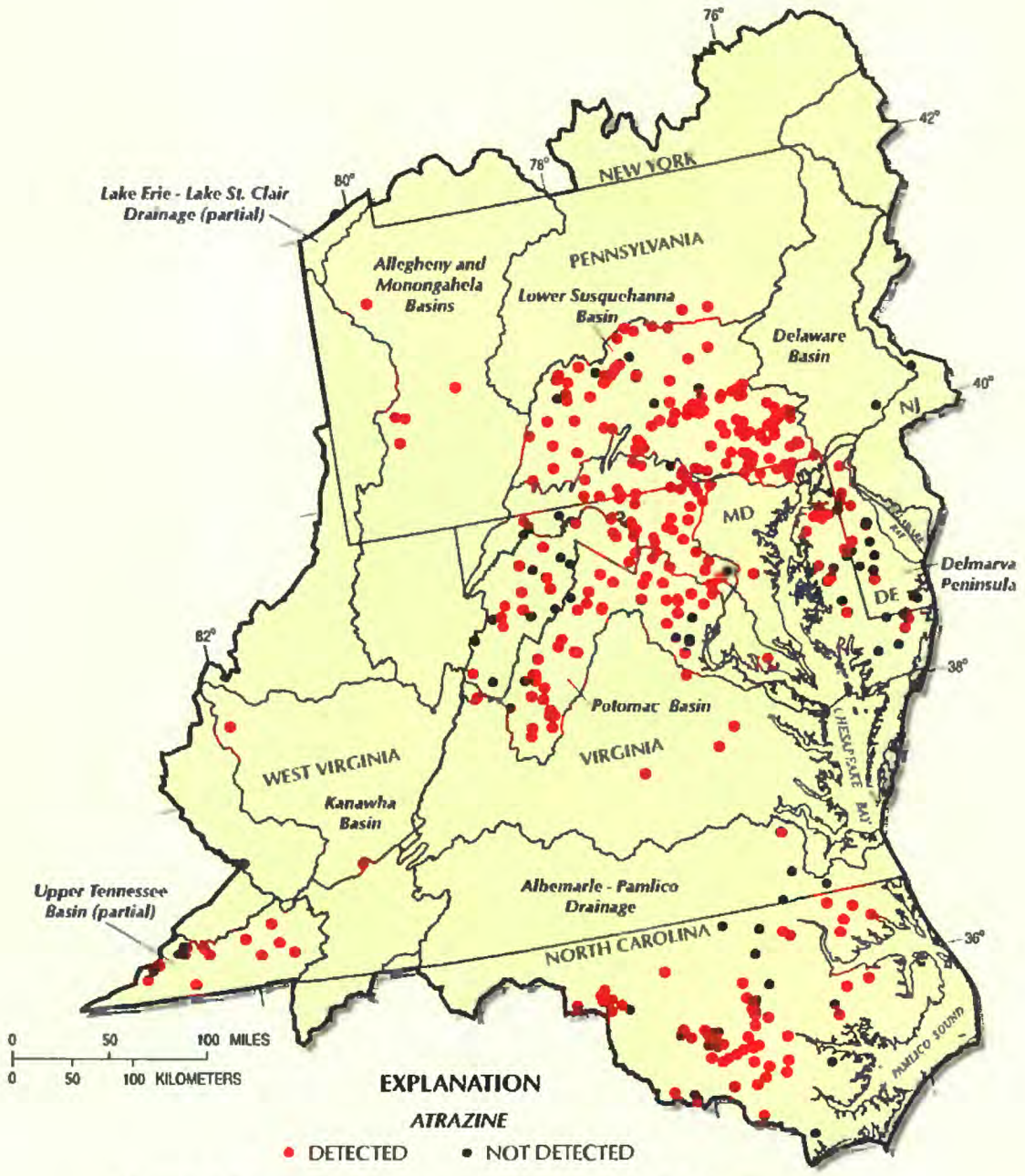


Figure 4. *Location of atrazine detections in the Mid-Atlantic region.*

Relation to established standards and criteria

Concentrations of pesticides and degradates in sampled surface-water areas of the Mid-Atlantic region are generally well below established water-quality standards and guidelines. Although the Maximum Contaminant Levels (MCL) and Health Advisories (HA) levels established by the USEPA (U.S. Environmental Protection Agency, 1996a) pertain to finished drinking water supplied by a community water supply, they do provide values with which ambient concentrations can be compared. Concentrations of atrazine were greater than the MCL of 3 µg/L in 67 samples (3 percent), and concentrations of simazine, alachlor, and toxaphene were greater than the MCL's in 17, 13, and 1 sample, respectively (table 5). For the 17 other compounds with established MCL's, no samples had concentrations greater than the MCL. It should be noted, however, that for three of these compounds (heptachlor epoxide, pentachlorophenol, and toxaphene), the

Table 3. *Pesticides and pesticide degradates analyzed in surface-water samples from the Mid-Atlantic region, October 1973 through March 1997*
(Italicized compounds are degradation products of pesticides; **Bold-faced** *compounds were detected.)*

Acetochlor	**Chlorpyrifos**	**Diuron**	**Methomyl**	**Prometryn**
Aciflurofen	Clopyralid	DNOC	**Methoxychlor**	**Pronamide**
Alachlor	**Cyanazine**	Endosulfan I (α -)	**Methyl parathion**	**Propachlor**
Aldicarb	Cycloate	**Endrin**	Methyl trithion	**Propanil**
Aldicarb sulfone	Cyprazine	**EPTC**	**Metolachlor**	**Propargite**
Aldicarb sulfoxide	**2,4-D**	Esfenvalerate	**Metribuzin**	**Propazine**
Aldrin	Dacthal, mono-acid	**Ethalfluralin**	Mirex	Propham
Ametryn	2,4-DB	Ethion	**Molinate**	Propoxur
Atratone	**DCPA (Dacthal)**	**Ethoprop**	*1-Naphtol*	**Silvex (2,4,5-TP)**
Atrazine	***o,p'-DDD***	Fenuron	**Napropamide**	**Simazine**
Azinphos-methyl	***p,p'-DDD***	**Fenvalerate (*cis*- and *trans*-)**	Neburon	**Simetone**
Benfluralin	***p,p'-DDE***	**Fluometuron**	***trans*-Nonachlor**	Simetryn
Bentazon	***p,p'-DDT***	**Fonofos**	Norflurazon	**2,4,5-T**
Bromicil	DEF	**α -HCH**	**Oryzalin**	**Tebuthiuron**
Bromoxynil	***Deisopropylatrazine***	**β -HCH**	Oxamyl	**Terbacil**
Butachlor	***Desethylatrazine***	**Heptachlor**	***Oxychlordane***	**Terbufos**
Butylate	**Diazinon**	***Heptachlor epoxide***	**Parathion**	**Thiobencarb**
Carbaryl	**Dicamba**	**Hexachlorobenzene**	**Pebulate**	**Toxaphene**
Carbofuran	Dichlorobenil	**Hexazinone**	**Pendimethalin**	**Triallate**
Carboxin	**Dichlorprop (2,4-DP)**	*3-Hydroxycarbofuran*	Pentachlorophenol (PCP)	**Triclopyr**
Chloramben	**Dieldrin**	**Lindane (γ -HCH)**	***cis*-Permethrin**	**Trifluralin**
Chlordane (α - and γ -)	***2,6-Diethylanaline***	**Linuron**	**Permethrin (*cis*- and *trans*-)**	**Trithion**
***cis*-Chlordane (α -)**	Dimethoate	**Malathion**	Perthane	Vernolate
***trans*-Chlordane**	Dinoseb	**MCPA**	**Phorate**	
γ -Chlordane	Diphenamid	MCPB	**Picloram**	
Chlorothalonil	Disulfoton	**Methiocarb**	**Prometon**	

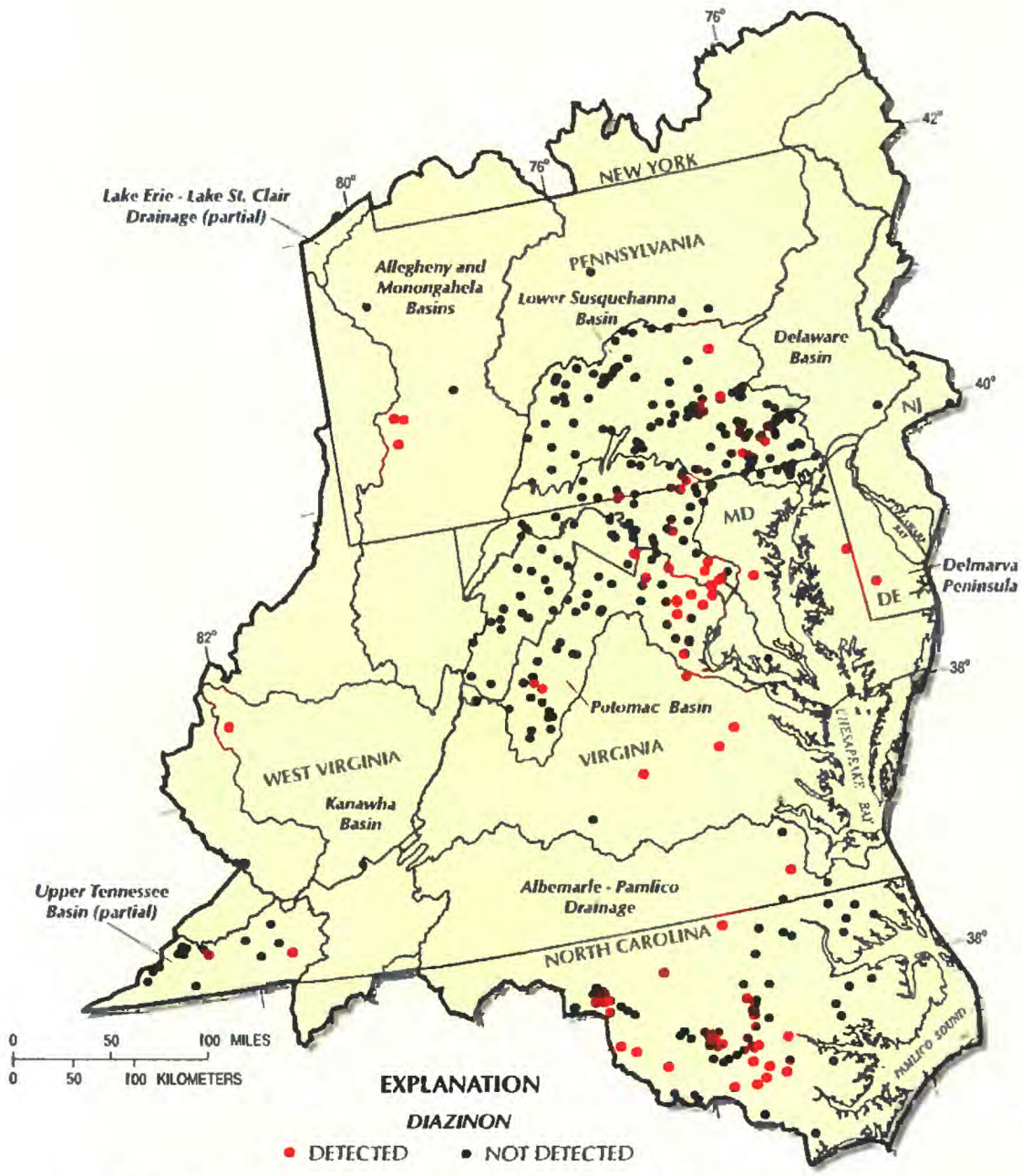


Figure 5. *Location of diazinon detections in the Mid-Atlantic region.*

laboratory method detection limit used for at least some of the samples was higher than the MCL. The concentration of only one pesticide in a single sample was greater than the HA level for children. Concentrations of four pesticides were greater than the adult HA levels, but for two of those compounds (atrazine and simazine), the adult HA level is the same as the MCL.

The USEPA has established Ambient Water-Quality Criteria for the Protection of Aquatic Organisms for 20 of the 127 pesticide compounds for which data were compiled for this report (table 6). However, of the 20 most widely used pes-

Table 4. *Sampling frequency, detection frequency, and summary statistics for selected pesticide compounds in surface water in the Mid-Atlantic region*

Type: H, *herbicide;* I, *insecticide;* D, *degradate* [Concentrations are in micrograms per liter, (µg/L); <, less than]

COMPOUND	TYPE	NUMBER OF ANALYSES	NUMBER OF DETECTIONS	PERCENT OF ANALYSES WITH DETECTIONS	NUMBER OF SITES SAMPLED	NUMBER OF SITES WITH DETECTIONS	PERCENT OF SITES WITH DETECTIONS	CONCENTRATION		
								MEDIAN	90th PERCENTILE	MAXIMUM
Alachlor	H	1,693	649	38.3	416	135	32.5	<0.012S	0.14	7.0
Atrazine	H	2,076	1,489	71.7	421	348	82.7	0.099	0.64	30.
Carbaryl	I	1,128	248	22.0	363	83	22.9	<0.003	0.072	2.0
Chlorpyrifos	I	1,218	175	14.4	37S	59	15.7	<0.004	0.010	0.09
Cyanazine	H	1,319	331	25.1	414	103	24.9	<0.004	0.20	32.
2,4-D	H	786	137	17.4	63	17	27.0	<0.035	0.060	13.
DCPA	H	1,056	132	12.5	360	32	8.9	<0.002	0.002	0.72
Desethylatrazine	D	1,271	907	71.4	409	314	76.8	0.050	0.20	3.1
Diazinon	I	1,795	300	16.7	391	76	19.4	<0.002	0.10	1.4
Dieldrin	I	2,168	133	6.1	391	42	10.7	<0.001	<0.010	0.39
Metolachlor	H	1,693	1,263	74.6	416	337	81.0	0.060	0.73	70.
Metribuzin	H	1,308	131	10.0	411	41	10.0	<0.004	0.050	0.34
Pendimethalin	H	1,056	138	13.1	360	33	9.2	<0.004	0.010	0.32
Prometon	H	1,531	855	55.8	416	268	64.4	0.029	0.15	1.7
Simazine	H	1,995	1,248	62.6	420	300	71.4	0.046	0.43	30.
Tebuthiuron	H	1,058	336	31.8	360	103	28.6	<0.010	0.025	0.26

Water-quality standards and guidelines

The USEPA has established water-quality standards and guidelines that indicate what concentrations of certain chemicals can have adverse effects on human health, aquatic organisms, or wildlife. Several of these standards and guidelines are referred to in this report and are defined below:

Maximum Contaminant Level (MCL) is defined as the maximum permissible level of a contaminant in water that is delivered to any user of a public water system serving a minimum of 25 people. Samples initially are collected quarterly and a running annual average is calculated to determine compliance (Code of Federal Regulations, volume 40, Part 141.24). MCL's are enforceable standards and are established on the basis of health effects, treatment capability, monitoring availability, and costs. These standards apply to finished (treated) drinking water and are used in this report solely for comparison.

Health Advisories (HA) are nonregulatory levels of contaminants in drinking water at which no adverse effects would be expected, and are used for guidance in the absence of regulatory limits. Health advisories have been issued for children and adults for several different exposure periods.

Longer-term health advisory (child) is defined as the concentration of a chemical in drinking water that is not expected to cause any adverse effects up to approximately 7 years of exposure, with a margin of safety. These health advisories are calculated for a 10-kilogram (22-pound) child and assumes the consumption of 1 liter of water per day.

Lifetime health advisory is defined as the concentration of a chemical in drinking water that is not expected to cause any adverse effects over a lifetime of exposure, with a margin of safety. These health advisories are calculated for a 70-kilogram (154-pound) adult and assumes the consumption of 2 liters of water per day.

Ambient Water-Quality Criteria for the Protection of Aquatic Organisms are nonenforceable guidelines for short-term (acute) and long-term (chronic) exposures to some pesticides. These guidelines provide the basis for state standards.

Freshwater acute criteria are concentrations at which 95 percent of a diverse group of genera would not be adversely affected based on an exposure time of 1 hour. If the 1-hour average concentration of a contaminant does not exceed the acute criteria more than once in a 3-year period, aquatic ecosystems should not be adversely affected.

Freshwater chronic criteria are the same as the acute criteria, except that the exposure period is 4 days.

More complete discussions of these standards and guidelines can be found in Nowell and Resek (1994), Larson and others (1997a), and U.S. Environmental Protection Agency (1994b, 1996a).

Table 5. *Water-quality standards and guidelines for protection of human health for pesticides targeted in surface water*

[nsg, no standard or guideline given, All concentrations are in micrograms per liter, (µg/L).]

Compound	Maximum Contaminant Level (MCL)[1]		Health Advisory (HA)[1]			
			Child[2]		Adult[3]	
	MCL	Number of samples greater than the MCL	HA	Number of samples greater than the HA	HA	Number of samples greater than the HA
Aciflurofen	nsg	---	100	0	nsg	---
Alachlor	2	13	nsg	---	nsg	---
Aldicarb	7	0	nsg	---	7	0
Aldicarb sulfone	7	0	nsg	---	7	0
Aldicarb sulfoxide	7	0	nsg	---	7	0
Aldrin	nsg	---	0.3	0	nsg	---
Ametryn	nsg	---	900	0	60	0
Atrazine	3	67	50	0	3	67
Bentazon	nsg	---	300	0	200	0
Bromacil	nsg	---	3,000	0	90	0
Butylate	nsg	---	1,000	0	350	0
Carbaryl	nsg	---	1,000	0	700	0
Carbofuran	40	0	50	0	40	0
Carboxin	nsg	---	1,000	0	700	0
Chloramben	nsg	---	200	0	100	0
Chlordane	2	0	nsg	---	nsg	---
Chlorothalonil	nsg	---	200	0	nsg	---
Chlorpyrifos	nsg	---	30	0	20	0
Cyanazine	nsg	---	20	1	1	8
2,4-D	70	0	100	0	70	0
Dacthal	nsg	---	5,000	0	nsg	---
Diazinon	nsg	---	5	0	0.6	3
Dicamba	nsg	---	300	0	200	0
Dieldrin	nsg	---	0.5	0	nsg	---
Dinoseb	7	0	10	0	7	0
Diphenamid	nsg	---	300	0	200	0
Disulfoton	nsg	---	3	0	0.3	0
Diuron	nsg	---	300	0	10	0
Endrin	2	0	3	0	2	0
Fluometuron	nsg	---	2,000	0	90	0
Fonofos	nsg	---	20	0	10	0
Heptachlor	0.4	0	5	0	nsg	---
Heptachlor epoxide	0.2	0[4]	0.1	0[4]	nsg	---
Hexachlorobenzene	1	0	50	0	nsg	---
Hexazinone	nsg	---	3,000	0	200	0
Lindane	0.2	0	30	0	0.2	0
Malathion	nsg	---	200	0	200	0
MCPA	nsg	---	100	0	10	0
Metolachlor	nsg	---	2,000	0	70	0
Methomyl	nsg	---	300	0	200	0
Methoxychlor	40	0	50	0	40	0
Methyl parathion	nsg	---	30	0	2	0
Metribuzin	nsg	---	300	0	100	0
Oxamyl	200	0	200	0	200	0
Pentachlorphenol	1	0[4]	300	0	nsg	---
Picloram	500	0	700	0	500	0
Prometon	nsg	---	200	0	100	0
Pronamid	nsg	---	800	0	50	0
Propachlor	nsg	---	100	0	90	0
Propazine	nsg	---	500	0	10	0
Propham	nsg	---	5,000	0	100	0
Simazine	4	17	70	0	4	17
Silvex	50	0	70	0	50	0
2,4,5-T	nsg	---	800	0	70	0
Tebuthioron	nsg	---	700	0	500	0
Terbacil	nsg	---	300	0	90	0
Terbufos	nsg	---	1	0	0.9	0
Toxaphene	3	1[4]	nsg	---	nsg	---
Trifluralin	nsg	---	80	0	5	0

[1] U.S. Environmental Protection Agency, 1996a
[2] For a 10-kilogram (22 pound) child over 7-year exposure period
[3] For a 70-kilogram (154-pound) adult over a lifetime exposure period
[4] The laboratory method detection limit for some samples is higher than the water-quality standard

ticides in the Mid-Atlantic region, aquatic life criteria have been established only for chlorpyrifos. Detected concentrations of two compounds, chlorpyrifos and toxaphene, were greater than the acute criteria, but in only one sample each. Concentrations of nine compounds were greater than the chronic criteria. Concentrations of six of these compounds were greater than the chronic criteria in multiple samples, including 14 sites at which this occurred within a 3-year period. However, reported concentrations above a criteria value, especially in a single sample, do not necessarily mean that aquatic organisms were or were not adversely affected. Aquatic life criteria are based on exposures over a specified period and actual exposure times cannot be determined from a single sample.

Temporal variability of selected pesticides

Repetitive sampling for pesticides at fixed sampling locations is necessary to characterize the occurrence and variability of pesticide concentrations in surface waters. Multiple samples collected over a period of at least 1 year allow for analysis of temporal and seasonal variability of pesticide concentrations and for analysis of pesticide concentrations under different flow conditions. More than one sample was collected at many of the surface-water sites, and 20 or more samples were collected at 32 sites (fig. 6, table 7). Collection periods for samples at these 32 sites range from 18 months (Accotink Creek, site 17) to more than 23 years (Delaware River, site 1). These sites also represent a range of basin sizes (7.3 to 27,100 square miles), different land uses, and different lithologies.

The 16 pesticide compounds most commonly detected in the Mid-Atlantic region (table 4) are found in streams year round, but usually at relatively low concentrations. Concentrations of some compounds, however, especially the herbicides, tend to be highest in samples collected during the spring and summer. This is illustrated in figure 7, which shows that the highest concentrations of atrazine tend to occur during May, June, and July; plots for most of the other herbicides are similar. Peak concentrations of the insecticides also tend to occur during these months, but tend to extend through September (fig. 7).

Table 6. *Water-quality guidelines for protection of aquatic life for pesticides targeted in surface water*

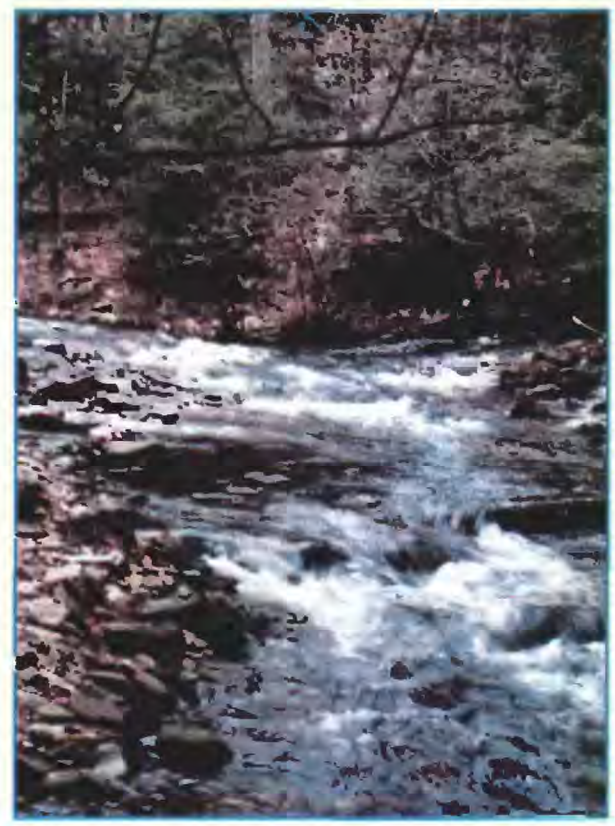
[nsg, no standard or guideline given, All concentrations are in micrograms per liter, (µg/L)]

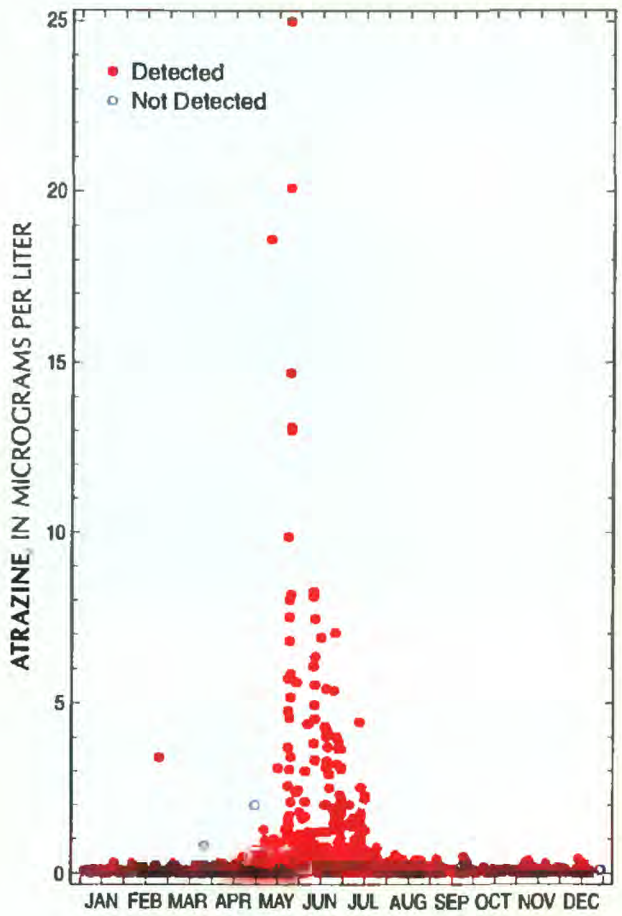
Compound	Ambient Water-Quality Criteria[1]			
	Acute		Chronic	
	Guideline	Number of samples greater than the guideline	Guideline	Number of samples greater than the guideline
Aldrin	3	0	nsg	---
Azinphos-methyl	nsg	---	0.01	14
Chlordane	2.4	0	0.0043	6
Chlorpyrifos	0.083	1	0.041	4
DDD	0.6	0	nsg	---
DDE	1,050	0	nsg	---
DDT	1.1	0	0.001	2
Dieldrin	2.5	0	0.0019	76
Endosulfan	0.22	0	0.056	0
Endrin	0.19	0	0.0023	1
Heptachlor	0.52	0	0.0038	0
Heptachlor epoxide	0.52	0	0.0038	0
Hexachlorobenzene	nsg	---	3.7	0
Lindane	2	0	0.08	1
Malathion	nsg	---	0.1	5
Methoxychlor	nsg	---	0.03	0
Mirex	nsg	---	0.001	0
Parathion	0.065	0	0.013	0
Pentachlorphenol	20	0	13	0
Toxaphene	0.73	1	0.0002[2]	1

[1] Larson and others, 1997a
[2] The laboratory method detection limit for some samples is higher than the water quality standard

Spatial variability of selected pesticides

Land use within a watershed, and implicitly the types and amounts of pesticides used, provides the basis for spatial patterns observed in the Mid-Atlantic region. Sites within basins that have a high percentage of urban land, such as Accotink Creek (site 17), have different pesticide detection frequencies and median concentrations than sites within basins with a high percentage of agricultural land, such as Pequea Creek (site 11;





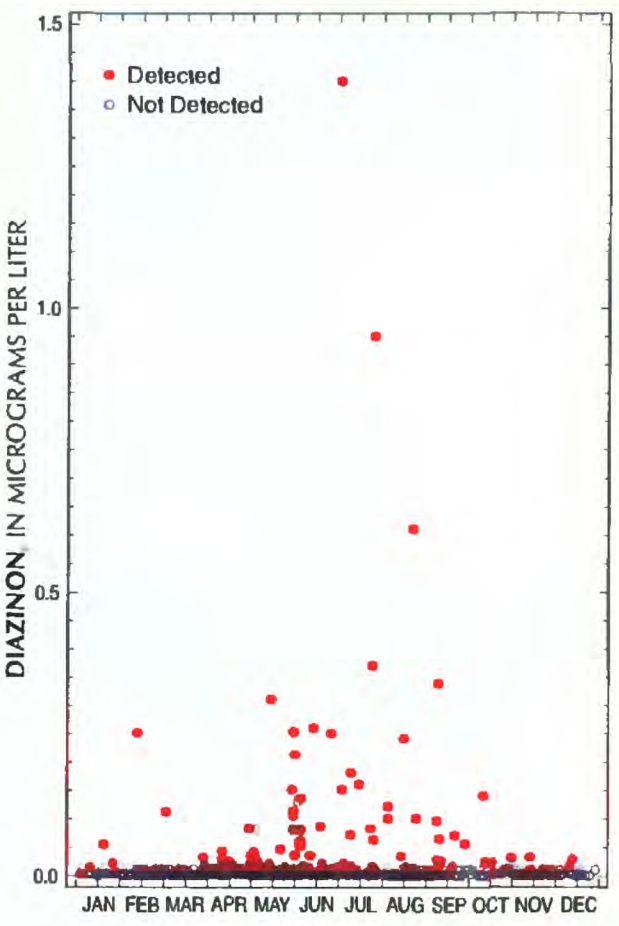


Figure 7. *Concentrations of atrazine (an herbicide) and diazinon (an insecticide) in samples collected at the 32 most frequently sampled sites, 1973-97.*

Figure 6. *Location of sites at which 20 or more samples were collected for analysis of pesticides.*

Table 7. *Number of samples, collection period, and basin characteristics for the surface-water sites in the Mid-Atlantic region with 20 or more samples analyzed for pesticides*

[mi², square mile]

Land Use: *Ag, agriculture; For, forested* ***Lithology:*** *Car, carbonate; Cry, crystalline; Sed, unconsolidated sediments; Sil, siliciclastic*

SITE NO.	USGS STATION NO.	STATION NAME	NUMBER OF SAMPLES	COLLECTION PERIOD	DRAINAGE AREA (mi²)	MAJOR LAND USE[1]	LITHOLOGY[2]
1	01463500	Delaware River at Trenton, NJ	32	8/73-1/97	6,780	Ag/For	Sil/Cry
2	01491000	Choptank River near Greensboro, MD	30	5/75-11/94	113	For/Ag	Sed
3	01553500	West Branch Susquehanna River at Lewisburg, PA	25	3/75-7/94	6,850	For	Sil
4	01555400	East Mahantango Creek at Klingerstown, PA	46	3/93-6/95	44.7	Ag	Sil
5	01570500	Susquehanna River at Harrisburg, PA	181	3/75-8/95	24,100	For/Ag	Sil
6	01571490	Cedar Run at Eberlys Mill, PA	101	3/93-8/95	12.6	Urban	Car
7	01573095	Bachman Run at Annville, PA	51	5/94-8/95	7.3	Ag	Car
8	01576000	Susquehanna River at Marietta, PA	28	10/91-6/94	26,000	For/Ag	Sil
9	01576540	Mill Creek at Eshelman Mill Rd. near Lyndon, PA	149	2/92-8/95	54.2	Ag	Car
10	01576754	Conestoga River at Conestoga, PA	82	2/92-7/95	470	Ag/For	Car
11	01576787	Pequea Creek at Martic Forge, PA	97	2/92-7/95	148	Ag	Car/Cry
12	01578310	Susquehanna River at Conowingo, MD	158	8/78-2/97	27,100	For/Ag	Sil
13	01621050	Muddy Creek at Mount Clinton, VA	39	3/93-5/95	14.2	Ag	Car
14	01636500	Shenandoah River at Millville, WVA	24	8/76-9/96	3,040	For/Ag	Car/Sil
15	01639000	Monocacy River at Bridgeport, MD	43	6/92-6/96	173	Ag	Sil
16	01646580	Potomac River at Chain Bridge at Washington, DC	65	10/76-9/96	11,600	For/Ag	Sil
17	01654000	Accotink Creek near Annandale, VA	43	3/94-8/95	23.5	Urban	Cry
18	01673000	Pamunkey River near Hanover, VA	25	3/75-10/94	1,080	For/Ag	Cry
19	02035000	James River at Cartersville, VA	82	11/79-11/94	6,260	For	Cry
20	02049500	Blackwater River near Franklin, VA	32	3/75-5/82	617	For/Ag	Sed
21	02082731	Devils Cradle Creek at SR 1412 near Alert, NC	28	3/93-8/94	13.4	Ag/For	Cry
22	02083500	Tar River at Tarboro, NC	20	3/93-8/94	2,180	Ag/For	Cry/Sed
23	02083833	Pete Mitchell Swamp at SR 1409, Penny Hill, NC	36	3/93-6/95	11.0	Ag/For	Sed
24	02084160	Chicod Creek at SR 1760 near Simpson, NC	42	5/92-6/95	45.0	For/Ag	Sed
25	02084558	Albemarle Canal near Swindell, NC	34	3/93-6/95	68.0	For/Ag	Sed
26	02085500	Flat River at Bahama, NC	20	4/88-2/94	149	For/Ag	Sil
27	02087570	Neuse River at Smithfield, NC	20	11/88-3/94	1,210	Ag/For	Sil
28	02089500	Neuse River at Kinston, NC	28	4/75-6/95	2,690	Ag/For	Sil/Sed
29	03049625	Allegheny River at New Kensington, PA	27	6/75-9/95	11,500	Ag/For	Sil
30	03085000	Monongahela River at Braddock, PA	27	3/75-9/95	7,340	Ag/For	Sil
31	03201300	Kanawha River at Winfield, WVA	27	4/75-3/97	11,800	For/Ag	Sil
32	03526000	Copper Creek near Gate City, VA	36	7/95-2/97	106	For/Ag	Sil

[1] *For sites with multiple land uses, the predominant land use is listed first.*

[2] *For sites with multiple lithologies, the predominant lithology is listed first.*

fig. 8). The highest maximum concentrations of 4 of the 16 most frequently detected compounds (carbaryl, diazinon, pendimethalin, and prometon) also were observed in samples from Accotink Creek. For the 16 most commonly detected compounds, the highest median concentrations of three out of four of the insecticides (carbaryl, chlorpyrifos, and diazinon) were found at Accotink Creek. Accotink Creek also had the highest detection frequencies of chlorpyrifos and diazinon (80 and 53 percent of samples) and the second highest detection frequency of carbaryl (79 percent) among the 32 long-term sites. Although atrazine and metolachlor were detected frequently at Accotink Creek (in 77 and 98 percent of samples, respectively), median concentrations of both compounds were lower (0.009 and 0.017 µg/L, respectively) than the overall median concentrations for the 32 long-term sites (0.06 and 0.046 µg/L, respectively). Conversely, streams draining basins with a high percentage of agricultural land use, such as Pequea Creek (site 11) and Conestoga River (site 10), had very few detections of carbaryl, chlorpyrifos, of diazinon, and the highest median concentrations of atrazine (Pequea Creek) and metolachlor (Conestoga River).

Hydrologic variability of selected pesticides

Some of the variability in pesticide concentrations in streams can be explained by examining streamflows during periods of pesticide application. During these periods, pesticide concentrations generally increase with increasing flow in streams of the Mid-Atlantic, although the reverse is true for atrazine in streams draining predominantly urban areas. Concentrations of the two most commonly detected herbicides (atrazine and metolachlor) and insecticides (diazinon and chlorpyrifos) in the Mid-Atlantic region were statistically correlated with streamflow during sample collection at each of the 32 most frequently sampled sites. Because the greatest variability in the concentrations of most pesticides in Mid-Atlantic streams occurred during the growing season, only herbicide data collected between May 1 and August 31, and insecticide data collected between April 1 and September 30, were used in these analyses. To ensure common minimum detection levels for each compound, data were further restricted to samples analyzed using a single laboratory method established for the NAWQA program. Correlations were statistically significant only for streams draining less than 55 square miles (table 8), which are typically affected more dramatically by high-flow events than are larger streams. Similar relations between streamflow and pesticide concentrations may exist for larger streams, but no statistical correlation could be established on the basis of available data.

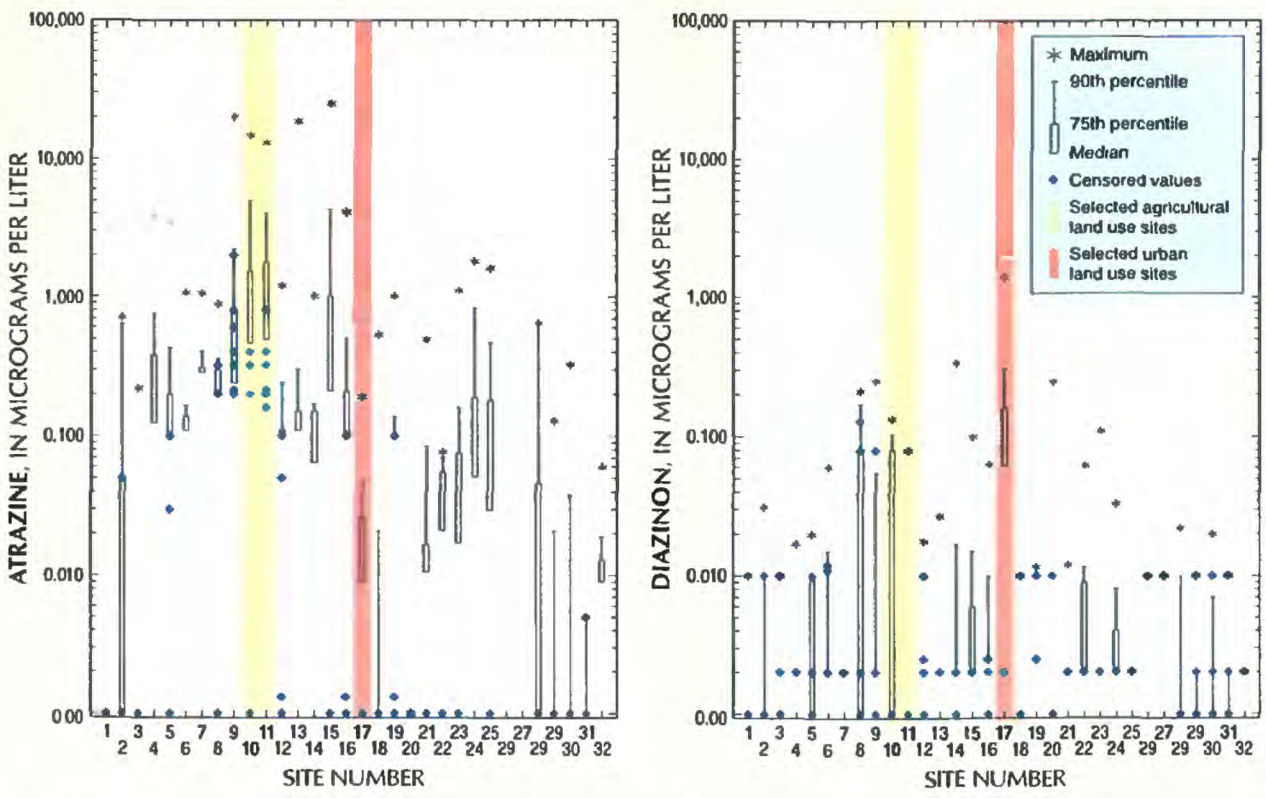


Figure 8. *Distribution of atrazine and diazinon in samples from the 32 most frequently sampled sites. (See site numbers and locations in Table 7.)*

Concentrations of several commonly detected pesticides generally increase during high-flow events in the growing season in small streams of the Mid-Atlantic region. Where significant correlations exist, atrazine, metolachlor, diazinon, and chlorpyrifos concentrations in small streams typically increase with increasing flow, although this is reversed for atrazine in streams draining predominantly urban watersheds (table 8). During storms, runoff can wash large amounts of pesticides to streams, particularly during or shortly after periods of application. Storm runoff during these periods often contains pesticides at concentrations far exceeding that of streams at low flow, which are composed mostly of groundwater discharge. In Mill Creek (site 9), for example, high-flow concentrations of metolachlor are as much as 30 times that of low-flow concentrations (fig. 9).

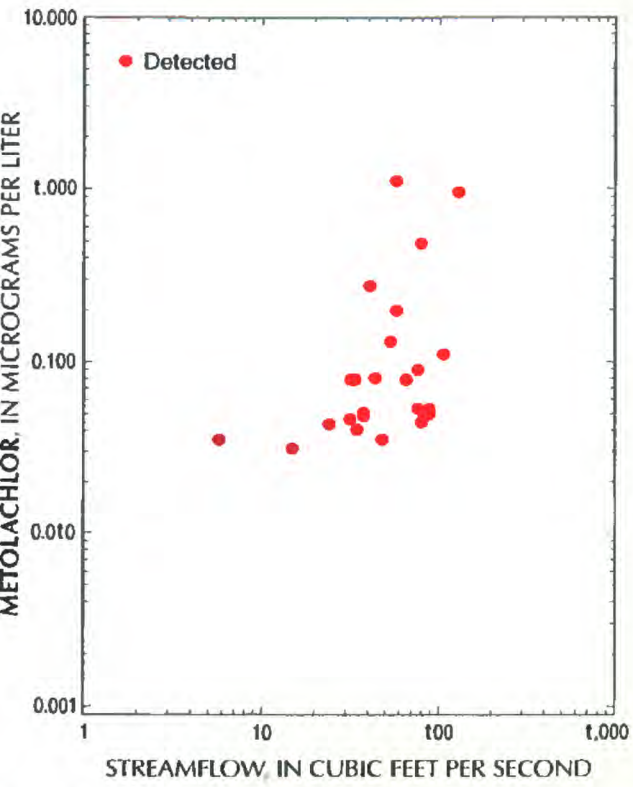


Figure 9. *Metolachlor concentrations and streamflow at Mill Creek at Eshelman Road near Lyndon, PA, May 1 through August 30.*

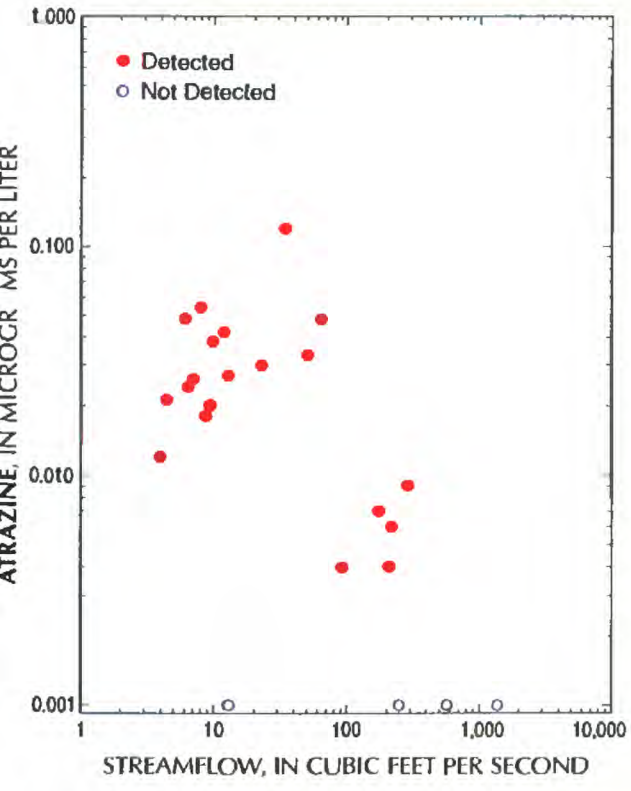


Figure 10. *Atrazine concentrations and streamflow at Accotink Creek near Annandale, VA, May 1 through August 30.*

Atrazine concentrations decrease during high-flow events in the growing season at Accotink Creek (site 17; fig. 10) and Cedar Run (site 6), which drain predominantly urban areas (table 8). This dilution may indicate that storm runoff from urban areas contains less atrazine than streams during low flow. In humid areas such as the Mid-Atlantic region, ground-water discharge provides most of the flow to streams during dry periods. Ground-water discharge to urban streams during the growing season may contain atrazine applied during previous seasons or years or in adjacent watersheds. Ground water typically flows much slower than water in streams and may flow across surface drainage divides (Greene, 1997). Although urban pesticide uses are not well documented, atrazine is used mainly on row crops and likely in much smaller quantities in urban areas than other pesticides, particularly insecticides such as diazinon or chlorpyrifos, which increase in concentration during high-flows at Accotink Creek and Cedar Run.

SUMMARY AND IMPLICATIONS

Pesticides were present in samples of surface water collected by the U.S. Geological Survey between October 1973 and March 1997 throughout the Mid-Atlantic region. Pesticide compounds were detected in about 75 percent of the samples collected and at more than 90 percent of the sites sampled. Atrazine and metolachlor, the most widely used agricultural pesticides in the Mid-Atlantic region, were the most commonly detected pesticide compounds, and were present in more than 70 percent of samples for which they were analyzed. Concentrations of several pesticides were found to be greater than the Federal Maximum Contaminant Levels or Health Advisory levels for drinking water. Concentrations of 9 pesticides were found to be greater than Federal Ambient Water-Quality Criteria for the Protection of Aquatic Organisms, but these concentrations do not necessarily imply that aquatic organisms have been adversely affected. However, although Ambient Water-Quality Criteria have been established for a number of pesticides, of the 20 most widely used agricultural pesticides in the Mid-Atlantic region, Ambient Water-Quality Criteria have been established only for chlorpyrifos. Possible cumulative effects of multiple pesticides present in water on human or environmental health are not known. In addition, chemical analyses of relatively few pesticide degradation products have been conducted and the possible adverse effects of these degradation products on human and ecological health are unknown.

Likely sources of pesticides to surface water in the Mid-Atlantic region include urban and agricultural practices. Median concentrations of herbicides tend to be highest in basins where agriculture is the major land use, whereas median concentrations of insecticides tend to be highest in basins where the major land use is urban. Concentrations of herbicides and insecticides usually are highest during the spring and summer, the usual application period for pesticides used in agriculture, although many pesticides are present at low concentrations in surface water throughout the year.

During periods of pesticide application (typically spring and summer), the occurrence of selected pesticides in surface water in the Mid-Atlantic region is related to streamflow at selected sites. Correlations between concentrations of selected pesticides and streamflow are statistically significant during spring and summer for small (draining less than 55 square miles) streams. Concentrations of selected pesticides in small streams increase during high flows in the growing season, up to 30 times the concentrations present during low-flow conditions in the growing season. In small streams draining urban areas, concentrations of atrazine decrease during high-flow events, but concentrations of the insecticides diazinon and chlorpyrifos increase. This may be due to the differences in the pesticides used in agricultural and urban areas and the amounts applied.

Table 8. *Correlations between pesticide concentrations and streamflow*

[mi^2, square mile]
Land Use: *Ag, agriculture, For, forested*
Results of Correlations: *+, positive correlation (concentration increases with increasing flow), −, negative correlation (concentration decreases with increasing flow), blank, no correlation*

SITE NO.	STATION NAME	DRAINAGE AREA (mi^2)	MAJOR LAND USE	RESULTS OF CORRELATIONS[1]			
				Atrazine	Metolachlor	Diazinon	Chlorpyrifos
6	Cedar Run at Eberlys Mill, PA	12.6	Urban	−	+	+	+
9	Mill Creek at Eshelman Mill Rd. near Lyndon, PA	54.2	Ag		+		
13	Muddy Creek at Mount Clinton, VA	14.2	Ag	+	+		
17	Accotink Creek near Annandale, VA	23.5	Urban	−			
21	Devils Cradle Creek at SR 1412 near Alert, NC	13.4	Ag/For	+	+		
23	Pete Mitchell Swamp at SR 1409, Penny Hill, NC	11.0	Ag/For	+			
24	Chicod Creek at SR 1760 near Simpson, NC	45.0	For/Ag			+	

[1]*Kendall's tau (Helsel and Hirsch, 1992). Results are shown only where significant at the 95 percent confidence level.*

A more thorough understanding of pesticides in surface water of the Mid-Atlantic region would require further study. Spatial gaps in existing regional data include much of Pennsylvania, Virginia, West Virginia, and southern New York and western New Jersey. Future sampling is planned in some of these areas. Long-term sampling for pesticides in surface water at additional urban sites would be necessary to allow statistical comparisons of pesticide concentrations in surface water from basins with different land uses. A random sampling of surface water from basins throughout the region would have consistent detection levels and therefore provide more statistical power for comparisons of water quality and possibly allow for the statistical analysis of explanatory variables such as land use and rock type. More complete information on drainage basin delineation also would be needed to determine land use and lithology within the basins.

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