Chapter 2

Introduction

CHAPTER HIGHLIGHTS

- U.S. agriculture is one of the most pervasive contributors to nonpoint-source water pollution; and contamination of groundwater by agricultural chemicals (agrichemicals) has become an issue of great public concern.
- Concerns about, and *policy responses to, agrichemical* contamination of groundwater cannot be isolated from other public concerns and potential policy responses related to agriculture and the environment.
- Agrichemical groundwater contamination *may result from* normal agrichemical use, from on-farm or offsite mishandling of agrichemicals, or from non-agricultural uses of agrichemicals. Each source is an important component of potential contamination.
- Agrichemicals we *many and varied; a number have been* implicated in groundwater contamination, however, the true extent of groundwater contamination by these is not known.
- Agrichemicals in groundwater can have three major forms of adverse impacts: human health risks, hazards for other agricultural uses of the water, and ecological impacts. Uncertainty about their magnitude makes risk determination problematic, but enough is known of these to raise concern.
- Monitoring groundwater for agrichemical contamination is costly, and remedial actions to decontaminate drinking water would impose a substantial burden on rural homeowners and small communities; the more efficient solution is to prevent contamination.

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Chapter 2
Introduction

Groundwater quality is one of the newest and most important issues in the continuing debate about the relationship between agriculture and the environment (see box 2-A). U.S. agriculture has been shown to be one of the most pervasive contributors to nonpoint-source pollution of surface water and ground water (5,23,68,69). The forms of this contaminant ion vary, but the most widespread public concern has been raised over the accumulating reports of agrichemicals—pesticides and nitrate-found in drinking water. Unlike most other groundwater pollutants (see table 2-l), the agrichemicals of concern are deliberately applied, integral to current agricultural production systems and, in the case of most pesticides, designed to be toxic.

In recent years concerns have focused on groundwater quality, which supplies drinking water to 50 percent of the U.S. population and at least 90 percent of rural residents (50). Potential agrichemical contamination of groundwater concerns rural populations as well as farm residents, and ultimately may affect some urban areas (see figure 2-l). While currently of local or regional extent, groundwater contamination has become a national issue. Public concerns indirectly reveal the extent of uncertainty about the amount and location of agrichemical use, environmental fate of agrichemicals under varying site conditions, and the implications of agrichemical

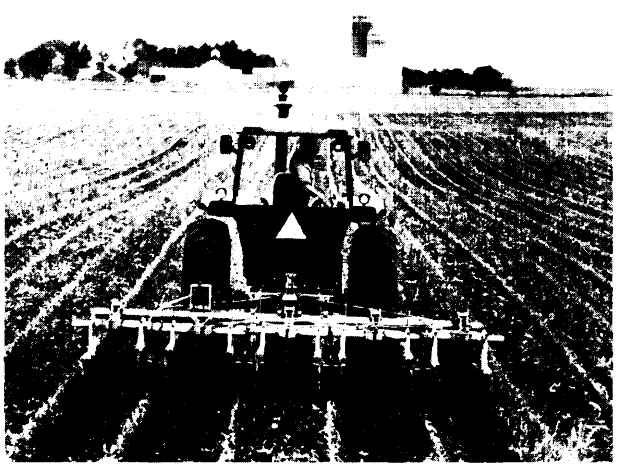


Photo credit: U.S. Department of Agriculture, Agricultural Research Service

Ridge tillage can reduce agrichemical use.

contamination of groundwater for human health, economic activities, or ecological values: we're learning that agrichemical contamination of groundwater resources happens, but we don't really know what it means.

Given the high level of public concern about groundwater contamination in some areas, many farmers, particularly those in areas where extensive groundwater monitoring has yielded negative contamination results, are worried about potential congressional and State ''overreaction' to the problem (2,51). Some farmers fear that public concern over sparse evidence of groundwater contamination will lead to excessively restrictive Federal and State regulations on agrichemical use that would increase production costs, put farmers at a competitive disadvantage, expose them to liability, and make it difficult if not impossible to grow certain crops in some areas. However, given the dearth of evidence that agrichemical contamination of groundwater is extensive and health-threatening, few members of the agricultural community oppose investments in research to learn more about the problem (54). Farmers also favor research and education programs to improve agrichemical management, because the presence of agrichemicals in groundwater indicates that they are being wasted. Information is needed on the types of farming practices that cause agrichemical waste, and on their extent and potential for modification.

To understand the causes for concern, and to indicate the extent of uncertainty, certain questions must be addressed:

- What do we know about the extent of agrichemical contamination of groundwater?
- What do we know about the causes of contamination?
- What do we know about the impacts of contamination?
- How do we deal with contaminated groundwater?
- What do we need to know to prevent groundwater contamination?

Before these issues can be explored, some definitions are needed.

Box 2-A-Other Concerns Potentially Affecting Agrichemical Contamination of Groundwater

A number of safety, environmental, and economic concerns reflect what is popularly called a "growing anti-chemical sentiment" or even public "chemophobia" (6). Policy decisions made in response to these issues will in turn affect availability and use of agrichemicals and, thus, the potential for agrichemical contamination of groundwater.

Food Safety-Agrichemical residues on or in food has become a major issue of public concern over the last few years (cf: 71) and is being addressed under EPA's pesticide reregistration requirements. Concern about Alar, for example, caused Washington State apple growers to lose millions of dollars as consumers refused to purchase apples for fear of adverse health effects (cf: 26,75). Direct public pressure forced a voluntary withdrawal of Alar from the market, brought it under EPA review, and forced eventual cancellation. Fruit and vegetable producers tend to be highly responsive to public perceptions. However, fiber and feed crop producers, and grain farmers whose products tend to be highly processed may not face equivalent pressure.

Freshwater Availability—Total withdrawals of freshwater (surface and groundwater) have increased at an annual rate of 2 percent during the last 25 years; withdrawals of groundwater have increased at an average of 3.8 percent each year. Increasing water supply requirements for urban areas (particularly in the Southwest), energy production, and drought protection; and objections to construction of surface reservoirs have contributed to increasing groundwater use. Growing populations, expanding per-capita use, and removal of contaminanted surface and groundwater supplies from the reserve necessitate an increased dependence on groundwater in the future (59).

Surface Water Concerns--Forty-eight States have completed assessments of nonpoint-source pollution of their waters as required by Section 319 of the Clean Water Act. Agriculture was identified as the most common source of this pollution. More than half of the surface waters (river miles and lake acreage) assessed are adversely affected by agricultural nonpoint source pollution (77). A 1989 study by the USGS reported that 55 percent of streams tested in 10 Midwestern agricultural States had measurable levels of pesticides prior to application, and 90 percent showed detections of pesticides shortly after spring application. Although most detections were very small, numerous samples exceeded the health advisory limits for atrazine and alachlor, restricted-use chemicals (28).

Nearshore Water Concern-Surface and groundwater in nearshore areas commonly flow into the sea. Nutrient loadings derived from contaminated surface water and, to a lesser extent, from contaminated groundwater entering the Nation's bays and estuaries is causing excessive algal growth loss of ecologically valuable marine and estuarine vegetation, and oxygen deprivation in certain waters. Pesticides in surface and groundwater outflows also may be causing more subtle impacts on marine species. For example, pesticides designed to disrupt the maturation process of commercially destructive arthropods such as grasshoppers may have adverse effects on commercially valuable arthropods, such as crabs and lobsters (17).

Wildlife and Endangered Species Protection-lhhancement of wildlife habitat has been a goal of numerous agricultural conservation programs and a continuing issue in agricultural policy development (70). Now, the impacts of agrichemicals on wildlife and, especially, endangered species has come under public scrutiny. In fact, one Federal district court ruled that EPA had violated the Endangered Species Act, Migratory Bird Treaty Act, and other Federal laws with registration of a rodenticide that posed a threat to endangered species (20), and the Department of the Interior has identified several wildlife refuges where agriculturally related water contamination has reached unacceptable levels (see box 3-A). In response to pressure from public environmental groups, EPA is developing a program to restrict or relabel pesticides to protect wildlife and endangered species (l). Further action to protect species may affect the extent of restriction and use of agrichemicals, may enhance development of alternative pest control methods, and may increase populations of insectivorous species (e.g., certain songbirds) that could ultimately benefit agriculture.

Climate Change-Nitrous oxides and methane are two primary "greenhouse gases" that are contributing to global warming (73) and some scientists expect that these will increase in importance to climate changeover time. Bogs, wetlands, rice paddies, wildlife and livestock, and burning forests and grasslands all produce methane. Some studies suggest that the world's cattle-a number that has doubled in the past 40 years-emit enough methane alone into the atmosphere to warm up the planet. The largest methane "sink" is believed to be the soil, but recent studies suggest that nitrogen fertilize may reduce the soil's ability to capture and sequester methane. Nitrous oxides now account for approximately one-quarter of greenhouse gases emitted to the atmosphere (55).

Pesticide Registration and Reregistration-The 1988 reauthorization of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) substantially increased the budget for pesticide reregistration and set a 1996 deadline for completion. New legislation proposed in Congress would speed the cancellation process, would streamline FIFRA and would reduce the economic benefit rationale for maintaining potential dangerous chemicals on the market. Some of the pesticides removed from the market, either voluntarily by a company not wishing to bear the costs of data collection for reregistration, or due to stricter registration requirements, may also be those with potential to leach to groundwater. In addition, proponents of alternatives to synthetic commercial pesticides have argued that an overwhelming emphasis placed on reregistration of pesticides, driven by Congress, has hindered the registration of new, potentially less persistent or mobile pesticides and alternative pest controls (36). Completion of the reregistration process may allow greater attention to be devoted to registration of these products, potentially allowing farmers greater choice in pest control methods.

Farmworker Safety—Agriculture is one of the most hazardous occupations. Farmers and farmworkers suffer from elevated incidence of traumas, certain cancers, respiratory diseases, dermatitis, and acute and chronic chemical toxicity. At the biochemical level, certain pesticides may affect humans in the same manner that they affect the insects for which they are intended

(74). Farm families also may be exposed to farm hazards; children represent a substantial proportion of those suffering from acute and chronic pesticide poisoning (47,74). Policies and programs promulgated to reduce risk to farmers, farmworkers, and farm families also may affect agrichemical availability and use.

Rural Revitalization--Federal natural resource conservation policies may conflict with or complement rural development goals, another major topic of agricultural policy debate for the 1990s (cf: 53). For example, rural communities and families would face a substantial burden from the costs of drinking water treatment due to agrichemical contamination, hindering allocation of funds to local development (50,76). More directly, farm policies that restrict farm production or use of agrichemicals will have impacts on farm chemical and implement dealers in rural communities. On the other hand, resource conservation and environmental protection policies may enhance rural redevelopment through recreation and tourism opportunities, which rely on a safe and esthetic environment (cf: 10). Also, water quality protection programs that rely on provision of specialized information or decisionmaking services might be designed to create new employment opportunities for rural residents.

Dependence on Fossil Fuels-Agriculture is a relatively energy-intensive industry. Production of one ton of grain requires, on average, expenditure of the equivalent of a barrel of oil. Natural gas is widely used to convert atmospheric nitrogen to chemical nitrogen fertilizers (7), and many pesticides are manufactured from petroleum (56,64). Movements to increase energy efficiency and conserve fossil fuel resources (or to reduce greenhouse gas emissions from manufacturing) may affect equipment design, size, and turnover; expansion of irrigated land and design of systems; and the price and availability of nitrogen fertilizers and certain pesticides.

Industrial Safety and Transportation of Hazardous Substances-Ammonium nitrate (NH_4NO_3), used in fertilizers and in explosive mixtures, has been implicated in industrial accidents, including fires and explosions when stored in bulk. For example, two nitrate-bearing freighters exploded in Texas City, TX setting off a major conflagration, killing 576 people. More recently, in 1988, two trailers of ammonium nitrate exploded near Kansas City, KS (22). Certain forms of nitrogen fertilizers also are considered hazardous substances in terms of highway transportation. Restrictions on movement of these formulations may restrict their availability to farmers.

Municipal Waste Reduction and Management—The United States generates at least 160 million tons of municipal solid waste (MSW) each year. Almost 80 percent of MSW is disposed of in landfills, most of which will close within the next 20 years (72). Organic yard and food waste make up about one-fourth of MSW, and thus contribute significantly to the loss of landfill capacity, to leaching from landfills, and to nitrogen oxide emissions from incinerators. Federal, State, or local policies and programs requiring or facilitating separation and comporting of yard and food wastes (and potentially of some paper wastes), would generate new materials that might be applied to agricultural lands. Depending on the mode of management, these have potential for creating new agrichemical leaching sites, or for providing soil conditioners and plant nutrients that might reduce dependence on chemical fertilizers in some areas (72).

Family Farms-Some suggest that preserving the family farm structure (presumably meaning moderate-sized farms) is necessary to maintaining a cadre of skilled agricultural entrepreneurs in the agricultural sector and preserving the quality of rural life (cf: 48). Efforts to accomplish this could affect regional cropping patterns, farm size, and other such factors potentially affecting agrichemical use.

New Crops and New Marketing Strategies-Even though organic fruits and vegetables-produce grown without the use of synthetic, chemical pesticides and, sometimes, fertilizers-may cost twice as much as conventionally grown produce, the market is growing. Farmers have moved rapidly to capture the returns available from the higher prices consumers are willing to pay. The trend toward organic farms is strongest in California with an estimated 1,500 organic farms (26). Some States, certain farmer cooperatives, and even some market chains will test and certify organic produce (or alternatively, produce showing no residues despite use of some pesticides), Fear of being "blackballed' by supermarkets or by food processing companies may spur other farmers to reduce agrichemical use and, thus, the potential for agrichemical leaching to groundwater. Furthermore, some marketing officials believe that ''environmentally friendly' may become a marketing tool--a means to differentiate a product and thus capture a larger market share or charge a premium price---and may become as popular as ''natural' is now (46).

Cosmetic Quality of Produce--Changes in consumer demand have spurred the recent decline in pesticide use, but consumer demands also drove farmers to use some pesticides in the first place; to achieve cosmetically perfect red apples or unscarred tomatoes. Cosmetic perfection today can be achieved only with pesticides. A recent study by the California Public Interest Research Group concluded that more than half of the pesticide applications on tomatoes and oranges are made primarily for cosmetic purposes (26). Continuing changes in consumer perceptions of safe and acceptable commodities may change the rates and types of application.

Trade and The Balance of Payments-Farm exports generate an eighth of total U.S. earnings, and may have contributed as much as $18 billion to the 1989 balance of trade (48). Agricultural technologies that preserve or enhance yield and product quality with reduced input costs may increase the competitive advantage of U.S. agriculture. Conversely, increased environmental restriction may increase farmers' costs of production and thus reduce competitive advantage over producers in countries operating without such restrictions (cf: 67,58).

For the first time, trade in agricultural products has become a major component of the ongoing international GAIT (General Agreement on Trade and Tariffs) talks. One important component of the ongoing GAIT talks is discussion of 'producer subsidy equivalents' which, in aggregate, measure a country's distortion of international trade flows. Any policies implemented through ' 'carrots' could be considered part of these subsidies and thus may come under pressure to reduce trade distortions. And, of course, international trade conditions and U.S. macroeconomic policies and conditions will affect farmers decisions.

Table 2-l—Major Sources of Groundwater Contamination by Synthetic Organic Chemicals

Waste disposal sources	Non-waste disposal sources
Landfills, surface impoundments, dumps	Abandoned, poorly constructed, or damaged wells
On-site wastewater disposal systems	Accidental spills
Land treatment of municipal and industrial wastes	Application of agricultural chemicals
Land application of sludges	Petroleum exploration and development
Underground injection wells	Above- and below-ground storage tanks

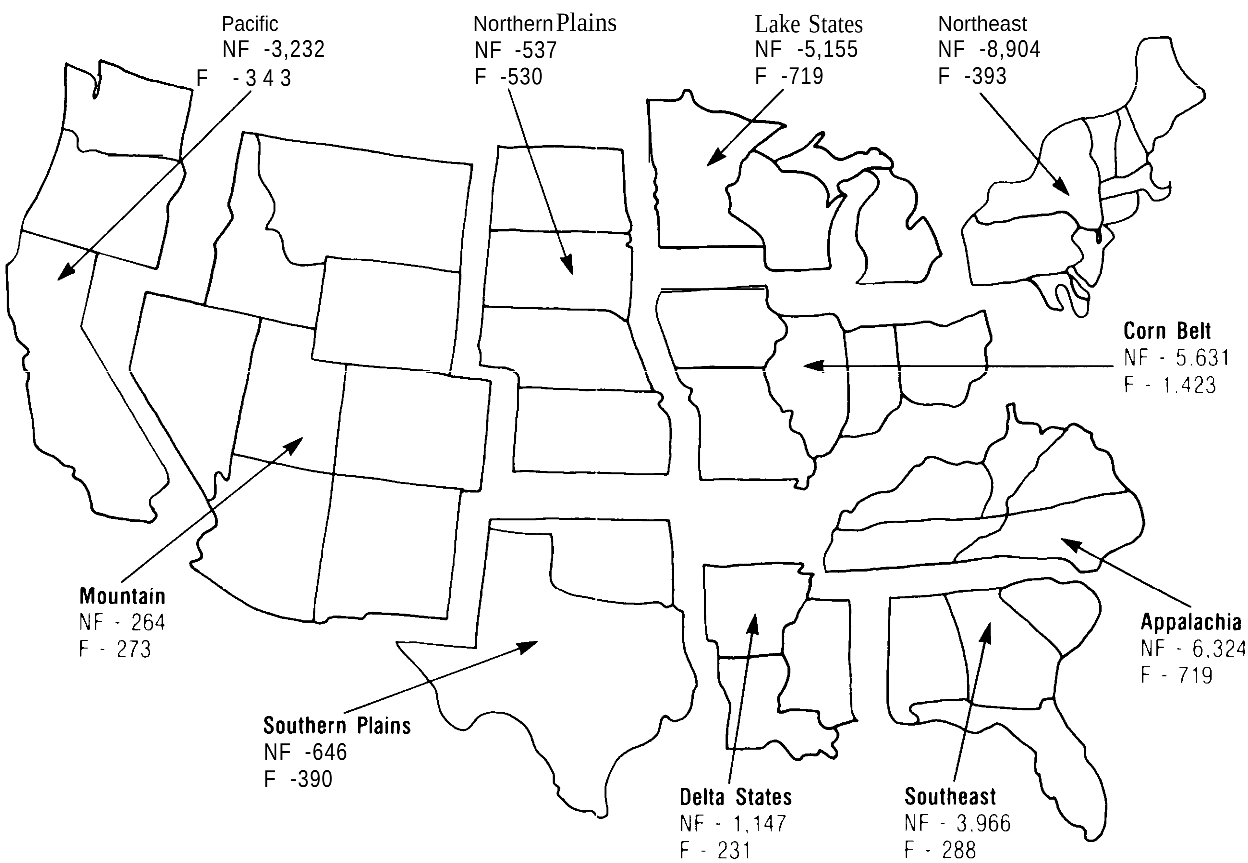
SOURCE: Adapted from F.R. Hall, "improving Pesticide Management Practices," contractor report prepared for the Office of Technoiogy Assessment (Springfield, VA: National Technical information Service, November 1989).

WHAT IS AN AGRICHEMICAL?

Pesticides are used for many purposes other than agriculture (see box 2-B), and many of these uses *also* raise public concerns. However, for the purposes of this assessment an agricultural chemical-agrichemical-is any chemical compound:

1. applied to an agricultural production system with intent to enhance plant productivity (e.g., nutrients, nutrient-release mediators, plant growth regulators);
2. applied to an agricultural production system with intent to prevent loss of productivity

Figure 2-l—Rural Dependence on Private Wells (hundreds of thousands)



Only 12 percent of the nearly 43 million rural residents dependent on private wells to supply drinking water are farm families (F), nonfarm residents (NF) are as likely as farm people to be concerned about potential agrichemical contamination of groundwater

SOURCE: J. Hostetler, "Groundwater Contamination is a Rural Problem," ***Choices,*** Third Quarter, 1988, p. 24.

Box 2-B—Where Pesticides Are Used

EPA has prepared a list of "EPA Site Categories for Preparing and Coding Pesticide Labeling" illustrating the extent of nonagricultural uses of pesticides. Pesticides include fungicides, herbicides, insecticides, nematicides, rodenticides, and disinfectants. The EPA list illustrates two important facts about pesticides: not all are used in agriculture, and not all that *are* used in agriculture are used to grow food crops,

- Fiber crops, such as cotton and hemp.
- Specialized field crops, such as tobacco.
- Crops grown for oil, such as castorbean and safflower.
- Forest trees and Christmas tree plantations.
- Ornamental lawns and turf (e.g., golf courses).
- Ornamental shrubs and vines.
- General soil treatments, such as manure and mulch.
- Household and domestic dwellings.
- Processed non-food products, like textiles and paper.
- Fur and wool-bearing animals, such as mink and fox; laboratory and zoo animals; and pets. (Pesticides are used in animal sprays, dips, collars, wound treatments, and litter and bedding treatments.)
- Dairy farm milk-handling equipment.
- Wood-protection treatments, such as those applied to railroad ties, lumber, boats, and bridges.
- Aquatic sites, including swimming pools, diving boards, fountains, and hot tubs.
- Uncultivated, non-agricultural areas, such as airport landing fields, tennis courts, highway rights-of-way, oil tank farms, ammunition storage depots, petroleum tank farms, saw mills, and drive-in theaters.
- General indoor/outdoor treatments, in bird-roosting areas, for example, or mosquito abatement districts.
- Hospitals. Pesticide application sites include syringes, surgical instruments, pacemakers, rubber gloves, bandages and bedpans.
- Barber shops and beauty shops.
- Mortuaries and funeral homes.
- Industrial preservatives used to manufacture such items as paints, vinyl shower curtains, and disposable diapers.
- Articles used on the human body, like human hair wigs, contact lenses, dentures and insect repellents.
- Specialty uses, such as moth proofing and preserving animal and plant specimens in museum collections.

SOURCE: Adapted from ***EPA Journal,*** "Pesticides and the Consumer, " vol. 13, No. 5, May 1987, pp. 2-43.

caused by disease or by pests such as insects (insecticides), weed competitors (herbicides), nematode worms (nematicides), fungi and molds (fungicides), and rodents (rodenticides); or

3. produced as a byproduct of that system (e.g., byproducts from livestock manures or crop residues, pesticide rinsate).

Clearly, this definition can describe myriad substances used in or produced by U.S. agriculture. However, at present only nitrate and certain categories of pesticides are believed to be significant groundwater contaminants.

Nitrate sources include commercial fertilizers, livestock wastes, crop residues (especially of nitrogen-fining plants), sewage sludges and wastewater, as well as non-agricultural sources such as septic tanks or natural mineral-bearing soil formations. Each of these may provide nitrate that may leach to groundwater. However, because most commercial fertilizers are highly soluble and concentrated, concern exists that such fertilizers may have long-term adverse impacts on nitrate leaching to groundwater—particularly if application rates are not matched to crop needs.

WHAT IS GROUNDWATER?

Groundwater is water stored below the land's surface in saturated soils and rock formations. However, groundwater is not necessarily drinking water, nor is it necessarily suitable for other uses. It may be naturally saline or otherwise unpotable, or it may not be available in sufficient quantity to allow withdrawals for human use. Therefore, in some cases, agrichemical contamination of groundwater may have little immediate impact on current groundwater uses, but may preclude future use as the demand for groundwater changes or as the contaminants migrate into drinking water sources.

WHAT IS GROUNDWATER CONTAMINATION?

Groundwater contamination here refers to the measurable presence of an agrichemical or its breakdown products in groundwater, regardless of the level of concentration or the current or projected uses of the water. Thus, it does not necessarily imply the existence or absence of a threat to human health or the environment. Advances in analytical chemistry now allow detection of chemicals in groundwater at concentrations as low as one part per billion (box 2-C), and even smaller amounts for a few chemicals; such would be considered contamination.

WHAT DO WE KNOW ABOUT THE EXTENT OF CONTAMINATION?

The state of knowledge, the degree of interest, and the degree of frustration in the area of agrichemicals in groundwater have all increased exponentially within the last decade. Studies, focused on vulnerable regions and on individual chemicals or small groups of chemicals, have found at least 5,500 wells with pesticide concentrations exceeding some health advisory level and at least 8,200 wells with nitrate concentrations exceeding the Maximum Contaminant Level established by the U.S. Environmental Protection Agency (EPA) to protect public health (13). Yet the true extent of the problem is not known. For example, many of the detections represent products that are no longer in significant use in the United States (e.g., DBCP). We do not know whether this nonrepresentative subsampling of the Nation's 13 million drinking water wells overstates the severity of the problem or whether it represents the tip of the iceberg.

The scientific community began to emphasize the study of nitrate in groundwater in the mid-1970s (52,30) and the study of pesticides in groundwater in the late 1970s (61,62,14). By 1984, 24,000 of 124,000 wells sampled nationwide were found to contain nitrate concentrations exceeding 3 milligrams per liter mg/L). Although natural background levels of nitrate in groundwater vary, concentrations above 3 mg/L suggest human sources of contamination (42) (figure 2-2).

Box 2-C—Detection Limits: What Do They Mean?

Advances in analytical chemistry have allowed detection of contaminants in groundwater at increasingly lower levels; however the meaning of such low levels of contamination have yet to be clearly defined, Parts per million (ppm) and parts per billion (ppb) are perhaps the most common units employed in reporting agrichemical contamination levels. Such sensitive detections largely are beyond common understanding, thus it may be helpful to illustrate their meanings in more readily understandable terms.

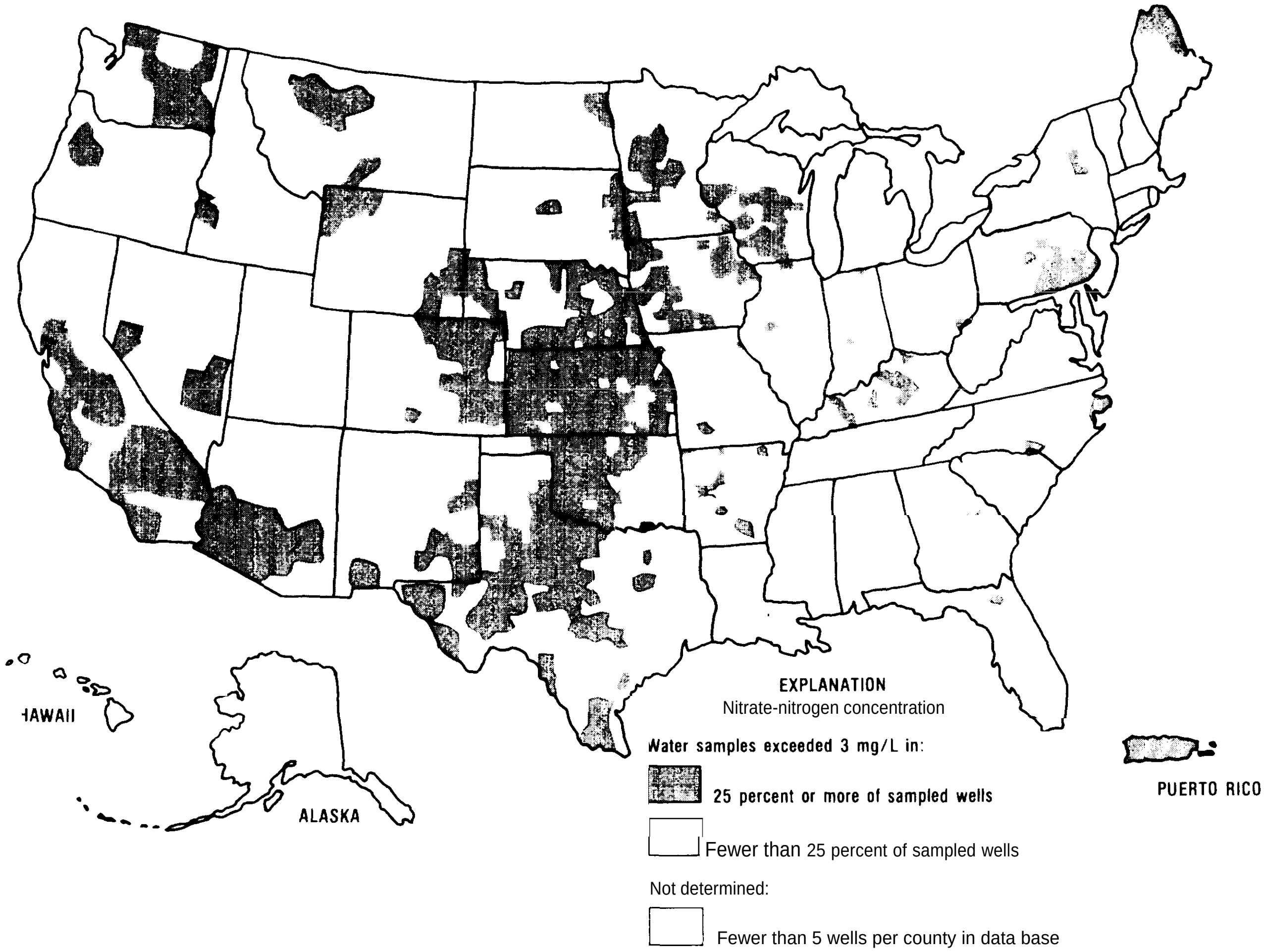
One part per million is equivalent to 1 second in 12 days while 1 part per billion is equivalent to 1 second in 32 years; beyond these, 1 part per trillion is equivalent to 1 second in 32,000 years. Alternatively, the unit ppm can be described as the equivalent of a one-inch square postage stamp in an area the size of a baseball infield. A ppb is this same stamp within an area 1/4 mile in diameter, while a part per trillion is the stamp in an area of 250 square miles. Some tests have sufficient sensitivity to detect parts per quadrillion (ppq). Detecting a ppq would be roughly equivalent to locating that same postage stamp within the area covered by the States of Illinois, Indiana, Michigan, Wisconsin, and Ohio (24).

However, despite such seemingly infinitesimal concentrations, implications for risk exist in certain cases. For example, the Maximum Contaminant Level for nitrate is 10 ppm and health risks have been clearly identified for ingestion of water containing above 10 ppm nitrate. Other agrichemicals have much lower Maximum Contaminant Levels or Health Advisory Limits.

That same year, EPA staff were able to document findings of 12 pesticides in groundwater from 18 States believed to be the result of field applications (14). This count was updated to at least 17 pesticides in 23 States in 1986, and 2 years later, to 46 pesticides in 26 States in association with field use (76) (figure 2-3; table 2-2). The EPA Pesticides in Ground Water Data Base is not complete, and some data remain under contention (cf: 16), yet these are the only data available to date.

A number of concerns about studies of agrichemical contamination of groundwater make it difficult to draw conclusions from these interim data. Some of these relate to study methodology, others refer to

Figure 2-2—Summary of Nitrate Detections in Drinking Water Wells



Although data are insufficient to draw specific conclusions, an analysis of historical nitrate detection data indicates areas of the country in which human activities have elevated the nitrate levels above 3 mg/L.

SOURCE: R.J. Madison and J. Brunett, "Overview of the Occurrence of Nitrate in Ground Water of the United States," ***National Water Summary 1984—Hydrologic Events; Selected Water-Quality Trends and Ground Water Resources,*** U.S. Geological Survey Water Supply Paper 2275 (Washington DC: U.S. Government Printing Office, 1985).

the complex and variable nature of the agroecosystem being evaluated.

- Source of contaminant—through normal field use or from a point source-was determined by EPA via interview with study authors rather than by verifying all detections.
- Most studies lack a statistical basis and many oversimple areas with relatively high groundwater vulnerability and pesticide use and thus may tend to overstate the extent of the problem. It is not valid to sample arbitrarily a few wells in an area and extrapolate the results to the whole area. Instead, sampling schemes with probability components must be implemented (11,15).
- Most studies focus on one pesticide or small groups of pesticides. This would tend to understate the extent of a problem relative to studies that use multiresidue methods and other techniques to detect multiple pesticides.
- Most studies also do not test for pesticide metabolizes, breakdown products, or ''inert' ingredients in addition to active ingredients; in some cases these byproducts can be more toxic than the parent compound. This may further understate agrichemical contamination.

Figure 2-3-EPA Estimates of Numbers of Pesticides Found in Groundwater as a Result of Known or Suspected Normal Agricultural Field Use Origin

Detections of pesticides in groundwater confirmed to derive from field uses have reached 46 pesticides in 26 States. However, these numbers are likely to be an underestimate of the national status of pesticide residues in groundwater due to lack of data or source verification of data in many areas. Information from EPA's ongoing well testing program should provide a more complete depiction of the extent of contamination.

SOURCE: U.S. Environmental Protection Agency, Office of Pesticide Programs, Environmental Fate and Ground Water Branch, "Pesticides in Ground Water Data Base 1988 Interim Report, December 1988.

- The analytical chemistry sometimes has not been trustworthy. Some reports of detections may be due to false positives—acceptable analytical techniques combined with a failure to confirm---or with actual laboratory errors.
- Capacity to detect contaminants in groundwater has outstripped understanding of the meaning of the detections for human or environmental health. The impacts of combinations of contaminants are even less clear.
- Increases in pesticides detected and States with detections may represent an increase in groundwater monitoring studies more than an increase in groundwater contamination.
- A drought over much of the agricultural Midwest since 1986 has confused analysis of data from that region (cf: 38).

EPA is conducting a statistically based, national survey of drinking water wells, which should characterize the national extent of groundwater contamination. Approximately 1,400 public and private wells are being tested. The survey's primary goal is to quantify the distribution of nitrate and summed pesticide residues in wells. Its secondary goal is to correlate the results with hydrogeologic and agronomic factors. The final report probably will be published in early 1991. The Monsanto Co. also conducted a statistically based, nationwide

Table 2-2—EPA Preliminary Data on Pesticides in Groundwater

Category	Description	No. of pesticides detected	No. of States with detected pesticides
6	Confirmed, quality data of known or suspected point source origin	32	12
5	Confirmed, quality data of known or suspected field use origin	46	26
4	Confirmed, quality data of unknown or suspected field use origin	52	27
3	Suspected field use data excluding known poor quality	65	36
2	All data except suspected point sources or known poor quality	74	38
1	All data	77	39

SOURCE: U.S. Environmental Protection Agency, Office of Pesticide Programs, Environmental Fate and Ground Water Branch, "Pesticides in Ground Water Data Base 1988 Interim Report," December 1988.

survey for nitrate and five herbicides in 1,430 private, rural, drinking water wells (45,34).

WHAT DO WE KNOW ABOUT THE CAUSES OF CONTAMINATION?

Agrichemicals may enter the hydrogeologic system through a number of activities, some of which are not strictly agricultural, such as treatment of highway or railroad rights-of-way (see box 2-B). Any one of these uses may result, through mishandling or, in some cases even through normal use, in contamination of groundwater.

Controversy remains over the relative contributions of point and nonpoint sources of agrichemical groundwater contaminants. Nonpoint sources[1] derive from the application of agrichemicals to agricultural lands; contaminants usually are not traceable to their exact source. Point sources, in this context, mean a localized introduction of chemicals to a well or to land via a spill, or through improper storage, mixing, loading, handling, or disposal. Clearly, both modes of groundwater contamination must be considered in any attempt to reduce introduction of agrichemicals to groundwater.

Nonpoint-source contamination has multiple and dispersed sites of entry into groundwater, is dynamic, usually intermittent, and has multimedia dimensions. Agrichemical residues may volatilize into the atmosphere, may cling to soils, may run off into surface water, or may leach into groundwater. Airborne chemicals may travel for hundreds of miles prior to deposition, perhaps in surface waters that can leach to groundwater (e.g., agrichemical contaminants in the Great Lakes have been linked to distant application and aerial transport). A compound released into one medium may have substantially different environmental persistence and reactions than the same compound released in another. Land uses may change over time, causing changes in the type and fate of agrichemicals applied, the speed and direction of agrichemical movement, and agrichemical concentrations and impacts of contaminated water.

Photo reedit: U.S. Department of Agriculture, Agricultural Research Service

Pesticides are applied to agricultural crops to reduce yield losses due to insects (such as the Colorado potato beetle shown), diseases, and weeds that even today destroy almost one-third of all food crops.

The capacity of agricultural systems to assimilate agrichemicals safely varies from site to site and in

[1]Nonpoint pollution is defined by EPA as pollution caused by sediment, nutrient, and organic and toxic substances originating from land-use activities and/or from the atmosphere, which are earned to surface water bodies through runoff or to groundwater.

time (e.g., season) depending on local natural conditions, and on the modifications made to the site by land uses and technologies (3). Determination of where, when, and under what conditions agrichemicals are likely to leach to groundwater depends on knowledge of numerous variables at multitudinous sites; many such data are lacking (43). However, preliminary analyses suggest that large regions of the country are potentially vulnerable to groundwater contamination by agrichemicals (50).

Point sources of agrichemical groundwater contaminants have received relatively little attention in the scientific literature, but in some areas they may be more of a problem than nonpoint sources (27). High concentrations of agrichemical contaminants may be indicative of a point source of contamination such as spills of pesticide concentrate, backsiphoning of pesticide solutions into wells, or rinsate spills. However, concentration level alone is insufficient to clearly identify the point or nonpoint source nature of contamination.

Point sources also may introduce different chemicals to the subsurface than nonpoint sources, because point sources commonly "short-circuit" the typical leaching process and directly introduce contaminants to groundwater through a wellhead. Point-source contaminants also may migrate through the soil in an organic phase, i.e., as bulk liquids, overcoming soil capacity to sequester organic chemicals. The implication of this short-circuiting process is that any chemical could contaminate groundwater through this route, not just those pesticides that are mobile and persistent (14).

The 1988 EPA report represents the first national accounting of groundwater contamination by pesticides from known or suspected point sources (32 pesticides in 12 States). Many of these pesticides are relatively immobile chemicals-i. e., tightly bound to soil-that are not likely to leach into groundwater following normal application (13).

Farm chemical supply dealerships may provide a particular point-source problem, since they store and handle large quantities of agrichemicals. Potentially serious point-source contamination problems have been associated with at least 10 of Iowa's approximately 1,500 farm chemical supply dealerships (30). Pesticide concentrations in soils sometimes exceeded 200,000 parts-per-billion (ppb) and concentrations in nearby groundwater exceeded 500 ppb, two orders of magnitude above normal background levels. Nitrate concentration was as high as 117 parts-per-million (ppm) in one location, and was 20 ppm or greater in all groundwater samples from the 10 farm chemical supply dealerships studied. Relatively high levels of contamination also were found in groundwater samples taken near agricultural dealerships in Illinois (39).

WHAT DO WE KNOW ABOUT THE IMPACTS OF CONTAMINATION?

Agrichemicals in groundwater can have three major forms of adverse impacts: human health risks, hazards for other agricultural uses of the water, and general ecological impacts. For pesticides, in addition to potential adverse impacts of the pesticide's active ingredient, risks involve impacts by metabolizes (chemicals resulting from transformation within a living organism), by breakdown products (resulting from partial degradation by physical or chemical interactions), and by ''inert ingredients. ' The latter are those compounds added to the active ingredient in order to prolong its shelf-life or facilitate its application, and may not be chemically or metabolically inert. For example, known carcinogens benzene and formaldehyde are inert ingredients added to certain pesticides.[2]

Determination of the potential risks of all the possible forms of an agrichemical that might develop after application would be impossible (19). In fact, isolation and identification of all possible ingredients, metabolizes, and breakdown products probably is not possible, given the breadth of factors involved in agrichemical transformations and variations of application sites. Any attempt to do so would most likely halt development of new chemicals. However, knowledge of certain chemical and metabolic reactions and their likely effects on the toxicity of specific chemical groups (e.g., triazine pesticides) may allow adequate predictions of overall risk (19).

[2]EPA is now reviewing and testing inert ingredients and classifying them based on their potential risk; List 1 includes those ingredients of known toxicity and these constituents must be identified on the pesticide label (e.g., benzene, formaldehyde); List 2 includes ingredients of potential toxicity and these will be re-classified based on test results; List 3 are ingredients of unknown risk and are also being tested; and List 4 are those ingredients of minimal risk (e.g., corn syrup, calcium sulfate, bees wax) (40).

Impacts on Human Health

EPA has detailed the health risks from pesticides, to the extent known, in Health Advisories for 70 pesticides developed in accordance with the Safe Drinking Water Act. Health Advisory Levels beyond which the water is considered to pose a potential human health risk are enumerated. Between 1979 and 1986, about half of the approximately 11,000 detections of pesticides in groundwater exceeded EPA's or State's Health Advisory Levels (12). Six percent of nitrate detections exceeded the 10 mg/L Maximum Contaminant Level, beyond which a health hazard maybe present. While a complete analysis of the health impacts of exposure to agrichemicals in groundwater is beyond the purview of this assessment, clearly there is cause for concern.[3]

The means for assessing potential health hazards from exposure to agrichemicals are found in EPA's toxicology data, and in epidemiologic studies of morbidity and mortality in certain populations. EPA frequently is criticized for not having a complete toxicology database on the 600 active ingredients it regulates (13). Statements that only a handful of pesticides have been "fully tested" are technically true, but may be misleading. Approximately three to four dozen studies and tests are required for registration of an agricultural pesticide. Data gaps exist for most chemicals, but these gaps can range from minor technical deficiencies to studies performed with unacceptable protocols to a total lack of data (13).

The toxicology database probably is more complete than the databases pertaining to ecological effects, residue and product chemistry, and environmental fate and exposure. This is due to the extensive "data call-ins" conducted in the early 1980s (25). Registrants of all food-use chemicals, which include most agrichemicals, were required to submit or resubmit data on chronic toxicity, oncogenicity, reproductive effects, and teratology (immunotoxicity and neurotoxicity may be added to the conventional pesticide toxicity testing guidelines in the near future (60,74). A similar, more limited data call-in program was instituted in 1984 to gather information on the environmental fate of approximately 100 pesticides that had some mobility potential.

Few epidemiologic studies have been conducted on exposure to agrichemicals through groundwater. Evidence linking agrichemicals with cancer and other diseases primarily derives from studies of occupationally exposed populations (9). Results of these more general epidemiologic studies point out possible relationships that require further investigation and raise concerns about mortality among people who work with certain classes of agrichemicals (13). Studies using crop production patterns as a proxy for chemical use have suggested connections with certain cancers, but little research has attempted to test directly the relationship between use of agricultural chemicals and county cancer mortality (63).

Although associations between certain pesticides and cancer are not yet clearly established (47,78), a clear relationship exists between nitrate in drinking water and infant methemoglobinemia (blue-baby syndrome). Some epidemiologic studies further indicate an association between nitrate and non-Hodgkin's lymphoma (NHL), stomach cancer, and possibly birth defects; others fail to show any elevated risk for these (47).

An increased incidence of NHL in some eastern Nebraska counties may be related to use of nitrogen fertilizers and resultant groundwater contamination. However, elevated nitrogen levels may just serve as a marker for pesticide contamination and several classes of pesticides have been associated with increased risk of NHL, including atrazine herbicides, organophosphates, carbamates, and chlorinated hydrocarbons (78). One recent study, covering 1,497 U.S. rural counties, attempted to determine predictors of cancer mortality. Agrichemical use was the best predictor of cancer mortality among nine variables tested in five multiple regression cancer models. Herbicides were associated with genital, lymphatic, and digestive cancer, and insecticides had a positive relationship to respiratory cancer (63).

Problems abound in attempting to derive conclusions or generalizations from existing studies. For example, exposure information depends on the subject's memories or on knowledge of relevant practices by next of kin (32). Other problems include (63):

[3] For analysis of the health risks from exposure to neurotoxic pesticides, see: U.S. Congress, Office of Technology Assessment *Neurotoxicity: Identifying and Controlling Poisons of the Nervous System, OTA-BA-436* (Washington DC: U.S. Government Printing Office, April 1990).

- Multiple pathways of non-occupational exposure to agrichemicals exist: through ingesting food or water with pesticide residues, inhalation, dermal contact with pesticide vapors, dusts, or pesticide-laden water,
- The 20- to 40-year latency period for many types of cancer exceeds the length of time that data have been collected on agrichemical use (Census of Agriculture data on county-level chemical use other than fertilizers are not available before 1964).
- The cancer latency period also commonly exceeds the length of time that county-level behavioral data have been collected on lifestyle factors such as diet, smoking, or alcohol consumption; such factors could confound associations observed in studies.
- Percentage of farmland treated is used as a proxy for agrichemical use due to a lack of detailed data on the types, quantities, and frequency of chemical applications, as well as behavioral practices in their application (e.g., use of masks, aerial spraying).

Additional factors potentially confounding interpretation of health impacts are: effect of nearby manufacturing industries; mining; urban exposures; ethnicity and socioeconomic status (education and income) (63). While no solid evidence exists showing a direct causal relationship between pesticide residues in drinking water at legally permissible levels and any human illness or death in the United States (47), the potential for some effect warrants continuing investigation.

Despite uncertainty in many of these areas, recognition of potential health hazards has led to numerous requirements to reduce or prevent human exposure to potentially harmful chemicals. Such requirements include bans on certain substances, product labeling and public education, licensing and certification of those wishing to apply restricted-use pesticides, requirements for certain types of protective gear for applicators, determination of acceptable ‘‘re-entry’ times into areas treated with certain chemicals, and initiation of training sessions by Cooperative Extension Service personnel in correct handling and application procedures (63).

The only non-controversial conclusion possible at this point: additional studies are necessary. Evaluations of the toxicity and possible carcinogenicity of agrichemicals will continue to fall under the purview of biological and medical researchers. However, more ‘‘ecological’ studies incorporating demographic, socioeconomic, and agricultural factors and thus involving environmental and rural sociologists, demographers, geographers, and agronomists, would seem to be of considerable value (63). A comprehensive analysis of studies performed to date and an evaluation of their findings, perhaps performed by the Institute of Medicine in cooperation with the National Academy of Sciences (e.g., Board on Agriculture), probably would clarify many of these issues.

Impacts on Agriculture

Agrichemical-bearing groundwater has been found to have adverse impacts on agriculture through re-use, including toxic responses in livestock and yield reductions in irrigated crops (41,65). In general, livestock seem to be more tolerant to drinking water contaminants of primary concern to humans, such as nitrate (31). However, species’ tolerances vary. Chemical constituent risk levels have been recommended (49, 18) but may need to be reexamined in light of recent veterinary diagnostic research and new chemical detection capabilities (65).

Irrigation may concentrate salts, nitrate, and persistent pesticides in surface and groundwaters. These waters may be re-used for irrigation, providing a source of stress to crops and potentially reducing their yield or product quality (66). Herbicide-laden shallow groundwater may “prune” root systems, hindering crop growth (41). Finally, groundwater contaminated by livestock wastes may damage or hinder operation of irrigation pumps and other equipment.

Ecological Impacts

It is now well-known that chemicals that may have little direct impact on human health may have potentially severe impacts on fish and wildlife. For example, DDT was only slightly toxic to mammals, including humans, but harmed species of game fish and certain bird species. No data exist that clearly indicate adverse ecological impacts from nitrate or pesticides in groundwater, but because of the nature of the hydrologic cycle, groundwater may be a contributor to degradation of surface and nearshore waters. For example, an estimated 45 percent of the total nitrogen found in Lake Mendota in Wisconsin moved into the lake as nitrate from groundwater (44); the role of nitrogen in eutrophication of water bodies is well-known. More recently, the U.S. Geological Survey (USGS) found that 55 percent of the streams tested in 10 Midwestern States had detectable levels of pesticides prior to spring planting when contaminant levels were expected to be lowest. The study leader speculated that the unexpected springtime detections might be due to infusions of groundwater contaminated in earlier months or years, or perhaps due to the dearth of soil "flushing" that occurred in the 1989 drought (28).

A new and rapidly expanding field of study termed ''ecotoxicology' is concerned with the fate and impacts of toxic compounds, such as pesticides, in ecosystems. Research in toxicology has paralleled interest in water quality problems since at least the 1960s (8); such research increased with the establishment of EPA and its mandate to protect human health and the environment (4). Ecotoxicological studies are required by EPA for pesticide registration under the Federal Insecticide, Fungicide, and Rodenticide Act (FWRA). The studies combine toxicological hazard data with exposure data in media of concern such as water. The studies may uncover: 1) no hazard, 2) a hazard that may be mitigated by restrictions on use, or 3) an unacceptable hazard preventing registration of the chemical. However, the types of studies that have been pursued by EPA are fraught with weaknesses (4), and they tend to focus more on specific ecosystem inhabitants (the ''indicator organisms' such as birds, mammals, and fish) rather than on the ecosystem as a whole.

In response to growing concerns about ecological impacts of toxic compounds, EPA's Risk Assessment Council established the Ecotoxicity Subcommittee in 1987 to develop ecological risk assessment guidelines. This Subcommittee developed an assessment framework based on the hierarchical ''levels' of an ecosystem, ranging from a single organism to the entire ecosystem. This allows both laboratory work on species and field work on ecosystem interactions. Guidelines drafted by the Subcommittee should be released for review in 1990 (4). While EPA's activities most closely related to protection of human health probably will continue to receive highest priority, the increasing public concern about ecological impacts likely will spur expanded efforts in ecotoxicology.

WHAT DO WE DO WHEN GROUNDWATER IS CONTAMINATED?

EPA and State agencies with Safe Drinking Water Act (SDWA) primacy[4] have the authority to close public wells (those serving at least 2,500 people or 25 outlets) when contamination exceeds acceptable levels defined by the EPA Maximum Contaminant Level standards. For example, the Hawaii Department of Health shut down several public wells on Oahu in 1983 when the nematicides EDB, DBCP, and trichloropropane were detected (37). Some residents of central Oahu had to obtain drinking water from a tank truck furnished by the State until alternative well connections could be put in place.

Although States such as New Jersey and Florida are increasingly establishing construction standards and monitoring programs for private wells, no State has reserved authority to close private wells. Instead, when water from private wells exceeds standards set by States or the EPA (box 2-D), State agencies generally advise people on whether their water is suitable for drinking, cooking, or washing. In addition, States may assist homeowners to procure water filters, bottled water, or to construct new wells or hook up to public water systems.

The State of Florida accepts applications for remedial relief to individuals with wells containing EDB (57). The State has spent nearly $3 million to install granular activated carbon falters and to connect homes to existing water systems (13). Union Carbide (now Rhone-Poulenc) also supplies water falters to Long Island homeowners where aldicarb concentration in drinking water is greater than 7 ppb (33). As of 1986, approximately 2,000 filters had been installed at a cost to the company of $450 each for installation and $60 to $70 for annual replacement (13).

To date, there are no reports that aquifer cleanup, as opposed to well or tapwater cleanup, has been attempted following nonpoint-source contamination of groundwater (13). Drinking water cleanup from

[4] Under SDWA, EPA identified State agencies with responsibility for implementation of drinking water quality programs legislated under that Act.

Box 2-D—Standards for Groundwater Quality Protection

Numerical groundwater standards have been suggested as a strategy to limit groundwater contamination, and standards have been promulgated by the Environmental Protection Agency and a number of States. For example, Wisconsin has established health-based enforcement standards and preventative action levels for potential groundwater pollutants, giving a two-tier system of standards. The Environmental Protection Agency provides two sets of standards for levels of contaminants in drinking water: Health Advisory Levels (HAL) and Maximum Contaminant Levels (MCL): HALs offer guidance to States and municipal water suppliers regarding contaminant levels approaching hazardous levels, MCLs

There may be dispute whether States should be allowed to set stricter standards than the Federal government, but all look for Federal involvement and leadership. A number of program administrators have complained that it is difficult to develop programs to protect groundwater from contamination when they don't know what level of groundwater purity they are trying to reach or maintain. Program costs may in fact be directly linked to setting of such a level.

Some benefits of standards:

- Standards provide clearly defined targets at which interested parties can aim.
- Standards provide a defined design goal against which various agricultural and resource management practices can be evaluated.
- Standards can be set for individual contaminants, groups of contaminants, or for contamination in aggregate (e.g., EEC)
- Standards can help identify areas of a State or the nation where management practices need modification.
- Standards provide the public with an estimate of the risk of consuming contaminated water and of the relative risk of different contaminants.
- Standards help the public determine when remedial drinking water treatments are needed.

Some disadvantages to standards:

- Standards may provide a level up to which polluters feel free to pollute.
- Establishment of scientifically-defensible standards require considerable time and money.
- Standards can focus on one group of potential pollutants and inadvertently miss others (e.g., potentially toxic "inert' ingredients that might leach to groundwater).

Unanswered questions:

- Costs of developing risk assessments and of monitoring to assess compliance are high; who should pay?
- Should standards could apply to ground water generally (resource protection) or the drinking water (health protection), or to both?
- What action should be taken to ensure compliance when standards are violated?
- Should the ultimate goal of a groundwater protection policy be nondegradation (no additional contamination over current levels) or achieving health-based standards?
- Can the standards be designed so that they do not provide a' 'license to pollute' up to the level of the standard?
- Will the sparcity of the health- or ecological-impacts database require that standards be continually revised (particularly for older chemicals)?

SOURCE: Adapted from National Coalition for Agricultural Safety& Health, "Environmental Health Strategies for Agriculture," May 1989.

agrichemical nonpoint-source contamination is likely to be very costly, and generally technically infeasible given the low concentrations involved. One study of potential costs of groundwater contamination estimated that initial household monitoring alone would cost approximately $1.4 billion (50). Potential remedial actions vary widely in cost and effectiveness, but would impose a large burden on rural homeowners and small communities. Clearly, the more efficient solution is to prevent contamination in the first place.

WHAT DO WE NEED TO KNOW TO MANAGE GROUNDWATER CONTAMINATION?

Several basic questions must be answered to identify means to reduce the potential for agrichemical contamination of groundwater:

- WHY do we use agricultural chemicals?
- WHERE is groundwater contaminated, where might it occur in the future, and why?

- WHAT crops, cropping systems, and technologies are associated with contamination?
- WHO is making the decisions that lead to contamination and why?
- HOW might incentives and influences be changed to-favor technologies and management systems that protect groundwater quality?

Discussion of these subjects form the remainder of this assessment.

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