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The Magnitude and Costs of Groundwater Contamination From Agricultural Chemicals

A National Perspective

Elizabeth G. Nielsen
Linda K. Lee

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ABSTRACT

Evidence is mounting that agricultural pesticide and fertilizer applications are causing groundwater contamination in some parts of the United States. A synthesis of national data has enabled researchers to identify regions potentially affected by contamination from pesticides and fertilizers and to estimate the number of people in these regions who rely on groundwater for their drinking water needs. The study found that pesticides and nitrates from fertilizers do not necessarily occur together in potentially contaminated regions. Monitoring and remedial costs, which would fall most heavily on rural people dependent on private wells, could be substantial.

Keywords: Groundwater contamination, agricultural chemicals, nitrates, pesticides, drinking water.

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SUMMARY

Evidence is mounting that agricultural pesticide and fertilizer applications are causing groundwater contamination in some parts of the United States. By synthesizing national data, researchers identify which regions are potentially affected by agriculturally induced contamination and estimate the number of people in these regions who rely on groundwater for their drinking water needs. Study results indicate that costs of monitoring for contamination and of taking remedial action, which would fall most heavily on rural people dependent on private wells, could be substantial.

Because there are now no national data on levels of agricultural chemicals in groundwater, this study is a first attempt at synthesizing and analyzing available data sources to indicate which areas are potentially affected. The data do not define local- or county-level contamination potential, but allow an analysis of regional trends. Among the major regions with potential pesticide contamination are the Eastern Seaboard, the Gulf Coast, and the Upper Midwest. Regions having a potential for nitrate contamination include the Great Plains and portions of the Northwest, Southwest, and the Corn Belt. Areas with potential for combined pesticide and nitrate pollution include portions of the Corn Belt, the Lake States, and the Northeast.

Over 50 million people rely on groundwater for their drinking needs in these potentially contaminated regions. Of these people, 19 million obtain their water from private wells. The remainder use public water systems. Private wells are more vulnerable to contamination because they are shallower than regulated public system wells and often not as well-built. Most of the people who rely on groundwater in potentially contaminated areas live where groundwater may contain pesticides or a combination of pesticides and nitrates.

Because monitoring groundwater contamination levels provides information on the need for remedial action, the report analyzes costs of testing for nitrates and pesticides in potentially contaminated areas. Using specific assumptions, researchers estimate that the first-time monitoring costs for households with private wells range from $0.9 to $2.2 billion, with a "best" estimate of $1.4 billion. Monitoring costs for public groundwater systems are estimated to be much lower, approximately $14 million, because less sampling is required even though the number of people served is larger. As a result, individual well owners, who are often rural residents, will bear the highest monitoring costs.

These findings have important implications for policymakers and water users alike. Farmers, for example, have incentives to reduce contamination if their applications of pesticides and fertilizers are affecting their own well water. Educational programs accompanied by expanded research on the effects of agricultural practices will consequently be important. Different strategies may be implied for different areas since data suggest that pesticides and nitrates from fertilizers are not necessarily found together in groundwater and may impose different costs on society. Finally, not all regions are vulnerable or equally dependent on groundwater. As a result, targeting of strategies will be important.

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INTRODUCTION

The United States relies heavily on groundwater: over 97 percent of rural America's drinking water taps underground sources, 55 percent of the country's livestock water comes from underground supplies, and 40 percent of all water used to irrigate crops is drawn from aquifers. Not only rural America relies heavily on groundwater. In 1980, 40 percent of the population served by public water supplies used groundwater, or nearly 74 million people. Moreover, reliance on groundwater is growing. Between 1950 and 1980, groundwater withdrawals increased 158 percent while surface withdrawals rose only 107 percent (65).1/

Little is known about the scope of most groundwater contamination generated by human activities. The question, however, is critical (9). There are documented and suspected risks to human health from exposure to contaminated groundwater (46). Because groundwater moves slowly in many areas and some chemicals degrade slowly, contamination can persist for years or even centuries. Cleanup costs can be prohibitive. Moreover, the interaction between surface waters and groundwaters can mean that aquifer contamination ultimately may lead to pollution of streams, lakes, and estuaries in some areas.

Although groundwater contamination has many sources, evidence suggests that agricultural activity may be a significant source. Substantiating that link is a recently published report by the U.S. Office of Technology Assessment that summarizes groundwater contamination and its effects (69). The report cites agricultural pesticides and fertilizers as significant groundwater contaminants. The conclusion appears to be supported by documented incidents of contamination attributed to agricultural chemicals in Pennsylvania, Florida, Wisconsin, California, New York, Iowa, and other States (52, 37, 60, 61, 81, 8, 80, 28, 41).

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1/ Underscored numbers in parentheses refer to items cited in the References section.

The problem is attracting public attention. According to a recent national poll, 80 percent of the U.S. population believes that groundwater pollution is a national problem, and 54 percent of the people think it is a problem in their community. Of those surveyed, nearly 70 percent responded that they believe agricultural fertililizers and pesticides cause water pollution (7).

This report assesses the scope and costs of groundwater contamination caused by agricultural fertilizers and pesticides in the United States. While other agricultural activities such as livestock operations may contaminate groundwater in some localities, we focus on crop chemicals because of their broad-scale use across diverse regions of the country.

We combine data from a variety of sources to develop an overview of regions potentially affected by agriculturally induced chemical contamination of groundwater. The report also summarizes the types of damages incurred by agriculturally polluted groundwater along with an appraisal of the costs of preventing potential damages to health and property. The costs of these damages represent the benefits of groundwater protection. The policies and programs now being put into place by several States, including Arizona, California, and Wisconsin, and under discussion by other States and the U.S. Environmental Protection Agency (EPA), require a better understanding of the benefits of groundwater protection. Only when the benefits are well understood can they be compared with the social and agricultural costs of alternative prevention and control measures, leading to the identification of efficient policy options.

AGRICULTURE AND GROUNDWATER QUALITY

The lack of a consistent and comprehensive data base has made it difficult to establish direct links between human activities and contamination episodes. This is particularly true with respect to diffuse or "nonpoint" pollution sources, which characterize many agricultural activities such as chemical applications. It is clear, however, that several trends over the past 40 years have increased the potential for agriculturally caused groundwater contamination.

The use of inorganic nitrogen fertilizers, a major source of nitrate-nitrogen groundwater contamination, increased fourfold between 1960 and 1980 (fig. 1). A major cause was heavier fertilizer applications, with the per-acre rate doubling between 1965 and 1984. At the same time, the agricultural use of pesticides rose sharply, nearly tripling since 1964 (fig. 2). Figure 3 shows that herbicides accounted for most of the increase. They constituted 82 percent of all pesticide use on major field and forage crops in 1982 (72).

Other trends increased the potential for contamination from both diffuse and concentrated "point" sources, at least in some locations. Wastes generated in concentrated livestock, dairy, and poultry operations have stretched the land's waste assimilative capacity and created a potential for nitrate contamination, particularly in areas where commercial fertilizers are also applied. This situation is particularly critical where the nitrogen content of animal manure which the land receives is underestimated or ignored.

Cultivation practices may also contribute. An increase in conservation tillage, for instance, may imply an increase in both pesticide and fertilizer contamination of groundwater through increased water infiltration and reduced runoff, although the relationships are not well understood and may vary from one area to another (19, 20, 31). Expanding the amount of irrigated land over the years also may have contributed to groundwater contamination. Irrigation can increase the concentration of salts, pesticides, and fertilizers in groundwater recharge, as well as in irrigation return flows (31, 39, 64).

The potential for groundwater contamination, as well as the magnitude, extent, and duration of contamination, depend not only on land uses and agricultural practices, but also on climate, hydrogeology, and other conditions. These include soil characteristics, net aquifer recharge rate, depth to the water table, and characteristics of the unsaturated zone and the aquifer.

The characteristics of a potential pollutant, such as water solubility, adsorption, and persistence, strongly affect its ultimate fate. In addition to increased pesticide and fertilizer use, changes in the types of pesticides applied (that is, generally less persistent, but less likely to attach to soil particles)2/ may mean a greater likelihood of contamination. Pesticides that are less adsorbent and more soluble in water have more potential to move out of the root zone toward groundwater, particularly when recharge rates are high.3/ The method and timing of chemical applications, in addition to tillage and

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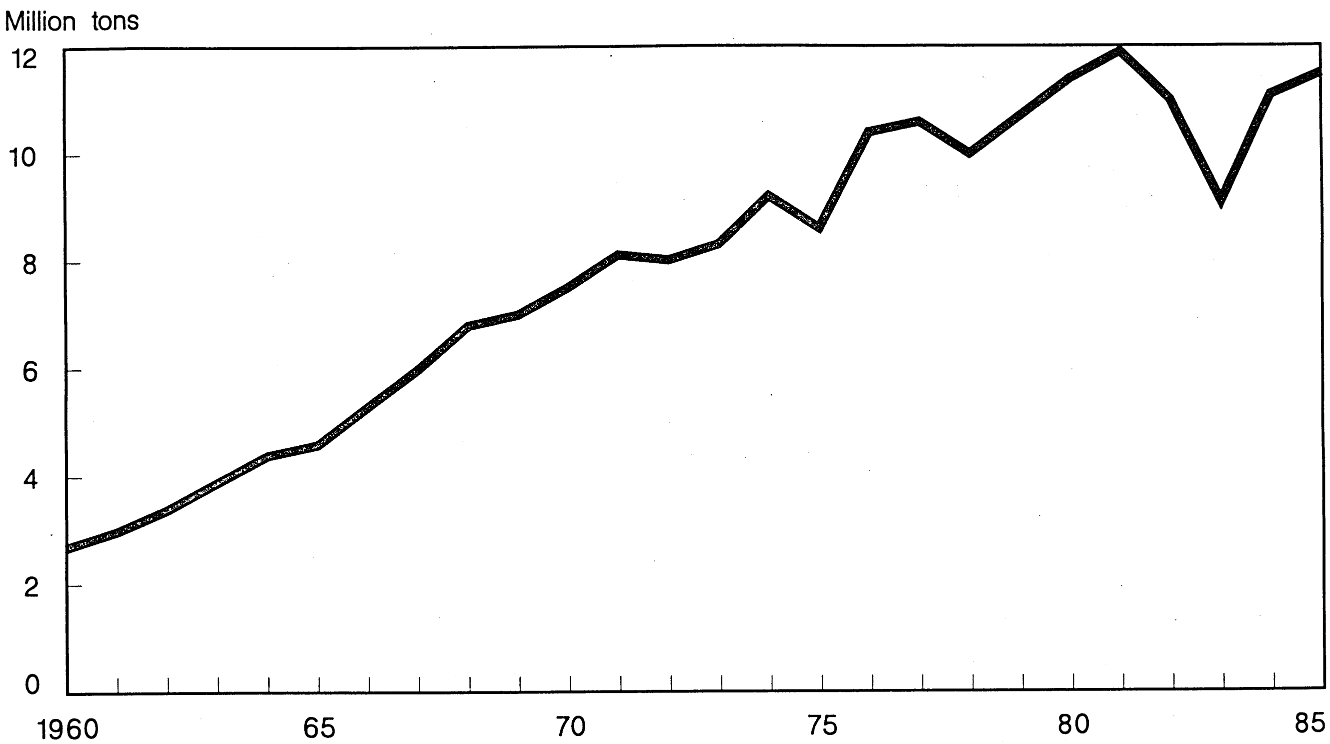
2/ In 1982, over half of all herbicide use on major field and forage crops was accounted for by four chemicals--alachlor, atrazine, butylate, and metolachlor (72)--all of which have a moderate to high potential to leach.
3/ See (16),(32), (39), and (54) for discussions of chemical characteristics and other factors which affect contamination potential.

Figure 1
Trends in U.S. Agricultural Nitrogen Use, 1960-85



Sources: *(70, 71, 73)*

irrigation practices, also affect the likelihood that a chemical will move to groundwater. Also, accidents, leaks, and improper chemical disposal practices can lead to local point-source contamination episodes.

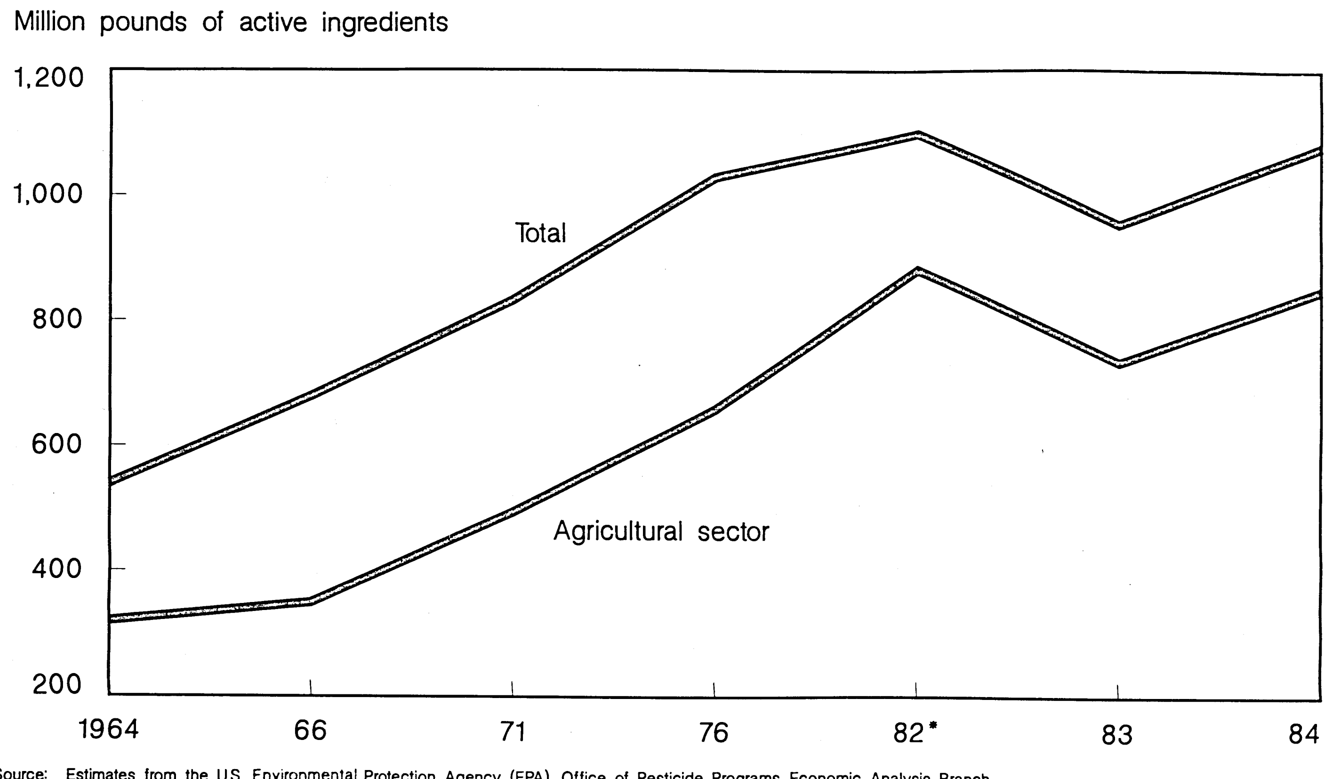
Predicting groundwater contamination clearly requires consideration of diverse factors which interplay in the process. Our data reflect the interaction of farming activities with physical vulnerability to aquifer contamination from pesticides and nitrogen fertilizers. We combine these to evaluate the potential for regional groundwater contamination.

POTENTIAL GROUNDWATER CONTAMINATION FROM AGRICULTURAL SOURCES

To estimate the areas in the United States potentially at risk to groundwater contamination from pesticides and fertilizers, we defined areas of potential contamination by using data on actual levels of contaminants in groundwater, where the data were available.4/ If data were unavailable, potential contamination was defined by synthesizing information on physical vulnerability to contamination with estimates on chemical use. In both cases, the population in areas of potential contamination is assumed to face a greater risk from agricultural chemicals in groundwater than the population in other regions. Because the costs associated with these risks largely depend on the population

4/ Alaska and Hawaii were not included in the analysis because the data sources used were not consistently available for these States.

Figure 2
U.S. Pesticide Use, 1964-84



Source: Estimates from the U.S. Environmental Protection Agency (EPA), Office of Pesticide Programs, Economic Analysis Branch.
Note: Pesticides exclude wood preservatives, disinfectants, and sulfur. * Revised 1982 numbers.

potentially exposed, we also made projections of the numbers and distribution of people using groundwater in potentially contaminated areas.

We based potentially contaminated areas on a synthesis of several data sources. Although each source has limitations which, taken together, lessen the sensitivity of localized analysis, we believe the regional trends depicted from the combined data sources reflect the best available information.

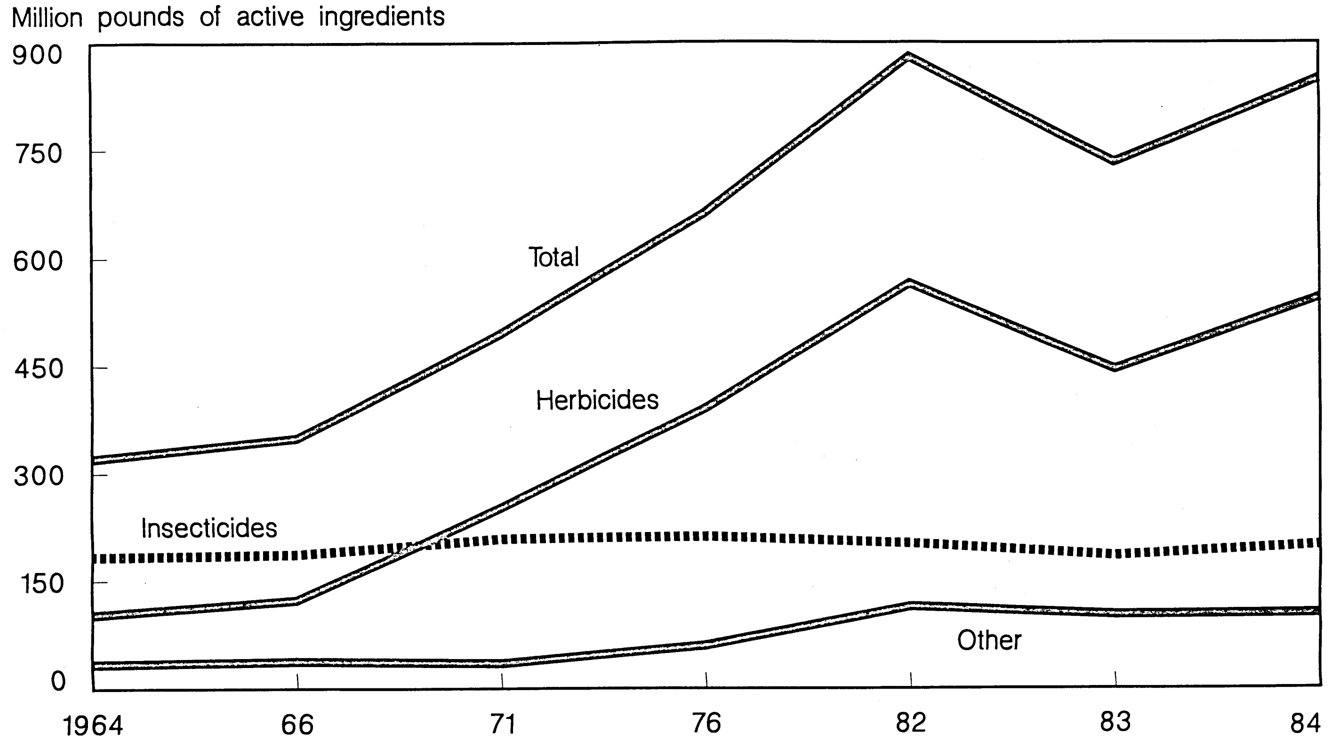
Pesticides

Because no national data base on pesticide levels in groundwater exists, we developed a method to simulate areas potentially affected by pesticides in groundwater resulting from agricultural chemical applications.

Approach and Data Sources

To simulate potential contamination, we synthesized two data sources. The first was the U.S. county-level "Pesticide DRASTIC" assessment (2). DRASTIC is an index that allows analysts to rate an area's relative vulnerability to groundwater contamination based on the area's hydrogeologic characteristics. These characteristics form the basis for the acronym DRASTIC (D = depth to the water table; R = net recharge; A = aquifer media; S = soil media; T = topography; I = impact of the vadose zone; C = hydraulic conductivity). The Pesticide DRASTIC index is a version of DRASTIC designed specifically to assess vulnerability to contamination from pesticide use. The second source was a

Figure 3
Trends in Agricultural Pesticide Use by Class, 1964-84



Source: Estimates from the U.S. Environmental Protection Agency (EPA), Office of Pesticide Programs, Economic Analysis Branch.

GROUNDWATER QUALITY TERMS

Adsorption--Adherence of molecules to the surface of the solids or liquids with which they are in contact.

Aquifer--A water-bearing geological formation.

Groundwater--Water that is found in the saturated zone.

Hydraulic conductivity--A measure of the ease with which a fluid will pass through a porous earth material.

Leaching--Passing through or out of by percolation. Agricultural chemicals leach when they move downward beyond the root zone with the flow of water. Chemical and environmental factors affect leaching.

Nonpoint-source contamination--Pollution from broad areas, such as areas in which fertilizers have been applied, rather than from concentrated discharge points.

Persistence--A substance's "lasting power" or stability, usually measured in half-life, or the time it takes for one half of the substance to be degraded or transformed.

Point-source contamination--Pollution originating from a distinct source, such as the outflow from a pipe or concentrated animal production facilities.

Recharge (net)--The amount of water per unit of land that penetrates the ground surface and reaches the water table.

Root zone--The area of the unsaturated zone from which plant roots draw water and nutrients. Its thickness depends on the plant, soil, and climate.

Saturated zone--The subsurface area in which all the pore spaces in the rock or soil materials are filled with water.

Soil media--The uppermost portion of the saturated zone that has significant biological activity.

Unsaturated (vadose) zone--A geological subsurface area located above the water table.

Volatility--The loss of a compound to the atmosphere.

Water solubility--The amount (mass) of a substance that will dissolve in water under specific conditions.

Water table--The top of the saturated zone.

data base on county-level pesticide use developed by an independent research organization, Resources for the Future (RFF).5/

To focus on potential problem pesticides, we limited our analysis to those chemicals recommended for inclusion in EPA's national survey of pesticides in well water (termed by EPA priority A and B categories). Of the 45 chemicals, we eliminated 7. Three (EDB, DBCP, and 1,2-dichloropropane) were not represented in the RFF file because EPA had banned them. Another four (tebuthiuron, prometone, propoxur, and pentachlor) were listed in the file but showed no agricultural uses. Table 1 lists the 38 pesticides used in our analysis along with information on the type and amount of use, the number of States in which each chemical has been found in groundwater, and other facts pertinent to EPA's classification of these chemicals as high-priority pesticides. These pesticides, which are primarily herbicides, represent 60 percent of all agricultural pesticide applications accounted for in the RFF file.

Because voids exist in the current data and since so little is known about how groundwater becomes contaminated, the process of identifying which pesticides are potential groundwater contaminants is a subjective one. In the absence of a definitively superior selection method, we chose to use the chemicals EPA has classified for its national water well survey as Priority A (recommended for inclusion) and Priority B (recommended, but subject to negotiation if the laboratory analytical method is difficult or unavailable).6/

The 38 high-priority pesticides we used are described by EPA as potential "leachers," which means they have a high probability of moving to groundwater. Note, however, that the 38 included pesticides vary in terms of volatility, persistence, and the other basic characteristics of pesticides that affect leaching probability. Each pesticide could behave differently under alternative climatic and agronomic conditions. However, we assigned them equal weights in our analysis so that each pound of active ingredient was assumed to contribute equally to the contamination potential, no matter what the pesticide. Equal weights were necessary because there is now no method available to accurately rate or rank pesticides according to their leaching potential.

We translated the total county-level pesticide use estimates into average per-acre applications, using cropland acres from the Census of Agriculture.7/ These ranged from 0 to 3.4 pounds of active ingredient per acre, with an average of 1.0. We grouped them into high (greater than 1.2), medium (0.5 to

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5/ The Appendix describes both the DRASTIC index and the RFF data base in more detail.

6/ A series of internal memoranda describes the year-long selection process undertaken by EPA (10, 11, 12, and 13). That information is available from the authors upon request.

7/ In counties where sugarcane is grown (in South Florida and Louisiana), sugarcane acreages were first subtracted from the cropland acres reported in the Census of Agriculture. This was done to compensate for the fact that pesticide applications on sugarcane are not included in the RFF file. Thus, the average application rate estimates for these counties represent crops other than sugarcane.

Table 1--Pesticides included in the analysis1/

Pesticide	Type2/	Estimated use3/	States in which pesticide is found in groundwater	EPA description
		Thousand lbs.	Number	
Acifluorfen	H	1,399	0	Leacher
Alachlor	H	85,015	4	Leacher
Aldicarb	I,N	2,271	15	Mobile; marginal persistence
Ametryn	H	96	0	Leacher
Atrazine	H	77,316	5	Leacher
Bentazon	H	8,410	0	Leacher; toxicological concern
Bromacil	H	1,234	1	Leacher
Butylate	H	55,095	0	Mobile; uncertain persistence; toxicological concern
Carbofuran	I,A,N	7,695	3	Leacher
Chloramben	H	6,069	0	Leacher
Chlordane	I	11	0	Persistent; possible direct contamination via termiticide use
Cyanazine	H	21,626	2	Leacher
Cycloate	H	52	0	Mobile; uncertain persistence; toxicological concern
Dalapon	H	261	0	Leacher
Dacthal/DCPA	H	196	1	Leacher
Dicamba	H	4,158	0	Leacher
2,4-D	H	37,217	0	Marginal leacher; heavy use
Dinoseb	H	8,835	1	Leacher
Diphenamid	H	698	0	Marginal leacher; toxicological data gaps
Disulfoton	I,A	2,105	0	Leacher
Diuron	H	1,861	0	Leacher
Fenamiphos	I,N	348	0	Moderate leacher; toxicological concern
Fluometuron	H	2,943	0	Leacher
Hexazinone	H	11	0	Leacher
Maleic Hydrazide	H	287	0	Leacher; toxicological data gaps
MCPA	H	9,861	*	Marginal leacher
Methomyl	I	425	0	Leacher
Metolachlor	H	37,940	2	Leacher
Metribuzin	H	10,603	1	Leacher
Oxamyl	I,A,N	51	2	Leacher
Picloram	H	549	0	Leacher
Pronamide	H	83	0	Leacher
Propazine	H	1,287	0	Leacher
Propham	H	445	0	Leacher
Simazine	H	3,975	3	Leacher
2,4,5-T	H	204	0	Marginal leacher
2,4,5-TP	H	7	0	Marginal leacher
Terbacil	H	833	0	Leacher

* indicates possible occurrence in groundwater.

1/ Included pesticides are those in high-priority categories for EPA's national survey of pesticides in well water. Other methods of identifying potential groundwater contaminants might produce different results.
2/ A = acaricide; H = herbicide; I = insecticide; N = nematicide.
3/ Thousands of pounds of active ingredient per year used for agricultural purposes only.

Sources: (10, 13, 14, 59).

1.2), and low (less than 0.5) categories.8/ We similarly grouped the pesticide DRASTIC scores, which had a maximum of 245 and averaged 133, into high (greater than 147), medium (107-147), and low (less than 107) categories. Using the hypothesis that the combined hydrogeologic and pesticide use factors provide more information on contamination potential than do either of the separate indexes, we then calculated three combinations of the high and medium categories for the two variables of per-acre applications and DRASTIC scores. Although the distinctions among the categories may be imprecise, particularly between the high pesticides/medium DRASTIC and the medium pesticides/high DRASTIC categories, we plotted all categories separately to give the reader added information on the factors that have caused areas to be identified as "potentially contaminated."

Results

Figure 4 shows which areas fall into the categories of "potentially contaminated." Three hundred and sixty-one counties fall into both the high DRASTIC score and high pesticide use categories. The remaining areas highlighted by figure 4 have either a high DRASTIC score and medium pesticide applications or the reverse combination. In total, 1,128 counties are represented in figure 4, or roughly one-third of the counties in the conterminous States.

The southern Coastal Plain (including Florida), the central Atlantic region, the Mississippi Delta, the northern Corn Belt, western Kentucky, and the central valleys of California are the major regions that have high pesticide contamination potential. Other smaller areas in the Northeast, Texas, and Idaho also have potential contamination.

The regions depicted in figure 4 as having potential groundwater contamination from pesticides correspond with production of pesticide-intensive crops such as corn and soybeans. Tobacco, cotton, rice, and peanut production in the Southeast also show high pesticide use as do fruit- and vegetable-producing areas in Florida, California, and portions of the Northeast and Lake States.

Although figure 4 is not based on actual levels of contaminants in groundwater, the data generally correspond to verified incidents of groundwater contamination from normal agricultural pesticide use. Figure 5 pinpoints actual contamination incidents as of mid-1986. Seventeen pesticides have been found in the groundwater of 23 States, with most located along the Eastern Seaboard, in the Midwest, and in some agricultural areas of the West. Because the data shown in figure 5 do not represent a random sample and because sampling incidence, frequency, and patterns vary dramatically from State to State, the data are best considered the lower bound on actual instances of groundwater contamination.

Data Limitations

The maps should not be used to single out individual counties, but rather should be viewed with regional trends in mind because of data limitations. For example, because DRASTIC data are averaged across counties, they mask factors that could point to contamination vulnerability at the subcounty level. Aggregating county-level pesticide use similarly allows data on crops with high

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8/ We determined ranges by identifying patterns in the distribution of the variable for all U.S. counties.

Figure 4

Potential Groundwater Contamination from Pesticide Use

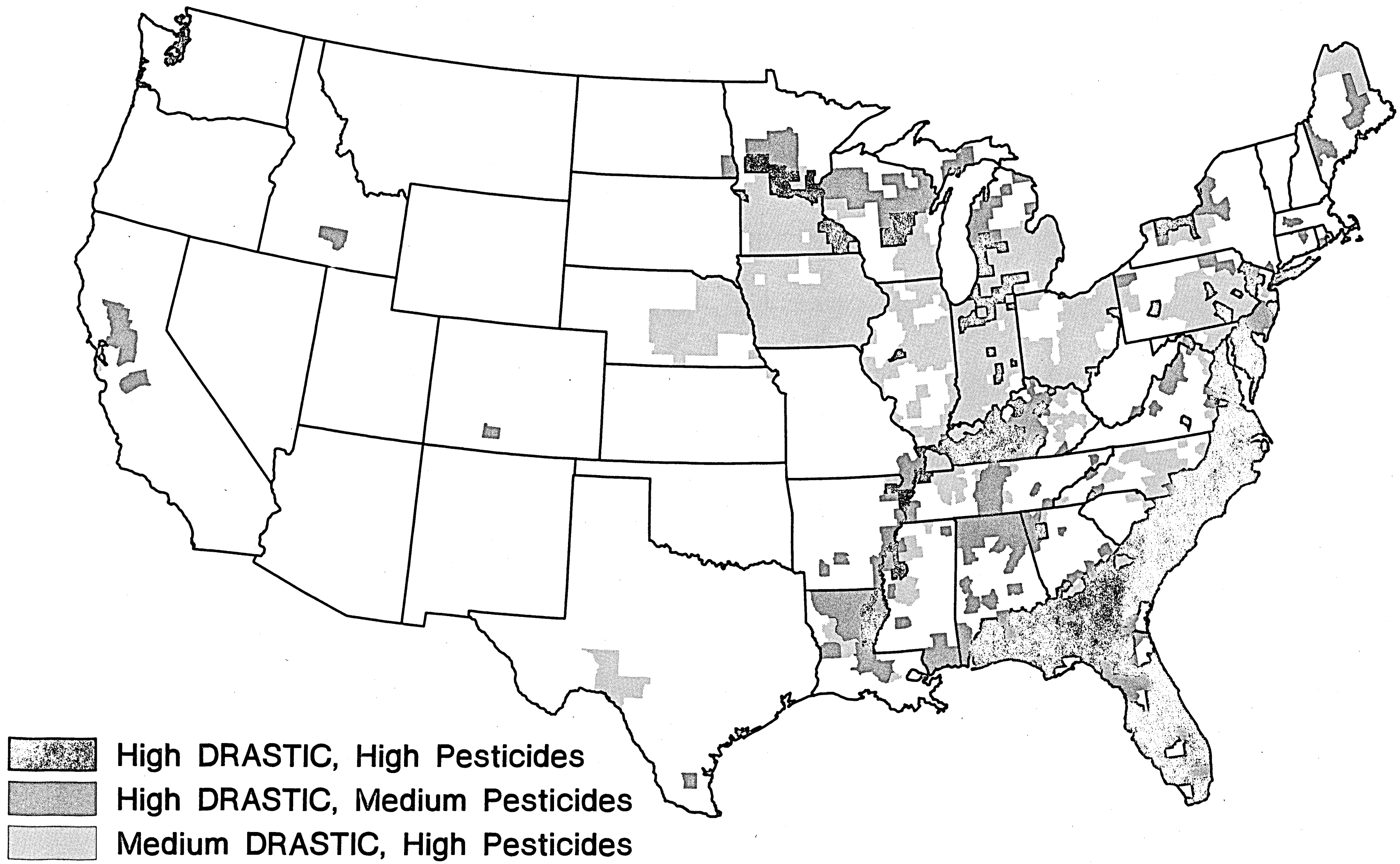
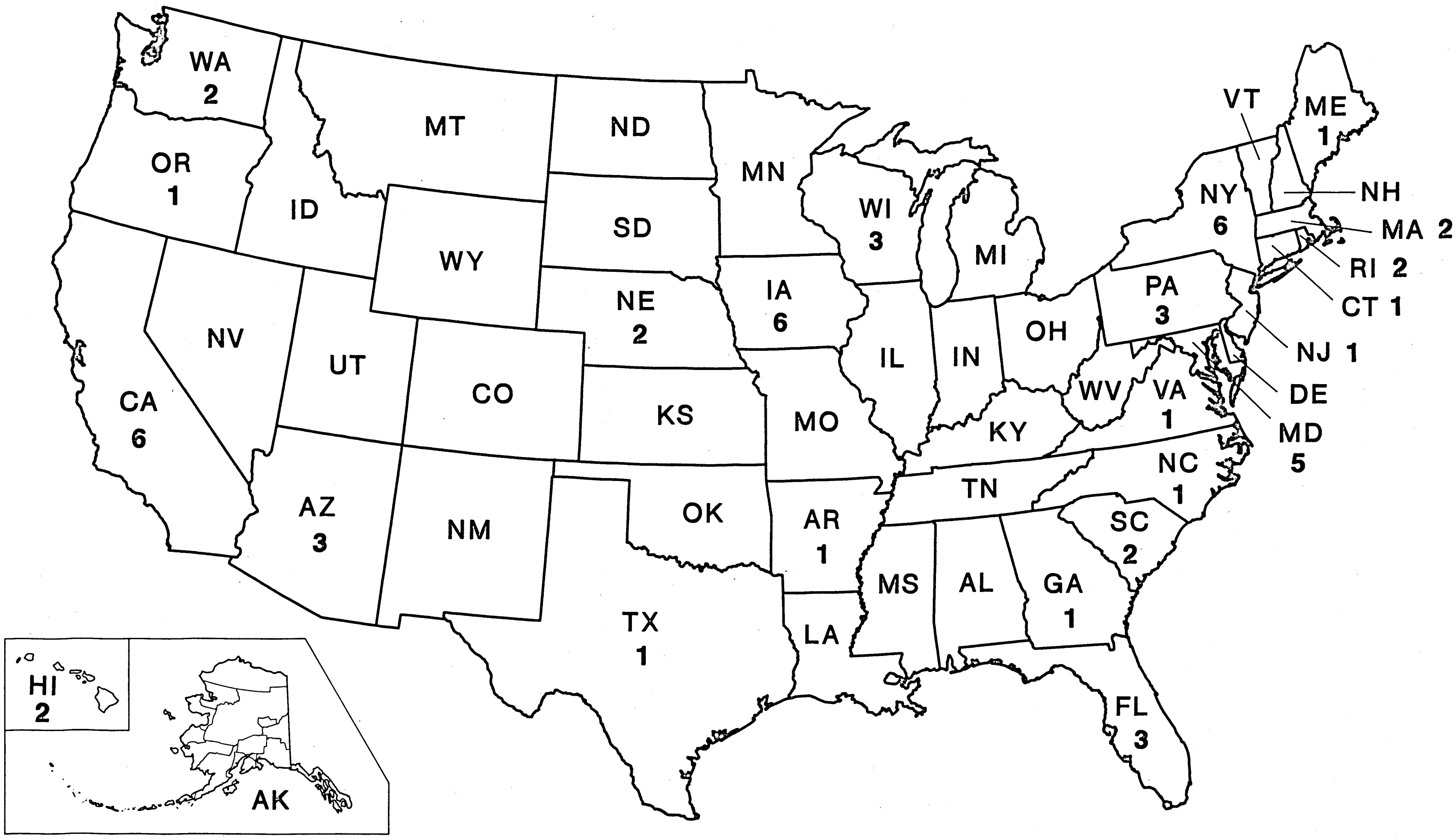


Figure 5

Numbers of Pesticides Found in Groundwater Caused by Agricultural Practices, 1986



Source: *(14)*

rates of pesticide applications to be averaged in with data on applications to less pesticide-intensive crops grown in the same county. On the other hand, moderate to high pesticide use may put the entire county "on the map" even if the high-application area represents a small percentage of the total county land area.

When one or a small group of counties stands alone, as some do in figure 4, there are several possible explanations. First, the area actually may be more vulnerable than surrounding areas because of its sensitive local hydrogeologic conditions, the production of pesticide-intensive specialty crops, or both. Second, some counties may be quite similar to surrounding counties but slightly exceed or fall short of cutoff points for pesticide use or for DRASTIC. Idaho's Lincoln and Minnedoka counties, which are located within an intensively cropped area with medium DRASTIC scores, appear to slightly exceed the high DRASTIC cutoff point. The counties on the northern Missouri border, however, just fail to meet the high pesticide use cutoff, and thus do not appear on the map even though their DRASTIC scores are similar to scores in southern Iowa. Finally, an isolated county may appear on the map because of bias in the data bases, and may not be a true indicator of either a county or a regional vulnerability trend.

Biases may be introduced from several sources. First, averaging may introduce bias. Both data bases we used yield average values which may be highly variable. For example, hydraulic conductivities vary greatly over small geographic areas, yet an average value is used. Second, bias can originate from measurement errors and inconsistencies in the DRASTIC data base, although these are largely unknown because comparisons with simulations or field data have not been conducted. However, the DRASTIC distribution generally corresponds with known hydrogeologic conditions (2). Finally, extrapolation techniques can introduce some distortions to estimates of regional crop pesticide use. Applying the coefficients derived from California's pesticide use on vegetables to all other States that grow these crops may be the most significant source of bias.9/ We considered the alternative of implicitly assuming no pesticide applications in areas with poor data to be less attractive, however. In a similar way, distortion can be caused by applying State or regional coefficients to all counties within the area, thereby masking cross-county variations.

Nitrates

We estimated areas of potential contamination from nitrogen fertilizer use by synthesizing three data sources.

Approach and Data Sources

The primary data source we used for the analysis was the U.S. Geological Survey (USGS) National Water-Data Storage and Retrieval System (WATSTORE), which contains nitrate levels in samples collected over the past 25 years from 87,000 wells throughout the country. To that data base, USGS added statistical

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9/ An alternative data base on pesticide use is available, based on survey information from Doane Marketing Research, Inc. While it avoids the problem of cross-regional extrapolation, it omits numerous crops. Since some of these crops, particularly vegetables, are often grown in areas vulnerable to contamination and are typically treated heavily with pesticides, we used the RFF data base for our analysis.

information on 36,000 wells obtained from the Texas Natural Resources Information System of the Texas Department of Water Resources. Because regional gaps exist in the USGS file, we supplemented the USGS data with a proxy for contamination developed from DRASTIC and fertilizer use data.

Starting with the USGS data, we used multiple criteria (based on metropolitan status and percent of county in cropland) to exclude from the analysis areas which have little or no agriculture. The exclusions were made to minimize the possibility that high nitrate levels caused by urban sources, such as septic tanks, would be attributed to agriculture. Thus, 753 counties, or one-fourth of the total, were eliminated. Counties with fewer than five wells sampled (661 counties) were also omitted from the analysis because of insufficient information. We analyzed the 1,663 counties remaining in the data base for nitrate levels recorded in their groundwater. Well data were analyzed according to the following categories of nitrate-nitrogen levels:

0-3 mg/L (milligrams per liter) -	Assumed to represent natural background levels, with minimal human influence.
3.1-10 mg/L -	May indicate elevated concentrations resulting from human activities.
More than 10 mg/L -	Exceeds maximum concentration in EPA's National Interim Primary Drinking-Water Regulations.

We developed a contamination proxy to supplement the USGS data for those 661 counties with insufficient data. In an approach resembling the analysis of pesticide pollution potential described earlier, we combined DRASTIC index county ratings with nationally available estimates of nitrogen fertilizer applications for five crops: corn, cotton, soybeans, sorghum, and wheat.10/

The proxy is a rough measure of excess nitrogen applied (amount added minus amount needed). Although the link between excessive nitrogen applications and nitrates in groundwater has been established 11/, there are other important influences which cannot be accounted for by nitrogen use or DRASTIC data. These influences, which include irrigation practices, natural nitrate-bearing deposits, and natural vegetation, help to explain the results of the analysis, and are discussed later in the report.

We summed the county-level estimates of pounds of nitrogen fertilizer applied per acre across crops and distributed totals into high (greater than 103), medium (52-103), and low (less than 52) categories. Counties at the higher end of the scale tend to be those that grow corn or cotton, or rotate corn and soybeans. As a single crop, soybeans typically fall into the lower levels. Wheat falls into the medium range. Application rates and percentages of acres treated vary widely across States for the same crop, however.

The regular DRASTIC scores were generally lower than the pesticide DRASTIC scores, averaging 109 nationally and ranging from 48 to 214. We grouped these into three categories: high (greater then 121), medium (89-121), and low (less

10/ At the recommendation of a developer of the DRASTIC index, we used the regular DRASTIC index ratings rather than the pesticide DRASTIC ratings for the nitrate assessment (3).

11/ See, for example, (27), (52), and (53).

than 89). Combinations of high and medium categories were identified and mapped.

Results

The USGS data indicate that of the 1,663 counties analyzed, 474 have 25 percent or more of sampled wells with nitrate-nitrogen levels exceeding 3 mg/L (fig. 6). Counties in which 25 percent or more of wells exceed 10 mg/L are a subset of these and total 87. Figure 6 also maps those 661 counties with insufficient data for which the DRASTIC and nitrogen fertilizer use scores are computed and presented later. Nonshaded areas represent both the 753 counties excluded from the analysis and the 1,189 counties which met the criteria for analysis but which had fewer than 25 percent of sampled wells exceeding 3 mg/L of nitrate-nitrogen.

According to these data, groundwater contamination from nitrate-nitrogen appears to be concentrated in the Central Great Plains; the Palouse and Columbia Basin in Washington; portions of Montana; southwest Arizona; the irrigated fruit-, vegetable-, and cotton-growing areas of California; portions of the Corn Belt; southeast Pennsylvania; and parts of Maryland and Delaware. Within these regions, Kansas, west Texas, and southern Arizona have the highest recorded concentrations, with 25 percent or more of sampled wells having nitrate-nitrogen levels exceeding 10 mg/L.

Some areas highlighted in figure 6 represent a combination of fertilizer applications and irrigation, particularly in California, the Columbia Basin in Washington, northern Texas, and portions of Kansas and Oklahoma. However, not all areas with this combination appear as problem areas in figure 6. Florida is an important example.

A major source of the high recorded levels in areas such as the Great Plains and the Southwest may be naturally occurring accumulations. Available information is inadequate to separate the natural from the human influences, however. It is important to note, though, that human influences such as cultivation or irrigation can cause previously stationary natural nitrate deposits to leach to groundwater (44).

Numerous studies focusing on specific locations have confirmed the high nitrate levels shown in figure 6 and, in some cases, have linked these elevated levels to agricultural activities. Examples include Long Island, New York and sections of Illinois, Nebraska, Iowa, Pennsylvania, California and Wisconsin (1, 5, 25, 28, 52, 53, 62).

Figure 7 shows the outcome of the analysis based on nitrogen applications and DRASTIC scores. Counties combining medium DRASTIC and high nitrogen applications make up the majority of the 441 counties shown on the map. The 441 counties are situated primarily in the Corn Belt, eastern Pennsylvania, and California. Other areas identified as having potential contamination by these criteria are in Washington, Texas, Oklahoma, Georgia, North Carolina, and the Chesapeake Bay area.

Although figures 6 and 7 have many similarities, they do not closely correspond. In particular, figure 7 does not indicate the potential for elevated concentrations of nitrate-nitrogen in groundwater in the Great Plains States although figure 6 shows that they have high levels. The reason may be that the method used to generate figure 7 does not account for some

Figure 6

Nitrate-Nitrogen Distribution in Groundwater in Agricultural Areas

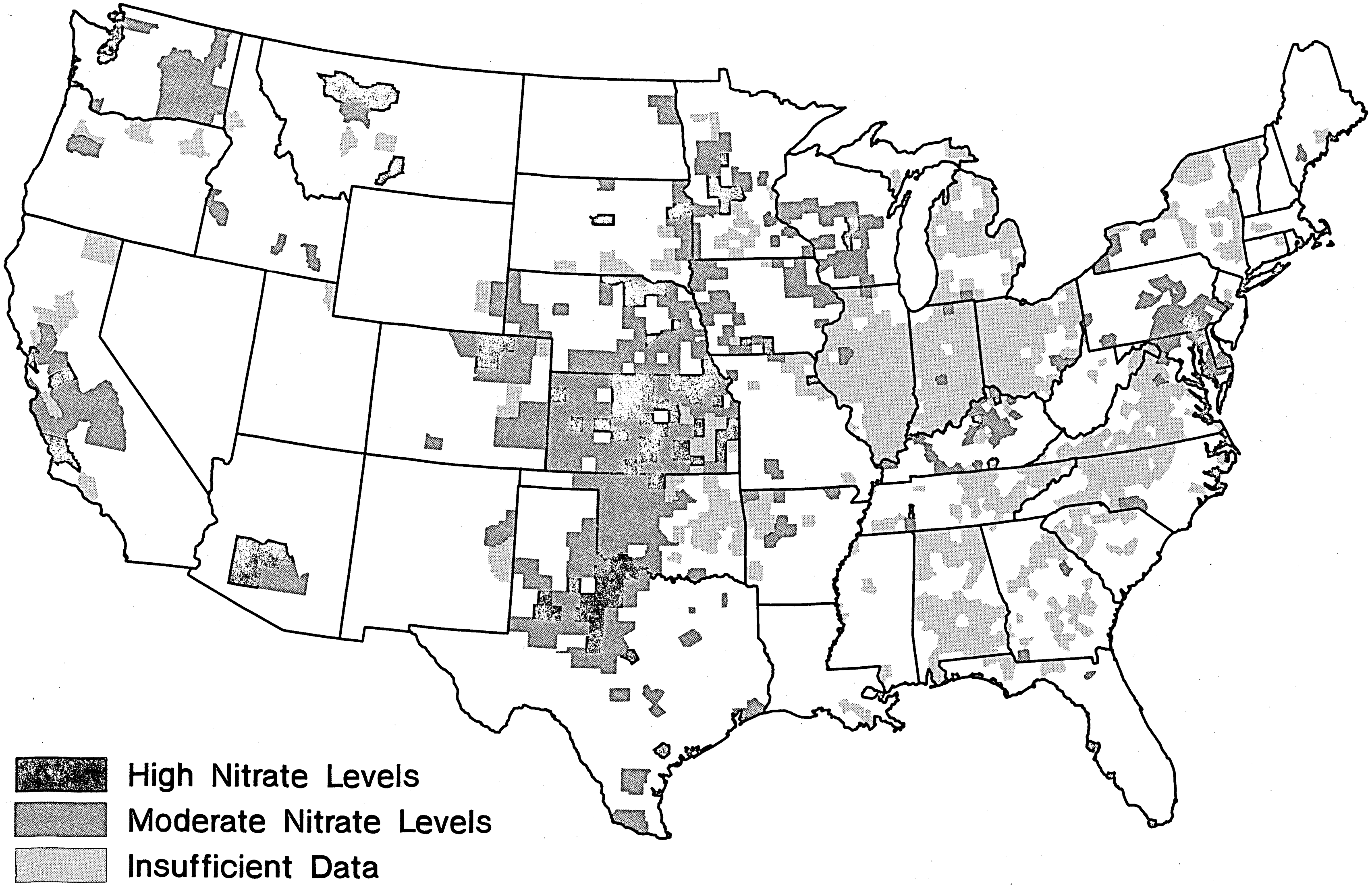
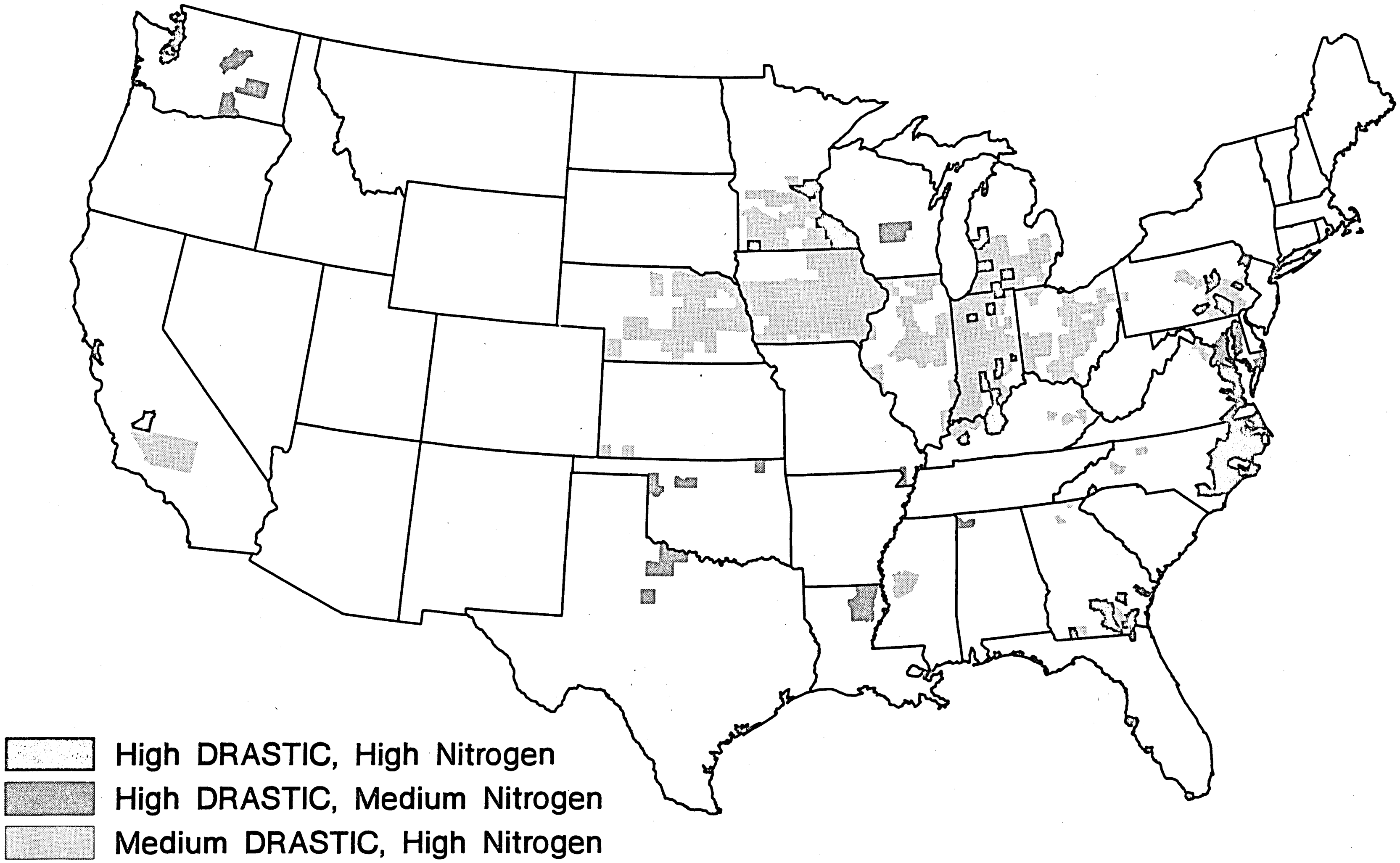


Figure 7

Combinations of Nitrogen Fertilizer Use and DRASTIC Ratings[1]



1/ Fertilizer use data include five crops: corn, wheat, soybeans, cotton, and sorghum.

agricultural and nonagricultural factors influencing nitrate levels, such as natural nitrate-nitrogen concentrations, livestock operations, differential crop uptakes, and fallowing effects.

Another lack of correspondence may be traced to hydrogeology and normal biological action. The investigation based on the combination of nitrogen applications to the soil and DRASTIC analysis predicts nitrate levels for Georgia's and eastern North Carolina's groundwater. This prediction is not borne out by the data displayed in figure 6, however. Eastern North Carolina and Georgia have high water tables, which may cause excess nitrate-nitrogen to be lost by denitrification or biological uptake by riparian vegetation (35, 36). Furthermore, in areas where the rate of groundwater flow is high and/or where a clay layer underlies the topsoil, nitrate-laden groundwater may be flushed to surface waters fairly quickly (79).

Despite these limitations, we felt that the high levels of nitrogen fertilizer use in the areas such as the Corn Belt where USGS data was insufficient warranted an attempt to estimate the groundwater's potential for nitrate contamination from fertilizer, and we used DRASTIC and fertilizer use data only in areas where USGS data were poor. Some information suggests that the analysis based on nitrogen use and DRASTIC data may reflect trends in the Corn Belt. For example, one of the Corn Belt States in which nitrates in groundwater are predicted by the nitrogen use/DRASTIC analysis but for which there is insufficient USGS monitoring data, is Illinois. Several studies have found a statistical relationship between fertilizer use and nitrate levels in groundwater in certain parts of that State (1, 42). Similar results have been found in Iowa (27). Because the Corn Belt States are in general hydrogeologically similar (30), these studies might indicate larger regional trends, although the data are unavailable to test such a hypothesis.

We synthesized the two data analyses on potential nitrate contamination by supplementing the USGS data base with information from the nitrogen applications/DRASTIC analysis. The 474 counties in which 25 percent or more of sampled wells exceeded 3 mg/L were identified as having elevated nitrate-nitrogen concentrations in groundwater due mainly to nitrogen fertilizer use. Those 661 counties with insufficient data shown in figure 6 were supplemented with information from the 441 counties identified through the analysis based on nitrogen applications and DRASTIC scores shown in figure 7. (Any identified county in figure 7 corresponding to a county with insufficient information in figure 6 became an additional county labeled as having potential nitrate problems.) The matching process identified 149 counties (principally in the Midwest), which when added to the 474 counties in the USGS data base, produced a total of 623 counties with nitrate-nitrogen in groundwater attributed chiefly to large nitrogen fertilizer applications.

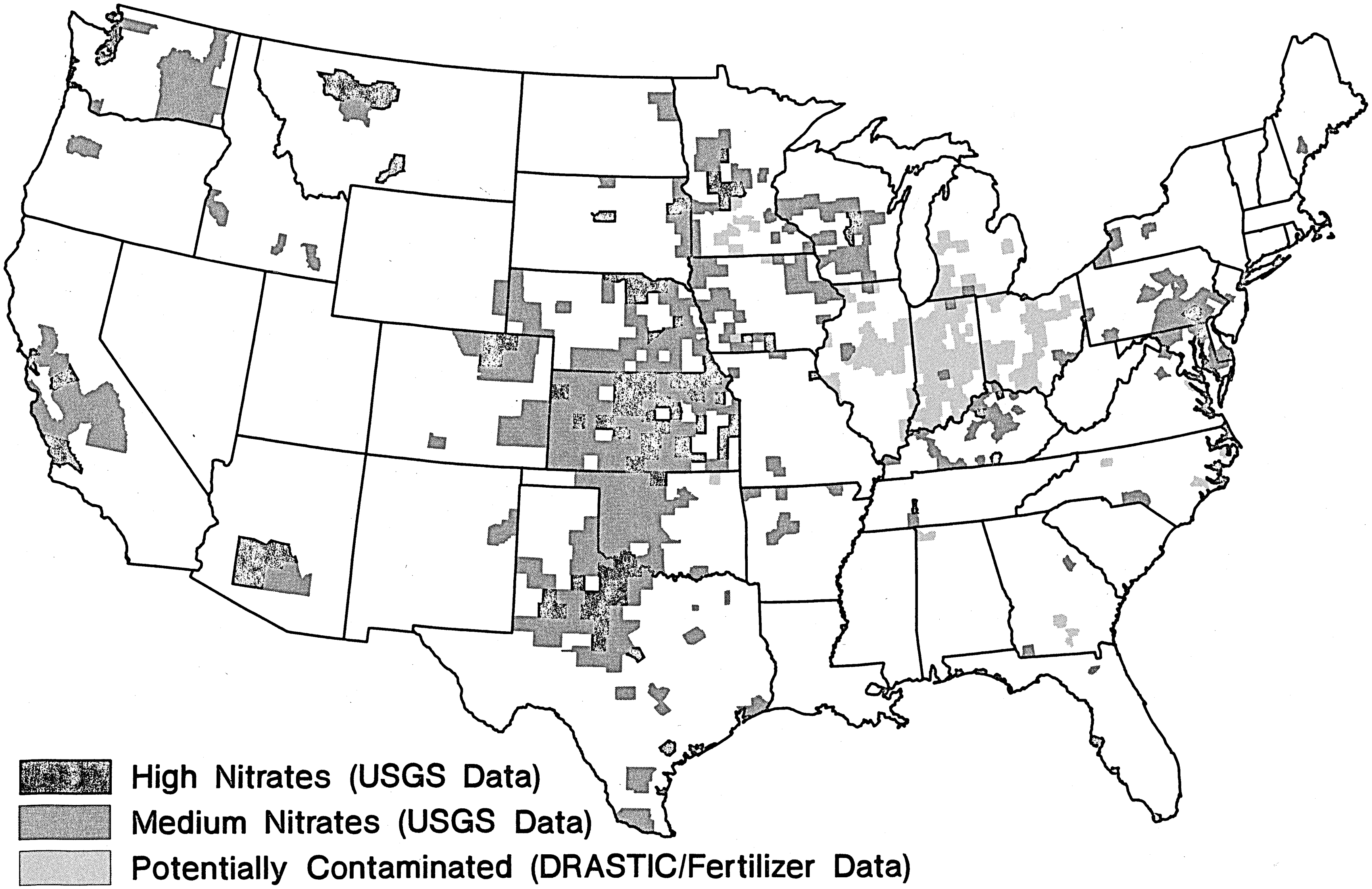
Figure 8 maps the combined analysis. The first two categories, high and medium nitrate levels in groundwater, correspond to the first two categories in figure 6. The third category, vulnerable areas with insufficient USGS data, represents those 149 counties identified by the nitrogen use/DRASTIC analysis as potentially contaminated.

Data Limitations

The USGS data represented by figures 6 and 8 do not represent a random sample of all U.S. wells or aquifers because the types of wells sampled, the numbers of wells, the time period covered, and the areal coverage of sampling networks

Figure 8

Potential Groundwater Contamination from Nitrogen Fertilizers



differ from State to State and within States (44). For example, the data from one county grouped in a high category may represent only observations from shallow wells in areas of suspected contamination while another county's data may reflect a more areally representative sample. Little information was available for portions of some States because data were not in a machine-readable form or there had been limited data collection and analysis efforts (44).

Nonagricultural influences cannot be completely eliminated, nor can those of natural background levels of nitrate-nitrogen and atmospheric deposition. All are unquantified and vary widely from one location to another. Moreover, agricultural influences independent of fertilization might be reflected in the data. For instance, intensive livestock operations such as dairy farming carried out in portions of Pennsylvania, New York, and Wisconsin, and feedlot operations in such areas as Texas and parts of the Southeast, may have influenced the data. We expect these influences to be primarily local, however.

Because the nitrogen fertilizer application data reflected in figure 7 and used to supplement the USGS analysis are limited to five crops in major producing areas, the data underestimate national commercial nitrogen fertilizer use. Since data on nitrogen fertilizers were used only as supplements to observed nitrate contamination levels in groundwater, however, the effect of this shortcoming is minimal. The Corn Belt and the Southeast are the major regions with missing USGS data. These are the regions for which it was possible to employ the supplemental nitrogen use/DRASTIC index analysis because they primarily grow the crops for which nitrogen fertilizer estimates are available.

Nitrogen application rates, as noted above, only roughly approximate excess nitrogen applied. Very high rates may not be excessive due to very high yields or the nature of the agronomic system. Low application rates may be excessive if yields or plant nitrogen requirements are very low.

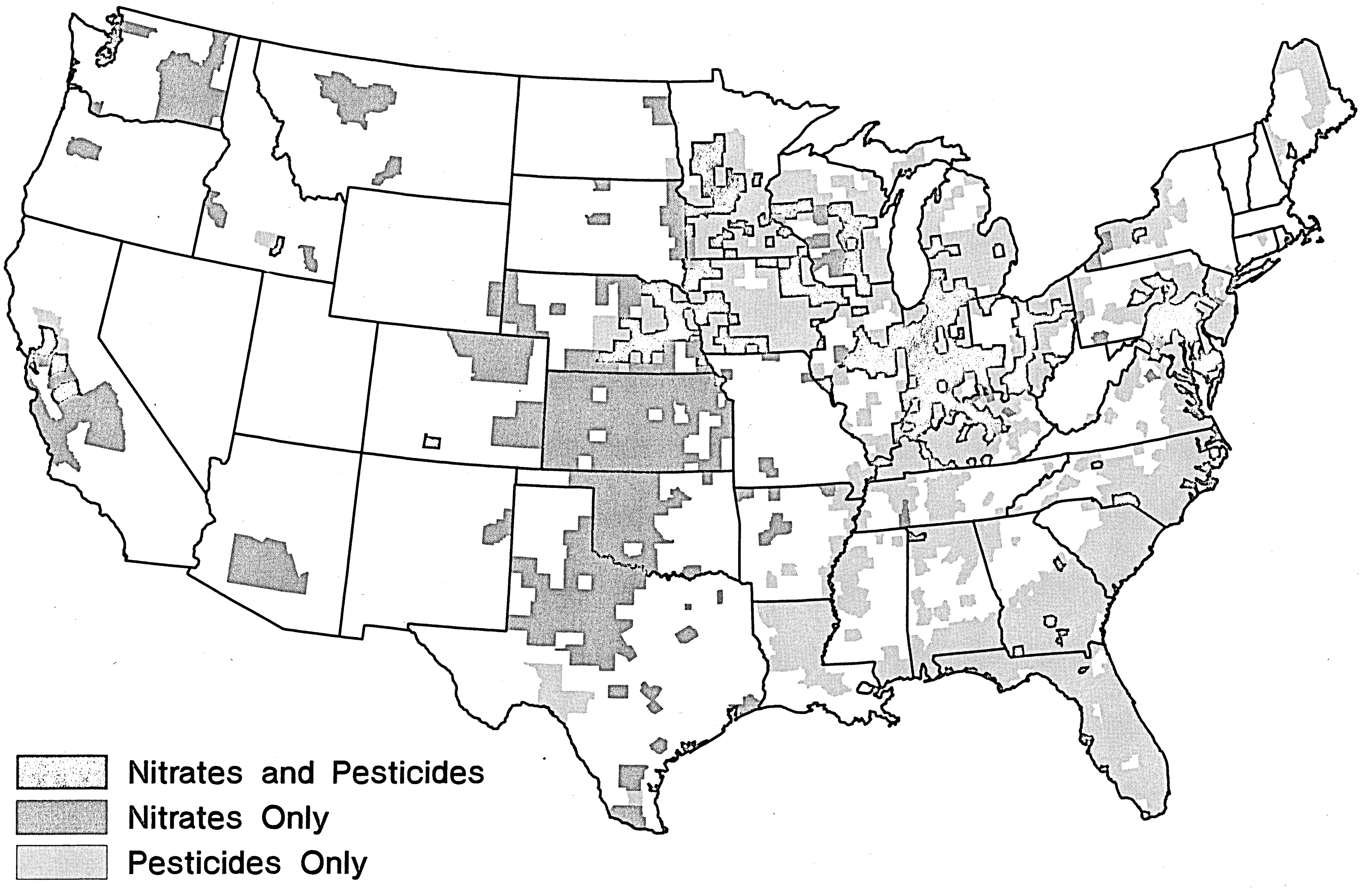
Furthermore, aggregated nitrogen application data, like the pesticide application data, were extrapolated to the county level based on crop acreages. As a result, individual counties may actually receive applications significantly different from statewide averages. Finally, the reader should note that the extent to which the DRASTIC index is appropriate for predicting potential contamination from nitrates is open to question because of the complexity of the factors and processes determining their fate. However, we believe the nitrogen use/DRASTIC index can provide useful supplemental data in some regions.

Areas Potentially Affected

Together, areas with potential contamination from pesticide and/or fertilizer use account for 1,437 counties, or about 46 percent of the counties in the conterminous States. Figure 9 shows evidence of regional trends. Counties with only potential pesticide contamination total 814, and are located largely along the Eastern Seaboard, Gulf Coast, and the upper Midwest. Counties with only potential nitrate contamination total 309, and are located principally in the Great Plains and portions of the Northwest and Southwest. Only 314 counties, or less than one-fourth of those identified as having potential contamination from agricultural chemicals, show both high pesticide and nitrate contamination potential. These are located chiefly in parts of the Corn Belt, the Lake States, and the Northeast.

Figure 9

Areas of Potential Groundwater Contamination from Agricultural Chemicals



These 1,437 counties with pesticide and/or nitrate contamination potential are cropped intensively, with 33 percent of all land area in crops compared with 16 percent nationwide. About 70 percent of the crop acreage in the sample is devoted to corn, wheat, and soybeans. Though strongly agricultural, these counties are heavily populated, with 27 percent of the land but 47 percent of the population.

Population Potentially Affected

People who live where the groundwater contamination potential from agriculture is high and consume mostly groundwater are most likely to incur the highest costs. To estimate the potentially affected population, we used data from the 1980 Census of Population and Housing on drinking water sources for the 1,437 potentially contaminated counties (74). The census provides data on populations using water from private wells and from public systems.12/ In its statistics on public supplies, the census does not differentiate between surface water and groundwater sources.

Over 19 million people in these counties obtain their drinking water from private wells (table 2). Over 65 percent of these people (12.5 million) live in areas where only potential pesticide problems are predicted, while less than 10 percent (1.7 million) live in areas with only potential nitrate problems. The remainder (5.1 million) reside in areas with a potential for both pesticides and nitrates in groundwater.

Figure 10 depicts the geographic distribution of people relying on private wells. Counties with at least 40,000 people using private wells are found in parts of Florida and North Carolina; portions of the Northeast including areas in Delaware, New Jersey, northern Maine, Pennsylvania, and northwestern New York; parts of the northern Midwest (particularly Michigan and Wisconsin); and in several portions of central California. Areas with at least 10,000 but fewer than 40,000 people using private wells are usually found surrounding the counties having the highest populations using wells. Other counties in this range can be found in the Northwest, in Arizona, and in scattered parts of the

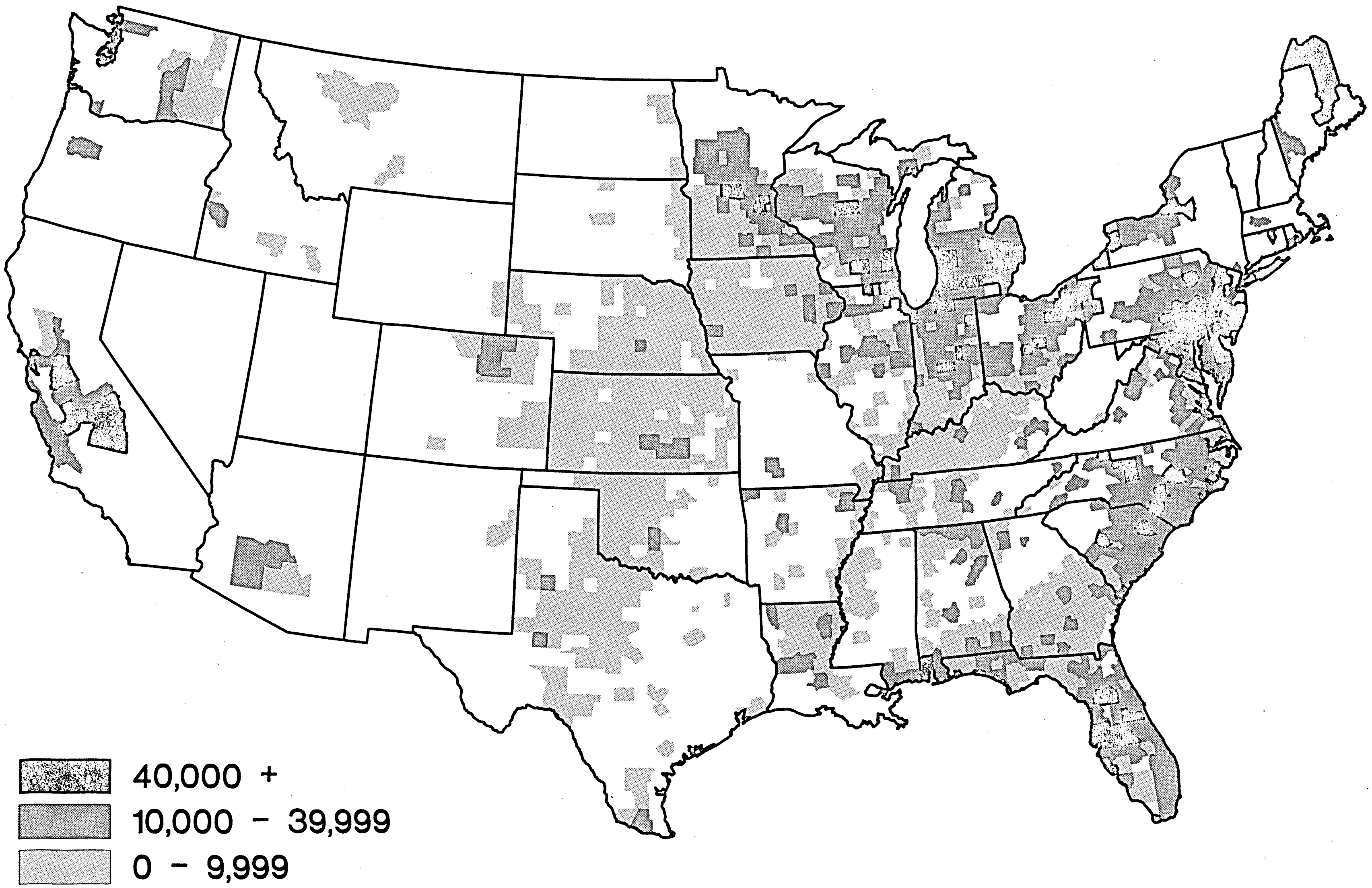
12/ The term "public system," as used in this report, refers to both public and private water supply systems which serve 6 or more households.

Table 2--Population obtaining drinking water from private wells in potentially contaminated areas

Contamination type	Persons
	Thousands
Nitrates only	1,674
Pesticides only	12,592
Nitrates and pesticides	5,075
Total	19,341

Figure 10

Distribution of Population Using Private Wells in Potentially Contaminated Areas



Great Plains, Midwest, and Southeast. Areas consistently showing lower levels of population using private wells are predominantly in the Plains States, portions of the Midwest, and in western Kentucky.

In these 1,437 counties, 19 percent of the population rely on private wells for their drinking water. In contrast, in all other counties in the conterminous United States (that is, all unshaded counties in figure 10), only 12 percent of the population use private wells as their drinking water source. Overall, private wells are more vulnerable to contamination than deeper, regulated public wells. Thus, not only do people in the areas we identified appear to face a greater likelihood of groundwater contamination from agricultural chemicals but they may also face a greater probability of exposure, given contamination, because of their heavy reliance on private wells.

Since a consistent county-level data base on the population relying on public groundwater supplies for drinking water needs is unavailable, we developed estimates based on State-level figures.13/ We derived ratios of persons served by public groundwater supplies to persons served by all public supplies from USGS data (65). We then applied these ratios to the county-level data on populations served by public water supplies. This methodology implicitly assumes that little or no within-State variability exists with respect to public groundwater supplies. As a result, there may be discrepancies between actual and estimated populations relying on public groundwater supplies in some areas.

An estimated 34.5 million people living in areas of potential contamination are served by public groundwater systems. Table 3 shows State-level statistics, derived by summing the individual county estimates. Florida, Illinois, Indiana, Ohio, California, Iowa, Minnesota, Michigan, Wisconsin, New Jersey, New York, and Pennsylvania all have populations of at least 1 million estimated to depend on public drinking water supplies. Add to these the 19 million people who rely on drinking water from private wells, and there are a total of nearly 54 million people living in potentially contaminated counties who obtain their drinking water from underground sources, both public and private.

As with users of private wells, the majority of the 34.5 million people served by public groundwater systems (68 percent) reside in areas with only potential pesticide contamination. The rest are divided nearly equally into those living in areas of potential nitrate contamination only and those living in areas of potential pesticide and nitrate contamination. Table 4 breaks down the estimated population using public groundwater supplies according to type of potential contamination.

Summary

The data presented in figures 4-10 have several implications for defining the magnitude of groundwater contamination from agricultural chemicals. First, they indicate that groundwater contamination from agricultural chemicals is not

13/ The EPA Federal Reporting Data System data base (FRDS), which is collected primarily for regulatory purposes, contains information on all public water supplies in the country. We explored the possibility of using this system to obtain county-level data but found that critical data items such as population served were inconsistently reported across States, making a broad geographical analysis impossible.

Table 3--Population served by all public water supplies in potentially contaminated areas, by State

State	Persons served by public supplies with a groundwater source 1/	Potentially contaminated counties		Persons served by public water supplies in potentially contaminated counties	
				Surface water and groundwater	Groundwater only (estimated)2/
	Percent	Number	Percent3/	------------Thousands------------	
Alabama	41	38	57	1,579	648
Alaska	60	NA	NA	NA	NA
Arizona	61	2	14	1,547	944
Arkansas	52	17	23	386	201
California	43	16	28	4,115	1,769
Colorado	13	14	23	842	110
Connecticut	21	1	13	44	9
Delaware	51	3	100	446	227
Florida	87	60	91	7,600	6,612
Georgia	32	93	59	1,587	507
Hawaii	95	NA	NA	NA	NA
Idaho	83	6	14	271	225
Illinois	38	58	57	7,364	2,798
Indiana	57	83	91	3,679	2,097
Iowa	75	93	94	2,151	1,613
Kansas	52	88	74	1,741	905
Kentucky	15	95	80	1,674	251
Louisiana	59	31	50	1,166	688
Maine	21	4	25	223	47
Maryland	12	21	91	2,557	307
Massachusetts	29	1	8	99	29
Michigan	20	51	61	6,382	1,276
Minnesota	65	62	71	2,145	1,395
Mississippi	91	24	29	653	595
Missouri	32	10	9	293	94
Montana	35	5	9	85	30
Nebraska	78	69	74	980	764
Nevada	46	0	-	-	-
New Hampshire	52	0	-	-	-
New Jersey	46	13	62	2,696	1,240
New Mexico	91	1	3	8	7
New York	22	21	37	5,593	1,230
North Carolina	15	66	66	2,006	300
North Dakota	51	3	6	82	42
Ohio	33	60	68	6,089	2,009
Oklahoma	28	33	43	501	140
Oregon	29	1	3	53	15
Pennsylvania	25	43	65	5,093	1,273
Rhode Island	16	1	20	63	10
South Carolina	23	30	65	1,353	311
South Dakota	71	10	16	156	111
Tennessee	39	32	34	1,839	717
Texas	44	67	26	1,986	874
Utah	51	0	-	-	-
Vermont	35	0	-	-	-
Virginia	18	43	45	1,182	213
Washington	64	13	33	484	310
West Virginia	31	4	7	105	32
Wisconsin	53	50	69	2,718	1,441
Wyoming	38	1	4	7	3
Total4/		1,437		81,850	34,492

- indicates that, according to the analysis, there are no potentially contaminated counties in the State.

NA indicates States not included in the analysis.

1/ Calculated as the total State population served by public groundwater supplies divided by the total State population served by all public supplies. 2/ Estimated by multiplying the number of people served by public surface water and groundwater supplies by the percent of people served by public supplies with a groundwater source. 3/ Calculated as the number of potentially contaminated counties divided by the total number of counties in the State. 4/ Totals may not add due to rounding.

Sources: (65, 74).

national in scope. Areas of potential contamination appear to be regional, often extending beyond local or State jurisdictions.

Second, they indicate that pesticides and nitrates in groundwater do not necessarily occur together. In fact, in three-fourths of the 1,437 potentially contaminated counties, pesticide and nitrate problems are not predicted simultaneously. The presence of nitrates may suggest pesticide problems and vice versa, but the association is weak. This finding suggests that strategies for controlling the entry of pesticides to groundwater may need to be different than those aimed at controlling groundwater contamination due to nitrates.

Finally, according to this assessment, chemical contamination of groundwater from agriculture primarily affects farming and rural areas, but has a potential effect on a significant part of the entire U.S. population, 53.8 million people. This large potential effect results from the density of population in the affected areas and a heavy reliance on groundwater.

POTENTIAL EFFECTS AND COSTS OF AGRICULTURALLY CONTAMINATED GROUNDWATER

The economic significance of the findings shown in figures 4-10 is reflected in the costs that society and individuals incur from agriculturally contaminated groundwater. Table 5 summarizes potential effects and documented incidents. As the table shows, the effects could be potentially very significant, particularly in terms of human health. However, available data on contamination occurences and costs are very limited at the national or regional level, making direct assessment difficult. Some analysis has been undertaken to measure the environmental and social costs, although an examination of these estimates reveals problems inherent in developing national cost assessments from extrapolations of limited or local data (51).

Assessing and Regulating Human Health Risks

The primary potential effects of agricultural chemicals in groundwater are human health risks. Evidence on human health risks associated with nitrates

Table 4--Population using drinking water from public groundwater supplies in potentially contaminated areas1/

Contamination type	Persons
	Thousands
Nitrates only	5,401
Pesticides only	23,450
Nitrates and pesticides	5,641
Total	34,492

1/ Numbers are estimates.

Table 5--Potential effects of groundwater contaminated by agricultural chemicals

Effects	Documented incidents	Costs incurred
Agricultural:		
Livestock poisoning and health problems	Nitrate/nitrite poisoning of livestock.	Unknown
Crop quality or quantity decreases	Salts leached from fertilizers can be concentrated through irrigation. Total contribution to salinity thought to be minor.	Unknown
Household:		
Health risks		
methemoglobinemia from nitrites	Infant deaths and illnesses. Infant death in South Dakota, June 1986 tentatively linked with nitrogen fertilizer applications (<u>18</u>).	Unknown
cancer	Herbicide use in Kansas linked with non-Hodgkin's lymphomas (<u>33</u>). Relationship between herbicides, groundwater contamination, and cancer unknown.	Unknown
miscellaneous health problems from pesticides and nitrates	No conclusive documentation.	Unknown
Environmental:		
Damage to vegetation, waterfowl, and aquatic life in recharge areas and in surface water contaminated by agricultural chemicals in the groundwater	No conclusive documentation.	Unknown

and pesticides in groundwater, however, is spotty and often contradictory for several major reasons.

First, while acute toxicities can be evaluated from laboratory research and accident case studies, risks from low-dose exposures over a long period of time are much more difficult to evaluate. If there is an effect, it may take years or decades to develop so that "cause and effect" is difficult to establish. Scientists therefore must often make inferences from high-dose responses to low-dose responses or from animals to humans.

Second, synergistic effects, or reactions from chemicals in combination, are extremely difficult to analyze. A factor that further compounds risk assessment problems is the difficulty of detecting some water pollutants at very low concentrations.

Finally, people can be exposed to pesticides and nitrates in a variety of ways. Besides ingesting water, people may be exposed to pesticides and/or nitrates from the food they eat. Contaminated household water can also lead to exposure to some organic chemicals from inhalation or skin absorption during showering or bathing. Pesticide applicators are subject to potentially high exposure levels if they do not take adequate precautions. In theory, all routes of exposure should be accounted for in risk analysis. In practice, risk assessment researchers normally assume that 20 percent of a person's daily intake of a particular drinking water contaminant actually comes from drinking water (76).

EPA is responsible for developing primary regulations for pollutants that may adversely affect human health under the guidelines of the Safe Drinking Water Act. Under the act, Maximum Contaminant Level Goals (MCLG's) are set for certain drinking water contaminants, based on established "safe" levels. The MCLG is a nonenforceable health goal for chronic exposure to those contaminants, and it is set to zero for carcinogens. The Maximum Contaminant Level (MCL) is an enforceable standard that is set as close to the MCLG as possible, given available treatment technology. EPA also establishes Health Advisories (HA's) for some chemicals, which are nonenforceable standards for short-term exposures.

EPA regulations apply to the 58,000 "community" water supplies in the United States that serve 25 or more people or have at least 15 service connections. "Noncommunity" systems, which serve transient populations (for instance, restaurants and campgrounds), must comply only with those regulations for pollutants thought to have potentially acute health risks (76). Monitoring requirements are stricter for systems drawing from surface water sources (such as reservoirs) than for groundwater systems. Residential water supplies, on the other hand, are unregulated by EPA.

Health Risks of Nitrates and Pesticides

Few documented human health risks have been attributed to direct exposure to nitrates. More health problems have been traced to nitrites. Once nitrates enter the body, some proportion is converted to nitrites. Bacteria in the mouth and, to a lesser extent in other parts of the digestive system, convert nitrate to nitrite. The percentage of nitrate converted to nitrite in the body apparently varies among individuals and no human conversion factor is now known. However, the major way that nitrites are formed in the body is thought to be bacterial reduction of nitrate in saliva (47).

The best documented human health risk from nitrites is infant methemoglobinemia. Nitrates are reduced to nitrites in an infant's digestive tract, apparently because a newborn lacks acidity in the stomach and upper part of its intestinal tract. Infants absorb nitrites into their bloodstream where the nitrites interact with hemoglobin to produce methemoglobin. Because that substance does not carry oxygen to body cells, the body's oxygen supply is reduced. Very high concentrations of nitrates in drinking water can be fatal to infants, particularly within the first 3 months of life. Reported instances of deaths from infant methemoglobinemia in the United States are rare. However, the true incidence is unknown because cases are not required to be reported. Several other categories of individuals are susceptible to methemoglobinemia, including pregnant women. Bottled water is now recommended in the United States where nitrate levels in the water exceed the Interim MCL of 10 mg/L. The MCL for nitrates applies to both community and noncommunity systems (76).

Though carcinogenic effects of nitrites have been investigated, a more direct cancer link has been traced to nitrosamines than to nitrites. Nitrosamines can be formed when nitrites combine with other substances such as amines. Most researchers agree that it is beyond question that nitrosamines are potent carcinogens for a wide range of target organs in many animal species (48).

However, because studies on humans are limited and in some cases produce contradictory results, it is difficult to prove conclusively that nitrites or nitrosamines are true risk factors in the development of forms of human cancer. The weight of animal evidence and results of limited human studies suggest that an association between nitrate consumption and its reduced forms of nitrites/nitrosamines and human cancer is plausible. Until further studies are conducted, no definitive conclusions can be reached.

The degree of risk associated with using and ingesting water containing pesticide residues is also much-studied but poorly understood. Since all pesticides are designed to be toxic to certain forms of life and because few are completely selective in their actions, most could adversely affect human health, depending on their concentrations. The degree of toxicity and the nature of the effects vary widely with the pesticide, as does the degree of knowledge about the mechanisms and effects of pesticide action (45).

Based on risk assessments, EPA canceled the uses of two nematicides, EDB and DBCP, due to evidence that they cause genetic mutations, reproductive disorders, and cancer (76). Both chemicals have been found in groundwater. Other chemicals are currently being studied by EPA. For example, alachlor, an acetanilide herbicide widely used on corn and soybeans and found in groundwater in four States, has also shown strong evidence of being a carcinogen (76). Triazine herbicides (for example, atrazine, cyanazine, and simazine) are groundwater contaminants and, though not known to be carcinogens, are suspected of causing long-term effects including central nervous system (CNS) disorders (22). Widely used phenoxy acid herbicides which are potential leachers, such as 2,4-D, 2,4,5-T, and 2,4,5-TP (Silvex), are also suspected of causing CNS disorders and a variety of other chronic effects (22, 43). A recent study has linked the application of 2,4-D with certain forms of cancer in farmers (33). MCLG's have been established for six pesticides: endrin, lindane, methoxychlor, toxaphene, 2,4-D, and 2,4,5-TP. EPA is currently developing MCLG's and MCL's for additional pesticides and other organic chemicals (66).

While the actual risks from low-level exposure to agricultural pollutants are uncertain, the public perception appears to be that they are significant. A recent national public opinion survey of randomly selected people found that only one person in five believes that drinking water which has small amounts of chemicals but which satisfies Government regulations is safe to drink. Moreover, one-third of the respondents said either that they thought their home drinking water was unclean or that they were not sure about its safety. One-fourth either drank bottled water or used a filtering system for their household water (7). Readers of National Wildlife magazine, presumably a group with a higher than average awareness of environmental issues, rank drinking water contamination as the number one environmental threat, according to a 1986 survey (49). Avoiding drinking water contaminated by agricultural and other chemicals is a clear priority of many, despite the lack of definitive answers about health risks.

Measuring Social Costs

Because it is difficult to directly address the costs to society from chemicals in groundwater by means of a risk assessment process, researchers have estimated the social costs of preventing or avoiding groundwater contamination. Estimations can be based on expenditures associated with groundwater protection procedures. Raucher, for example, has examined the benefits and costs of groundwater contamination policies using a "damages avoided" framework on a site-by-site basis (55, 56). Such an approach has several limitations, however, as Raucher notes. It ignores values that society may place on uncontaminated aquifers independent of current or anticipated use. Option values, existence values, or bequest values have been extensively discussed in the resource economics literature and some limited evidence suggests that the size of these benefits may be significant. Raucher also notes that the framework he proposes is useful for a case study analysis but may not be equally applicable to a more comprehensive analysis. The magnitude of benefits from protecting any one aquifer may be small in isolation, but the contamination of many aquifers could be extremely costly to society.

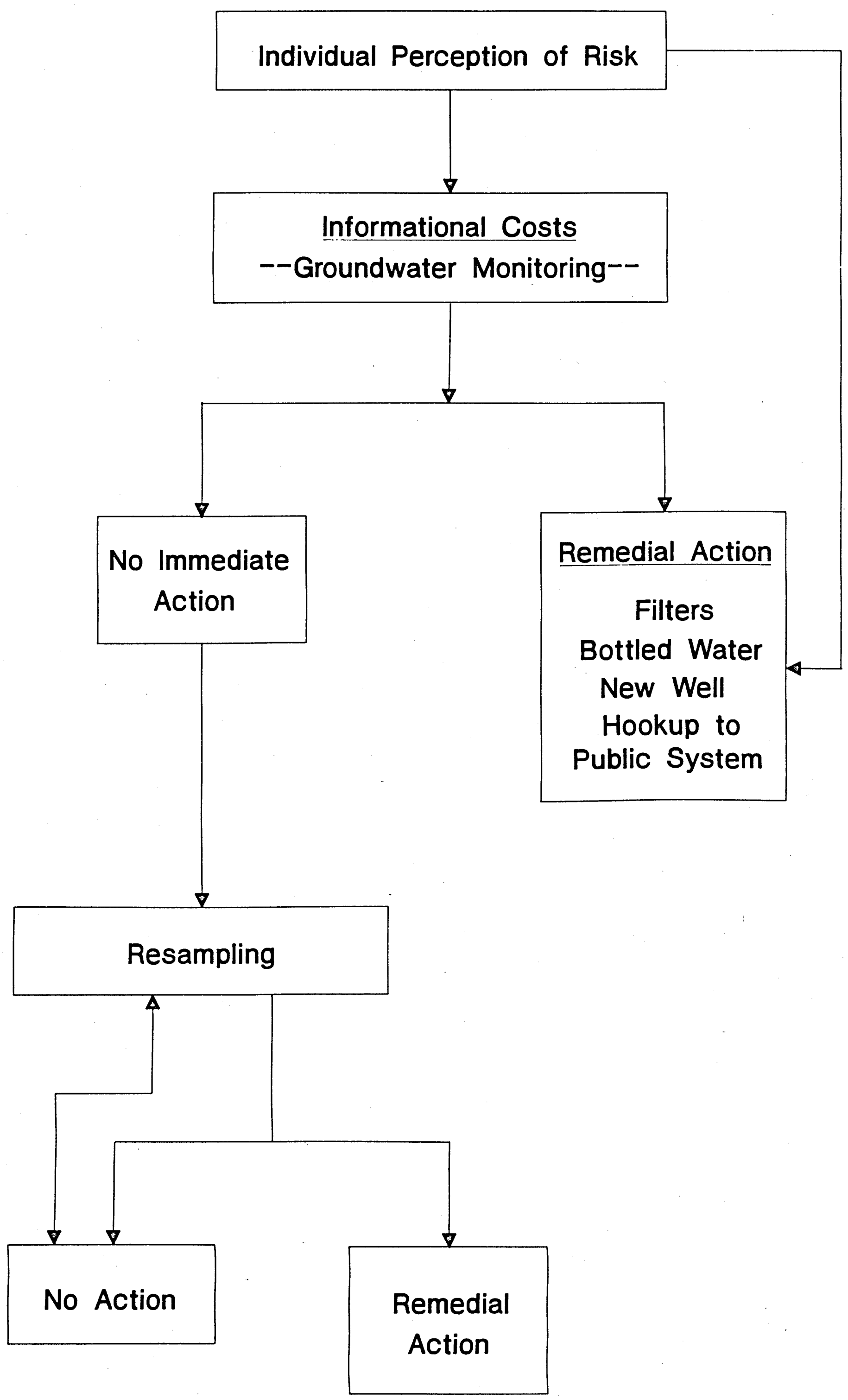
Recognizing the limitations, this report uses a "damages avoided" approach to evaluate macro-level costs of agriculturally induced groundwater contamination. One way to estimate what society must pay to reduce an unspecified contamination risk is to appraise avoidance costs. To do this, we analyzed avoidance costs for households using private wells and public systems. We studied the household sector because private wells are a significant water source in potentially contaminated areas, and the health risks faced by households are the most widely cited effect of groundwater contamination.

Figure 11 presents a framework for household decisionmaking in areas facing groundwater contamination. The first step in any decisionmaking process is to obtain information about potential risks. In the case of groundwater, information gathering is normally done by sampling well water and conducting laboratory tests. If positive test results are obtained and verified, households can assess the information based on their own risk preferences.

If the monitoring information indicates that groundwater contamination is a problem, or if a household decides that it faces significant risks, remedial action can then be taken. Bottled water, filters, or new wells are the most likely alternatives for rural households. Hooking up to deeper, public system wells may be an alternative for some households.

Figure 11

Household Decisionmaking in Areas with Potential Groundwater Contamination



For a household situated in a potentially contaminated area where no immediate remedial action is needed, resampling for contaminants at periodic intervals is probably desirable. Remedial action may be necessary later.

A framework of this kind suggests that estimating what household monitoring costs will be is the first step in appraising groundwater contamination avoidance costs. Because appropriate remedial responses can only be determined on a site-specific basis, estimating remedial response costs for potentially contaminated counties is infeasible. Instead, we discuss a range of remedial options for households and public systems.

Monitoring Costs

Using the framework shown in figure 11, the first step in estimating avoidance costs is to determine monitoring costs. We estimated monitoring costs for households in potentially contaminated areas as well as those of public systems for comparative purposes.

Households

Not every household in a potentially contaminated area would choose to undergo monitoring. Some would decide that any potential risk warrants remedial action, bypassing monitoring altogether. Others may decide that no matter what the monitoring results indicate, no action is necessary. Our current data base does not allow us to determine individual risk preferences. Consequently, the household monitoring costs we provide are estimates of initial monitoring costs of all households served by private wells in areas of potential groundwater contamination, given the assumptions made in the analysis. These estimates can be used, however, to make comparisons between monitoring costs for pesticides and nitrates and between monitoring costs for private wells and public systems. The comparisons have useful implications for public policies.

To estimate household monitoring costs, we obtained a list of laboratories from EPA which are capable of testing water for pesticides and nitrates.14/ We selected a sample of those laboratories located in the 1,437 potentially contaminated counties and obtained price information on nitrate and pesticide testing. Since prices of public laboratories may not reflect market prices, only estimates from private laboratories were used in the analysis.

The laboratories provided cost analysis information on nitrates and pesticides that can be analyzed by four EPA-approved analytical methods. The pesticides were alachlor, metribuzen, bromacil, atrazine, aldicarb, carbofuran, methomyl, dinoseb, and 2,4-D. These pesticides were selected from the 38 used in our analysis of potentially contaminated areas.

Based on discussions with the University Hygienic Laboratory of the University of Iowa and with private laboratories, we developed several criteria for determining monitoring costs. These criteria and the assumptions we used are:

1. The number of chemical tests performed is a major determinant of monitoring costs. Although groups of pesticides can be analyzed with one laboratory method, each chemical requiring a separate procedure is

14/ This list was provided by Maria Gomez-Taylor, Office of Drinking Water, EPA.

priced individually. Thus, the number of tests performed rather than the number of chemicals analyzed determines the cost. We assumed that two chemical tests for pesticides were conducted.

2. The resampling required to assure quality control varies widely from laboratory to laboratory depending on the reliability of the analytic procedure used. A 33-percent resampling rate for nitrates and pesticides was used in our analysis to allow for quality control analysis of positive results.

3. Pesticide testing costs vary widely across laboratories. No discernible regional patterns were detected. Water sample bottles were sometimes included in the laboratory prices. The type of test performed was a major determinant of cost, but laboratories did not uniformly charge more for a particular test. Pesticide laboratory costs, including bottles, were estimated to average from $53 to $139 per test, with $84 a midpoint.

4. Testing for nitrates is a much simpler procedure than testing for pesticides. Our estimates on nitrate costs, including bottles, range from $10 to $25, averaging $16.

5. Shipping and labor costs add to monitoring costs because households must collect samples and mail them to laboratories. One-half hour of labor to collect samples was estimated at an hourly wage rate of $3.35, or $1.68. Shipping costs were estimated to be $1.30 for a 4-ounce nitrate sample, and $3.50 for an 8-pound pesticide sample for two tests. Pesticide tests require larger water samples than do nitrate tests. A 100-mile distance was used to estimate shipping costs with both the United Parcel Service and the U.S. Postal Service. An average of the costs of the two shippers was developed. Estimated shipping and labor costs were $3.00 per well for nitrates and $5.18 per well for pesticides, with and without additional tests for nitrates.

Table 6 shows cost estimates for monitoring various agricultural contaminants per private well. The wide-ranging costs for detecting pesticides reflect laboratory costs which were estimated by averaging data on four pesticides: alachlor, atrazine, aldicarb, and 2,4-D. Variations in nitrate costs also reflect laboratory cost differences.

Table 6--Monitoring cost estimates per private well by contaminant

Contaminant	Low	Average	High
		Dollars	
Pesticides and nitrates	123	189	308
Pesticides	113	173	283
Nitrates	13	19	28

We multiplied the estimates of monitoring costs by private well in table 6 by estimates of the numbers of private wells in potentially contaminated areas derived from census data on nonpublic well systems (table 7). Approximately 10.9 million private well systems are in use in the 1,437 potentially contaminated counties. The calculations include a 33-percent resampling rate.

Data in table 7 reflect a range of initial monitoring costs for these private wells. The estimates range from a high of $2.2 billion to $0.9 billion, depending on the laboratory cost estimate used. The average or "best" estimate is $1.36 billion. Although these estimates reflect the upper limits on the number of wells monitored, other assumptions in the analysis, such as the resampling rate and number of tests performed, may yield more conservative estimates. A study conducted by the Iowa Department of Water, Air, and Waste Management supported that view. The study reported that shallow wells serving six city water supplies in northwestern Iowa contain pesticides and other synthetic organic chemicals (38). Seven wells serving five communities contained measurable amounts of pesticides, although the levels did not violate any MCL standards. Furthermore, the contamination often involved more than one chemical. In one case, a well contained six pesticides. The Iowa study suggests that many wells in potentially contaminated areas may have low concentrations of pesticides, possibly indicating a need for a higher resampling rate (greater than 33 percent) and more than two laboratory tests.

In addition, in cases where low concentrations of pesticides are detected, it is likely that monitoring will be an ongoing process rather than a one-time cost. Consequently, some portion of the initial estimate of $1.36 billion for monitoring costs could be spent annually.

Table 8 presents monitoring costs by contaminant. Only $14 million of the $1.36 billion in monitoring costs are attributable to nitrates alone. Pesticides, alone or in combination with nitrates, represent the majority of monitoring costs because they affect a larger geographical area and incur higher laboratory costs.

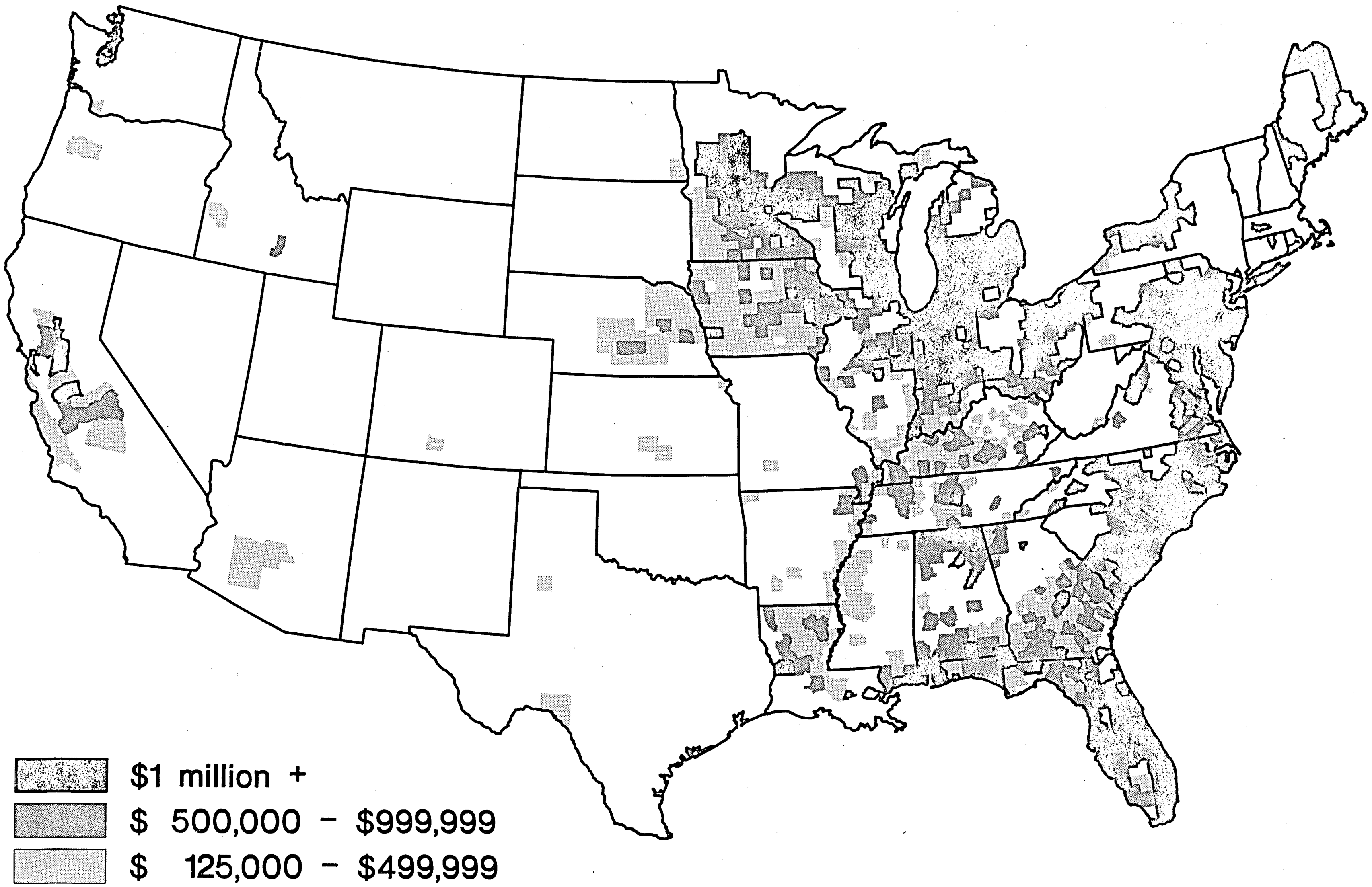
Figure 12 shows how monitoring costs are distributed regionally. High-cost counties (those with $1 million or more in monitoring costs) account for nearly 74 percent of total monitoring costs nationwide and are concentrated in Wisconsin, Michigan, Ohio, Pennsylvania, New York, Maine, parts of the southeastern Coastal Plain, Florida, and California. These areas are more densely populated than other potentially contaminated locales. They average

Table 7--Range of initial monitoring costs for private wells in areas of potential groundwater contamination

Monitoring cost assumptions	Cost
	Billion dollars
High	2.21
Average or "best"	1.36
Low	.89

Figure 12

Groundwater Monitoring Costs in Potentially Contaminated Areas



230 persons per square mile compared with 102 persons per square mile in all areas with potential groundwater contamination. These areas also have a slightly higher percentage of population using private wells: about 21 percent compared with 19 percent in potentially contaminated areas nationwide. Finally, the areas with high monitoring costs are those which have high predicted potential pesticide contamination, or where pesticides and nitrates are potentially found together.

Public Systems

Approximately 34 million people living in the areas with potential contamination obtain their water from public systems drawing on groundwater. Public wells are also subject to groundwater contamination from agricultural chemicals, although they are likely to intercept deeper aquifers and draw from much larger areas than a typical private well. Public systems are usually more highly regulated than private wells, which are subject to no Federal regulatory standards. Nitrates, however, are the only agricultural chemical that community groundwater systems periodically analyze on a nationwide basis.

To compare contamination avoidance costs between private wells and public systems, we developed monitoring cost data for public systems in potentially contaminated areas. Because nitrates are monitored under an ongoing program, we analyzed only costs associated with pesticide monitoring. Our starting points were the county-level estimates of populations using public groundwater supplies, derived earlier in our analysis.

Because data were not available on the size distribution of public groundwater systems, we assumed that the average public system in the study counties serves 3,300-10,000 people. Then we applied EPA assumptions about a public system of this size.15/ For an analysis of the costs associated with implementing standards for volatile organic chemicals (VOC's), EPA assumed that a system of this size would be served by eight wells with four entry points. Further, samples are taken at each entry point, so that an average of four samples per

15/ Unpublished data provided by Maria Gomez-Taylor, Office of Drinking Water, EPA.

Table 8--Initial monitoring costs, by contaminant, for private wells in areas of potential groundwater contamination

Contamination type	Total cost	Counties
	Million dollars	Number
Pesticides and nitrates	414	314
Pesticides	929	814
Nitrates	14	309
Total	1,357	1,437

year is taken for each chemical. EPA assumed a 30-percent resampling rate to screen for VOC's in systems serving more than 3,300 people.

We added to the EPA assumptions one more assumption made in the analysis of private wells; namely, that two chemical tests would be performed. We presumed a 5-percent quantity discount on laboratory costs for a system of this size. Monitoring costs for a typical system then became the product of:

> $160 (the average cost of two chemical tests at $84 per test with a 5-percent quantity discount) and
>
> 4 (the number of entry points) and
>
> 4 (the number of samples per year),
>
> or $2,560.

We do not know the number of public groundwater systems in the 1,437 potentially contaminated counties. There are, however, approximately 29 million people served by public groundwater systems in counties with pesticide contamination potential. Dividing $2,560 by the midpoint of the population served by a typical system (6,650) yields a monitoring cost estimate of $0.38 per person. Multiplying the per-person cost of $0.38 by 29 million people would result in a total of nearly $11 million in initial monitoring costs for a 1-year period. Assuming a 30-percent resampling rate to confirm positive samples, initial monitoring costs for public systems in potentially contaminated areas would be $14 million.

As with household monitoring costs, the choice of assumptions can determine cost estimates. If the average public system serves fewer than 3,300 people and/or if more than two chemical tests are performed, the estimate would increase. On the other hand, if the average system serves more than 10,000 people, the estimate would decrease. Limited data on public groundwater systems prevents developing more precise estimates. However, even if we allow for a confidence interval of ±100 percent for public system monitoring costs, those costs are significantly less than the $1.4-billion estimate developed for private wells in the same areas. The major reason for large differences in monitoring costs between private and public systems is that public groundwater systems afford economies of size.

Summary

The monitoring cost approach does not directly address the costs of damages society incurs from groundwater contamination caused by agricultural chemicals. Lack of documentation about health and other risks makes such an aggregate damage assessment difficult. The monitoring cost approach also ignores values society may place on uncontaminated groundwater for reasons independent of current or anticipated aquifer use.

We present the monitoring cost data to partially illustrate the costs households and communities incur in identifying risks. Monitoring is often the first, informational step in an avoidance strategy. While measuring monitoring costs does not directly ascertain risk preferences of people in affected areas, it does allow useful comparisons among groundwater users in potentially contaminated counties.

The data suggest that the costs of avoiding risks imposed by groundwater contamination from agricultural chemicals are potentially significant. Initial monitoring costs for households would range between $0.9 and $2.2 billion, with $1.4 billion being a "best" estimate. Monitoring for pesticides constitutes the major expense.

The data also clearly indicate that, within the potentially contaminated areas, the consequences created by agricultural chemicals in groundwater will be borne by the rural sector. Because monitoring costs are the same regardless of well size, communities with more and larger volume wells can spread monitoring costs over a network of users. In addition, quantity discounts are likely available. Private well owners, on the other hand, must directly bear all costs, whether they are for monitoring or remedial action. Thus rural residents who rely on private wells, and farmers in particular, will incur a large portion of the expenses.

Remedial Responses

Communities and households have a number of options available to them in responding to known or suspected contamination (see fig. 10). Possible responses range from accepting perceived risks (continuing to drink the water) to avoiding risk (adopting a remedial strategy). We provide only a brief overview of these options, not a decisionmaking guide.16/ We make no attempt to relate remedial costs to the identified potentially contaminated counties because the choice of remedial options depends on the risk preferences of individual well owners and on local conditions.

Households

Households seeking to avoid potential risks from chemicals in their drinking water may choose either to remove the contaminant(s) from the water or to obtain alternative drinking water supplies. The alternative chosen will depend on the costs and effectiveness of the various options, and on household preferences. Table 9 summarizes the major options available and their estimated costs.

Installing home water treatment ("point-of-use") units can reduce contaminants in water that is publicly or privately supplied. The type of contaminant and the natural constituents in the water will determine which kind of device should be used. Pretreatment for natural substances such as iron might be necessary to ensure that treatment for pesticides or nitrates will be effective.

Cost ranges for treatment units shown in table 9 reflect in part the system's capacity and coverage (for example, single-tap or whole-house treatment). Costs also vary with the way that dealers market their products, and while they may vary with the quality of the product, they do not necessarily reflect the unit's effectiveness. These units are not regulated by the Federal Government, nor are they regulated by many State governments.

16/ The descriptions and costs presented are based on information in published sources and from discussions with treatment unit manufacturers and suppliers, water quality association representatives, and local public officials.

Table 9--Household remedial options to reduce agricultural chemicals in drinking water

Option	Estimated costs
Water treatment unit1/:	
Activated carbon filtration (to reduce pesticides)	Faucet-mounted: $25-$50 Under-the-sink: $50-$300 Whole-house: $500-$800
Distillation (to reduce pesticides and nitrates)	Countertop: $300-$350 Automatic: $600-$800
Ion exchange (to reduce nitrates)	Whole-house: $500-$800
Reverse osmosis (to reduce pesticides and nitrates)	Single-tap: $400-$600
Bottled water	$7-$15 weekly for a family of four2/
New well	$3.50-$4.50 per inch diameter per foot of depth, plus casing and pump costs3/
Hookup to public system	$12,000+ per household depending on distance to water main, plus water payments4/

1/ Cost ranges were estimated based on conversations with suppliers and trade representatives and information in published literature. (See boxed item for definitions of the various processes.) Estimates do not include maintenance costs.

2/ Costs are based on use of 2 liters per person per day for drinking water only, with prices ranging from $0.13 to $0.26 per liter ($0.50 to $1.00 per gallon).

3/ Costs are for a well up to 8 inches in diameter and up to 300 feet in depth. They will be higher if the ranges are exceeded. Prices were updated to 1986 levels with the Consumer Price Index. Source: (75).

4/ Sources: (15, 34).

WATER TREATMENT TERMS

Activated carbon filtering--A process that relies on adsorption to remove gases, liquids, and/or suspended matter from water. The water is filtered through carbon, usually in the form of granular activated carbon (GAC). Faucet-mounted and under-the-sink units connect to a single tap, while whole-house units connect to the main water line.

Ion exchange--A process that uses resins having an affinity for certain ions to draw particular substances from water. Anion exchange is the appropriate ion exchange process for reducing nitrates. Units are usually sold as whole-house models.

Distillation--A process in which water is converted to its vapor state by heating, after which the vapor is cooled and condensed to the liquid state and collected. It is used to remove solids and other impurities from water. Water is poured by hand through countertop distillation units. Automatic units are connected directly a water tap.

Reverse osmosis--A process in which pressure is used to force water through a semipermeable membrane which transmits water but rejects most other dissolved ions. Most household models have GAC filters attached, and connect to a single tap.

Most treatment processes have periodic maintenance costs in addition to the purchase price. For instance, maintenance costs for activated carbon units include periodic filter replacement, which could cost from $200 to $350 annually for a whole-house system. Annual costs of replacing membranes and filters in reverse osmosis units could cost $100 to $150. Ion exchange units also require periodic maintenance to assure continued reduction of nitrates.

Households can obtain new sources of water by purchasing bottled water for drinking and cooking needs, connecting to a public water supply, or drilling a new and deeper well. In some cases, bottled water is used as a short-term source until a new permanent supply is secured.

Drilling a new well may be a feasible household response to contamination if an acceptable deeper water source is available. The probability of eventual contamination of the deeper source, however, must be low. The costs of installing a new well can be quite high, as table 9 indicates, and can vary depending on the season and the availability of local drillers (75). In the Big Spring area of northeast Iowa, where wells must be drilled 450 to 500 feet deep to reach uncontaminated groundwater, a new well could cost, conservatively, $6,750 (40).

Connecting to a public water system is often the safest alternative for owners of contaminated wells, although the expense may be prohibitive if water mains are not reasonably close. In Connecticut, the cost to extend water lines to houses with contaminated wells was found to range from $12,000 to $20,000 (34). In areas where housing density is lower and/or distances to water mains are greater, the costs could be substantially higher. Moreover, households connected to public systems usually must pay for their water, unlike those with private wells.

Even if distance to water lines and cost are not prohibitive, there may be other barriers or drawbacks. For example, some water districts do not have enough extra capacity to service new demand. Also, public water supplies are not necessarily free of all agricultural chemicals.

Public Systems

Communities, like households that find their water supply wells to be contaminated, have a number of potential remedial choices open to them. Some options to control point sources of contamination from hazardous waste sites, such as plume containment or control strategies, would likely be technically infeasible or unaffordable if used on agricultural nonpoint-source contamination.

Options which are sometimes workable include closing contaminated wells while maintaining water supply from purer wells, drilling new wells, purchasing water from nearby suppliers, or tapping surface water sources. In some cases, water from contaminated wells is blended with purer water to reduce the concentration of the contaminants by dilution. Conserving water also can help stretch existing supplies.

The technical and economic feasibility of the various options varies widely from one place to another. Some options are very expensive. For instance, drilling a new large-capacity well can run into the tens of millions of dollars.17/

Like households, communities can reduce pesticide levels in their water with GAC filters. However, the process is not widely used at the community level; in 1984, the number of public water treatment plants using GAC adsorption for all purposes, including taste and odor control, was estimated to be between 50 and 60 (68). Table 10 presents estimated capital equipment costs and annualized per-unit GAC treatment costs for two system sizes. The operating expenses include periodic carbon regeneration. GAC filtering systems, as the table indicates, afford significant economies of size.

Treating community well water to reduce nitrates is uncommon. Because of high treatment costs, wells with high nitrate levels usually have been closed or their water has been mixed with water from other wells to bring nitrate levels to acceptable standards.

The EPA Municipal Environmental Research Laboratory evaluated experimental reverse osmosis and ion exchange units for single contaminated wells in small community systems to bring nitrate levels in the final water supply (treated water mixed with raw water) to drinking water standards (26). Table 10 shows the cost involved.

The study indicated that the ion exchange process is preferable to reverse osmosis for small systems because it has lower capital equipment costs and fewer mechanical problems. Both systems generate wastes that require disposal, increasing potential unit costs by as much as 50 percent. Neither process for reducing nitrate levels was evaluated for larger systems, although the authors

17/ See, for example, (55) and (63).

argued that economies of scale would make the processes more cost-effective for larger system sizes (26).

While these costs are only examples and can vary widely depending on location, they do show that treatment costs are potentially high. Costs range at the higher end of the scale if supply systems are small and if water contains both pesticides and nitrates. Because treatment costs for public water supplies can be high and because treatment is sometimes the only feasible alternative, programs that take a collective approach to providing point-of-use treatment of public water supplies are being studied and initiated in several small communities with polluted groundwater sources (6). Under these circumstances, communities set up legal entities that assume responsibility for purchasing and installing all point-of-use units, overseeing monitoring activities, and supervising maintenance. Providing individual treatment units to all affected households can result in lower capital outlays than those for central treatment, but an ongoing maintenance program is essential if all sites are to receive the desired quality of water (6).

Table 10--Public groundwater supply treatment technologies and their costs

Treatment technology	Agricultural contaminant controlled	System size1/	Capital equipment costs	Annualized costs per 1,000 gallons2/
		Million gal/day	--------Dollars-------	
Granular activated carbon (GAC)3/	pesticides	1	1,000,000	1.14
		100	25,000,000	.23
Reverse osmosis4/	nitrates	1	800,000	.99
Ion exchange4/	nitrates	.5	< 100,000	.17
		1	< 160,000	NA

NA indicates that data are unavailable.

1/ A 1-million-gallon-per-day (mgd) system serves approximately 5,000 people, while a 1,000-mgd system serves approximately 500,000 people.
2/ Includes annual operating expenses plus amortized capital costs.
3/ Costs are expressed in March 1980 dollars.
4/ Costs are expressed in 1981 dollars, and annualized costs do not include waste disposal expenses.

Sources: (17, 26).

Summary

The overview of remedial actions and their costs for households and public systems shows the range of options for treating contaminated groundwater or developing alternative drinking water sources. They vary widely in cost and effectiveness. Without precise knowledge of local conditions, it is impossible to predict how many households or communities would require remedial action or what type of action would be appropriate. Consequently, no national estimate of remedial costs in potentially contaminated areas is possible. The data presented in tables 9 and 10 do suggest, however, that some of the remedial actions could result in substantial costs to households with private wells and to small communities that rely on groundwater. Further, remedial actions that reduce both pesticides and nitrates in drinking water appear to be more costly than reducing only one contaminant. Areas with private wells and a simultaneous threat of pesticides and nitrates in their water thus could also face high monitoring and remedial costs.

IMPLICATIONS FOR GROUNDWATER PROTECTION STRATEGIES

Despite limitations of the current data, the statistics presented in this report do serve as indicators of broad regional and national trends. These data have implications for groundwater contamination protection strategies nationwide.

The information suggests that farmer education programs can play a major role in preventing or minimizing groundwater contamination. If incentives for farmers to take voluntary action are ever going to be effective, it is likely to be in the groundwater contamination area. Farmers are much more directly affected by agricultural pollution of groundwater than of surface water because their wells are likely to be close to the sources of contamination. There is, however, currently little advice to give to farmers about how agricultural practices such as conservation tillage affect groundwater quality. The success of farmer education programs depends, in part, on well-documented research programs, many of which are just getting started.

The statistics also suggest that different strategies may be appropriate for dealing with nitrates than with pesticides. In areas of nitrate contamination, taxing fertilizers may be sufficient to offset well monitoring costs or to provide alternative water sources for those affected. It is noteworthy that about 556,000 private wells are located in areas potentially affected only by nitrate contamination compared with 5.6 million private wells in areas with a high potential pesticide contamination or combined pesticide and nitrate contamination potential. Moreover, monitoring costs for nitrates are relatively inexpensive, and the small number of private wells potentially affected may make a remedial program feasible.

In contrast, costs of monitoring for pesticides, whether alone or in combination with nitrates, are so high that a household monitoring program for 5.6 million wells, coupled with remedial actions, would be very costly. Prevention, rather than detection and remedial action, is a more probable strategy, particularly where pesticide contamination is to be avoided. Effective and economical onfarm prevention measures need to be developed.

The data clearly indicate that targeting is needed for any protection strategy. Not all regions are vulnerable. In those regions where agricultural chemicals are being used, not all are equally dependent on groundwater or are densely populated. The monitoring cost approach laid out in this report combines physical vulnerability characteristics, chemical use data, number of wells, and population data. Monitoring cost data shown in figure 12 suggest which regions should be given priority in targeting groundwater protection strategies.

CONCLUSIONS

The objective of this report was to define the physical and economic dimensions of the potential for groundwater contamination from agricultural chemicals in the United States. Major uncertainties remain concerning the human health risks and costs associated with contamination. Despite limitations of the data and analysis presented, the report sets the stage for further, more detailed analyses of the economic issues associated with agriculture and groundwater contamination. The development of economic analysis would depend on the simultaneous development of improved data on the physical processes of groundwater contamination.

A major research issue that will have to be addressed is the relationship between the social benefits and social costs of groundwater protection programs and policies. In the absence of any broad-based research results, policymakers are beginning to propose and enact legislation designed to safeguard groundwater from agricultural chemicals and other contaminants. Arizona, Wisconsin, and other States have already enacted groundwater protection legislation, and EPA is now formulating a strategy aimed at protecting groundwater from agricultural chemicals. Other legislative and regulatory measures are sure to be forthcoming, some of which may impose restrictions on the agricultural sector.

The costs of these regulatory measures on the agricultural sector are not yet well understood. The relationships among agricultural practices, farm income, and changes in groundwater contaminant levels remain to be defined and the economic damages to human health and property need to be directly addressed. All of this information is needed to compare the benefits of controlling societal damages from agriculturally induced groundwater contamination with the social costs of groundwater protection programs and policies. Such an analysis could lead to more efficient and effective strategies for controlling groundwater pollution from pesticides and fertilizers.

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APPENDIX--DATA SOURCES FOR THE PESTICIDES ASSESSMENT

We used two major data sources, the DRASTIC index and the pesticide usage data base developed by Resources for the Future, for the analysis of potential contamination from pesticides.

The DRASTIC Index: County-Level Assessments

The DRASTIC index is a system for evaluating an area's relative vulnerability to groundwater contamination from various sources of pollution (4). The hydrogeologic factors which determine the DRASTIC score and which are the basis for the acronym "DRASTIC" are: Depth to water, Recharge (net), Aquifer media, Soil media, Topography (slope), Impact of the vadose zone, and Conductivity (hydraulic) of the aquifer.

Each DRASTIC factor receives a rating for the geographic area under consideration. The rating is, in turn, multiplied by a weight which reflects the factor's relative importance to contamination potential. The weighted ratings are totaled, yielding the DRASTIC score. A higher score implies a higher degree of vulnerability.

Two sets of weights form the basis for two distinct DRASTIC indexes: the DRASTIC index for agricultural pesticides and the regular (generic) DRASTIC index for all other contaminants. Appendix table 1 shows the assigned weights for both the regular and pesticide DRASTIC indexes. The weights were derived by a committee that used a Delphi or consensus approach. In the case of the agricultural pesticide index, the committee arrived at the weights by considering characteristics of a "generic" pesticide (3).

Each DRASTIC factor is divided into either ranges or significant media types which have an impact on pollution potential, and each range has a corresponding rating (see app. table 2). The DRASTIC score (or pollution potential) for the area is determined by the following formula:

$$\text{DRASTIC SCORE} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$$

where: r = rating
w = weight.

Appendix table 1--Assigned weights for DRASTIC features

Feature	Regular weight	Pesticide weight
D = Depth to water table	5	5
R = Net recharge	4	4
A = Aquifer media	3	3
S = Soil media	2	5
T = Topography	1	3
I = Impact of the vadose zone	5	4
C = Hydraulic conductivity of the aquifer	3	2

Appendix table 2--DRASTIC factor ranges and ratings

DRASTIC factor	Range	Rating	Typical rating
Depth to water (feet)	0-5	10	
	5-10	9	
	15-30	7	
	30-50	5	
	50-75	3	
	75-100	2	
	100+	1	
Net recharge (inches)	0-2	1	
	2-4	3	
	4-7	6	
	7-10	8	
	10+	9	
Aquifer media	Massive shale	1-3	2
	Metamorphic/igneous	2-5	3
	Weathered metamorphic/ igneous	3-5	4
	Thin bedded sandstone, limestone, shale sequences	5-9	6
	Massive sandstone	4-9	6
	Massive limestone	4-9	6
	Sand and gravel	6-9	8
	Basalt	2-10	9
	Karst limestone	9-10	10
Soil media	Thin or absent	10	
	Gravel	10	
	Sand	9	
	Shrinking and/or aggregated clay	7	
	Sandy loam	6	
	Loam	5	
	Silty loam	4	
	Clay loam	3	
	Nonshrinking and nonaggregated clay	1	
Topography (Percent slope)		0-2	10
		2-6	9
		6-12	5
		12-18	3
		18+	1

See footnotes at end of table.

Continued--

Appendix table 2--DRASTIC factor ranges and ratings--Continued

DRASTIC factor	Range	Rating	Typical rating
Impact of vadose zone media	Silt/clay	1-2	1
	Shale	2-5	3
	Limestone	2-7	6
	Sandstone	4-8	6
	Bedded limestone, sandstone, shale	4-8	6
	Sand and gravel with significant silt and clay	4-8	6
	Metamorphic/igneous	2-8	4
	Sand and gravel	6-9	8
	Basalt	2-10	9
	Karst limestone	8-10	10
Hydraulic conductivity (Gallons/day/ft^2)	1-100	1	
	100-300	2	
	300-700	4	
	700-1000	6	
	1000-2000	8	
	2000+	10	

Source: (4)

County-level DRASTIC assessments were carried out in 1985 under an EPA-sponsored project. The county-level ratings were used to aid in sample stratification for EPA's national survey of pesticides in well water (2). To derive the DRASTIC scores which we subsequently used in our analyses, evaluators derived overall ratings for each DRASTIC factor by weighting each rating category by the percent of the county falling in the corresponding range. Weighted ratings were totaled. All ratings are meant to reflect the vulnerability of the county's first potable aquifer.

Resources for the Future Pesticide Usage Data Base

Resources for the Future (RFF) has drawn together a variety of data sources to make pesticide application estimates for all States and counties in the United States.18/

State usage survey data for 13 major crops in 33 states were assembled from the 1982 Crop and Livestock Pesticide Usage Survey, which was conducted by the Economic Research Service (ERS) and reported in Duffy (21) and other ERS publications. Other source material came from ERS reports covering national estimates of annual pesticide use for selected fruits, vegetables, potatoes, and citrus products (23, 29, 50, 78).

18/ See (24) for a complete descripton of the methodology.

Annual pesticide use for all California crops was estimated from data contained in (67). Also, pesticide use by urban applicators and nurseries was estimated from survey results of the U.S. Environmental Protection Agency, Office of Pesticide Programs (OPP) (57, 58). All solvents, banned and minor chemicals, and undefined substances were excluded from the file, which left a total of 184 pesticides accounted for in the data base.

RFF carried out a number of extrapolations to account for pesticide applications in States not covered in available surveys. They are summarized below.

1. For the 33 States included in the ERS survey of 13 major crops, State crop pesticide use estimates were divided by the corresponding State's harvested crop acreage, as reported in the 1982 Census of Agriculture. Pesticide application coefficients (in terms of lbs/acre/year) from a nearby State were assigned to States not included in the ERS survey. By multiplying these coefficients by estimates of State harvested crop acreage, estimates of pesticide use for the 13 crops were obtained for all States that reported harvested acreage in the 1982 Census of Agriculture.

2. For applications to citrus fruits, pesticide application coefficients were derived from the ERS data on Florida, Arizona, and Texas. Applications to citrus crops in Louisiana were estimated using the derived Texas coefficients.

3. For the fruits and vegetables (including potatoes) included in the ERS surveys, national pesticide use coefficients were derived and applied to the State level. Total harvested acreage for each crop was used to derive total State application estimates.

4. For those crops included only in the California report (that is, onions, celery, cauliflower, carrots, cabbage, brussels sprouts, broccoli, lettuce, cantaloupes, cucumbers, green peas, snap peas, and watermelon), pesticide use coefficients were derived by crop. The coefficients were applied to other States based on the reported harvested acreages of those crops.

5. For the pesticide use of nurseries and urban applicators, the OPP national estimates were divided by the number of nurseries and single-unit housing structures, respectively, to yield pesticide use coefficients. The coefficients were then multiplied by the number of nurseries and single-unit housing structures, by State, to obtain estimates of statewide applications for these categories.

Pesticide applications were estimated for a total of 76 crops (app. table 3). County-level estimates of pesticide applications on crops were obtained by prorating State-level estimates to the county level based on the number of harvested acres.

Appendix table 3--Crops for which pesticide applications are included in the RFF pesticide usage data base

Alfalfa
Almonds
Apples
Apricots
Artichokes
Asparagus
Avocados
Barley
Beets
Boysenberries
Broccoli
Brussels sprouts
Cabbages
Cantaloupes
Carrots
Cauliflower
Celery
Cherries
Citrus
Collard
Corn
Cotton
Cucumbers
Dates
Eggplants
Figs
Garlic
Grapefruits
Grapes
Green beans
Kale
Kiwi
Lemons
Lettuce
Melons
Mustard
Nectarines
Oats
Okra
Olives
Onions
Oranges
Other hay
Parsley
Pasture/range
Peaches
Peanuts
Pears
Peas
Pecans
Peppers
Persimmons
Pistachios
Plums
Pomegranates
Potatoes
Pumpkins
Radishes
Rice
Rye
Safflowers
Sorghum
Soybeans
Spinach
Squash
Strawberries
Sugar beets
Sunflowers
Sweet corn
Sweetpotatoes
Tobacco
Tomatoes
Turnips
Walnuts
Watermelons
Wheat