U.S. Department of the Interior
U.S. Geological Survey

Pesticides in Ground Water

Current Understanding of Distribution and Major Influences

This report summarizes a comprehensive analysis of existing information on pesticides in ground waters of the United States; major influences on their sources, transport, and detection; and the status of efforts to predict their presence. It is one of a four-part series that synthesizes current knowledge and understanding of pesticides in water resources of the nation as part of the National Water-Quality Assessment.

Pesticides in the Hydrologic System

Synthetic organic pesticides are used to control weeds, insects, and other organisms in a wide variety of agricultural and non-agricultural settings in the United States. National use of pesticides has grown from about 540 million pounds of active ingredient in 1964 to about 1.1 billion pounds in 1993. Of this total, agricultural use accounts for about 75 percent (U.S. Environmental Protection Agency, 1994). The use of pesticides has helped to make the United States the largest producer of food in the world and has provided other benefits, but has also been accompanied by concerns about their potential adverse effects on the environment and human health.

Highlights

- Over 300 studies of pesticide occurrence in ground water and soils have been carried out during the past 30 years.
- Pesticides from every major chemical class have been detected in ground water.
- Pesticides are commonly present in low concentrations in ground water beneath agricultural areas, but seldom exceed water-quality standards.
- Little information is available on pesticide occurrence beneath non-agricultural land, such as residential areas and golf courses, despite application rates that often exceed those for most crops.
- Frequencies of pesticide detection are almost always low in low-use areas, but vary widely in areas of high use.
- Pesticide levels in ground water show pronounced seasonal variability in agricultural areas, with maximum values often following spring applications.
- Factors most strongly associated with increased likelihood of pesticide occurrence in wells are high pesticide use, high recharge by either precipitation or irrigation, and shallow, inadequately sealed, or older wells.

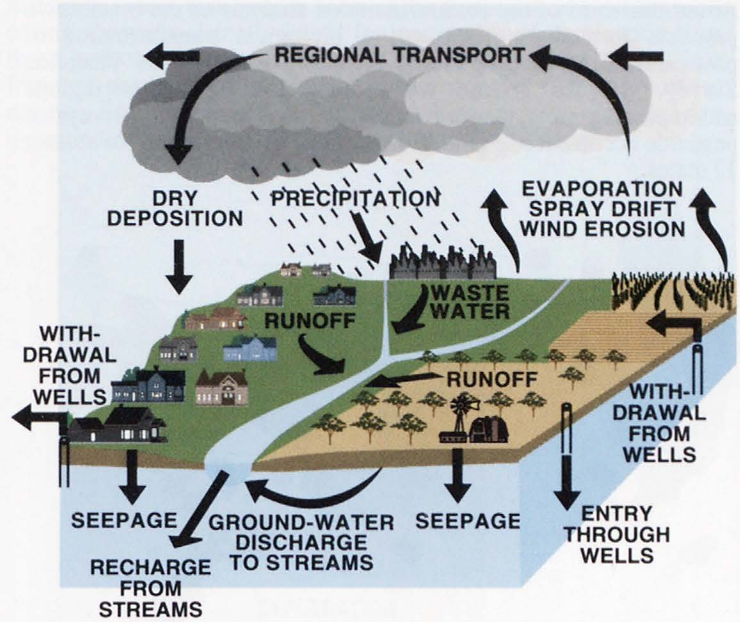

Figure 1. Pesticide movement in the hydrologic cycle (adapted from Majewski and Capel, 1995).

The greatest potential for unintended adverse effects of pesticides, in many respects, is through contamination of the Earth's hydrologic systems, which supply water for both humans and natural ecosystems. Water is one of the primary media in which pesticides are transported from application areas to other locations in the environment (see Figure 1).

Importance of Ground Water

Pesticide contamination of ground water is a national issue because ground water is used for drinking water by about 50 percent of the nation's population. Concern about pesticides in ground water is especially acute in agricultural areas, where most pesticides are used, and where over 95 percent of the population relies upon ground water for drinking water.

Prior to the mid-1970's, it was generally assumed that soil provided a protective "filter" or "barrier" that stopped infiltrating contaminants before they reached ground water. The detection of pesticides and other contaminants in ground water, however, has demonstrated that this is not always the case. By 1980, contamination of ground water by the insecticide aldicarb was discovered in New York and Wisconsin, and contamination by the fumigant 1,2-dibromo-3-chloropropane (DBCP) was found in California, Arizona, South Carolina, and Maryland.

In addition to their application to targeted areas, pesticides are discharged to the environment through accidental spills and leaks, and through improper disposal. They may then reach ground water not only by leaching through soil, but by a variety of other routes as well. Some of these routes include seepage of contaminated surface waters into underlying ground-water reservoirs or "aquifers," transport down abandoned or poorly sealed wells, and injection through wells used to dispose of agricultural or urban runoff.

Historical Study Efforts

Over 300 studies of pesticide occurrence in ground water and soils have been carried out during the past 30 years (see Figure 2). These studies include areas that range in scale from field plots of less than 1 m^2 to large multistate regions. The largest of these studies to date was the National Pesticide Survey conducted by the U.S. Environmental Protection Agency in all 50 states from 1988 to 1990 (U.S. Environmental Protection Agency, 1990). Approximately half of the reviewed investigations included measurements of pesticide concentrations specifically made in ground water; most focused primarily on soils and tile drainage. About one third of the studies included analysis of the breakdown products formed by chemical or biological transformation of pesticides. Five investigations, including the National Pesticide Survey, sampled ground water for pesticides across regions encompassing more than one state. To date, statewide surveys of pesticide occurrence in ground water have been reported for at least 17 states.

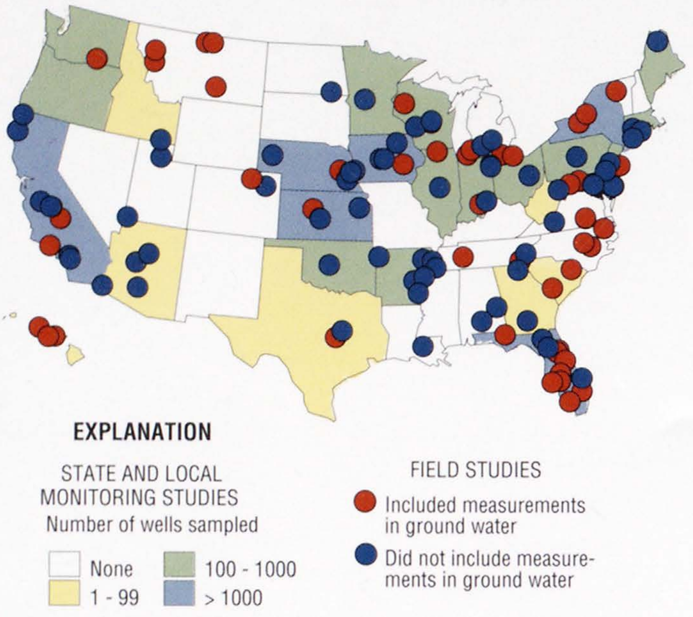

Figure 2. Number of wells sampled for pesticides by monitoring studies in each state, and locations of small-scale field investigations.

The areas of the United States where ground waters have been monitored intensively for pesticides are those where agricultural pesticide use is most extensive: California, Florida, New York (especially Long Island), New England, the central Atlantic Coastal Plain, and the central and northern midcontinent. In the Rocky Mountain states and the arid southwest, where pesticide use is less extensive, sampling has been sparse and infrequent. With the exception of Florida, ground-water sampling for pesticides in the southeast and southern midcontinent has also been limited, in spite of extensive pesticide use. To date, there have been few studies of golf courses, urban areas, and other settings where non-agricultural use of pesticides may be high.

Pesticides Found in Ground Water

Over the past two decades, pesticides or their transformation products have been detected in ground waters of more than 43 states. At least 143 pesticides and 21 transformation products have been detected, including compounds in every major chemical class. For two of the multistate studies — the National Pesticide Survey and the midcontinent investigation by Kolpin and others (1995) — the most frequently detected pesticide compounds were transformation products, rather than parent compounds. Pesticides that have been detected more frequently (see Figure 3) include those that have been used more extensively, such as the triazine and acetanilide herbicides (atrazine, simazine, alachlor, and metolachlor), and those for which sampling has been most extensive because of contamination problems (aldicarb and its transformation products, DBCP, and ethylene dibromide, or EDB).

Pesticides and their transformation products are commonly present at low concentrations in ground water beneath agricultural areas, and only seldom at concentrations that exceed water-quality standards. For the five multistate studies carried out to date — which focused mainly on agricultural areas — the proportions of sampled wells with pesticide detections ranged from four percent (nationwide, rural domestic wells) to 62 percent (corn-and-soybean areas of the northern midcontinent, post-planting). Pesticide concentrations were 1 µg/L or less in over 95 percent of the wells sampled during these studies.

Frequencies of pesticide detection in ground water may also be substantial in non-agricultural settings. The National Pesticide Survey and the midcontinent pesticide study (Kolpin and others, 1995) included analyses of ground waters for non-agricultural pesticides. In both studies, two predominantly non-agricultural herbicides — DCPA (in the form of one of its principal transformation products) and prometon — were among the pesticides detected most frequently. Non-agricultural settings in which pesticides have been detected in ground water include golf courses, commercial and residential areas, rights-of-way, timber production and processing areas, and public gardens.

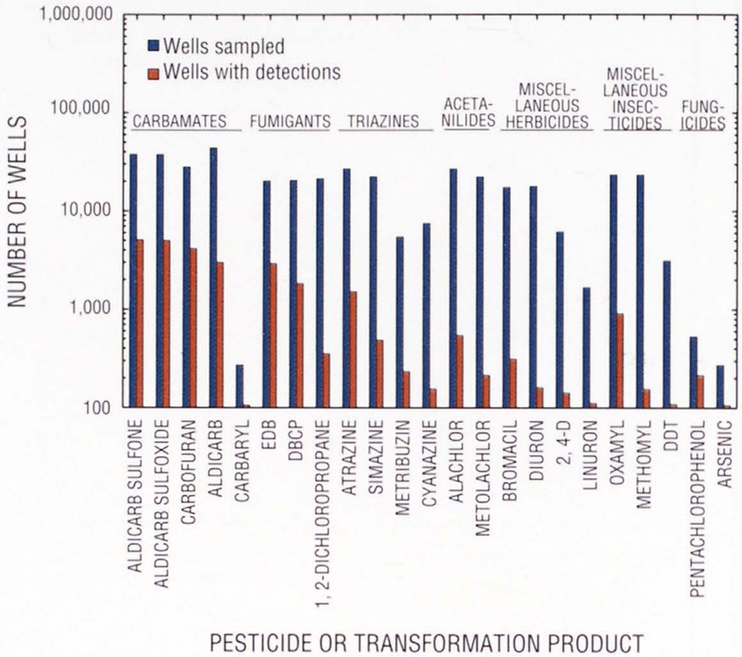

Figure 3. Pesticide compounds detected in at least 100 wells in the United States (U.S. Environmental Protection Agency, 1994).

Detection Frequencies in Relation to Use

The frequency of detection of a pesticide in ground water is usually low in areas where its use is low (see Figure 4), as is expected, since most pesticides have no natural sources. Conversely, areas where a pesticide is detected frequently are usually those in which its use is high. For example, detections of triazine (see Figure 5) and acetanilide herbicides and their transformation products are widespread in the ground waters of the corn and soybean regions of the northern midcontinent, where these compounds are used extensively. Often, however, low rates of pesticide detection are encountered in areas of high use, indicating that other factors also affect the occurrence of pesticides in ground water.

Influence of Study Design and Seasonal Variability

Substantial variations in study design among previous monitoring investigations hinder attempts to obtain a consistent picture of the spatial distributions of pesticides in ground waters across the nation. Design features that have the greatest influence on study results include: (1) the spatial extent of sampling, (2) the types and number of compounds examined, (3) the criteria used for well selection, and (4) the analytical detection limits. The spatial extent of pesticide detection in ground water and the number of pesticide compounds detected both tend to be greater in areas where more sampling has been conducted. As expected, sampling that targets areas of suspected contamination usually leads to more frequent detections than the sampling of randomly selected wells. In addition, studies that employ lower detection limits for a given compound predictably yield more frequent detections than those using higher detection limits.

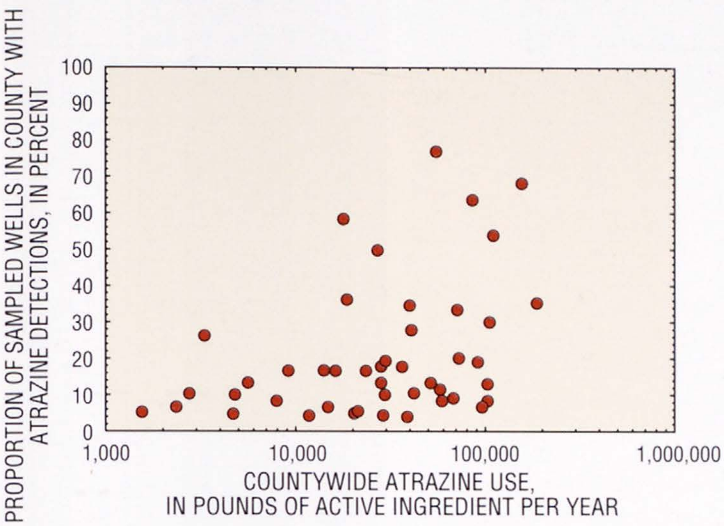

Figure 4. Proportion of sampled wells with atrazine detections in relation to countywide use. Wells were sampled as part of the National Alachlor Well-Water Survey (data from A.J. Klein, Monsanto Corp.) and pesticide use estimates are from Gianessi and Puffer (1991).

Few investigations have been designed to examine long-term trends in pesticide levels in ground water. Such trends may be obscured by the substantial seasonal variations in detection frequencies and concentrations that are usually observed during the year. For example, minimum values of both parameters are typically encountered before, and maximum values after, spring applications of herbicides (see Figure 6).

Effects of Agricultural Practices and Well Construction

Much effort has been directed toward evaluating the many natural and human factors that govern the transport and fate of pesticides in soil and ground water (see Figure 7). However, the nature of many of these influences is not yet well understood because of the difficulty of sorting out the confounding effects of numerous variables. Extensive research indicates that, in addition to reducing use, the most effective ways to reduce the likelihood of ground-water contamination by pesticides are to minimize the rate of water movement through the soil, especially following pesticide application; and to slow the rate at which the active ingredients are released to the soil. Efforts to minimize water movement affect not only irrigation techniques, but the timing of pesticide applications and the manner in which the soil is tilled. Field studies have shown that, other factors being equal, pesticides have a greater potential to move to ground water under "no-till" conditions than under conventional tillage, even though the effects of tillage on water and pesticide movement may be seasonal.

Of all the factors that may affect pesticide detections in wells, construction characteristics have been among the most frequently studied. Pesticide concentrations and detection frequencies usually decrease with increasing well depth. In addition, pesticides are more likely to be detected in springs, and in dug, bored, or driven wells, than in drilled wells. Drilled wells are typically deeper and provide more complete isolation of ground water from contaminant sources. Similarly, wells with proper seals at the surface or around the well casing show consistently lower frequencies of contamination than those without seals. Bedrock wells with deep casings exhibit less frequent pesticide contamination than boreholes installed without casings. Pesticide detection frequencies also increase with well age — an indirect indicator of well integrity and well depth.

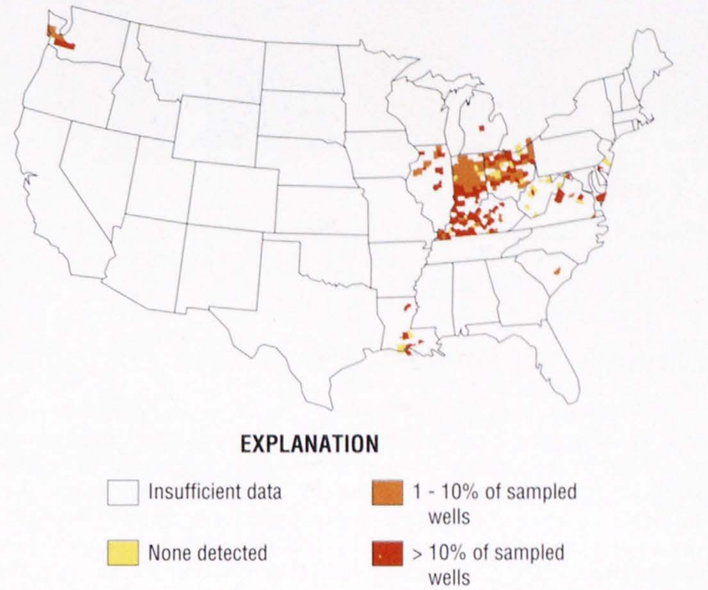

Figure 5. Frequency of triazine herbicide detection in counties with ten or more wells sampled during the Cooperative Private Well Testing Program (data from P. Richards, Heidelberg College).

Influence of Hydrogeologic Factors

In areas where pesticides are used, hydrogeologic factors influence their movement to ground water mainly by controlling the movement of water (see Figure 7). Pesticide detections in shallow ground water are generally more common in areas with permeable soils than in areas covered by glacial tills, clays, and other low-permeability geologic materials. Detections are also more common in unconsolidated and solution-weathered bedrock (karst) aquifers than in other bedrock aquifers. In addition, unconfined aquifers are more susceptible to contamination than those that are confined. Pesticide contamination is generally more likely in shallow ground water than in deep ground water, and where well screens are located close to the water table, but such relations are not always clear cut. Temporal variations in pesticide concentrations decrease with increasing depth and are generally larger in unconsolidated deposits than in bedrock.

High concentrations of pesticide contaminants in rivers may lead to contamination of shallow ground waters in agricultural areas during periods of extensive seepage of river water into underlying "alluvial aquifers," particularly following spring applications, when pesticide loads and river flows reach maximum levels. Conversely, pesticides in alluvial aquifers may flow into adjoining rivers during periods of low runoff. In many areas, "bank filtration" by alluvial aquifers has been found to be ineffective in removing pesticides from water drawn from pesticide-contaminated rivers into adjacent supply wells.

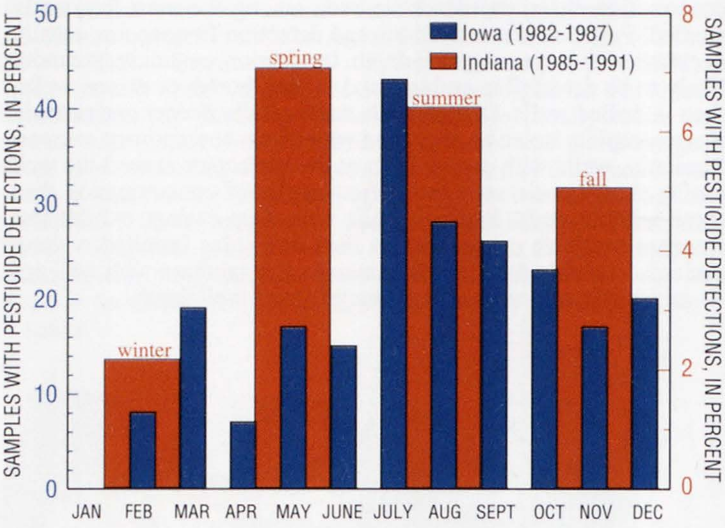

Figure 6. Statewide average seasonal patterns in pesticide detection frequencies in shallow ground waters of Iowa (Detroy and others, 1988) and Indiana (Risch, 1994).

Prediction of Pesticide Occurrence

Relatively few predictions of pesticide contamination of ground water have been tested against data on pesticide occurrence in ground water. In most cases where such comparisons have been carried out, computer simulations and ground-water vulnerability assessments have shown only limited ability to predict pesticide occurrence in ground water. In addition, other solutes, most commonly nitrate and tritium, have been examined as potential indicators of pesticide occurrence in ground water, but none have proven to be reliable for this purpose.

Significance to Water Quality

Most concern about pesticides in ground water stems from their potential impact on drinking water. The U.S. Environmental Protection Agency establishes Maximum Contaminant Limits (MCLs) for pesticides in drinking water. Nationally, fewer than two percent of the wells sampled by multistate studies, which mostly focused on agricultural areas, had concentrations that exceeded MCLs. Although this suggests that the problem is small at the national scale, our current ability to assess the significance of pesticides in ground water is limited by several factors. First, MCLs or other water-quality criteria have not been established for many pesticides and for most transformation products, and existing criteria may be revised as more is learned about the toxicity of these compounds. Second, MCLs and other criteria are currently based on individual pesticides and do not account for possible cumulative effects if several different pesticides are present in the same well. Finally, many pesticides and most transformation products have not been widely sampled for in ground water and very little sampling has been done in urban and suburban areas, where pesticide use is often high.

The widespread detection of pesticides in ground water at levels below current MCLs — particularly high-use compounds in vulnerable areas — indicates that exceedances of water-quality criteria are likely to increase if existing criteria are lowered; as criteria are established for more compounds; as a wider range of pesticides and their transformation products are analyzed for; and as sampling expands to include more non-agricultural areas. Together, these factors create uncertainty in our present ability to make strong conclusions about the national significance of pesticide contamination of ground water, and suggest that major data gaps will need to be filled in order to reduce this uncertainty. Differences in scale or approach among existing studies, and the shortage of data on many compounds and on temporal trends, indicate that long-term investigations are required that have consistent study designs and that involve more comprehensive chemical analyses.

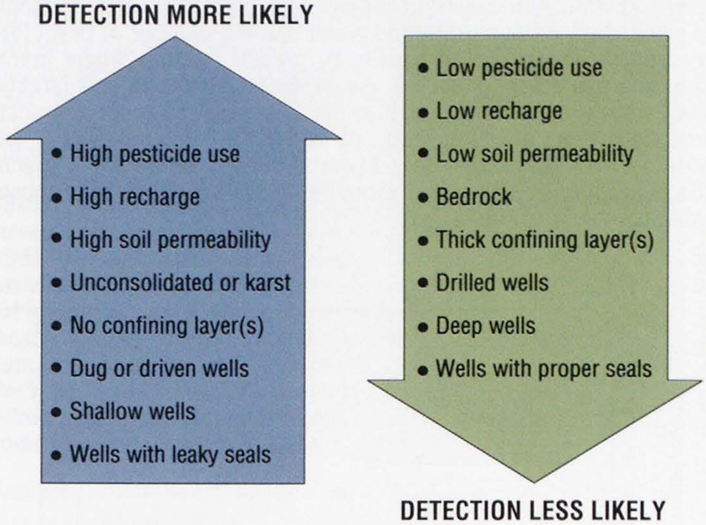

Figure 7. Factors associated with pesticide detections in ground water.

Additional Reading:

Based on the book by J.E. Barbash and E.A. Resek, in press, Pesticides in Ground Water: Distribution, Trends, and Governing Factors, Ann Arbor Press, Inc., Chelsea, MI; for more information call 1-800-858-5299.

References:

Detroy, M.G., Hunt, P.K.N., and Holub, M.A., 1988, Ground-water-quality monitoring program in Iowa: Nitrate and pesticides in shallow aquifers: U.S. Geological Survey Water Resources Investigation Report 88-4123, 31 p. [Available from National Technical Information Service]

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Kolpin, D.W., Goolsby, D.A., and Thurman, E.M., (1995). Pesticides in near-surface aquifers: An assessment using highly sensitive analytical methods and tritium. Journal of Environmental Quality, v. 24, no. 6, pp. 1125-1132.

Majewski, M.S. and Capel, P.D., 1995, Pesticides in the Atmosphere: Distribution, Trends, and Governing Factors, Ann Arbor Press, Inc., Chelsea, MI.

Risch, M.R., 1994, A summary of pesticides in ground-water data collected by government agencies in Indiana, December 1985 to April 1991: U.S. Geological Survey Open-File Report 93-133, 30 p.

U.S. Environmental Protection Agency, 1990, National survey of pesticides in drinking water wells: Phase I report (EPA 570/9-90-015).

_____, 1992, Pesticides in ground water database: A compilation of monitoring studies, 1971-1991, National summary (EPA 734/12-92-001).

_____, 1994, Pesticides Industry Sales and Usage: 1992 and 1993 Market Estimates (EPA 733-K-94-001).

For more information:

Information on technical reports and hydrologic data related to National Water Quality Assessment (NAWQA) pesticide studies can be obtained from:

Chief, Pesticide National Synthesis
U.S. Geological Survey
2800 Cottage Way, Room 2232
Sacramento, CA 95825

Additional information on NAWQA and other U.S. Geological Survey programs can be found by accessing the NAWQA "home page" on the World Wide Web at "http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html."

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