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Pesticides in Ground Water of Central and Western Maryland

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Abstract

Selected pesticides and degradates (products of pesticide degradation) are detectable in ground water in many parts of central and western Maryland, although concentrations are generally less than 0.1 micrograms per liter. Ground-water samples collected recently (1994–2003) from 72 wells in areas of Maryland underlain by consolidated carbonate, crystalline, or siliciclastic aquifers (areas north and west of the Fall Line) were analyzed for selected pesticides and degradates. Pesticides were typically detected in mixtures of multiple compounds in ground water, and degradates were commonly detected, often at greater concentrations than their respective parent compounds. No pesticides were observed at concentrations greater than established standards for drinking water, and nearly all observed concentrations were below other health-based guidelines. Although such standards and guidelines are generally much greater than measured concentrations in ground water, they do not exist for many detected compounds (particularly degradates), or for mixtures of multiple compounds. The distribution of pesticides and degradates in ground water is related to application practices, as well as chemical and environmental factors that affect the fate and movement of individual compounds.

Introduction

Pesticides are synthetic organic chemicals used to control weeds, insects, and other pests. Nationally, about 75 percent of all pesticide use is agricultural, although pesticides also are used for commercial, domestic, industrial, transportation, public-health, and other applications (Kiely and others, 2004).

The occurrence and distribution of pesticides in ground water is affected by the chemical and physical properties of individual compounds and natural factors that affect their fate and movement in the environment, as well as land use and application patterns (Barbash and Resek, 1996). Pesticides applied to the land surface or incorporated into soil can be carried as dissolved compounds in water from rainfall or irrigation that travels through the soil and unsaturated zone to ground water. Pesticide transport into ground water is most likely in well-drained areas with highly permeable sandy soils and aquifers (Helling and Gish, 1986), such as coarse-grained sediments or highly fractured rock (Gilliom and others, 2006). Pesticides that are typically detected most frequently in ground water are those that are used most frequently, are relatively water soluble, and (or) have the greatest mobility and (or) persistence in the environment (Gilliom and others, 2006). Chemicals with low persistence rapidly degrade to other compounds, referred to as degradates.

Pesticides in ground water may cause ecological and human-health effects. Many pesticides are toxic or known or suspected carcinogens (Toccalino and others, 2004; U.S. Environmental Protection Agency, 2004), and the occurrence of pesticides may affect the suitability of ground water for human consumption. Ground water also contributes the majority of water to streams in many areas, and may be the only source of water during dry periods. Ground water may thus contribute pesticides to streams and downstream estuaries.

The occurrence and distribution of selected pesticides and degradate compounds in ground water in parts of central and western Maryland (north and west of the Fall Line, fig. 1) are described and discussed in this report. Concentrations of selected compounds measured in water samples collected recently (1994–2003) as part of U.S. Geological Survey (USGS) or Maryland Geological Survey (MGS) programs from 72 wells throughout the study area are included. The importance of natural and human influences on the distribution of pesticides in ground water in such settings is discussed, along with potential implications of observed pesticides for water supply, stream ecology, and water-resources management.

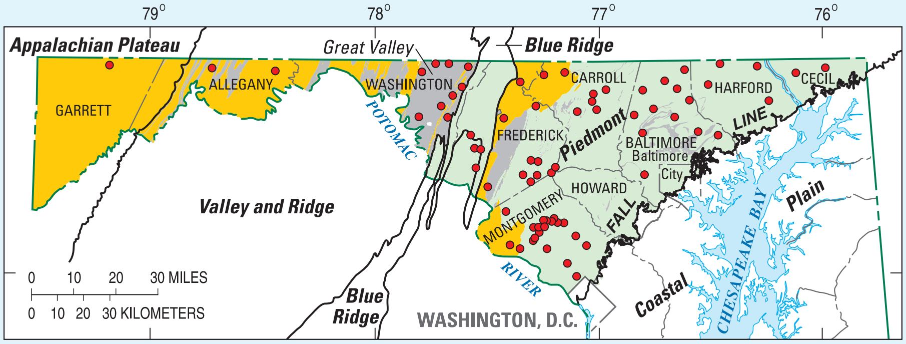


Figure 1. Generalized geology and physiography in central and western Maryland and locations of 72 wells sampled, 1994–2003.

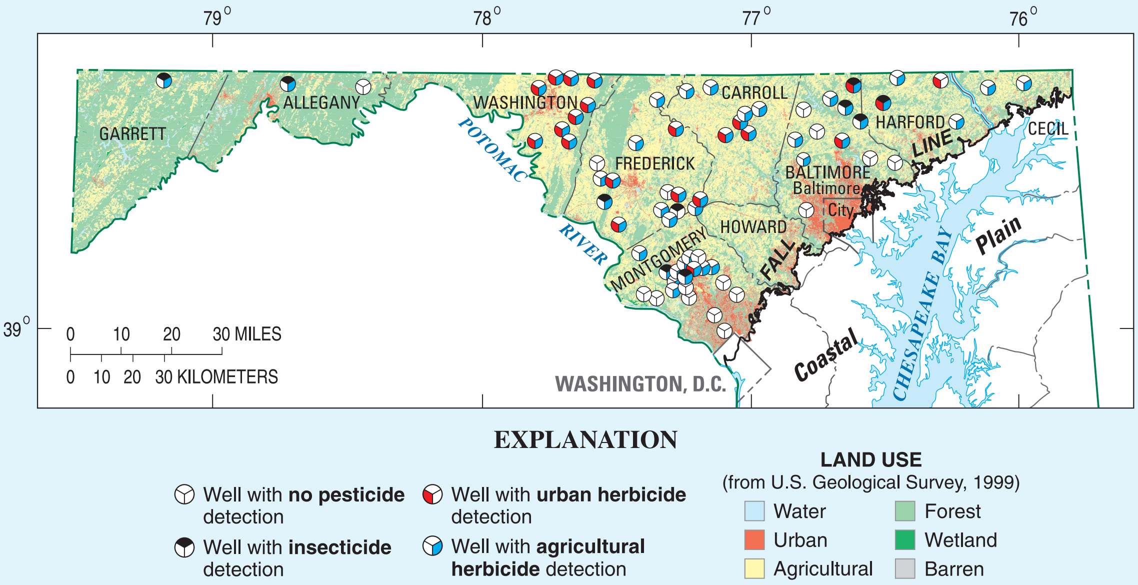


Figure 2. Generalized land use and summary of pesticides in ground water in central and western Maryland, 1994–2003.

Central and Western Maryland

Central and western Maryland are geologically diverse and underlain primarily by consolidated rocks of three major types (Bolton, 1996) (fig. 1). The Blue Ridge and most of the Piedmont Physiographic Provinces are underlain by crystalline (metamorphic or igneous) rocks. The remainder of central and western Maryland is underlain by sedimentary rocks, including siliciclastic rocks (such as sandstone), and carbonate rocks (such as limestone). Consolidated crystalline, siliciclastic, and carbonate rocks outcrop at the surface in many places, but are commonly overlain by regolith (weathered rock) of varying thickness (over 100 feet in places).

Ground water originates as precipitation and occurs throughout the study area, primarily in fractures, joints, and other secondary openings in the otherwise relatively impermeable consolidated rocks, and in voids and openings in the overlying regolith (Bolton, 1996). Ground water continually flows through these fractures and other voids, generally from upland recharge areas to discharge areas in nearby streams and other surface waters. Ground-water discharge provides the majority of flow in most streams in the area. Ground-water flow is generally slow, however, and years or decades are often required for ground water to move even relatively short distances. Because carbonate minerals are particularly soluble, fractures and other voids in carbonate rocks are often enlarged by dissolution and become considerably larger than in other types of rock. Ground-water flow in carbonate aquifers is therefore often unusually rapid, and such aquifers are particularly vulnerable to contamination from chemicals applied at the land surface.

Pesticide applications (table 1) reflect primary land-use activities (fig. 2) in different areas. The most heavily applied compounds are herbicides used primarily for agricultural applications, such as glyphosate, atrazine, and metolachlor. Insecticides and other herbicides (such as simazine) often are used for both agricultural and urban purposes. Pesticide use has changed over time as new compounds are introduced and others are discontinued. Alachlor use, for example, has greatly declined since the introduction of acetochlor in the mid-1990s (Maryland Department of Agriculture, 1996, 2002). In addition, the use of several insecticides, including diazinon, chlorpyrifos, and dieldrin, was recently banned or greatly reduced.

Ground-water quality in central and western Maryland reflects natural sources of ions in consolidated rocks, regolith, and soils, as well as human influences from overlying land-use and related activities (Bolton, 1996). Ground water is vulnerable to contamination from surficial sources in many areas, particularly where infiltration is enhanced by permeable regolith and (or) abundant fracturing or (particularly in carbonate aquifers) solution cavities. Chemicals from human activities that have been detected in ground water of central and western Maryland include nutrients from fertilizer and manure applications, pesticides, and volatile organic compounds (Bolton, 1996).

Measuring Pesticides in Ground Water

Concentrations of pesticides and degradate compounds described herein were measured in samples collected as part of water-quality studies conducted by the USGS and MGS (table 2). Recent pesticide data for parts of central and western Maryland are available from several regional ground-water studies conducted as part of the USGS National Water-Quality Assessment (NAWQA) Program (table 2) (Gilliom and others, 2006). ***Land-use studies*** are designed to evaluate the quality of relatively shallow, recently recharged ground water in a particular land-use setting, whereas ***major-aquifer studies*** are designed to evaluate ground water throughout an aquifer. In addition, ***drinking-water studies*** are designed specifically to evaluate ground water used for public supply. Regional networks are established for each type of study, typically including 15 to 30 wells that are areally distributed throughout the targeted setting. Pesticide concentrations measured using comparable analytical methods as part of additional ground-water studies conducted cooperatively by MGS and USGS in parts of Maryland (Bolton, 1996, 1998) were also included (table 2). Due to the unusually high density of such data (at more than 100 wells) in Baltimore County (Bolton, 1998), a random subset of these data were included herein.

Water samples were recently collected (1994 through 2003) from each well in the regional networks and analyzed for various chemical compounds, including selected pesticides and degradates (table 3). Although some network wells are used for water supply, samples were collected prior to any treatment, and therefore represent the available ground-water resource rather than (necessarily) drinking water. Pesticides and degradate compounds were measured in filtered water samples using analytical methods designed to measure low concentrations, around 0.001 – 0.005 µg/L (micrograms per liter) for some compounds. Although these concentrations may be far below established water-quality standards, such information is useful for detecting trends in pesticide concentrations and understanding natural and human influences affecting pesticide occurrence in ground water.

Pesticides in Ground Water of Central and Western Maryland

A variety of pesticides and degradate compounds are detectable in ground water of central and western Maryland, although measured concentrations are typically low. Of the more than 150 different pesticide and

Table 1. Estimated applications of selected pesticides[1] in central and western Maryland, 2000.

[Compounds in parentheses were not included in ground-water analyses (see table 3); FM, fumigant; FN, fungicide; H, herbicide; I, insecticide]

Compound	Type	Active ingredient applied[2] (pounds)
(Glyphosate)	H	374,000
Pendimethalin	H	336,000
Atrazine	H	317,000
Metolachlor[3]	H	258,000
2,4-D	H	172,000
Simazine	H	138,000
Isofenphos	I	133,000
(Metam-Sodium)	FM	127,000
Imidachloprid	I	121,000
Chlorpyrifos	I	105,000
(Paraquat)	H	87,000
Chlorothalonil	FN	75,000
S-Metolachlor[3]	H	41,000
(Glyphosate-trimesium)	H	33,000

[1] Data modified from Maryland Department of Agriculture, 2002. Compounds with more than 100,000 pounds of active ingredient applied statewide are included. Excludes chromated copper arsenate (CCA), cuprous oxide, and petroleum oils.

[2] Sum of total application estimates for counties in central and western Maryland.

[3] Ground-water analyses described herein do not distinguish between these compounds.

degradate compounds for which samples were analyzed, 27 were detected at least once (table 3, fig. 3). Measured concentrations of pesticide compounds rarely exceeded 1 µg/L, and typically were less than 0.1 µg/L. No samples contained any detected pesticide at a concentration exceeding established Federal drinking-water standards (MCLs), although such standards exist for only five of the detected compounds (fig. 3). Non-regulatory health-based screening levels (HBSLs) (see inset, page 4) for an additional 12 detected compounds were similarly rarely exceeded, although 1 sample contained dieldrin at a concentration exceeding 0.002 µg/L.

Herbicides typically used for agricultural applications and their degradates were the most commonly detected pesticide compounds in ground water of central and western Maryland (fig. 3). Atrazine and metolachlor were the most commonly detected parent compounds; each was detected in more than half of the 72 samples for which they were analyzed (fig. 3). Degradates of atrazine, metolachlor, and alachlor also were detected in at least half of the typically more limited number of samples for which such data are available. No insecticides or herbicides commonly used for non-agricultural purposes were detected in more than 30 percent of samples for which they were analyzed, and only two such compounds (the herbicides simazine and prometon) were detected in more than 10 percent of such samples (fig. 3). Carbofuran was the most commonly detected insecticide (in 4 of 62 samples); no other insecticide or insecticide degradate was detected in as many as 5 percent of samples for which it was analyzed. The prevalence of agricultural herbicides and their degradates among detected compounds likely reflects the estimated applications of these compounds (table 1) and the prevalence of such compounds among target analytes (table 3). Also, agriculture is a dominant land use in some sampled areas (particularly in parts of the Piedmont and Great Valley) (fig. 2) and was specifically targeted in some studies (table 2). Agricultural herbicides are similarly the most commonly detected pesticide compounds in ground water of the Maryland Coastal Plain, likely for similar reasons (Denver and Ator, 2006).

Pesticide degradates represent a significant part of the total pesticide occurrence in ground water of central and western Maryland, and concentrations may exceed those of their respective parent compounds. Nine of the 27 compounds detected in ground water are pesticide degradates (fig. 3). Most pesticide degradation occurs in the soil zone prior to infiltration to ground water (Barbash and Resek, 1996). ESA (ethanesulfonic acid) and OA (oxanilic acid) degradates of metolachlor and alachlor are also more soluble than their respective parent compounds (Phillips and others, 1999), and these degradates have therefore often been detected at greater concentrations and frequencies than their parent compounds in ground water and streams in Maryland and other areas (Denver and others, 2004; Debrewer and others, 2007). Limited available data from 13 wells in the Maryland Piedmont and Great Valley suggest a similar pattern of occurrence; the median metolachlor concentration among these samples (0.005 µg/L) was 10 times smaller than the median metolachlor OA concentration (0.05 µg/L), and more than 100 times smaller than the median metolachlor ESA concentration (0.59 µg/L). Similarly, the median alachlor ESA concentration among these samples was 0.05 µg/L, whereas only 1 such sample contained alachlor at concentrations greater than 0.005 µg/L. Concentrations of deethylatrazine, however, are more comparable to those of its parent compound, atrazine. Atrazine degrades primarily to hydroxyatrazine, a degradate that is less mobile and more likely to sorb to soils (Barbash and Resek, 1996). Deethylatrazine concentrations in ground water therefore do not likely reflect the complete occurrence of atrazine degradates in the environment.

When present in ground water of central and western Maryland, pesticide compounds often occur in mixtures. Because the 72 ground-water samples were analyzed for a widely variable number of compounds (table 3), direct comparisons of the number of compounds and specific individual compounds occurring in mixtures among samples are difficult. Of the 55 samples with at least 1 detectable compound, however, 48 (87 percent) contained multiple compounds. Forty percent (22) of these samples contained

Table 2. U.S. Geological Survey and Maryland Geological Survey ground-water-quality studies from which data were compiled for this report.

[C, carbonate; S, siliciclastic; X, crystalline]

Study	Targeted setting	Geographic extent	Included rock type(s)	Number of wells	Median well depth (feet)
Land-Use Study— *Piedmont*[1]	Shallow ground water beneath recently developed urban areas, and reference conditions in a nearby forested area	Piedmont, Potomac River Basin, Washington, D.C. metropolitan area	X	14	59
Major-Aquifer Study— *Piedmont*[1]	Ground water typically used for domestic supply	Piedmont, Potomac, and Susquehanna River Basins	C, S, X	24	146
Drinking Water Study— *Piedmont*[1]	Ground water typically used for public supply	Piedmont, Potomac River Basin	X	10	300
Land-Use Study— *Valley and Ridge*[1]	Shallow ground water beneath agricultural areas, and reference conditions in nearby forested areas	Valley and Ridge, Potomac River Basin	C, S	4	196
Other Ground-Water Studies[2]	Unconfined ground water	Maryland	C, S, X	20	136

[1] Gerhart and Brakebill, 1997; Lindsey and others, 2006.
[2] Bolton, 1996, 1998.

Ground Water and Drinking Water

Available standards and guidelines for drinking water provide a context for understanding the significance of observed pesticide concentrations in ground water. ***Maximum Contaminant Levels*** (MCLs) are enforceable standards for the maximum level of a contaminant in drinking water (U.S. Environmental Protection Agency, 2004). For unregulated compounds (those with no established MCL or other standard), non-enforceable ***Health-Based Screening Levels*** (HBSLs) have been estimated on the basis of U.S. Environmental Protection Agency (USEPA) methodologies and toxicity data for comparison to water quality (Toccalino and others, 2004). Both MCLs and HBSLs apply to concentrations in drinking water, rather than untreated ("raw") ground water described in this report, however. Also, single samples from a well have limited utility for estimating potential exposure over time. Interpreting observed ground-water quality in a human-health context is also complicated by the lack of MCLs or HBSLs for many compounds, and the HBSL for one detected compound (dieldrin) is lower than the current laboratory reporting level (Toccalino and others, 2004). Also, MCLs and HBSLs do not exist for mixtures of multiple compounds; understanding potential effects of multiple compounds on human health is complicated by a current lack of information on the toxicity of such mixtures (Toccalino and others, 2004; Gilliom and others, 2006).

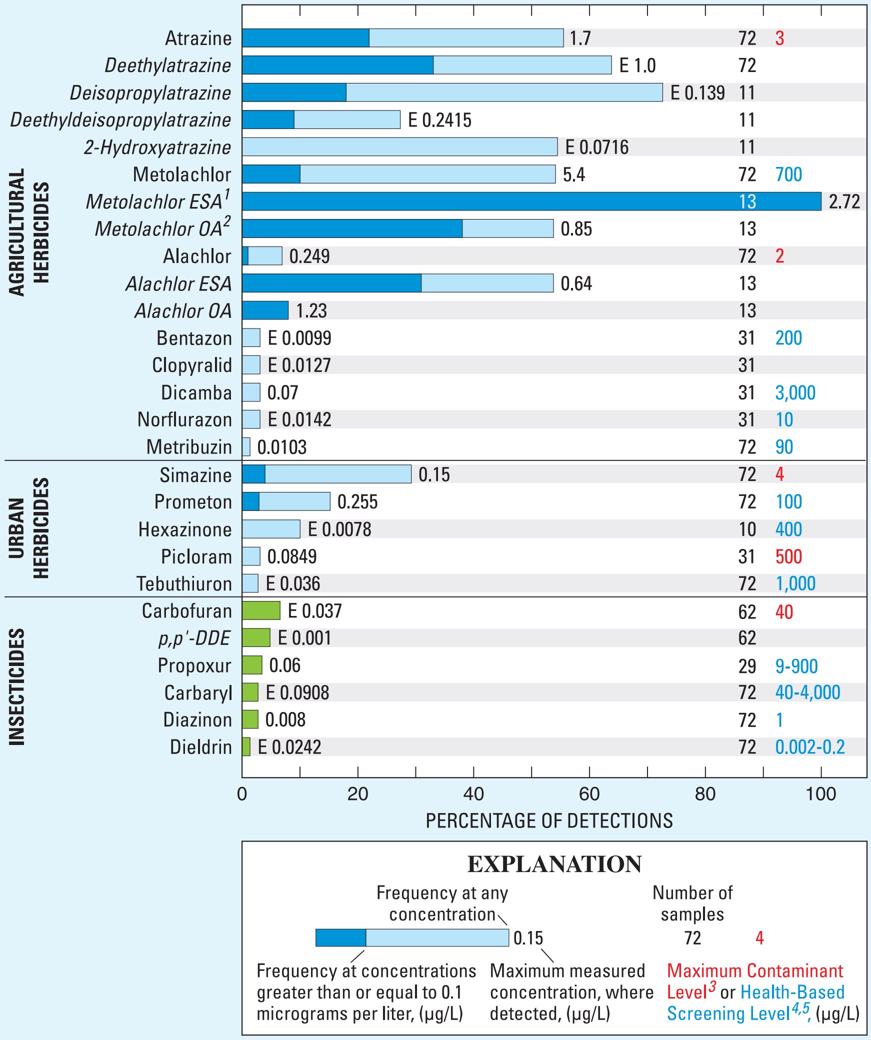
5 or more compounds, and one sample contained 15 different detectable compounds. Multiple compounds also were detected in a majority of ground-water samples recently collected (2001–2004) in the Maryland Coastal Plain (Denver and Ator, 2006), and about half (47 percent) of shallow wells in agricultural areas and 37 percent of such wells in urban areas across the Nation sampled recently (1992–2001) by the NAWQA Program contained two or more detectable pesticides or degradates (Gilliom and others, 2006). The prevalence of pesticide mixtures in ground water reflects similar patterns in usage; multiple compounds are often applied to the same area (often in mixed formulations) for greater pest control. In addition, many pesticides have similar chemical properties that control their fate and movement in the environment.

The occurrence and distribution of pesticides in ground water are generally related to broad land-use patterns reflective of application practices, although such relations are complicated by local variability in land use and multiple uses of some compounds (Gilliom and others, 2006). Pesticides are typically most commonly detected near agricultural or urban areas where they are used (Gilliom and others, 2006; Lindsey and others, 2006). The wide distribution of agricultural herbicides and corresponding degradates in ground water in central and western Maryland reflects the similarly wide distribution of agriculture (fig. 2); insecticides and other herbicides are less commonly detected (fig. 3) and less widely distributed (fig. 2). Lindsey and others (2006) found that the occurrence of alachlor, atrazine, deethylatrazine, and simazine in ground water in

Table 3. Pesticides and degradate compounds for which ground-water samples were analyzed in central and western Maryland, 1994–2003.

[Degradates are listed in *italics*; compounds detected in ground water are shown in **bold** (see fig. 3); ESA, ethanesulfonic acid; OA, oxanilic acid; SSA, sulfynilacetic acid; number of samples is shown in parentheses.]

1-Naphthol (30)	Chloro DiEthyl Acetanilide (10)	Ethoxyoctylphenol (10)	Napropamide (62)
2,4,5-T (20)	Chloro phenyl methyl urea (11)	Ethyl methyl phenyl amino propanol (10)	Neburon (31)
2,4-D (31)	Chlorothalonil (31)	Fenamiphos (10)	Nicosulfuron (11)
2,4-D methyl ester (11)	Chlorpyrifos (72)	*Fenamiphos sulfone* (10)	**Norflurazon** (31)
2,4-DB (31)	*Chlorpyrifos oxon* (10)	*Fenamiphos sulfoxide* (10)	Oryzalin (31)
2,6-Diethylaniline (72)	*cis*-Permethrin (72)	Fenuron (31)	Oxamyl (31)
2-Ethyl-6-methylaniline (10)	**Clopyralid** (31)	Fipronil (24)	***p,p'-DDE*** (62)
2-Hydroxyatrazine (11)	Cyanazine (62)	*Fipronil sulfide* (24)	Parathion (62)
3,4-Dichloroaniline (10)	Cycloate (11)	*Fipronil sulfone* (24)	Pebulate (62)
3-Hydroxycarbofuran (31)	Cyfluthrin (10)	*Flufenacet ESA* (13)	Pendimethalin (72)
3-Ketocarbofuran (11)	Cypermethrin (10)	*Flufenacet OA* (13)	Phorate (72)
4-Chloro-2-methylphenol (10)	Dacthalmonoacid (31)	Flumetsulam (11)	*Phorate oxon* (10)
Acetochlor (45)	DCPA (72)	Fluometuron (31)	Phosmet (10)
Acetochlor ESA (13)	***Deethylatrazine*** (72)	Fonofos (72)	*Phosmet oxon* (10)
Acetochlor OA (13)	***Deethyldeisopropylatrazine*** (11)	*Fonofos oxon* (10)	**Picloram** (31)
Acetochlor SSA (13)	***Deisopropylatrazine*** (11)	**Hexazinone** (10)	**Prometon** (72)
Acifluorfen (31)	Desulfinylfipronil (24)	Imazaquin (11)	Prometryn (10)
Alachlor (72)	*Desulfinylfipronil amide* (24)	Imazethapyr (11)	Propachlor (62)
Alachlor ESA (13)	**Diazinon** (72)	Imidacloprid (11)	*Propachlor ESA* (13)
Alachlor OA (13)	*Diazinon oxon* (10)	Iprodione (10)	*Propachlor OA* (13)
Alachlor SSA (13)	**Dicamba** (31)	Isofenphos (10)	Propanil (62)
Aldicarb (31)	Dichlobenil (20)	Lindane (62)	Propargite (62)
Aldicarb Sulfone (31)	Dichlorprop (31)	Linuron (62)	Propham (31)
Aldicarb Sulfoxide (31)	Dichlorvos (10)	*Malaoxon* (10)	Propiconazole (11)
alpha-HCH (62)	Dicrotophos (10)	Malathion (72)	**Propoxur** (29)
Atrazine (72)	**Dieldrin** (72)	MCPA (31)	Propyzamide (72)
Azinphos-methyl (72)	*Dimethenamid ESA* (13)	MCPB (31)	Siduron (11)
Azinphos-methyl oxon (10)	*Dimethenamid OA* (13)	Metalaxyl (13)	Silvex (20)
Bendiocarb (11)	Dimethoate (15)	Methidathion (10)	**Simazine** (72)
Benfluralin (72)	Dinoseb (31)	Methiocarb (31)	Sulfometuron (11)
Benomyl (11)	Diphenamid (11)	Methomyl (31)	**Tebuthiuron** (72)
Bensulfuron-methyl (11)	Disulfoton (62)	Methyl paraoxon (10)	Terbacil (62)
Bentazon (31)	Diuron (31)	Methyl parathion (72)	Terbufos (72)
Bromacil (33)	DNOC (20)	**Metolachlor** (72)	*Terbufos-O-analogue sulfone* (10)
Bromoxynil (31)	EPTC (62)	***Metolachlor ESA*** (13)	Terbuthylazine (10)
Butylate (62)	Esfenvalerate (20)	***Metolachlor OA*** (13)	Thiobencarb (62)
Carbaryl (72)	Ethalfluralin (62)	**Metribuzin** (72)	Triallate (62)
Carbofuran (62)	Ethion (10)	Metsulfuron (11)	Triclopyr (31)
Chloramben, methyl ester (31)	*Ethion monoxon* (10)	Molinate (62)	Trifluralin (72)
Chlorimuron (11)	Ethoprophos (62)	Myclobutanil (10)	



[1] ESA, ethanesulfonic acid [2] OA, oxanilic acid
[3] U.S. Environmental Protection Agency, 2004
[4] Toccalino and others, 2004
[5] NAWQA Warehouse HBSL search: *http://water.usgs.gov/nawqa/HBSL*

Figure 3. Detection frequency and maximum measured concentration for 27 pesticides and *degradates* detected in ground water in central and western Maryland, 1994–2003 [E, estimated. The uncertainty in the reported concentration is expected to be generally greater than those without an "E" code (Gilliom and others, 2006)].

a wider area of the Piedmont is most likely in agricultural areas, and the occurrence of prometon is most likely in agricultural or residential areas. Concentrations of atrazine, deethylatrazine, and simazine in ground water also increase with increasing proportion of cropland in the Great Valley of the Potomac River Basin (Ferrari and Denis, 1999). Simazine is used for agriculture as well as other applications; the occurrence of prometon in agricultural areas likely reflects non-agricultural uses (such as around buildings and along fences and rights-of-way) in these areas (Gilliom and others, 2006; Lindsey and others, 2006). Comparable rates of pesticide occurrence in ground water in primarily forested and agricultural areas of Baltimore County may be due (at least in part) to mixed land use, and the proximity of agriculture to forest in some areas (Bolton, 1998).

Pesticide occurrence in ground water is related to chemical factors that affect the solubility, fate, and movement of different compounds, as well as application practices. Pesticides such as atrazine, metolachlor, and their degradates that are relatively common in ground water (fig. 3) are generally more water soluble and (or) persistent than other compounds, which may be used more frequently. Conversely, many commonly used pesticide compounds (table 1) were not detected in ground-water samples compiled for this study (table 3, fig. 3). Pendimethalin, 2,4-D, and chlorpyrifos, for example, are widely used (table 1) but have chemical properties that limit their movement to ground water. Pendimethalin is used more heavily than atrazine (table 1), but is much less soluble in water (Gilliom and others, 2006).

Pesticide occurrence in ground water also is related to environmental factors that affect the movement of these compounds from the land surface to the water table. The common occurrence of herbicides in ground water in the Great Valley in Washington County (fig. 2) likely reflects the greater natural vulnerability of carbonate aquifers (fig. 1) to surficial contamination, as well as the prevalence of agriculture in these areas (fig. 2) (Ferrari and Denis, 1999). Pesticide occurrence in the wider Piedmont is related to soil composition and drainage, as well as land use and application rates (Lindsey and others, 2006). Metolachlor and prometon are more likely found in such areas with well-drained soils, for example, and concentrations of dieldrin (which has a relatively high affinity for organic matter) in parts of this area decrease with increasing soil organic matter (Lindsey and others, 2006). The detection of dieldrin, use of which was discontinued in 1987, in these areas and in one sample in Maryland (fig. 3) also illustrates the importance of slow ground-water flow and the resulting long residence time to the occurrence of pesticides. The relatively infrequent pesticide detections in some urban areas of Montgomery County (fig. 2) may reflect the influence of formerly forested land use, considering that recently developed urban areas were specifically targeted for sampling (table 2). Similarly, the occurrence of pesticides in some residential and forested areas of Baltimore County may reflect the influence of former cropland (Bolton, 1998).

Discussion and Implications

Implications of observed pesticide occurrence on the potability of water from aquifers in the area are uncertain on the basis of available information. Pesticides are present at relatively low levels in ground water in many areas, and mixtures are common. Similar patterns of occurrence have been noted in the Maryland Coastal Plain (Denver and Ator, 2006; Debrewer and others, 2007) and wider areas of the Mid-Atlantic Region (Ator and Ferrari, 1997; Ferrari and Denis, 1999; Lindsey and others, 2006). Although measured pesticide concentrations as part of these studies were generally below MCLs or HBSLs, such standards or guidelines are not available for many compounds, particularly the degradates. In addition, little information about possible additive or synergistic effects of multiple compounds is available.

Pesticides in ground water may have ecological impacts on Maryland streams and downstream estuaries. Ground-water discharge provides the majority of flow to streams in many parts of the State, and is often the only source of water during dry periods. Dissolved pesticides and chemicals in ground water may move into streams with ground-water discharge, and on to downstream estuaries such as Chesapeake Bay. Pesticides have been detected in streams of central and western Maryland during base-flow periods, when streamflow is mainly derived from ground-water discharge (Ator and others, 1998; Ferrari and Denis, 1999).

Management practices designed to protect aquifers from chemical contamination are complicated by the unique nature of the ground-water resource. Infiltration to ground water occurs over broad areas of the land surface, particularly in well-drained areas most suitable for cultivation or other development. Limiting pesticide applications in ground-water recharge areas may therefore be particularly difficult. Traditional management practices such as forested riparian buffers, contour tillage, or grassed swales may be effective at limiting overland movement of sediment, nutrients, pesticides, and other chemicals to streams, but may increase infiltration of stormwater, and divert soluble chemicals to ground water. Water-resources management also is complicated by the particularly slow movement and resulting long residence times of ground water in aquifers. Many decades may pass before the implications of management practices at the land surface are fully realized throughout the extent of the aquifer.

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