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Overview of Findings and Implications

About 1 billion pounds of conventional pesticides are used each year in the United States to control weeds, insects, and other pests. The use of pesticides has resulted in a range of benefits, including increased food production and reduction of insect-borne disease, but also raises questions about possible adverse effects on the environment, including water quality. The NAWQA assessment of pesticides provides the most comprehensive national-scale analysis to date of pesticide occurrence and concentrations in streams and ground water. NAWQA results show where, when, and why specific pesticides occur in streams and ground water across the Nation, and yield science-based implications for assessing and managing the quality of our water resources.

Photograph by Rand Schaal

This chapter provides a broad overview of NAWQA findings about the occurrence and distribution of pesticides in the Nation's streams and ground water and summarizes the implications of these findings for water-quality assessment and management. Priorities for filling remaining information gaps also are addressed. Detailed discussions of each major topic are provided in subsequent chapters, including selected case studies of pesticide occurrence within individual NAWQA Study Units.

Introduction—

New results confirm and expand findings from earlier NAWQA studies

This report is based on the National Water-Quality Assessment (NAWQA) Program's first decade of water-quality assessments, which were completed on a rotational schedule during 1992–2001 in 51 major hydrologic systems across the country, referred to as Study Units (see p. iv and v). Assessments were conducted using a nationally consistent approach in 20 Study Units during 1992–1995; in 16 Study Units during 1996–1998; and in 15 Study Units during 1998–2001.

Nationally, water samples for pesticide analysis were collected from 186 stream sites within the 51 Study Units, bed-sediment samples were collected from 1,052 stream sites, and fish samples were collected from 700 stream sites. Ground-water samples were collected from 5,047 wells. In this report, most data analyses for stream water are based on the single year of most intensive sampling; data analyses for bed sediment and fish tissue are based on one composite sample per site; and data analyses for ground water are based on one sample per well. Sampling sites for streams and ground water were selected to represent the specific agricultural, urban, undeveloped, and mixed-land-use settings of greatest significance to water resources in the primary hydrologic settings within each of the Study Units. Shallow ground water (generally less than 20 ft below the water table) was sampled in agricultural, urban, and undeveloped areas, whereas deeper ground water was sampled from wells that tap major aquifers, most of which are affected by a mixture of land uses and are important as potential sources of drinking water.

Most NAWQA water samples were analyzed for 75 pesticides and 8 pesticide degradates, including 20 of the 25 most heavily used herbicides and 16 of the 25 most heavily used insecticides, but few fungicides, fumigants, or other types of pesticides were analyzed. Degradates are new compounds formed by transformation of a pesticide by chemical, photochemical, or biological reactions. In addition, 32 organochlorine pesticide compounds were analyzed in bed sediment and (or) fish tissue—19 parent pesticides and 13 degradates and manufacturing by-products (hereinafter referred to as by-products). Most of the organochlorine pesticides are no longer used in the United States, but the parent compounds, degradates, or by-products may persist in the environment. Pesticide compounds analyzed are listed in Appendix 1.

This analysis of NAWQA results for 1992–2001 builds upon an initial national assessment of pesticides in streams and ground water that was based on results from NAWQA's first 20 Study Unit investigations (summarized in the first report of this series, U.S. Geological Survey, 1999). The more extensive data and expanded geographic coverage available for this report confirm and reinforce many of the previously reported findings, allow more detailed analyses of each topic, and support new analyses, such as the development of statistical models that extend the results from targeted NAWQA studies to areas of the Nation that have not been assessed. In addition, water-quality benchmarks for assessing the potential significance of pesticide concentrations to aquatic life and fish-eating wildlife have been substantially updated to incorporate the most recent values available from the U.S. Environmental Protection Agency (USEPA) and other sources.

NAWQA findings are summarized below for major topics, each of which is identified with the chapter in this report where more detailed results, explanations, and references are provided. Key implications are also summarized for each topic, focusing on the extension of study results to national assessment of water quality, applications to water-quality management, and needs for additional information.

The NAWQA approach and design are summarized in Chapter 3. Details on data-analysis methods, as well as all data used in this report, are available at *http://ca.water.usgs.gov/pnsp/pubs/circ1291/*.

Relation to Previous Studies

Over the past 50 years, a vast amount of research has been conducted to investigate the spatial and temporal distributions of pesticides and their degradates in the hydrologic system, the biological effects of these compounds, and the myriad chemical, physical, and biological processes that control their transport and fate in the environment. Much of this previous work was summarized in a NAWQA book series entitled "Pesticides in the Hydrologic System," which examined these issues in relation to pesticides in the atmosphere (Majewski and Capel, 1995), ground water (Barbash and Resek, 1996), surface water (Larson and others, 1997), and bed sediment and aquatic biota (Nowell and others, 1999). In addition, since this book series was published, there have been many more studies and new reviews of specific topics by scientists in government, academia, corporations, and other organizations. This report is not intended to be a comprehensive review of all of these topics, although investigations directly relevant to the findings discussed in this report are cited in the text. The focus of this report is on the summary and interpretation of NAWQA data collected during 1992–2001.

Unique Features of the NAWQA Approach

Water-quality assessments by NAWQA, which is a single program among many local, State, and Federal programs, were not designed to address all of the Nation's water-resource information needs and issues. Listed below are several characteristics and limitations of the NAWQA approach that are important to consider when interpreting the findings on pesticides presented in this report.

- NAWQA assessments characterized the quality of the available, untreated water resources, and not the quality of drinking water (as would be done by monitoring water from water-treatment plants or from household taps). By focusing on the quality of streams and ground water in their present condition (ambient water quality), NAWQA complements many Federal, State, and local drinking-water monitoring programs.
- NAWQA assessments did not focus on specific sites with known water-quality problems or narrowly defined "issues of the day," but rather on the condition of the total resource, including streams and ground water in a wide range of hydrologic and land-use settings across the country.
- NAWQA assessments of pesticides focused primarily on non-point sources resulting from applications for pest management in agricultural, urban, and other land-use settings, although some sites—particularly those downstream from major metropolitan areas—also may be influenced by point sources, such as discharges from wastewater treatment plants.
- NAWQA assessments targeted specific land-use settings that are most extensive or important to water quality in a wide range of hydrologic and environmental settings across the Nation. This targeted approach gives priority to understanding the most critical factors influencing water quality. Extension of results to national analysis, however, requires careful definition of each type of water resource and environmental setting for which conclusions are drawn and the use of statistical models to extrapolate results to resources that have not been measured.
- USGS analytical methods were designed to measure concentrations as low as economically and technically feasible. Studies of contaminant occurrence and behavior benefit from the most information possible at all concentration levels, and such data help to identify emerging issues and to track changes in concentrations over time. By this approach, however, pesticides were commonly detected at concentrations far below Federal or State standards and guidelines for protecting water quality. Detections of pesticides do not necessarily indicate that there are appreciable risks to human health, aquatic life, or wildlife, which must be assessed by comparing measured concentrations with those that may cause adverse effects.
- USGS methods for analyzing pesticides in water measured concentrations in filtered water samples and, thus, may underestimate concentrations of compounds that have strong affinities for suspended particles. The potential for underestimation is greater for stream water compared with ground water because of the generally greater amounts of suspended particles present in stream water—which are removed by filtration along with any pesticides contained in or on the particles.
- Pesticide compounds analyzed in water by NAWQA included many of the most heavily used herbicides and insecticides, but they included only a fraction of all pesticides currently in use and few of their degradates. NAWQA findings provide insights about what to expect for pesticides and degradates that were not measured, but must be considered as only a partial assessment of currently used pesticides.
- Organochlorine pesticide compounds analyzed by NAWQA in bed sediment and fish tissue are predominantly related to pesticides that were no longer in use by 1990. Of the pesticide compounds measured in bed sediment and fish tissue, only dacthal, endosulfan, lindane, methoxychlor, and permethrin were used during all or part of the study period.

NAWQA studies used nationally consistent methods for sample collection and laboratory analysis. Urban ground-water studies, for example, often required the installation of new observation wells to ensure comparable data among studies.

Pesticide Occurrence—

Pesticides were frequently detected in streams and ground water (Chapter 4)

Pesticides or their degradates were detected in one or more water samples from every stream sampled. One or more pesticides or degradates were detected in water more than 90 percent of the time during the year in agricultural streams, urban streams, and mixed-land-use streams (fig. 1–1). This finding is based on a time-weighted analysis of results for 4,380 water samples, which adjusts results for variable sampling frequencies to avoid biases that may be caused by differences in sampling intensity among sites and seasons. Undeveloped streams had one or more detectable pesticides or degradates 65 percent of the time. The presence of pesticide compounds in predominantly undeveloped watersheds may result from past or present uses within the watershed for purposes such as forest management or maintenance of rights-of-way, uses associated with small areas of urban or agricultural land, or atmospheric transport from other areas.

Organochlorine pesticides (such as DDT) and their degradates and by-products were found in fish or bed-sediment samples from most streams in agricultural, urban, and mixed-land-use settings—and in more than half the fish samples from streams draining undeveloped watersheds (fig. 1–1). Most organochlorine pesticides had not been used in the United States for a number of years prior to the study period, but the continued occurrence of some historically used organochlorine pesticide compounds demonstrates their persistence in the environment.

Pesticides were less common in ground water than in streams (fig. 1–1). Nevertheless, more than half of the shallow wells sampled in agricultural and urban areas, and 33 percent of the deeper wells that tap major aquifers, which are influenced by a mixture of land uses, contained one or more pesticides or degradates.

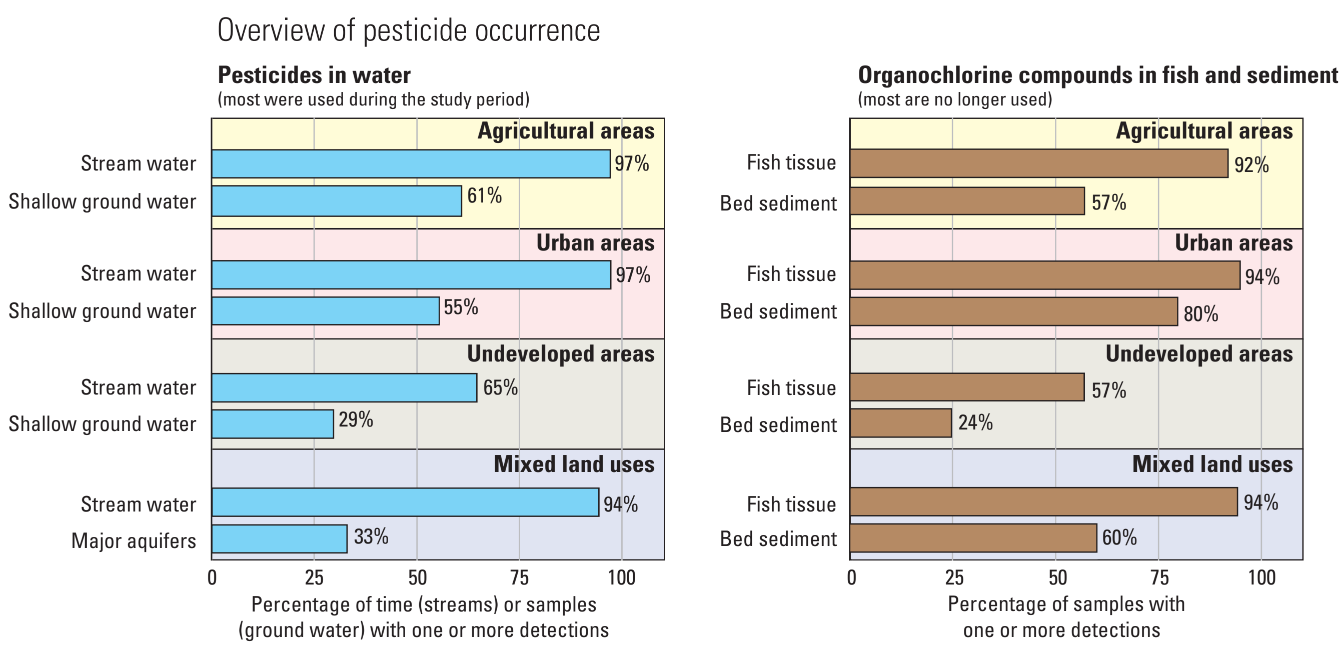

Figure 1–1. One or more pesticides or degradates were detected in water more than 90 percent of the time during the year in streams draining watersheds with agricultural, urban, and mixed land uses. In addition, some organochlorine pesticides that have not been used in the United States for many years were detected along with their degradates and by-products in most samples of whole fish or bed sediment from streams sampled in these land-use settings. Pesticides were less common in ground water, but were detected in more than 50 percent of wells sampled to assess shallow ground water in agricultural and urban areas.

Implications

- Pesticides and degradates are likely to be present at detectable levels throughout most of the year in streams that have substantial agricultural or urban land use in their watersheds.
- Streams are more vulnerable to pesticide contamination than ground water in most hydrologic settings, as indicated by much more frequent detections in stream water.
- The frequent detection of pesticides and degradates in shallow wells in agricultural and urban areas indicates that ground water may merit special attention in these land-use settings. Shallow ground water is used in some areas for drinking water—and can also move downward into deeper aquifers. Early attention to potential ground-water contamination is warranted because the movement of ground water is usually slow and contamination is difficult to reverse.
- Pesticide occurrence in streams and ground water does not necessarily cause adverse effects on aquatic ecosystems or humans. The potential for effects can be assessed by comparing measured pesticide concentrations with water-quality benchmarks, which are based on the concentrations at which effects may occur.

NAWQA studies included assessments of water quality in the most important agricultural and urban settings in each Study Unit, with studies of urban areas focused mostly on residential areas.

Potential Significance to Human Health—

Pesticides seldom occurred at concentrations greater than water-quality benchmarks for human health (Chapter 6)

A screening-level assessment of the potential significance of pesticides to human health was based on comparing measured concentrations in streams and ground water with water-quality benchmarks for human health. These human-health benchmarks were derived from standards and guidelines developed by USEPA for drinking water.

Although none of the NAWQA stream sites is located at actual drinking-water intakes, comparison of time-weighted annual mean concentrations to human-health benchmarks provides perspectives on (1) the likelihood that some current drinking-water intakes on streams may withdraw water with pesticide concentrations that exceed a benchmark, and (2) the potential long-term significance of pesticides to the quality of water that may be used as sources of drinking water in the future.

Annual mean concentrations of pesticides in streams studied by NAWQA were seldom greater than human-health benchmarks (fig. 1–2). No streams draining undeveloped land, and only one stream in a watershed with mixed land uses, had an annual mean concentration greater than a human-health benchmark. The annual mean concentrations of one or more pesticides exceeded a human-health benchmark in about 10 percent of the 83 agricultural streams and in about 7 percent of the 30 urban streams sampled by NAWQA. The 2 urban streams where benchmarks were exceeded are in Texas (diazinon) and Hawaii (dieldrin). Agricultural streams located in the Corn Belt (Illinois, Indiana, Iowa, Nebraska, Ohio, and parts of adjoining states) and Mississippi River Valley accounted for most concentrations that exceeded benchmarks, all involving atrazine (5 sites), cyanazine (4 sites), or dieldrin (2 sites). If, as examined in Chapter 6, the atrazine human-health benchmark were changed to values from the updated atrazine risk assessment (USEPA, 2003a), then there would be 2 sites rather than 5 sites with exceedances (although NAWQA did not measure 2 of the 3 degradates required for that benchmark).

Of pesticides accounting for most exceedances, atrazine use remains high, use of cyanazine has been reduced sharply since the mid-1990s (with corresponding decreases in stream concentrations; Chapter 8), and dieldrin and aldrin uses were discontinued before the 1992–2001 study period. Changes through the study period in the frequency of benchmark exceedances by atrazine and cyanazine were consistent with changes in agricultural use. As described in Chapter 6, the proportion of agricultural stream sites in the Corn Belt with atrazine concentrations that exeeded the human-health benchmark was greater for streams sampled during 1998–2000 than for streams sampled during either 1993–1994 or 1995–1997. In contrast, most sites where cyanazine exceeded its benchmark were sampled during 1993–1994, and no sites that were sampled during 1998–2000 had exceedances of the cyanazine benchmark.

For perspective on the relevance of NAWQA findings to drinking-water supplies, NAWQA land-use classifications for 1,679 public water-supply intakes that withdraw water from streams in the United States indicate that 55 percent of the intakes withdraw water from streams that drain watersheds with predominantly undeveloped land, 32 percent from streams with mixed land use, 12 percent from streams with agricultural land use, and 1 percent from streams with urban land use. Although the watershed land uses of NAWQA sites and water-supply intakes were

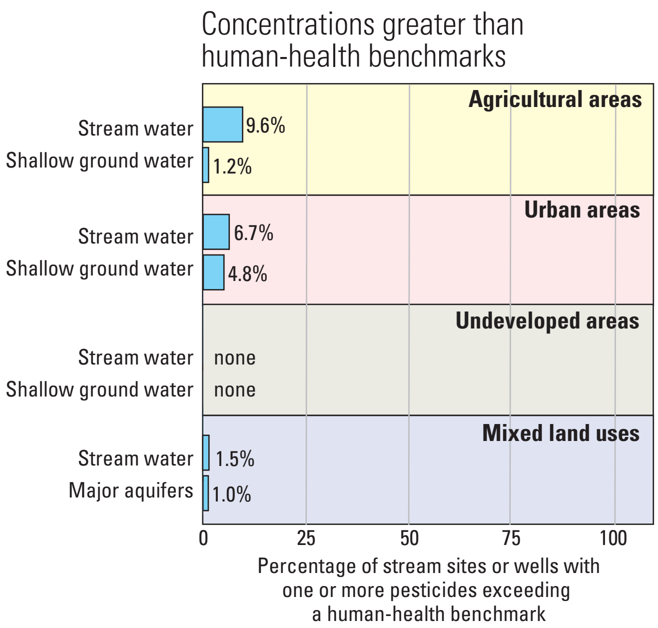

Figure 1–2. Concentrations of pesticides and degradates measured in streams and ground water usually were lower than human-health benchmarks for the pesticide compounds analyzed by NAWQA. Many of the wells sampled for ground-water studies, but none of the stream sites sampled, were sources of domestic or public water supplies during the study period.

classified in the same way, NAWQA sites tend to have more agricultural and urban land in their watersheds than do water-supply intakes in the same land-use categories.

Human-health benchmarks were exceeded less often in ground water than in streams (fig. 1–2). One or more pesticides exceeded a benchmark in about 1 percent of the 2,356 domestic wells and 364 public-supply wells sampled among studies in the three land-use settings and major aquifers. In contrast to the streams that were sampled, however, these wells are sources of drinking water—commonly without treatment in the case of domestic wells and with variable amounts and types of treatment for public-supply wells. Shallow ground water sampled in urban areas had the greatest proportion of wells with concentrations of one or more pesticides that were greater than a benchmark, including 1 of 9 public-supply wells, 3 of 17 domestic wells, and 37 of 835 observation wells, for a total of about 5 percent. About 1 percent of wells sampled in agricultural areas (shallow ground water) and in major aquifers had concentrations greater than one or more benchmarks. Wells with a concentration greater than a benchmark were scattered among 36 of the 187 ground-water studies. All concentrations greater than a benchmark were accounted for by dieldrin (72 wells), dinoseb (4), atrazine (4), lindane (2), and diazinon (1).

Implications

- Concentrations of pesticides measured in streams draining undeveloped and mixed-land-use watersheds indicate that public water-supply intakes on streams in these land-use settings, which compose about 87 percent of all intakes on the Nation's streams, are unlikely to withdraw water with concentrations that are greater than a human-health benchmark.
- The likelihood of pesticide concentrations exceeding a human-health benchmark in streams is greatest for those streams draining agricultural or urban watersheds, which account for about 12 and 1 percent, respectively, of public water-supply intakes on streams (based on NAWQA land-use classification). Such streams may warrant a priority for enhanced monitoring.
- The likelihood of pesticide concentrations exceeding a human-health benchmark in a public-supply well or domestic well is low on the basis of NAWQA results. About 1 percent of such wells sampled by NAWQA in all land-use settings had a pesticide concentration greater than a benchmark—most frequently dieldrin, which is no longer used.

Characteristics and Limitations of the Screening-Level Assessment of Potential Effects

The NAWQA screening-level assessment provides an initial perspective on the potential importance of pesticides to water quality in a national context by comparing measured concentrations with water-quality benchmarks. The screening-level assessment is not a substitute for risk assessment, which includes many more factors, such as additional avenues of exposure. The screening-level results are primarily intended to identify and prioritize needs for further investigation and have the following characteristics and limitations.

- Most benchmarks used in this report are estimates of no-effect levels, such that concentrations below the benchmarks are expected to have a low likelihood of adverse effects and concentrations above a benchmark have a greater likelihood of adverse effects, which generally increases with concentration.
- The presence of pesticides in streams or ground water at concentrations that exceed benchmarks does not indicate that adverse effects are certain to occur. Conversely, concentrations that are below benchmarks do not guarantee that adverse effects will not occur, but indicate that they are expected to be negligible (subject to limitations of measurements and benchmarks described below).
- The potential for adverse effects of pesticides on humans, aquatic life, and wildlife can only be partially addressed by NAWQA studies because chemical analyses did not include all pesticides and degradates. In addition, some compounds analyzed by NAWQA do not have benchmarks.
- Most benchmarks used in this report are based on toxicity tests of individual chemicals, whereas NAWQA results indicate that pesticides usually occur as mixtures. Comparisons to single-compound benchmarks may tend to underestimate the potential for adverse effects for some sites.
- Water-quality benchmarks for different pesticides and media are not always comparable because they have been derived by a number of different approaches, using a variety of types of toxicity values and test species.
- For some benchmarks, there is substantial uncertainty in underlying estimates of no-effect levels, depending on the methods used to derive them and the quantity and types of toxicity information on which they are based. This is especially true of fish-tissue benchmarks for the protection of fish-eating wildlife, for which there is no consensus on national-scale benchmarks or toxicity values.
- Estimates of pesticide exposure derived from NAWQA concentration measurements are also uncertain—particularly estimates of short-term exposure of aquatic organisms to pesticides in stream water. Generally, short-term average concentrations in stream water, such as 4-day values, are underestimated from NAWQA data.

Potential Significance to Aquatic Life and Wildlife—

Concentrations of pesticides were frequently greater than water-quality benchmarks for aquatic life and fish-eating wildlife (Chapter 6)

A screening-level perspective on the potential significance of pesticides to aquatic life and fish-eating wildlife was obtained by comparing concentrations measured in streams—including those in water, bed sediment, and whole fish—with water-quality benchmarks derived from guidelines established by USEPA, toxicity values from USEPA pesticide risk assessments, or selected guidelines from other sources.

Water—NAWQA findings for streams indicate that pesticides detected in water, most of which were in use during the study period, frequently exceeded aquatic-life benchmarks (fig. 1–3). Of 186 stream sites sampled nationwide:

- 57 percent of 83 agricultural streams had concentrations of at least one pesticide that exceeded one or more aquatic-life benchmarks at least one time during the year (68 percent of sites sampled during 1993–1994, 43 percent during 1995–1997, and 50 percent during 1998–2000).
- 83 percent of 30 urban streams had concentrations of at least one pesticide that exceeded one or more aquatic-life benchmarks at least one time during the year (90 percent of sites sampled during 1993–1994, 100 percent during 1995–1997, and 64 percent during 1998–2000).
- 42 percent of 65 mixed-land-use streams had concentrations of at least one pesticide that exceeded one or more aquatic-life benchmarks at least one time during the year (38 percent of sites sampled during 1993–1994, 40 percent during 1995–1997, and 46 percent during 1998–2000).

Streams in which concentrations of one or more pesticides exceeded an aquatic-life benchmark for water were distributed throughout the Nation in agricultural, urban, and mixed-land-use settings. In urban streams, most concentrations greater than a benchmark involved the insecticides diazinon (73 percent of sites), chlorpyrifos (37 percent), and malathion (30 percent). A potential revision of the acute invertebrate benchmark for diazinon from 0.1 micrograms per

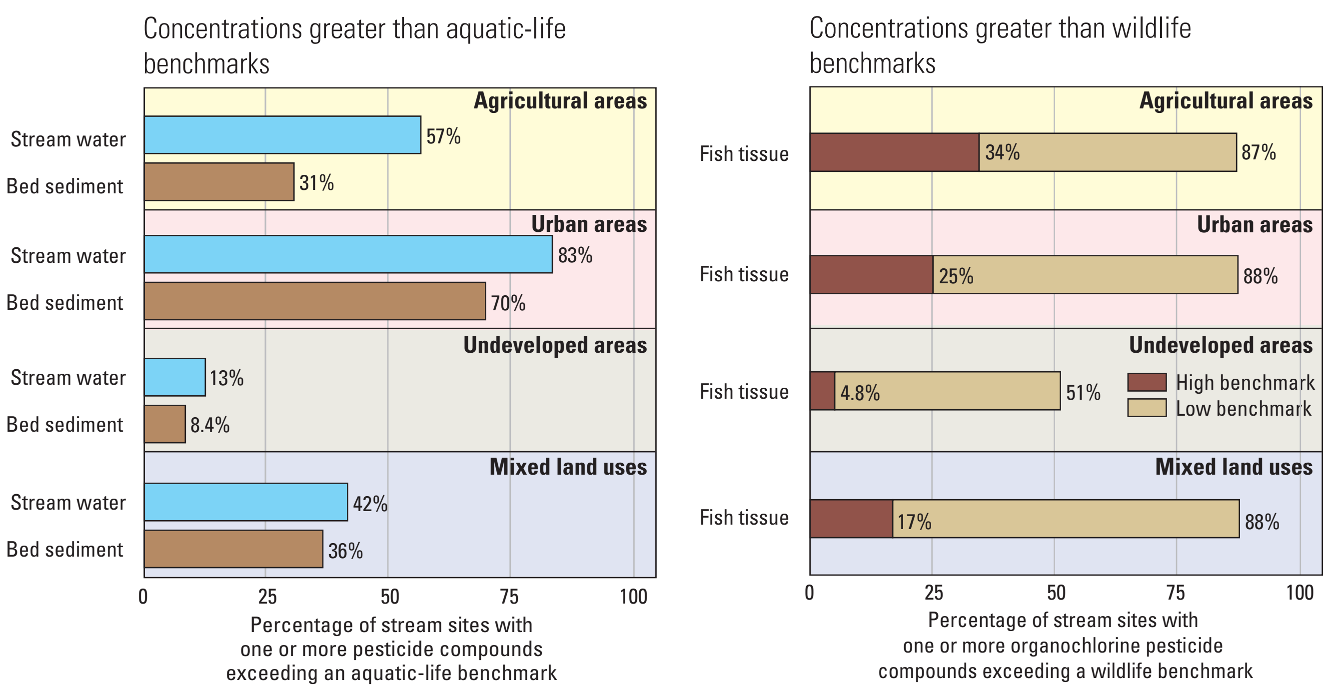

Figure 1–3. Pesticide concentrations measured in stream water and bed sediment frequently exceeded water-quality benchmarks for aquatic life. Concentrations of organochlorine pesticide compounds measured in whole-fish tissue were frequently greater than benchmarks for fish-eating wildlife, although the wide range of results for low and high benchmark values indicates relatively high uncertainty in the potential for effects, mainly because of uncertainty in the benchmark for total DDT.

liter (µg/L) to 0.4 µg/L, as discussed in Chapter 6, would reduce the percentage of urban streams with exceedances by diazinon from 73 percent to 40 percent. As described in Chapter 6, all three of these insecticides exceeded aquatic-life benchmarks least frequently at urban sites sampled near the end of the study period (1998–2000), compared with sites sampled during 1993–1997. Agricultural and nonagricultural uses of diazinon and chlorpyrifos have been restricted to varying degrees since 2001, as discussed for diazinon in Chapter 8.

In agricultural streams, most concentrations greater than a benchmark involved chlorpyrifos (21 percent of sites), azinphos-methyl (19 percent), atrazine (18 percent), *p,p′*-DDE (16 percent), and alachlor (15 percent). Findings for agricultural streams in the Corn Belt indicate that alachlor exceedances declined through the study period, with none during 1998–2000; atrazine exceedances increased, with the most frequent for sites sampled during 1998–2000; and chlorpyrifos exceedances varied through the study period, but were most frequent during 1998–2000.

Generally, insecticides most commonly exceeded benchmarks that are based on acute or chronic effects on aquatic invertebrates, or those that are based on ambient water-quality criteria for aquatic life. Herbicides most commonly exceeded benchmarks that are based on acute or chronic effects on vascular or nonvascular plants. Because of the wide variability in the number, type, and degree of benchmark exceedances among sites and the complexity of translating exceedances of screening-level benchmarks into specific potential for effects, the screening-level results should be used as the starting point for further site-specific investigation.

Bed Sediment—Concentrations of organochlorine pesticide compounds measured in bed sediment were greater than one or more aquatic-life benchmarks at 70 percent of urban stream sites, 31 percent of agricultural sites, 36 percent of sites with mixed land use, and 8 percent of undeveloped sites (fig. 1–3). The geographic distribution of sites where aquatic-life benchmarks for bed sediment were exceeded is similar to findings for water in many respects, including urban streams throughout the country, and many agricultural and mixed-land-use streams in the Southeast, East, and irrigated areas of the West. In urban streams, aquatic-life benchmarks were most frequently exceeded by individual compounds in the DDT group or total DDT (58 percent of sites), total chlordane (57 percent), and dieldrin (26 percent). Compounds in the DDT group are derived from 2 parent pesticides, DDT and DDD, and include several degradates and by-products (DDD is also a degradate of DDT). Total DDT is the sum of the concentrations of six individual compounds. Total chlordane concentration is the sum of concentrations of the *cis* and *trans* isomers of chlordane and nonachlor, plus the chlordane degradate oxychlordane. In agricultural streams, aquatic-life benchmarks were exceeded most often by individual compounds in the DDT group or by total DDT (28 percent of sites) and by dieldrin (8 percent).

Fish Tissue—Comparisons of concentrations of organochlorine pesticide compounds measured in whole fish with benchmarks for fish-eating wildlife indicate a wide range of potential for effects, depending on the type of wildlife benchmark used (fig. 1–3). Because there is no consensus on tissue-based benchmark values for wildlife, measured concentrations were compared with both the high and low benchmark values from the range available for each compound. The high benchmark values for fish tissue were exceeded most frequently in streams in the populous Northeast; in high-use agricultural areas in the upper and lower Mississippi River Basin; in high-use irrigated agricultural areas, such as eastern Washington and the Central Valley of California; and in urban streams distributed throughout the country. In urban streams, low benchmarks were exceeded most often by total DDT (88 percent of sites), dieldrin (18 percent), and total chlordane (10 percent). In agricultural streams, low benchmarks were exceeded most often by total DDT (87 percent of sites), dieldrin (11 percent), and toxaphene (9 percent).

Implications

- The screening-level assessment indicates that the most widespread potential impact of pesticides on water quality is adverse effects on aquatic life and fish-eating wildlife, particularly in streams draining watersheds with substantial agricultural and urban areas.
- Assessment and management of potential effects on aquatic life and wildlife are complicated by the combined presence of (1) currently used pesticides and their degradates, and (2) organochlorine pesticide compounds derived from pesticides that, for the most part, had their uses cancelled prior to 1990.
- The widespread potential for adverse effects shown by the screening-level assessment—and the uncertainty in this potential because of the preliminary nature of the assessment and the complexity of pesticide exposure—indicate a continuing need to study the effects of pesticides on aquatic life and wildlife under the conditions of pesticide exposure that occur in the environment.

Frequently Detected Pesticides and Relations to Use—

Pesticides detected most frequently were among those used most heavily during the study period or in the past (Chapter 4)

The pesticides detected most frequently in streams and ground water were primarily those with the greatest use—either during the study period or in the past—and with the greatest mobility and (or) persistence in the hydrologic system (fig. 1–4).

The pesticides detected most frequently in stream water included: (1) five agricultural herbicides that were among the most heavily used during the study period—atrazine (and its degradate deethylatrazine), metolachlor, cyanazine, alachlor, and acetochlor; (2) five herbicides extensively used for nonagricultural purposes, particularly in urban areas—simazine, prometon, tebuthiuron, 2,4-D, and diuron; and (3) three of the most extensively used insecticides during the study period—diazinon, chlorpyrifos, and carbaryl (fig. 1–4). Simazine, prometon, diuron, 2,4-D, diazinon, and carbaryl, which are commonly used to control weeds, insects, and other pests in urban areas, were frequently found at relatively high levels in urban streams throughout the Nation. The use of individual pesticides often changes over time, and may have increased or decreased during or since the end of the study period. For example, the uses of diazinon and chlorpyrifos have been substantially restricted since 2001, and analysis of recent data for diazinon shows that concentrations in some streams have now declined as well.

The pesticide compounds detected most frequently in fish and bed sediment were historically used organochlorine pesticides, along with their degradates and by-products (fig. 1–4). Most organochlorine pesticides were heavily used during the 1950s and 1960s, but had their agricultural uses cancelled during the 1970s and remaining urban uses cancelled by the late 1980s. Some organochlorine compounds, however, persist in soils, sediment, and biota. Several compounds in the DDT group, chlordane compounds, dieldrin (from use of both dieldrin and aldrin), and heptachlor epoxide (degradate of heptachlor), were found most frequently. Although quantitative information on urban pesticide use is limited, the relatively high concentrations found in fish and bed sediment from urban streams indicate that historical use of these pesticides in urban areas was probably intensive.

Compared with streams, ground-water detections were dominated by fewer compounds—mainly those with relatively high mobility and persistence, which allows them to move greater distances to and within the ground-water flow system (fig. 1–4). The most prevalent pesticides in both agricultural and urban areas were the herbicides atrazine (and deethylatrazine), metolachlor, prometon, and simazine.

Implications

- The correlations of the pesticides found most frequently in streams and ground water with the amounts and characteristics of pesticides used can help managers to anticipate and prioritize the pesticides most likely to affect water quality in different land-use settings.
- For pesticides that are still being applied, reducing their use is likely to be an effective way to reduce their concentrations in the hydrologic system, particularly for streams (other approaches may also be effective).
- For organochlorine pesticide compounds derived from past use, management practices that control the erosion of soil may help to reduce their transport to streams.

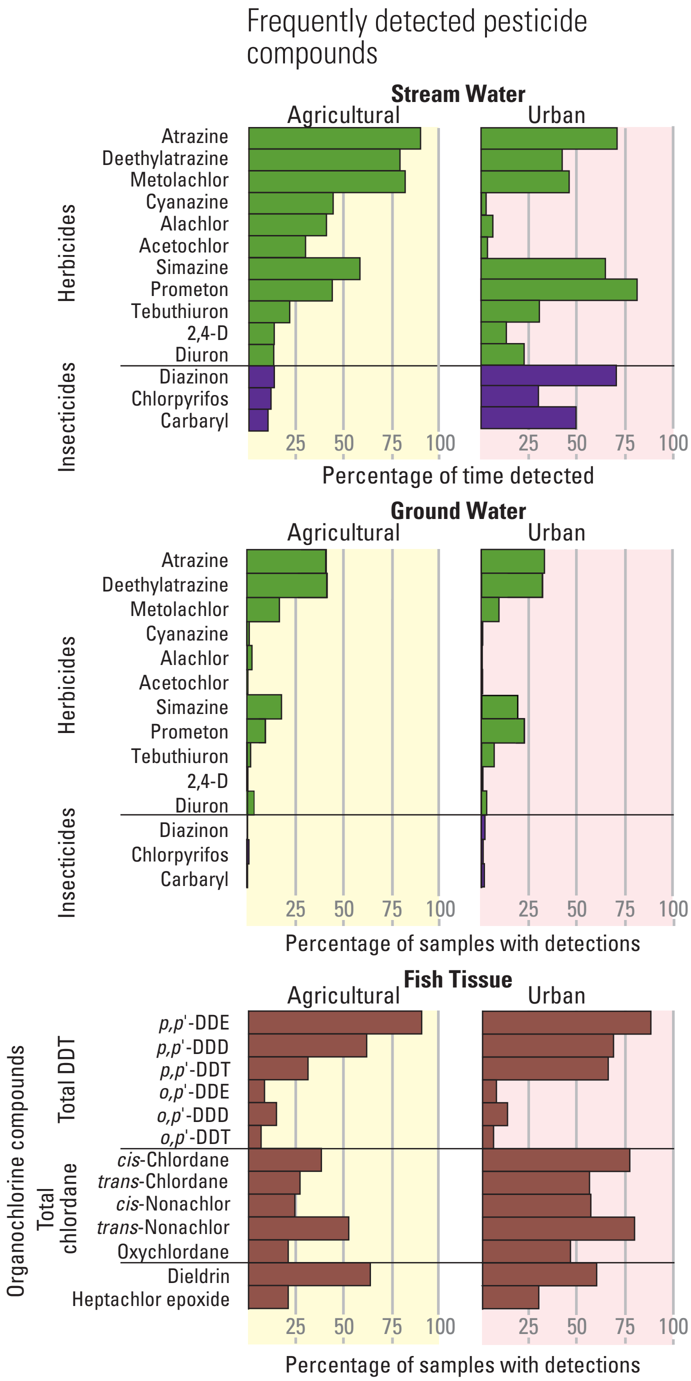

Figure 1–4. The pesticide compounds detected most frequently in streams and ground water in agricultural and urban areas were mainly those with the most extensive use—either during the study period or historically—and those with the greatest mobility and (or) persistence in the hydrologic system.

The most intensive pesticide applications are in agricultural and urban areas, including substantial use for home, lawn, and garden pest control in residential areas (photograph ©2003 Corbis [top]).

Geographic Patterns—

Patterns of pesticide occurrence in streams primarily followed the distribution of use, whereas patterns in ground water were more affected by management practices and natural susceptibility to contamination (Chapter 4)

The types and concentrations of pesticides found in agricultural streams primarily reflect the geographic distributions and intensity of use, along with additional influences by climate, soil characteristics, and water-management practices. For example, geographic patterns in stream concentrations of atrazine, metolachlor, simazine, acetochlor, 2,4-D, chlorpyrifos, and diazinon directly correlate with where they are used on crops. Some of the highest concentrations of atrazine were observed in streams within the Corn Belt and other areas where corn is a primary crop and where the herbicide is most heavily used (fig. 1–5). Total DDT was found at some of the highest concentrations in bed sediment and fish in parts of the Southeast, where DDT was historically used on cotton, tobacco, and peanuts, as well as in parts of California, Oregon, and Washington, where it was used extensively on orchards, potatoes, vegetables, and specialty crops. Dieldrin, on the other hand, was found most frequently and at some of the highest concentrations in the Corn Belt, where aldrin and dieldrin were extensively applied to corn.

The geographic distribution of pesticides in ground water also is influenced by the distributions of land use and pesticide use, but is more strongly affected by natural features, such as hydrogeology and soil characteristics, and by agricultural management practices, such as irrigation and drainage. For example, ground water is more susceptible to contamination in areas where the soil and unsaturated zone are more permeable than in areas where they are less permeable. A management practice that can influence pesticides in ground water is the use of subsurface tile-drain systems, which are buried networks of perforated pipes that collect shallow ground water for the purpose of lowering the water table and draining water-logged soils, as well as other subsurface drainage systems. These drain systems may reduce pesticide levels in underlying ground water by diverting shallow ground water to surface waters.

Detection frequencies of atrazine (fig. 1–6), metolachlor, and simazine generally were highest in ground water sampled in areas with permeable soils and geologic formations in parts of

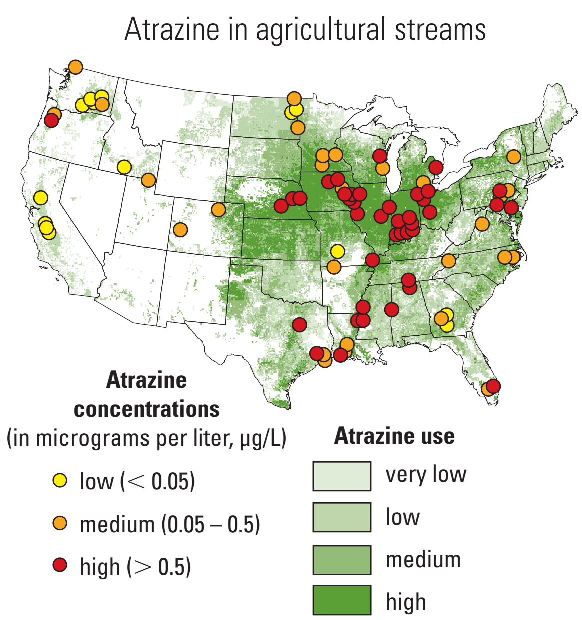

Figure 1–5. The concentrations of atrazine measured in agricultural streams correlated with the distribution of its use on crops—primarily corn. Some of the highest concentrations occurred in the corn-growing areas of Illinois, Indiana, Iowa, Nebraska, and Ohio.

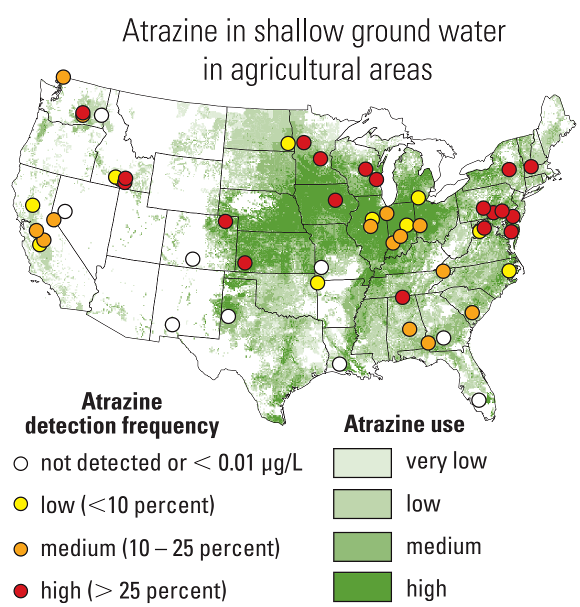

Figure 1–6. Atrazine was detected most frequently in shallow ground water in agricultural areas where soils and the underlying unsaturated zone are highly permeable and use is moderate to high, such as in parts of Iowa, Minnesota, Pennsylvania, and Wisconsin.

the country where these compounds are used for corn production—such as parts of Iowa, Minnesota, Pennsylvania, and Wisconsin. In contrast, these herbicides were found less frequently and at lower concentrations in ground water within many areas sampled in the central Corn Belt, despite some of the highest use in the Nation. This apparent anomaly, which has also been noted by other studies, is probably caused by the relatively impermeable soils and glacial till that cover much of this region, combined with the resulting widespread use of subsurface drainage systems. As observed for streams, each pesticide has a unique pattern and story regarding its occurrence in ground water, in large part resulting from its use on particular crops and its characteristic mobility and persistence. Pesticide properties more strongly control the occurrence of pesticides in ground water than in streams, however, because longer travel times in ground water and prolonged contact with soil and aquifer materials reduce concentrations of pesticides or degradates with low persistence or mobility.

Implications

- Pesticide occurrence in streams can be largely anticipated from the geographic distribution of land use, crops, and associated chemical use. Other factors, such as soil and runoff characteristics, also influence the amount and timing of the transport of pesticides to streams, but these factors are generally less important than the amount used in determining pesticide concentrations in streams.
- Compared with streams, natural features and management practices are more important considerations for anticipating the occurrence of pesticides in ground water. Ground water is most susceptible to contamination in areas where soils and the underlying unsaturated zone are most permeable and drainage practices do not divert recharge to surface waters.
- The entire hydrologic system and its complexities need to be considered in evaluating the potential for pesticide contamination of streams and ground water. Some hydrologic settings where ground water is least vulnerable to contamination are those where streams are most vulnerable, and vice versa. For example, subsurface drains may help protect deep ground water, but increase pesticide transport to streams.

Different pesticides are applied during different seasons in each region of the country. In the San Joaquin Valley, California, many orchards were sprayed with diazinon during the winter when they are dormant, whereas herbicides were applied to corn fields before and after spring planting throughout much of the Corn Belt (photograph by Dave Kim, California Department of Pesticide Regulation [left]).

Seasonal Patterns—

Pesticide concentrations in streams followed distinct seasonal patterns (Chapter 5)

Pesticide concentrations in stream water vary through the year, usually characterized by long periods with low or undetectable concentrations of most pesticides, punctuated by seasonal pulses of much higher concentrations. The timing and magnitude of seasonal pulses were correlated with the timing and intensity of pesticide applications, the frequency and magnitude of runoff from rainstorms or snowmelt, and the timing and distribution of land-management practices such as irrigation and artificial drainage. Concentrations in agricultural streams generally were highest during periods of runoff resulting from precipitation or irrigation that occurred soon after pesticide applications—a combination that causes seasonal patterns that are unique to each region. Spray drift and other modes of atmospheric transport can also be sources of pesticides to streams during high-use periods within an agricultural region. Most streams that drain farmland in the Corn Belt and other corn-growing areas, for example, had elevated concentrations of herbicides during spring runoff that followed applications (fig. 1–7). In contrast, agricultural streams in parts of the San Joaquin–Tulare Basin had high concentrations of diazinon during the winter, resulting from applications on dormant almond orchards followed by rainfall. Patterns also may vary because of differences in the timing of local water-management practices, such as irrigation and reservoir releases.

Implications

- Effective management of streams may require increased monitoring—including high-frequency sampling during seasons when intense pesticide use coincides with periods of high runoff—so that the periods with the highest pesticide concentrations are adequately characterized.
- Seasonal patterns in pesticide concentrations are important to consider in managing the quality of drinking water withdrawn from streams in agricultural and urban settings. Knowledge of seasonal patterns may help managers to adapt treatment strategies, or avoid or minimize withdrawals in favor of alternative sources of water, during high-concentration seasons.
- Seasonal patterns may result in adverse effects on aquatic life in some streams. Both acute and chronic aquatic-life benchmarks for water were most frequently exceeded during seasonal periods of high concentrations. Concentration pulses of some pesticides during sensitive stages of aquatic life cycles may have the greatest effects in some streams, and site-specific assessments may be required.

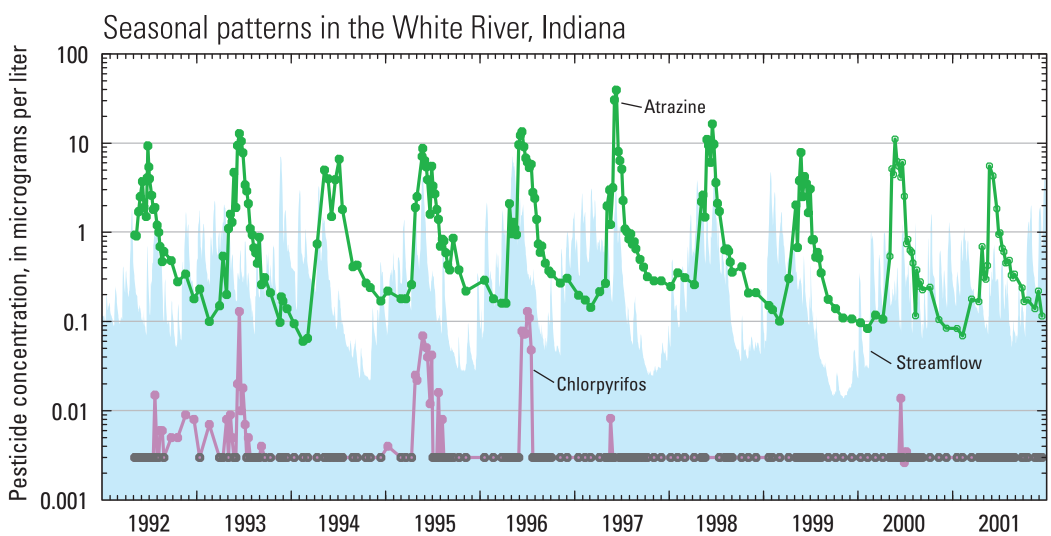

Figure 1–7. Atrazine concentrations in the White River, Indiana, were typical of streams throughout much of the Corn Belt, following similar seasonal patterns every year. Concentration pulses corresponded to the timing of runoff events and atrazine use on corn fields each spring. In contrast, seasonal patterns in concentrations of chlorpyrifos were more variable because of its more sporadic use.

Mixtures—

Pesticides were most commonly detected as mixtures of multiple pesticide compounds (Chapter 5)

Samples from streams in areas with substantial agricultural or urban land use almost always contained mixtures of multiple pesticides and degradates (fig. 1–8). More than 90 percent of the time, water from streams with agricultural, urban, or mixed-land-use watersheds had detections of 2 or more pesticides or degradates, and about 20 percent of the time they had detections of 10 or more. In addition, samples of fish tissue and bed sediment from most streams contained mixtures of historically used organochlorine pesticides and their degradates and by-products.

Mixtures were less common in ground water than in streams, which is consistent with the lower frequencies of detection for individual pesticide compounds. Nevertheless, 47 percent of shallow wells in agricultural areas and 37 percent of shallow wells in urban areas contained 2 or more detectable pesticides or degradates. Less than 1 percent had detections of 10 or more compounds.

The environmental significance of mixtures is ultimately determined by the specific combinations of individual compounds—known as “unique mixtures”—their concentrations and combined toxicity, and how often and where they occur. A unique mixture is a specific combination of 2 or more compounds, regardless of the presence of other compounds. Thus, a single sample with several pesticides contains many unique mixtures. Depending on the specific compounds, the toxicity of a mixture to a particular type of organism may result from additive effects among the compounds, independent effects, antagonistic effects (less than additive), or synergistic effects (greater than additive). Each of these toxicity models, except for the antagonistic model, usually results in a toxicity of the mixture that is greater than any of its individual components.

More than 6,000 unique 5-compound mixtures were found at least 2 percent of the time in agricultural streams (only 1 unique 5-compound mixture was found in ground water). Evaluating the potential significance of mixtures can be simplified, however, because many mixtures do not occur very often at high concentrations, and the most frequently occurring mixtures are composed of relatively few pesticides. For example, the number of unique 5-compound mixtures found in agricultural streams is less than 100 when only concentrations greater than 0.1 micrograms per liter (µg/L) are considered. More than 30 percent of all unique mixtures found in streams and ground water in agricultural and urban areas contained the herbicides atrazine (and deethylatrazine), metolachlor, simazine, and prometon. The insecticides diazinon, chlorpyrifos, carbaryl, and malathion were common in mixtures found in urban streams.

Implications

- Because of the widespread and common occurrence of pesticide mixtures, particularly in streams, the total combined toxicity of pesticides in water or other media often may be greater than that of any single pesticide compound that is present.
- Continued systematic assessment is needed of the potential toxicity of pesticide mixtures to humans, aquatic life, and wildlife. NAWQA information on the occurrence and characteristics of mixtures can help to target and prioritize toxicity assessments.

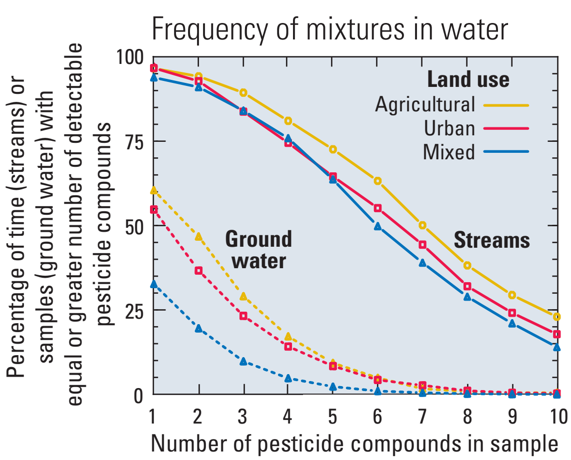

Figure 1–8. Pesticides commonly occurred in streams and ground water as mixtures. For example, agricultural stream samples contained 10 or more different pesticides or degradates more than 20 percent of the time.

Chapter 1

Degradates—

Concentrations of degradates were often greater than concentrations of parent pesticides (Chapter 5)

Once released into the environment, pesticides undergo many types of transformation reactions that create degradates. Factors that govern the formation and distribution of degradates in the hydrologic system include the use and persistence of parent pesticides, the persistence and mobility of the degradates, and the physical, chemical, and biological conditions in the environment. In many cases, transformation results in the conversion of the parent compound to a compound that is less toxic, but some degradates have toxicities that are similar to, or greater than, that of their parent pesticide.

Some degradates were found more frequently and at higher concentrations than their parent pesticide. For example, DDT, which was first used more than 50 years ago and was discontinued about 20 years before this study began, was detected in fish from about 30 percent of agricultural streams sampled by NAWQA, whereas DDE, a more stable degradate of DDT, was detected in fish from 90 percent of sampled agricultural streams. Atrazine, the most heavily used herbicide in the Nation during the study period, was found together with one of its several degradates, deethylatrazine, in about 75 percent of stream samples and about 40 percent of ground-water samples collected in agricultural areas across the Nation. In the Eastern Iowa Basins, where NAWQA conducted special studies of herbicide degradates, an average of nearly 85 percent of the total mass of herbicide compounds in stream samples was composed of 10 degradates of the herbicides acetochlor, alachlor, atrazine, cyanazine, and metolachlor (fig. 1–9). The summed concentrations of degradates were more than 10 times higher than the summed concentrations of their parent compounds during much of the year, and the degradates accounted for the largest proportion of pesticide compounds that are transported by the Iowa River to the Mississippi River.

Degradates are particularly important in ground water, which moves relatively slowly through soils and aquifers, providing the extended time and conditions favorable for transformation of pesticides to their degradates. Ground water in the Delmarva Peninsula, for example, contained degradates of alachlor and metolachlor at median concentrations 10 times higher than those of the parent herbicides. Degradates in ground water can ultimately reach streams when ground-water discharge contributes to streamflow. In the Iowa River, substantial transport of herbicide degradates occurred during low streamflow conditions (fig. 1–9).

Implications

- Pesticide degradates should continue to be considered and accounted for in assessments of pesticide exposure and in evaluating the potential effects of pesticides on humans, aquatic life, and wildlife.
- Enhanced assessments of the occurrence and behavior of degradates in the hydrologic system require improved coverage of degradates in water-quality monitoring and continued research on pesticide transformations and transport in the hydrologic system. Enhanced assessments would supplement the toxicity testing of major degradates now required by USEPA as part of risk assessments for pesticide registration.

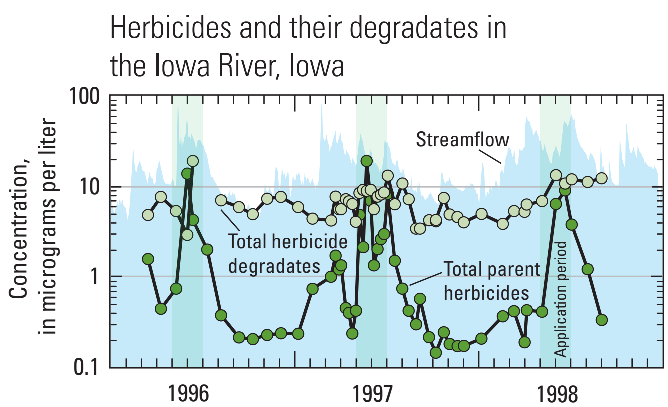

Figure 1–9. The total concentration of degradates commonly exceeded the total concentration of parent herbicides (acetochlor, alachlor, atrazine, cyanazine, and metolachlor) in the Iowa River.

Prediction—

Extensive data and improved understanding enable prediction of pesticide occurrence and concentrations for streams and ground water where they have not been measured (Chapter 7)

NAWQA data from 1992 to 2001 are sufficiently extensive to support statistical models that can be used to estimate the concentrations or occurrence of some pesticides in streams and ground water where they have not yet been assessed. Such spatial extrapolation is fundamental to extending NAWQA's targeted local and regional studies to a comprehensive national assessment. The statistical models were developed from measured pesticide concentrations, together with information on key factors and processes that affect pesticide occurrence, including pesticide use and land use, climate and soil characteristics, and other features.

The NAWQA approach to extrapolation for streams is illustrated by a model used to estimate concentrations of atrazine in stream water, specifically the likelihood that the annual average atrazine concentration in any particular stream in the Nation would exceed a human-health benchmark of 3 µg/L (fig. 1–10). The human-health benchmark used for atrazine is the USEPA drinking-water standard, or Maximum Contaminant Level (MCL). Predictions are for annual mean concentrations in untreated stream water (including consideration of predictive uncertainty), regardless of whether a stream is presently a source of drinking water. Atrazine concentrations were predicted to be highest in the Corn Belt and parts of the southern Mississippi River Valley, where use is high and natural features favor the transport of pesticides by runoff to streams. In these areas, many streams are estimated to have more than a 5-percent chance of having a mean annual concentration of atrazine that is greater than the benchmark (shown in red in figure 1–10). In other words, more than 1 out of 20 of these streams are predicted to have mean concentrations greater than the human-health benchmark, and thus, may not be suitable as sources of drinking water without the use of strategies to lower concentrations. Similar analyses can be developed for other probability criteria or concentration estimates.

Implications

- The development of national-scale predictive models with quantified reliability is increasingly possible for some pesticides, particularly for streams. Expanding this capability is a critical step for national water-quality assessment, as well as for cost-effective management of water resources, because both require more information (compounds, places, and times) than can be directly measured under current technology and budget constraints.
- Model estimates can be used to identify locations that have the greatest likelihood of water-quality problems and that are, therefore, the highest priority for additional monitoring.
- Future success with development and application of statistical models—as well as more complex simulation models—will depend upon continued, carefully targeted monitoring of pesticide concentrations in the hydrologic system, coupled with continued and improved collection of supporting data on pesticide use, natural features, and other explanatory factors needed to update and validate the models.

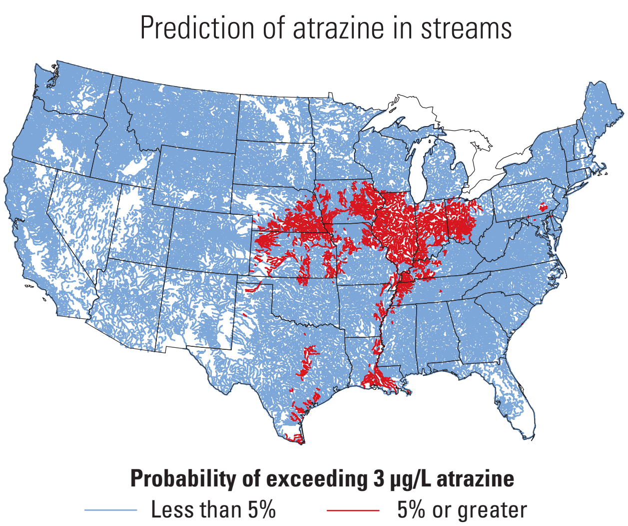

Figure 1–10. Streams predicted to have a 5 percent or greater chance of having annual mean atrazine concentrations that are higher than its human-health benchmark of 3 µg/L—USEPA's Maximum Contaminant Level for drinking water—are located throughout much of the Corn Belt and in other high-use areas such as the southern Mississippi River Valley. These estimates were based on 1997 atrazine use for agriculture and will change if use changes.

Trends—

A first look at trends shows examples of both decreasing and increasing levels of pesticides in streams and ground water (Chapter 8)

NAWQA results from 1992 to 2001 provide a framework for assessing whether pesticide levels in the Nation's streams and ground water are increasing or decreasing over time. For many pesticides and locations, it is too early to discern changes because historical data are insufficient to measure trends. Some trends, however, are already evident and others are just emerging.

The most complete story of trends in response to regulatory action and reduced pesticide use is the decline in concentrations of organochlorine pesticide compounds that followed reductions in use during the 1960s and bans on their uses in the 1970s and 1980s. For example, concentrations of total DDT in fish decreased rapidly from the 1960s through the 1970s, then more slowly during the 1980s and 1990s, as documented by data for 1969–1986 from the U.S. Fish and Wildlife Service (Schmitt and Bunck, 1995), and by data for the 1990s from NAWQA (fig. 1–11). The trends in concentrations of organochlorine compounds in fish, however, also show that responses to reductions in sources can take a long time for chemicals that are persistent in the environment.

More recent regional changes in corn herbicide use have resulted in corresponding trends in concentrations in Corn Belt streams. For example, in response to the partial replacement of alachlor by the new herbicide acetochlor in 1994, streams quickly—generally within 1 to 2 years—showed increasing acetochlor concentrations and decreasing alachlor concentrations. Findings show that concentrations of relatively mobile and short-lived pesticides in stream water will respond rapidly to changes in use—much more quickly than the less mobile and more persistent organochlorine compounds in fish tissue.

Ground water responds more slowly than streams to changes in pesticide use—taking years and even decades for changes in quality to occur. A persistent pesticide or degradate can remain in ground water long after its use has been discontinued because of the slow rates of ground-water flow and the resulting long residence time of water and contaminants in ground-water flow systems. This is evident from a number of studies in different parts of the country. For example, bromacil remained at detectable levels in ground water in parts of Florida for several years after it was no longer used. Similarly, dieldrin, which was no longer used during the study period, was still detectable at concentrations greater than its human-health benchmark in 72 wells sampled by NAWQA.

Continued NAWQA studies and monitoring will build on the baseline assessment established during the 1990s to assess trends in basins across the Nation. Assessment of trends is a primary objective during the second decade of the NAWQA Program when study areas are systematically reassessed and an increasing number of stream and ground-water sampling sites will have had 10 years of monitoring. Equally important, the NAWQA studies will continue to link changes in pesticide occurrence and concentrations over time with those factors that control the timing of trends, such as changes in pesticide use, land management, and natural factors.

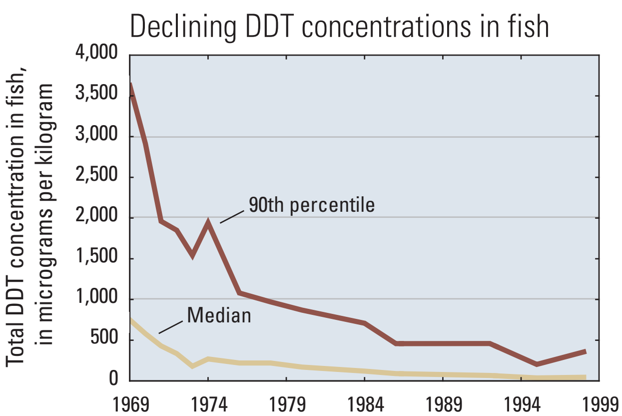

Figure 1–11. Total DDT concentrations in whole fish (wet weight) from rivers and streams throughout the Nation that drain watersheds with mixed land uses decreased rapidly from the 1960s through the 1970s, and then more slowly during the 1980s and 1990s.

Implications

- Increases or decreases in pesticide use can result in rapid corresponding changes in pesticide concentrations in stream water—generally within 1 to 2 years. In contrast, pesticide occurrence in ground water, and the occurrence of persistent compounds in aquatic organisms or sediment, may change slowly—sometimes taking decades to respond to changes in use.
- Long-term and consistent monitoring of pesticides in streams and ground water is essential for distinguishing actual trends from short-term fluctuations and for accurately tracking changes.
- Assessment of trends in stream-water concentrations of most currently used pesticides requires consistent annual data, with a particular focus on critical seasons of high use and transport. Assessment of trends in more persistent pesticides, such as organochlorine compounds in fish tissue, can rely on samples collected several years apart.
- Assessment of trends in concentrations of pesticides in ground water usually requires estimation of ground-water age and an understanding of the ground-water flow system because of the slow rate of ground-water flow and the uncertainty in flow paths.

Priorities for Filling Information Gaps

The NAWQA assessment provides the most comprehensive analysis to date of pesticides in streams and ground water at the national scale and serves as a foundation for improving water-resource assessment and management. Nevertheless, major gaps in critical information about pesticides still persist and continue to present challenges to scientists, managers, and policy makers. As present-day knowledge is brought to bear on decision making, there is a continuing need to improve the data and scientific understanding required for future decisions. Some of the most important steps needed to fill information gaps for pesticides are outlined below:

- **Improve tracking of pesticide use.** Existing data on pesticide use are sparse (infrequent, with coarse geographic coverage) for agricultural uses and virtually nonexistent for nonagricultural uses. Given the direct relations between pesticide use and occurrence, improvement in the extent, frequency, and quality of quantitative data on agricultural use—and development of comparable and reliable data sources for nonagricultural pesticide use—would have major benefits for assessment and management of pesticides in streams and ground water.

- **Add assessments of pesticides not yet studied.** Many important pesticides have not yet been assessed in the Nation's streams and ground water using a nationally consistent approach because of budget constraints and limitations of current analytical methods. These pesticides include most fungicides and fumigants in current use, as well as many new or increasingly used herbicides and insecticides, such as glyphosate and pyrethroid insecticides. Pesticides targeted for analysis need to be re-evaluated regularly as use changes over time and new pesticides are introduced.

- **Improve assessment and understanding of degradates.** Closely related to the gaps in pesticides that have been assessed, are the even greater gaps in information about the distribution of degradates in streams and ground water. Specific needs include the development of analytical capabilities for measurement of a broader suite of pesticide degradates, continued research on pesticide transformations and the implications for transport and persistence in the hydrologic system, and improved assessment of potential exposure to degradates and their potential to affect humans, aquatic life, and wildlife. This information is needed to supplement the information on the toxicity and environmental behavior of major degradates that is now developed as part of the pesticide registration process.

- **Evaluate toxicities of mixtures.** Existing standards and guidelines for exposure to individual pesticides may not address all potential effects because actual exposure is most often to mixtures of multiple pesticides and degradates. Additional research is needed regarding the toxicities of mixtures to humans, aquatic life, and wildlife.

- **Evaluate the performance of management practices.** Evaluations are needed for making direct links between management practices—such as irrigation methods, subsurface drains, integrated pest management, and retention of wetlands and buffers—and the concentrations and transport of pesticides in streams and ground water. Field-scale studies have shown that certain management practices can influence pesticides in streams and ground water, but the effectiveness of these practices has not been systematically assessed at regional and national scales.

- **Improve methods for prediction.** Successful assessment and management of the Nation's water quality requires a commitment not only to monitoring pesticides and their degradates in streams and ground water, but also to the continued development of predictive tools, such as statistical and simulation models. NAWQA assessments demonstrate that models can play an important role in the assessment of water quality and provide a cost-effective approach for extrapolating measured water-quality conditions to unsampled areas. Predictive capabilities are critical because the expense of monitoring prevents direct assessment of pesticides for all of the places and times required. Models, however, are successful only if they are developed and verified on the basis of measured data. Thus, the integration of monitoring and modeling, which is heavily emphasized in NAWQA's second decade of assessments, is critical to expanding and improving methods for prediction.

- **Sustain and expand long-term monitoring for trends.** Long-term, consistent data for assessing trends is essential for tracking water-quality response to changes in pesticide use and management practices, for providing early warning of unanticipated problems, and for updating and improving models. The second decade of NAWQA assessments will include long-term monitoring of a broad range of pesticides and degradates in water at a national network of selected sampling locations, but the geographic coverage and range of pesticides measured should be increased in cooperation with other agencies.