USGS
science for a changing world

Pesticides in Ground Water of the Maryland Coastal Plain

by Judith M. Denver and Scott W. Ator

Prepared in cooperation with the
Maryland Department of Agriculture

Abstract

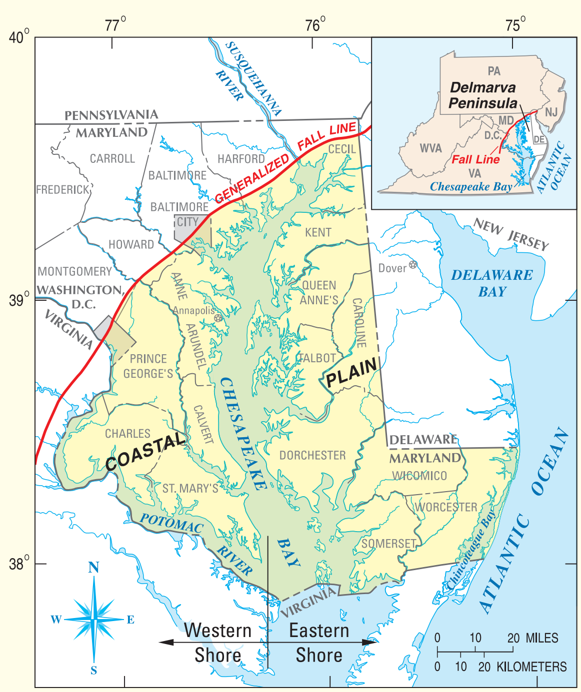
Selected pesticides are detectable at low levels (generally less than 0.1 microgram per liter) in unconfined ground water in many parts of the Maryland Coastal Plain. Samples were recently collected (2001–04) from 47 wells in the Coastal Plain and analyzed for selected pesticides and degradate compounds (products of pesticide degradation). Most pesticide degradation occurs in the soil zone before infiltration to the water table, and degradates of selected pesticides were commonly detected in ground water, often at higher concentrations than their respective parent compounds. Pesticides and their degradates often occur in ground water in mixtures of multiple compounds, reflecting similar patterns in usage. All measured concentrations in ground water were below established standards for drinking water, and nearly all were below other health-based guidelines. Although drinking-water standards and guidelines are typically much higher than observed concentrations in ground water, they do not exist for many detected compounds (particularly degradates), or for mixtures of multiple compounds.

The distribution of observed pesticide compounds reflects known usage patterns, as well as chemical properties and environmental factors that affect the fate and transport of these compounds in the environment. Many commonly used pesticides, such as glyphosate, pendimethalin, and 2,4-D were not detected in ground water, likely because they were sorbed onto organic matter or degraded in the soil zone. Others that are more soluble and (or) persistent, like atrazine, metolachlor, and several of their degradates, were commonly detected in ground water where they have been used. Atrazine, for example, an herbicide used primarily on corn, was most commonly detected in ground water on the Eastern Shore (where agriculture is common), particularly where soils are well drained. Conversely, dieldrin, an insecticide previously used heavily for termite control, was detected only on the Western Shore, where urban land is more common. Use of dieldrin was suspended in 1987, but this compound is relatively persistent in the environment, and several decades are typically required for ground water to move completely through the surficial aquifer.

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 are also used for commercial, industrial, transportation, public-health, and other applications (Kiely and others, 2004).

The occurrence and distribution of pesticides in ground water is affected by land use and pesticide application, as well as chemical and physical properties of different pesticides, and natural factors that affect their fate and movement in the environment (Barbash and Resek, 1996). Pesticides that are detected most frequently 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). The mobility of a pesticide is related to its water solubility and partitioning among different environmental media, such as air, water, soil, and biota. Some pesticides are highly volatile and likely to disperse into the air, for example, while others may sorb strongly to soil organic matter and accumulate in the soil or sediment rather than in water. Persistence refers to the tendency of a compound to remain in its original chemical form in the environment. Chemicals with low persistence rapidly transform to other compounds, referred to as degradates. These transformations occur through both abiotic and biotic processes. Abiotic processes involve photochemical or chemical transformations that require sunlight or naturally occurring chemicals in the soils and water. Biotic



Location of the Maryland Coastal Plain.

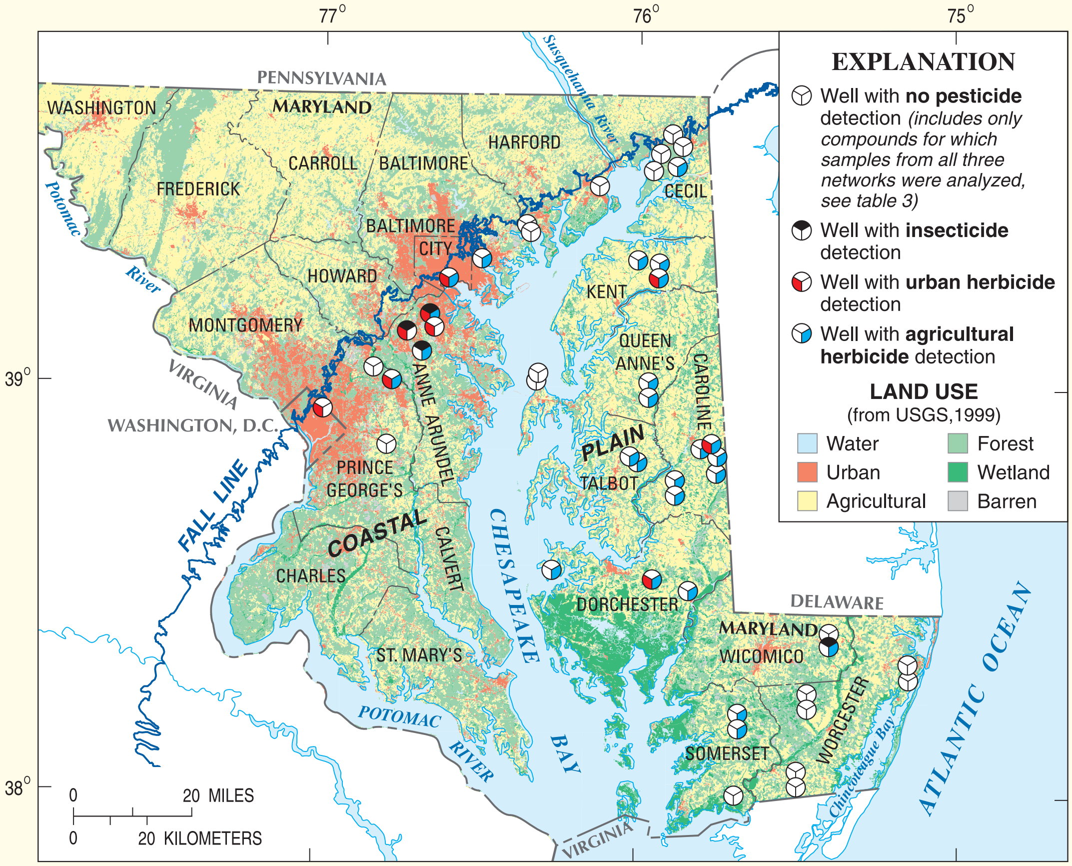


Figure 1. Land use, location of sampled wells, and summary of pesticides in ground water (2001–04) in the Maryland Coastal Plain.

processes involve transformations by animals, plants, or microbes. Most pesticide transformation occurs in the soil zone where these processes are most active (Barbash and Resek, 1996). Pesticides are complex molecules and a wide variety of degradates may form from one parent compound. The degradates may have similar or different chemical properties that affect their mobility and transformation in the environment. Over time they will break down into simple molecules like carbon dioxide and water.

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 aquifer sediments (Helling and Gish, 1986). In such areas, water moves to the water table relatively quickly and easily, and soils and sediments often contain little organic matter that may sorb pesticides and restrict their movement to ground water. Pesticides are not commonly transported into confined aquifers because of fine-grained confining-bed sediments that impede downward transport of dissolved pesticides or other contaminants. In addition, decades or centuries are often required for water to move from the land surface to confined aquifers, and much of the water currently in confined aquifers infiltrated the land surface prior to the widespread use of pesticides in recent decades.

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 use of ground water for human consumption. This may be of particular concern in areas with limited alternative water supplies, or where supplies (such as domestic wells) are not routinely monitored. Ground water also contributes the majority of water to streams in many areas, and may be the only source of water during dry periods. Pesticides in ground water may thus contribute to the overall pesticide load in streams and downstream estuaries.

The occurrence and distribution of selected pesticides and pesticide degradates in shallow unconfined ground water of the Maryland Coastal Plain (fig. 1) are described and discussed in this report. Potential implications of observed pesticides for water supply, stream ecology, and water-resources management also are discussed. Concentrations of pesticides and degradates measured in samples collected recently (2001–04) from 47 wells in Maryland are included. These wells were sampled as part of three wider regional studies for the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program (Gilliom and others, 1995). Sampled wells in Maryland represent ground water in primarily agricultural areas on the Eastern Shore, and along the Fall Line on the Western Shore, which has more variable land use and is typically more urban (fig. 1). No data are available for the southern part of the Western Shore, although that area is predominantly forested and has relatively limited unconfined ground water.

The Maryland Coastal Plain

The Coastal Plain includes the part of Maryland south and east of the Fall Line (fig. 1). This area is underlain by unconsolidated sand, gravel, silt, clay, and shells (Vroblesky and Fleck, 1991), and is geologically distinct from areas to the north and west, where consolidated rocks occur at or near the land surface. Unconsolidated sediments of the Coastal Plain form a wedge of aquifers and confining units that thickens from 0 ft (feet) along the Fall Line to greater than 8,000 ft along the Atlantic Coast. Most of the ground water used for drinking water on the Western Shore and much of the Eastern Shore comes from confined aquifers. Although these aquifers are confined at depth, along the Fall Line where they subcrop or outcrop at the land surface they are under water-table conditions and

Table 1. Estimated applications of selected pesticides in the Maryland Coastal Plain, 2000, including compounds with greater than 100,000 pounds active ingredient applied statewide.[1]

[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)	Proportion on Eastern Shore[3] (percent)	Proportion on Western Shore[4] (percent)
Glyphosate	H	719,000	70	30
Metolachlor	H	389,000	77	23
Atrazine	H	380,000	74	26
Pendimethalin	H	289,000	13	87
Simazine	H	183,000	87	13
(Metam-Sodium)	FM	152,000	3	97
(Isophenphos)	I	143,000	5	95
Glyphosate-trimesium	H	143,000	97	3
2,4-D	H	96,000	45	55
(Paraquat)	H	92,000	77	23
Cholothalonil	FN	78,000	35	65
S-Metolachlor	H	53,000	84	16
Chlorpyrifos	I	47,000	35	65
Imidachloprid	I	17,000	5	95

[1] Data modified from Maryland Department of Agriculture, 2002. Excludes chromated copper arsenate (CCA), cuprous oxide, and petroleum oils.

[2] Sum of application estimates for counties including at least part of the Coastal Plain. Total Coastal Plain applications may be overestimated for counties that include areas outside of the Coastal Plain.

[3] Caroline, Cecil, Dorchester, Kent, Queen Anne's, Somerset, Talbot, Wicomico, and Worcester Counties.

[4] Anne Arundel, Baltimore, Calvert, Charles, Harford, Howard, Prince George's, and St. Mary's Counties, and Baltimore City.

Table 2. U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program ground-water-quality networks used for this report.

Network	Targeted setting	Geographic extent	Number of wells in Maryland (total)	Median well depths in Maryland, in feet
Delmarva Land-Use Study[1]	Shallow ground water beneath agricultural areas, surficial unconfined aquifer	Delmarva Peninsula	15 (29)	22
Delmarva Major-Aquifer Study[1]	Ground water typically used for domestic supply, surficial unconfined aquifer	Delmarva Peninsula	15 (29)	43
Fall Line Major-Aquifer Study	Unconfined ground water along the Fall Line in recharge areas of major Coastal Plain confined aquifers	Areas near the Fall Line, northern Virginia through New Jersey	17 (25)	85

[1] Debrewer and others, in press.

part of the unconfined aquifer system. On the Eastern Shore, the confined aquifers are overlain by an extensive unconfined surficial aquifer, which is a major source of drinking water for small towns and individual homes.

Ground-water quality is determined by sediment type, natural geochemical conditions, and — particularly where an aquifer is unconfined — infiltration of chemicals from human sources. In confined aquifers, water chemistry reflects the mineralogy of the sediments, such as having high concentrations of calcium and bicarbonate from dissolution of shell material. Confined ground water also is generally suboxic or anaerobic (with little or no dissolved oxygen). There are typically no chemicals present from human sources because the confining layer provides protection from the influence of overlying land use. Water quality also is affected by mineral dissolution in the unconfined surficial aquifer system. Over much of the Maryland Coastal Plain, the surficial aquifer is susceptible to infiltration of chemicals from human sources because the sediments are permeable and the water table is relatively shallow. Most of the sediments of the surficial aquifer are composed of relatively insoluble quartz sands, and water chemistry is naturally dilute; chemicals leached from agricultural and urban sources can locally dominate ground-water chemistry (Shedlock and others, 1999).

The average annual rainfall in Maryland is about 43 inches (Wheeler, 2003), about a third of which infiltrates through the soil zone and recharges the unconfined surficial aquifer. The resulting water chemistry in the surficial aquifer reflects the spatially variable land use in aquifer recharge areas and the susceptibility of different areas to leaching of pesticides and other chemicals to ground water. Once infiltrating water and any associated chemicals enter the surficial aquifer, they are carried along ground-water flow paths to discharge areas in local streams and coastal waters. A small amount of water also moves downgradient into underlying confined aquifers. Most of the water in the surficial aquifer is less than 50 years old, and in many places, the entire aquifer has been impacted by chemicals from modern land uses (Debrewer and others, in press; Focazio and others, 1998).

Pesticide use in the Maryland Coastal Plain reflects variable land use in different areas. Of the hundreds of pesticides produced, few are widely used (Maryland Department of Agriculture, 2002). The most commonly used pesticides in the Maryland Coastal Plain are herbicides used to control weeds in corn, soybean, and small grain crops (table 1). These include glyphosate, metolachlor, and atrazine, which are used most heavily on the Eastern Shore where agriculture is the dominant land use (fig. 1). The herbicide 2,4-D and the insecticides chlorpyrifos and diazinon, conversely, are used for both urban and agricultural purposes. These compounds are applied

Table 3. Pesticides and degradate compounds for which ground-water samples were analyzed in the Maryland Coastal Plain, 2001–04.

[Degradates are listed in *italics*; compounds detected in ground water are shown in **bold** (see fig. 2); ESA, ethanesulfonic acid; OA, oxanilic acid]

2,4-D
2,4-D methyl ester
2,4-DB
2,6-Diethylaniline
2-Hydroxyatrazine
3(4-Chlorophenyl)-1-methyl urea
3-Hydroxycarbofuran
3-Ketocarbofuran
Acetochlor
Acetochlor ESA
Acetochlor OA
Acifluorfen
Alachlor
Alachlor ESA
Alachlor OA
Aldicarb
Aldicarb sulfone
Aldicarb sulfoxide
alpha-HCH
Amino-methyl-phosphonic acid
Atrazine
Azinphos-methyl
Bendiocarb
Benfluralin
Benomyl
Bensulfuron-methyl
Bentazon
Bromacil
Bromoxynil
Butylate
Carbaryl
Carbofuran
Chloramben, methyl ester
Chlorimuron-ethyl
Chlorothalonil
Chlorpyrifos
cis-Permethrin
Clopyralid
Cyanazine
Cycloate
Dacthal
Dacthal monoacid
Deethylatrazine
Deethyldeisopropylatrazine
Deisopropylatrazine
Desulfinylfipronil
Desulfinylfipronil amide
Diazinon
Dicamba
Dichlorprop
Dieldrin
Dimethenamid ESA
Dimethenamid OA
Dinoseb
Diphenamid
Disulfoton
Diuron
EPTC
Ethalfluralin
Ethoprophos
Fenuron
Fipronil
Fipronil sulfide
Fipronil sulfone
Flufenacet ESA
Flufenacet OA
Flumetsulam
Fluometuron
Fonofos
Glufosinate
Glyphosate
Imazaquin
Imazethapyr
Imidacloprid
Lindane
Linuron
Malathion
MCPA
MCPB
Metalaxyl
Methiocarb
Methomyl
Metolachlor
Metolachlor ESA
Metolachlor OA
Metribuzin
Metsulfuron-methyl
Molinate
Napropamide
Neburon
Nicosulfuron
Norflurazon
Oryzalin
Oxamyl
p,p'-DDE
Parathion
Parathion-methyl
Pebulate
Pendimethalin
Phorate
Picloram
Prometon
Propachlor
Propanil
Propargite
Propham
Propiconazole
Propoxur
Propyzamide
Siduron
Simazine
Sulfometuron-methyl
Tebuthiuron
Terbacil
Terbufos
Thiobencarb
Tri-allate
Tribenuron-methyl
Triclopyr
Trifluralin

Compounds for which samples for all networks were analyzed.
Compounds for which only samples from the Eastern Shore networks were analyzed.

more equally on the Eastern Shore and the Western Shore, which has more variable land use, and includes heavily urbanized areas along the Fall Line (fig. 1). Pesticide use has changed over time as new compounds are introduced and others are discontinued. Acetochlor was introduced in the mid-1990s to replace alachlor, for example; alachlor use has greatly declined since then (Maryland Department of Agriculture, 1996, 1999, 2002). In addition, use of several insecticides, including diazinon, chlorpyrifos, and dieldrin, was recently banned or greatly reduced (U.S. Environmental Protection Agency, 2000).

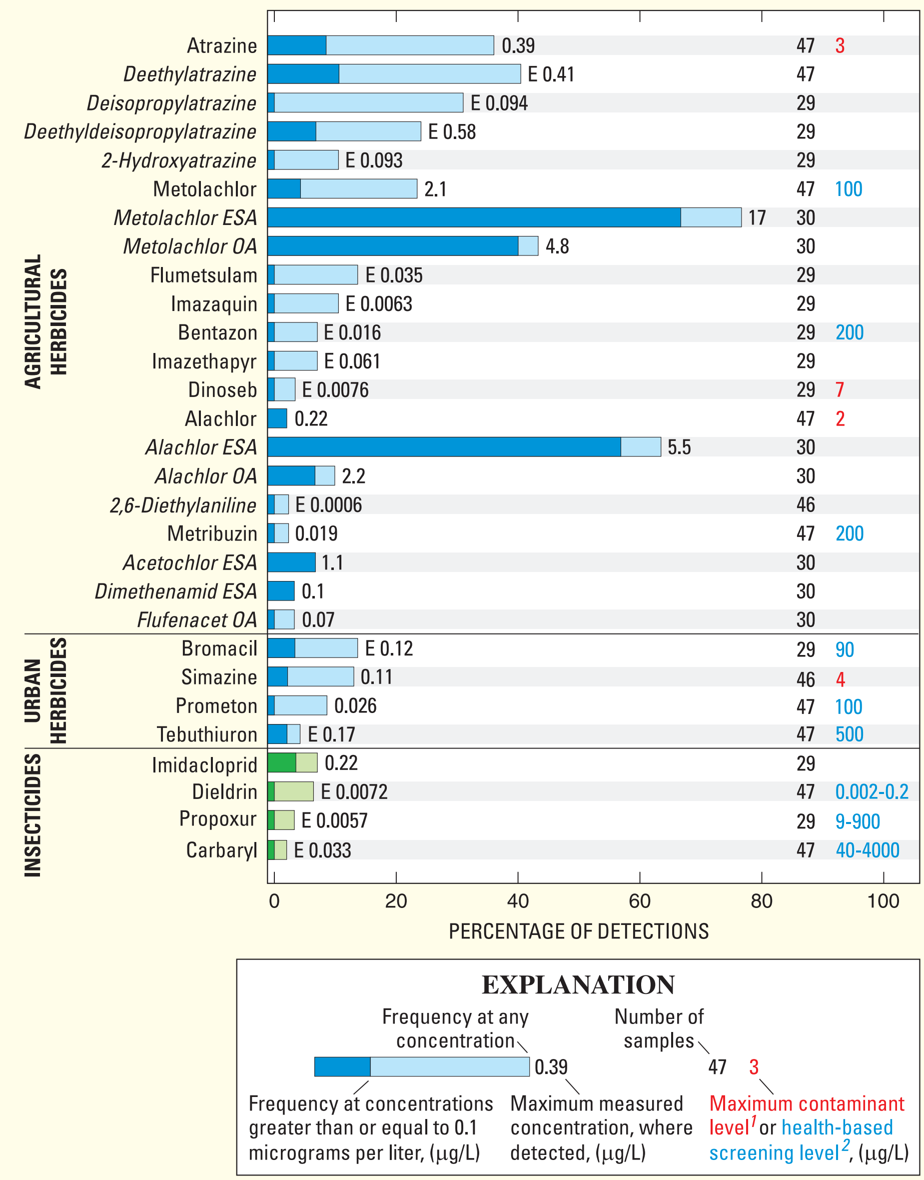
Measuring Pesticides in Ground Water

Water-quality data described in this report were collected from 47 wells that are part of three regional NAWQA networks that include parts of the Maryland Coastal Plain (table 2). Regional NAWQA ground-water surveys are designed to document and explain (to the extent possible) the occurrence and distribution of selected chemical compounds (such as pesticides) in ground water in particular types of settings (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. Regional networks are established for each type of study, typically including 20 to 30 wells that are areally distributed throughout the targeted setting. Regional NAWQA ground-water networks that include parts of the Maryland Coastal Plain include an agricultural land-use study and a major-aquifer study in the surficial aquifer on the Delmarva Peninsula (Debrewer and others, in press), and a major-aquifer study in the unconfined aquifer along the Fall Line from the Washington, D.C. area through New Jersey (table 2).

Water samples were recently collected (2001 through 2004) from each well in the regional networks and analyzed for selected chemical compounds, including selected pesticides and degradates. Sample collection, processing, and analysis for the Eastern Shore networks are described in Debrewer and others (in press); similar protocols were used for wells on the Western Shore. Although some network wells are used for water supply, samples were collected prior to any filtering or treatment, and are therefore representative of the available ground-water resource rather than necessarily of drinking water. Samples were analyzed for a broad (though not complete) suite of commonly used pesticides and degradates (table 3); these compounds were measured in filtered water samples using analytical methods designed to measure particularly low concentrations, around 0.005 µg/L (micrograms per liter) for some compounds. Although these concentrations may be far below established water-quality standards, such information can be particularly useful for detecting trends in pesticide concentrations, and for understanding natural and human influences affecting pesticide occurrence in ground water.

Pesticides in Ground Water of the Maryland Coastal Plain

A variety of pesticide compounds are detectable at typically low concentrations in unconfined ground water of the Maryland Coastal Plain. Of the more than 100 pesticides and degradate compounds for which samples were analyzed (table 3), 29 were detected at least once (fig. 2). Concentrations were generally less than 0.1 µg/L for most compounds. No samples contained any pesticide compounds at concentrations exceeding established Federal drinking-water standards, although such standards exist for only 4 of the 29 compounds detected (see inset, page 6). Non-regulatory health-based guidelines for an additional nine detected compounds also were rarely exceeded, although three samples contained dieldrin at concentrations exceeding 0.002 µg/L.



[1] U.S. Environmental Protection Agency, 2004
[2] Toccalino and others, 2004

Figure 2. Detection frequency and maximum measured concentration for 29 pesticides and *degradates* detected in ground water in the Maryland Coastal Plain, 2001–04 [E, estimated].

Most (21 of 29) of the detected compounds are herbicides typically used for agriculture (such as atrazine and metolachlor) or their degradates, reflecting the importance of agricultural herbicides among pesticides used in Maryland (table 1). The dominance of agricultural herbicides among pesticides detected also reflects the prevalence of agriculture in sampled areas, however (fig. 1, table 2), as well as the dominance of herbicides among target analytes (table 3). Only 4 of the 29 detected compounds are insecticides; no insecticide was detected in more than 10 percent of the samples for which it was analyzed (fig. 2).

Concentrations of selected herbicide degradates often substantially exceed concentrations of their respective parent compounds in ground water (Debrewer and others, in press). Selected degradates of atrazine, metolachlor, and alachlor were among the most frequently detected compounds in ground water of the Maryland Coastal Plain (fig. 2), even though many metolachlor and alachlor degradates were measured in samples from only 30 of 47 wells (those from the Eastern Shore networks). Metolachlor ESA (ethanesulfonic acid), metolachlor OA (oxanilic acid), and alachlor ESA were each detected in more than 40 percent of the 30 samples for which they were analyzed, and measured concentrations were typically greater than or equal to 0.1 µg/L (fig. 2). The median metolachlor ESA concentration among these 30 samples was 0.59 µg/L. By contrast, metolachlor and alachlor concentrations were each greater than or equal to 0.1 µg/L in only 1 of these same 30 samples. The relative magnitude of concentrations of selected degradates and parent compounds in Coastal Plain ground water reflects the fact that most pesticide degradation occurs in the soil zone, before infiltration reaches the water table (Barbash and Resek, 1996). Also, ESA and OA degradates of metolachlor and alachor are more soluble than their respective parent compounds (Phillips and others, 1999). The similar detection frequencies of atrazine and deethylatrazine relative to those of metolachlor and its degradates (fig. 2) likely reflect the fact that atrazine degrades primarily to hydroxyatrazine, which is less mobile and more likely to sorb to soils (Barbash and Resek, 1996). Observed concentrations of metolachlor and alachlor degradates similarly

Ground Water and Drinking Water

Available standards and guidelines for drinking water provide some context for understanding 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, 2003, 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 each 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 or for mixtures of compounds, and the HBSL for one detected compound (dieldrin) is lower than the current laboratory reporting limit (Toccalino and others, 2004).

exceeded concentrations of parent compounds in two streams on the Eastern Shore, which receive most of their flow from ground-water discharge (Ator and others, 2005). Pesticide degradates also have been frequently detected in ground water and streams in other parts of the Nation (Gilliom and others, 2006).

When present, pesticides commonly occur in mixtures in ground water. Of the 47 wells from which samples were analyzed, 32 (68 percent) contained detectable concentrations of at least 1 pesticide compound or degradate (fig. 1). Only 2 of these 32 samples contained only 1 detectable compound, however, and both of these were samples from the Western Shore, which were analyzed for a relatively limited number of analytes (table 3). On the Eastern Shore, 24 of 30 samples (80 percent) contained at least 1 detectable pesticide or degradate compound, and 16 (53 percent) contained at least 5 detectable compounds. One sample contained 11 different compounds. Multiple compounds also were detected in about half (19) of 37 ground-water samples with detectable pesticides collected from 1988 through 1990 on the Delmarva Peninsula (Koterba and others, 1993). Similarly, 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 NAWQA 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.

Pesticides are detectable in many parts of the Maryland Coastal Plain, although the occurrence of different compounds generally reflects known usage patterns. The 32 wells from which samples with detectable pesticides or degradates were collected are located in many areas of the Coastal Plain, primarily near likely sources in agricultural or urban areas (fig. 1). Atrazine or deethylatrazine, for example, was detected in 18 of the 30 samples (60 percent) from the Eastern Shore (where agriculture is common and atrazine use is consequently relatively high), but in only 2 of 17 wells on the Western Shore (fig. 3). Debrewer and others (in press) noted that atrazine and metolachlor concentrations in ground water on the Delmarva Peninsula (including the 30 Eastern Shore samples described in this report) increase with an increasing proportion of agriculture near sampled wells. Dieldrin, an insecticide that was primarily used for termite control, however, was only detected in 3 of 47 wells, each in relatively urban areas on the Western Shore. Seven of the eight samples from the Western Shore with detectable pesticide or degradate compounds contained dieldrin and (or) an herbicide typically used in urban areas (prometon, simazine, or tebuthiuron), although five of these samples also contained atrazine or metolachlor. The 15 wells with no detectable pesticides are mostly located in relatively forested areas (such as parts of Cecil County), or where

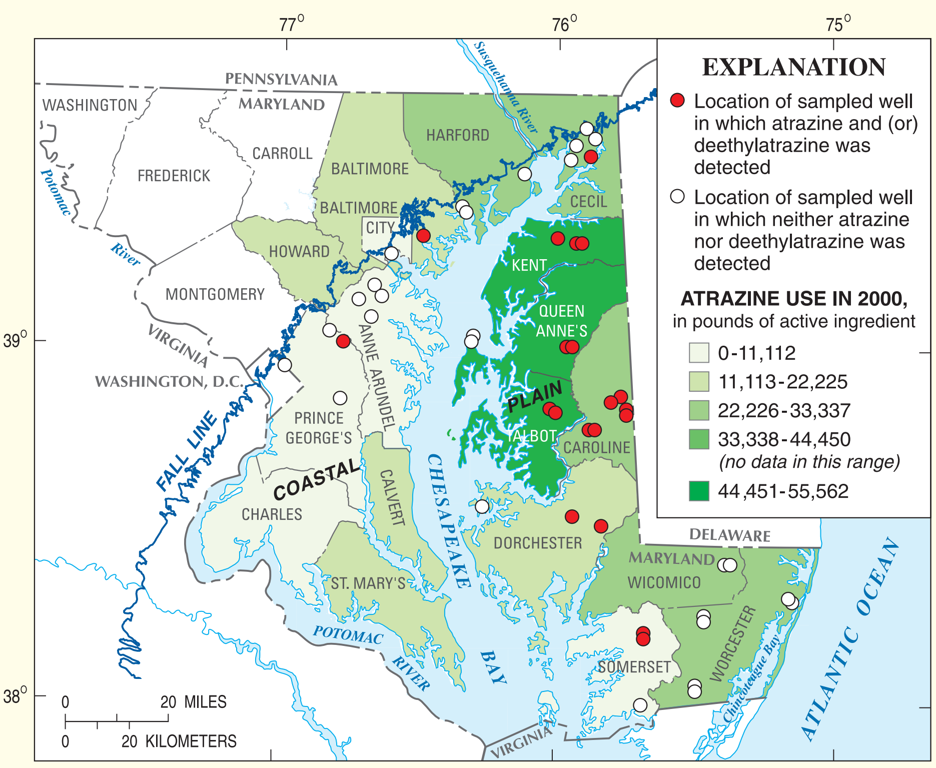


Figure 3. Atrazine usage in the Maryland Coastal Plain and detection of atrazine and (or) deethylatrazine in ground water (2001–04).

poor drainage or organic soils limit pesticide movement to ground water (such as parts of the lower Eastern Shore) (fig. 1).

The occurrence of pesticides in ground water is related to chemical properties and environmental factors that affect their fate and transport, as well as usage patterns. Pesticides such as atrazine, metolachlor, and their degradates that are relatively commonly detected in ground water are generally more water soluble and (or) persistent than other compounds, which may be used more frequently. Glyphosate, pendimethalin, 2,4-D, and chlorpyrifos, conversely, are widely used but have chemical properties that limit their movement to ground water. Glyphosate, for example, is more soluble in water than atrazine, but less persistent and more likely to sorb onto organic matter in soils or sediments (Debrewer and others, in press). Soluble compounds are less likely to accumulate in soil, sediment, or wildlife, but more likely to occur in ground water or streams. Pesticide occurrence in ground water is also related to environmental factors that affect the movement of these compounds from the land surface to the water table. Atrazine concentrations in shallow ground water in agricultural areas of the Delmarva Peninsula are greater in relatively well-drained areas (such as the central Eastern Shore) than in areas with more poorly drained soils (such as parts of the lower Eastern Shore) that may limit the movement of pesticides to the water table (fig. 3) (Koterba and others, 1993; Debrewer and others, in press). Atrazine concentrations also are greater in the surficial aquifer on the Delmarva Peninsula in more recently recharged ground water, as might be expected if older ground water entered the aquifer in previous years when less atrazine was used (Koterba and others, 1993; Debrewer and others, in press). The importance of ground-water residence time on the occurrence of pesticides is further demonstrated by the detection of dieldrin in three samples. Its use was discontinued in 1987.

Summary and Discussion

Selected pesticides and degradate compounds are detectable in surficial, unconfined ground water in many areas of the Maryland Coastal Plain, although measured concentrations were generally less than 0.1 µg/L, and no existing Federal drinking-water standards were exceeded. As noted previously in other areas, pesticides and degradates typically occur in ground water in mixtures of multiple compounds, and concentrations of degradates of selected compounds generally far exceed those of parent compounds. Spatial patterns in pesticide occurrence in ground water of the Maryland Coastal Plain generally reflect known usage patterns, as well as chemical properties and environmental factors that affect the fate and transport of these compounds in the environment.

Implications of observed pesticide occurrence on the potability of drinking water from the surficial aquifer in the Maryland Coastal Plain are uncertain on the basis of available information. Pesticides are present at relatively low levels in parts of the aquifer. Debrewer and others (in press) noted similar patterns of occurrence in the entire Delmarva Peninsula, and pesticides also have been detected in deeper parts of the aquifer more typically used for public supplies in Delaware (Ferrari, 2002; Denver and others, 2004). 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 streams in the Maryland Coastal Plain and downstream estuaries. Ground-water discharge provides the majority of flow to streams in many parts of the Maryland Coastal Plain, and is often the only source of water during dry periods. Much of this discharge (particularly for smaller streams) is generated from the surficial aquifer. Dissolved pesticides and chemicals in ground water may move into streams with ground-water discharge, and contribute to the overall load of these compounds in streams and downstream estuaries such as Chesapeake Bay. Pesticides have been detected in streams of the Delmarva Peninsula during baseflow periods, when streamflow is mainly derived from ground-water discharge (Denver and others, 2004; Ator and others, 2005).

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 of ground water and resulting long residence times in aquifers. Many decades may be required before implications of management practices at the land surface are fully realized throughout the extent of the surficial aquifer (Kaufmann and others, 2001).

References Cited

Ator, S.W., Denver, J.M., and Brayton, M.J., 2005, Hydrologic and geochemical controls on pesticide and nutrient transport to two streams on the Delmarva Peninsula: U.S. Geological Survey Scientific Investigations Report 2004–5051, 34 p.

Barbash, J.E., and Resek, E.A., 1996, Pesticides in ground water — Distribution, trends, and governing factors: Chelsea, Michigan, Ann Arbor Press, 588 p.

Debrewer, L.M., Ator, S.W., and Denver, J.M., in press, Factors affecting spatial and temporal variability in nutrient and pesticide concentrations in the surficial aquifer on the Delmarva Peninsula: U.S. Geological Survey Scientific Investigations Report 2005–5257.

Denver, J.M., Ator, S.W., Debrewer, L.M., Ferrari, M.J., Barbaro, J.R., Hancock, T.C., Brayton, M.J., and Nardi, M.R., 2004, Water quality in the Delmarva Peninsula — Delaware, Maryland, and Virginia, 1999–2001: U.S. Geological Survey Circular 1228, 26 p.

Ferrari, M.J., 2002, Occurrence and distribution of selected contaminants in public drinking-water supplies in

the surficial aquifer in Delaware: U.S. Geological Survey Open-File Report 01–327, 62 p.
Focazio, M.J., Plummer, L.N., Böhlke, J.K., Busenberg, Eurybiades, Bachman, L.J., and Powars, D.S., 1998, Preliminary estimates of residence time and apparent ages of ground water in the Chesapeake Bay Watershed, and water-quality data from a survey of springs: U.S. Geological Survey Water-Resources Investigations Report 97–4225, 75 p.
Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program — Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.
Gilliom, R.J., Barbash, J.E., Crawford, C.G., Hamilton, P.A., Martin, J.D., Nakagaki, Naomi, Nowell, L.H., Scott, J.C., Stackelberg, P.E., Thelin, G.P., and Wolock, D.M., 2006, Pesticides in the Nation's streams and ground water, 1992–2001: U.S. Geological Survey Circular 1291, 172 p.
Helling, C.S., and Gish, T.J., 1986, Soil characteristics affecting pesticide movement into groundwater *in* Garner, W.Y., Honeycutt, R.C., and Nigg, H.N., eds., Evaluation of pesticides in ground water: American Chemical Society Symposium Series, no. 315, p. 14–38.
Kauffman, L.J., Baehr, A.L., Ayers, M.A., and Stackelberg, P.E., 2001, Effects of land use and travel time on the distribution of nitrate in the Kirkwood-Cohansey Aquifer System in southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 01–4117, 49 p.
Kiely, Timothy, Donaldson, David, and Grube, Arthur, 2004, Pesticide industry sales and usage — 2000 and 2001 market estimates: U.S. Environmental Protection Agency, accessed March 29, 2006 at *http://www.epa.gov/oppbead1/pestsales/01pestsales/market_estimates2001.pdf*
Koterba, M.T., Banks, W.S.L., and Shedlock, R.J., 1993, Pesticides in shallow groundwater in the Delmarva Peninsula: Journal of Environmental Quality, v. 22, no. 3, p. 500–518.
Maryland Department of Agriculture, 1996, Maryland pesticide statistics for 1994: Report MDA–265–96, 52 p.
Maryland Department of Agriculture, 1999, Maryland pesticide statistics for 1997: Report MDA–265–99, 56 p.
Maryland Department of Agriculture, 2002, Maryland pesticide statistics for 2000: Report MDA–265–02, 52 p.
Phillips, P.J., Eckhardt, D.A., Terracciano, S.A., and Rosenmann, Larry, 1999, Pesticides and their metabolites in wells in Suffolk County, New York, 1998: U.S. Geological Survey Water-Resources Investigations Report 99–4095, 12 p.
Shedlock, R.J., Denver, J.M., Hayes, M.A., Hamilton, P.A., Koterba, M.J., Bachman, L.J., Phillips, P.J., and Banks, W.S.L., 1999, Water-quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia — Results of investigations, 1987–91: U.S. Geological Survey Water-Supply Paper 2355–A, 41 p.
Toccalino, P.L., Norman, J.E., Phillips, R.H., Kauffman, L.J., Stackelberg, P.E., Nowell, L.H., Krietzman, S.J., and Post, G.B., 2004, Application of health-based screening levels to ground-water quality data in a state-scale pilot effort: U.S. Geological Survey Scientific Investigations Report 2004–5174, 64 p.
Toccalino, Patricia, Nowell, Lisa, Wilber, William, Zogorski, John, Donohue, Joyce, Eiden, Catherine, Krietzman, Sandra, and Post, Gloria, 2003, Development of health-based screening levels for use in state or local-scale water-quality assessments: U.S. Geological Survey Water-Resources Investigations Report 03–4054, 22 p.
U.S. Environmental Protection Agency, 2000, Chlorpyrifos revised risk assessment and agreement with registrants, accessed August 1, 2006 at *http://www.epa.gov/pesticides/op/chlorpyrifos/agreement.pdf*
U.S. Environmental Protection Agency, 2004, 2004 Edition of the drinking water standards and health advisories: U.S. Environmental Protection Agency Report EPA 822–R–04–005, 12 p.
U.S. Geological Survey, 1999, Maryland land-cover dataset, edition 1, accessed August 9, 2006 at *http://edc.usgs.gov/products/landcover/nlcd.html*
Vroblesky, D.A., and Fleck, W.B., 1991, Hydrogeologic framework of the Coastal Plain of Maryland, Delaware, and the District of Columbia: U.S. Geological Survey Professional Paper 1404–E, 45 p.
Wheeler, J.C., 2003, Freshwater use trends in Maryland, 1985–2000: U.S. Geological Survey Fact Sheet FS 112–03, 4 p.

Prepared by USGS Publishing Service Center 3.
Edited by Valerie M. Gaine.
Graphics and design by Timothy W. Auer.

For additional information, contact:
Director, MD-DE-DC Water Science Center
U.S. Geological Survey
8987 Yellow Brick Road
Baltimore, MD 21237

or visit our Web site at:
http://md.water.usgs.gov

Also contact:
Maryland Department of Agriculture
Pesticide Regulation Section
50 Harry S. Truman Parkway
Annapolis, MD 21401
410-841-5710

or visit the MDA Web site at:
http://www.mda.state.md.us

USGS Fact Sheet
FS 2006–3119

Maryland Department of Agriculture

USGS
science for a changing world