Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemical Contamination of Groundwater

November 1990

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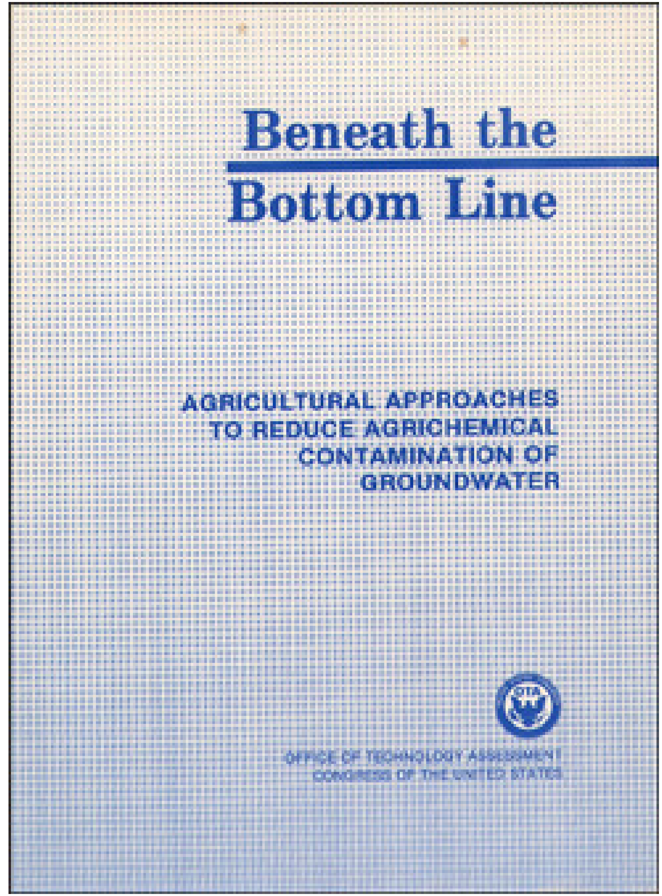

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Foreword

Agriculture has always been a mainstay of the U.S. economy, and an important component of our cultural heritage. However, this century has seen an ‘‘environmental revolution’ occur, emerging into a force of widespread national significance since the late 1960s. The environmental concerns specifically attributed to agriculture have followed a progression: from recognition of ‘on-site’ problems (e.g., loss of soil fertility due to erosion), to ‘‘off-site’ (e.g., degradation of surface-water quality due to nutrient runoff from agricultural fields) and, today, to “out-of-sight” concerns such as groundwater contamination by agricultural chemicals (’ ‘agrichemicals ”).

Surveys show that public concern over agrichemical contamination of groundwater (as well as other related issues such as food safety and surface-water quality) is high. Further, this concern extends to farmers and farm communities-the individuals in closest proximity to potentially contaminated groundwater. Because of the nature of groundwater contamination-largely out-of-reach of remedial actions and, thus, essentially irreversible-prevention of groundwater contamination is the only means currently available for responding to the need to protect essential resources, environmental quality, and health.

Protection of the Nation’s groundwater resources has become an issue of pressing concern to the public, to Congress, and to many Federal, State, and local agencies. Agencies and organizations at all levels are undertaking programs designed to affect a farmer’s choice of technology, and thus the potential for introduction of agrichemicals into groundwater. Such programs include extensive efforts in data collection and management, research and development, extension and education, and regulatory actions.

Several primary conclusions derived from the analysis covered in this assessment have clear policy implications. First, agriculture is a national, strategic resource: options that severely reduce the U.S. capacity to produce food to feed the domestic population are clearly adverse to the interests of society. Second, protection of environmental quality is high on the public lists of societal goals. Certain agricultural technologies—in nutrient and pest management; in crop, sod, and water management practices; in data analysis and planning; and in design of farming systems-show considerable promise for reducing the potential for agrichemicals to enter groundwater.

Four congressional committees and five subcommittees requested the Office of Technology Assessment in 1988 to conduct an assessment of the potentials for agricultural technologies to reduce groundwater contamination by agricultural chemicals: House Committee on Agriculture, its Subcommittee on Department Operations, Research, and Foreign Agriculture; House Committee on Science, Space, and Technology; House Committee on Public Works and Transportation; Subcommittee on Environment, Energy, and Natural Resources of the House Committee on Government Operations; Subcommittee on Water and Power Resources of the House Committee on Interior and Insular Affairs; and Senate Committee on Agriculture, Nutrition, and Forestry. The assessment identifies and discusses in-depth constraints to and opportunities for agricultural approaches to reduce the potential for agrichemical contamination of groundwater.

OTA greatly appreciates the contributions of its advisory panel and authors of commissioned papers. We are especially grateful for the time and effort donated by the numerous contributors who served as reviewers and as liaisons from Federal agencies. The information and assistance provided by those individuals-too numerous to list-proved invaluable to the completion of the assessment. As with all OTA studies, the content of the report is the sole responsibility of OTA.

JOHN H. GIBBONS
Director

Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemical Contamination of Groundwater Advisory Panel

Sandra S. Batie, *Chair*
Professor
Department of Agricultural Economics
Virginia Polytechnic Institute and State University

John Abernathy
Resident Director of Research
Agricultural Research and Extension Center
Texas A & M University

Donald Duvick
Vice President of Research
Pioneer i-Ii-Bred International

Richard S. Fawcett
Agricultural Consultant
Iowa

Scott Ferguson
Partner, McLeod & Pires
Washington, DC

Roger Gold
Coordinator, Environmental programs
Institute of Agriculture and Natural Resources
University of Nebraska

George Hallberg
Supervisor, Environmental Geology
Geological Survey Bureau
Iowa Department of Natural Resources

Joseph Harkins
Director
Kansas Water Office

Roland Hauck
Senior Scientist
National Fertilizer & Environmental Research Center
Tennessee Valley Authority

Dennis Keeney
Director
Leopold Center for Sustainable Agriculture
Iowa State University

Bobby McKown
Executive Vice President
Florida Citrus Mutual

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Dean, College of Natural Resources
University of Rhode Island

Peter Nowak
Professor
Department of Sociology
University of Wisconsin

Donna Pratt
Chairman, Natural Resources
Women Involved in Farm Economics

Carl Pulvermacher
Farmer
Wisconsin

Richard Rominger
Farmer
California

Velma Smith
Project Director
Groundwater Protection
Environmental Policy Institute

Ford West
Vice President
Government Relations
The Fertilizer Institute

L Garth Youngberg
Executive Director
Institute for Alternative Agriculture

NOTE: OTA is grateful for the valuable assistance and thoughtful critiques provided by the Advisory Panel and other reviewers. The reviewers do not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

(OTA Project Staff on Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemical Contamination of Groundwater

Roger Herdman, *Assistant Director, OTA*
Health and Life Sciences Division

Walter E. Parham, *Program Manager*
Food and Renewable Resources Program

Alison L. Hess, *Project Director*

Analytical Staff

Mary A. Bruns, *Analyst*

Patricia J. Durana, *Research Analyst*

Laura Dye, *Intern*[1]

Lyn E. Raue, *Intern*[2]

Susan J. Wintsch, *Contracted EditorWriter*

Clerical Staff

N. Ellis Lewis, Office *Administrator*

Nellie Hammond, *Administrative Secretary*

Carolyn Swarm, *PC Specialist*

[1]From May 1989 to September 1989.

[2]From September 1988 to December 1988.

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INTRODUCTION

Agriculture has always been an important part of the economy and cultural heritage of the United States. Although the number of farmers has declined over the last 50 years, food and fiber still accounts for about 18 percent of the gross national product. Because of the scientific and technological advances occurring largely since World War II, farms have become more automated, specialized, productive, and increasingly dependent on off-farm inputs. Among these, commercial fertilizers and pesticides have been widely used to save time and labor. Agrichernical use increased 15 percent between 1974 and 1985. In 1986, approximately 57 percent and 75 percent of U.S. farms had pesticide and fertilizer expenditures, respectively.[1]

However, environmental concerns about agrichemicals, especially pesticides, are growing. These concerns revolve around long-term hazards to the consuming population, to wildlife, and to the environment generally, including surface and groundwater. Agriculture is one of the most, if not the most, pervasive contributors to nonpoint-source pollution of surface- and groundwater. Nonpoint-source pollution derives from multiple sources spread over wide areas (box l-A; figure l-l).

In 1988, the Environmental Protection Agency (EPA) documented the presence of 46 pesticides in groundwater from 26 States. Approximately 24,000 of 124,000 wells sampled nationwide in 1984 contained nitrate concentrations above 3 milligrams per liter (mg/L) indicating a likely human source, yet considerably below the Health Advisory level of 10 mg/L. Reports of groundwater contamination are increasing with time. Information from the forthcoming EPA National Survey of Pesticides in Drinking Water should clarify the extent of contamination.

Whether the widespread occurrence of agrichemicals in groundwater implies chronic mismanagement of these substances, or reflects the consequences of normal, label-specified field use (or both) is not clear, nor is the full extent of the problem known. To date, well monitoring has been patchy and some data emerging from well-sampling efforts around the country remain under contention. The actual or potential human health impacts of agrichemicals in groundwater are also unknown, especially in the case of very low pesticide concentrations now easily detectable with modern scientific equipment and methods. Despite--a perhaps because of—these uncertainties, public concern over ground-

Box I-A—Definitions

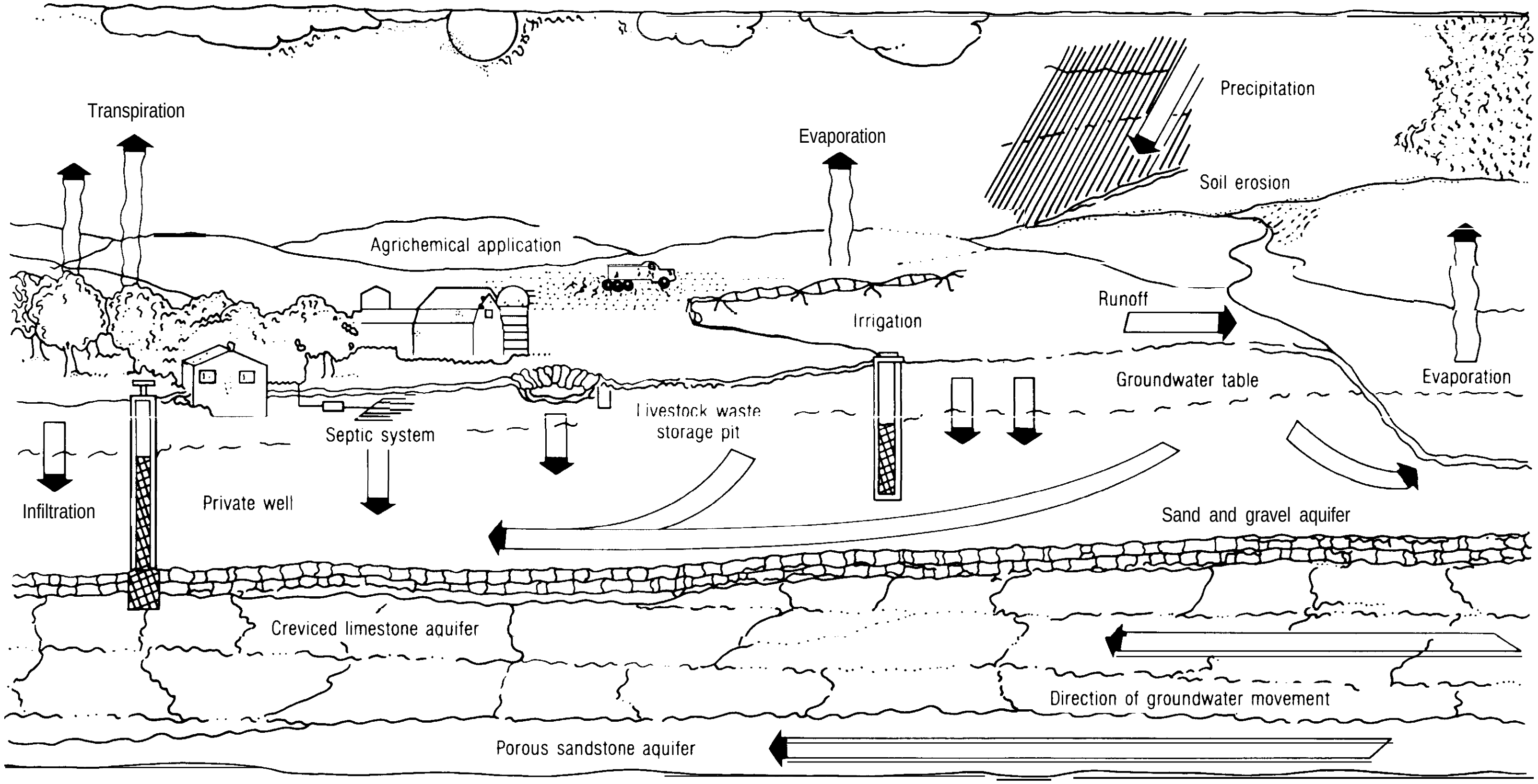
***What** is an agrichemical?* For the purposes of this assessment an agricultural chemical-agrichemical-is any chemical compound applied to an agricultural production system with intent to enhance plant productivity or prevent loss of productivity caused by disease or by pests; or produced as a byproduct of the farm system (e.g., byproducts from livestock manures or crop residues).

What is a groundwater contaminant? 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. Only nitrate and certain categories of pesticides are believed to be significant groundwater contaminants. A number of agronomic nitrate sources exist, including commercial fertilizers, livestock wastes, crop residues, and sewage sludges and wastewater. 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 exceed crop needs.

An *agroecosystem* refers to the blend of physio-chemical and ecological parameters as modified by agronomic practices. Areas characterized by similar climatic, hydrogeologic, farming system, and other agroecological features may be classified as *agroecoregions.*

IF-s not using agrichemicals commonly are extensive livestock operations, organic farms, and small hobby farms

Figure 1-1—Primary On-Farm Pathways of Agrichemical Contamination of Groundwater



Agrichemical contamination of groundwater can occur from myriad sources and through numerous pathways. In addition, potential contaminants can move considerable distances prior to deposition on soils or in surface waters and subsequent leaching to groundwater. The direction and speed of contaminant movement within groundwater depends on the nature of subsoil layers.

SOURCE: Adapted from Soil and Water Conservation Society, "Treasure of Abundance or Pandora's Box?: A Guide for Safe, Profitable Fertilizer and Pesticide Use," pamphlet, 1989.

Box l-B—Uncertainty and Risk

Public concern over agrichemical contamination of groundwater illustrates the extent to which perceptions of risk are changing. Public surveys have shown that contaminated groundwater commonly is believed more risky than other conditions that some scientists suggest are actually more hazardous to personal health (e.g., indoor air pollution). People tend to accept risks more readily if they are self-imposed or if they are familiar. Agrichemically contaminated drinking water involves an involuntary risk, one associated with a resource for which there are no substitutes (i.e., water), with unfamiliar multisyllabic chemical names, and with uncertain and far distant consequences.

Moreover, differing values held by different groups in society (e.g., consumers, producers, urban environmentalists), imply that risk-management and communication decisions must be negotiated. When organizations are perceived to be ignoring the values voiced in the debate, the public may undertake risk management on its own, for example by changing consumption patterns. Such unanticipated changes in consumption could have far more adverse impacts than a gradual shift in production practices in response to public concerns.

Clearly, the public is unwilling to wait until scientific inquiry provides all the facts necessary to determine an uncontroversial, measurable level of risk. Instead, it is calling on Congress to meet a challenge "posed by policy-related science issues, characterized by uncertain facts, disputed values, high stakes, and a need for urgent decisions."[1]

[1] J.A. Bradbury, "The Policy Implications of Differing Concepts of Risk," *Science, Technology, & Human Values*, vol. 14, No. 4, Autumn 1989, pp. 380-399.

water quality has grown significantly in recent years to become an issue of national importance (box l-B).

Groundwater supplies drinking water to approximately 50 percent of the U.S. population, and to at least 90 percent of rural residents and is also essential to agriculture in many regions of the country. Reliance on groundwater likely will increase as the population grows, per capita use expands, and contaminated surface and groundwater supplies are removed from the water supply reserve. For this reason, and because surface and groundwater are closely linked parts of the hydrologic cycle, sustaining the supply of relatively pure groundwater will confer long-term benefits to the quality of human life and the environment.

Preventing or minimizing groundwater contamination from agricultural sources is not a simple task. Because most agrichemicals are intentionally and intermittently applied to the land at multiple sites distributed over wide areas, contaminants detected in surface and groundwater may have come from almost anywhere. Little is known about local and regional patterns of agrichemical use, making it all the more difficult to assign culpability for groundwater contamination to specific places or practices, and to identify effective mitigation strategies.

Photo credit: State of Florida Department of Environmental Regulation

Groundwater supplies drinking water to half of the U.S. population and 90 percent of the rural population. Reliance on groundwater supplies for drinking water and other uses is expected to continue to increase.

Another major obstacle to easy development of policy approaches is the complexity and variability inherent to all components of the agroecosystem. These components include the hydrogeologic environments in which agriculture is conducted (box l-C), the nature of cropping systems and other practices related to farm management, the size and physical layout of farms, and the resources, skills, attitudes, and motivations of farmers. This complex-

Box 1-C—Hydrogeology and Agrichemical Contamination of Groundwater

Water is a critical component of agroecosystems. It is also the agent most likely to transport agrichemicals over the land to surface-water reservoirs and through soil and rock to groundwater aquifers. Water continually cyles among the atmosphere, oceans, freshwater reservoirs (lakes, rivers), plants, soils, and other materials at and below the Earth's surface. The movement and exchange of water among these various components of the geologic and ecologic environment is referred to as the ''hydrologic cycle.

In devising strategies to reduce agrichemical contamination of groundwater it is important to understand how the cycle works, and to appreciate how heterogeneities in the physical components of agroecosystems affect the hydrologic cycle and the potential for agrichemicals to migrate to groundwater along a loop of that cycle. Climate, for example, varies regionally. Weather patterns that affect the amount of water moving in and through soils and the depth to the water table, also change seasonally.

Different distributions of vegetative cover, soil types, and other geologic materials also characterize different parts of the country and even different parts of the same farm field, The physical texture, mineral and chemistry of soils and other geologic materials affect the mobility of water and soluble agrichemicals. Soils change in character vertically as well as laterally. Water thus can flow rapidly through some soil layers and geologic materials, but slowly or not at all through other adjacent or enclosing layers.

Some regions of the United States are underlain by extensive geologic formations that store considerable amounts of groundwater. Once in groundwater, contaminants can spread in ways that are not predictable from the land's surface topography and drainage patterns. Contaminants introduced to groundwater at one site (where, for example, downward leaching is facilitated by physical parameters) can migrate considerable distances laterally. Thus, areas where soils and other materials tend to retard downward leaching may still experience contaminated well-water because of lateral groundwater movement of contaminants from another part of the aquifer. Such incidents of contamination may be impossible to trace.

ity and variability, along with regional variations in growing season, average farm size and commodities grown, rule out simple solutions. Clearly, no set of ''prescriptions' to reduce potential agrichemical contamination of groundwater is likely to work everywhere agriculture is practiced, nor is any one strategy likely to appeal to all farmers.

Further, environmental and ecological cycles affect agrichemical behavior, movement, and fate. Hydrologic, nutrient, and pest cycles may be modified, but cannot be halted. A major obstacle to mitigating groundwater contamination by agrichemicals is incomplete understanding of how natural cycles and farming inputs operate as a system. The fundamental question is how to integrate management of water, crops, soil, nutrients, and pests to reduce potential agrichemical contamination of groundwater without significantly compromising productivity or profitability, or degrading other natural resources.

TECHNOLOGIES

Despite the paucity of knowledge of how natural processes and agronomic practices interact, some steps can be taken to protect groundwater from further contamination. These opportunities range from continued, yet improved use of agrichemicals to the use of nonchemical technologies; and can be grouped into four general categories:

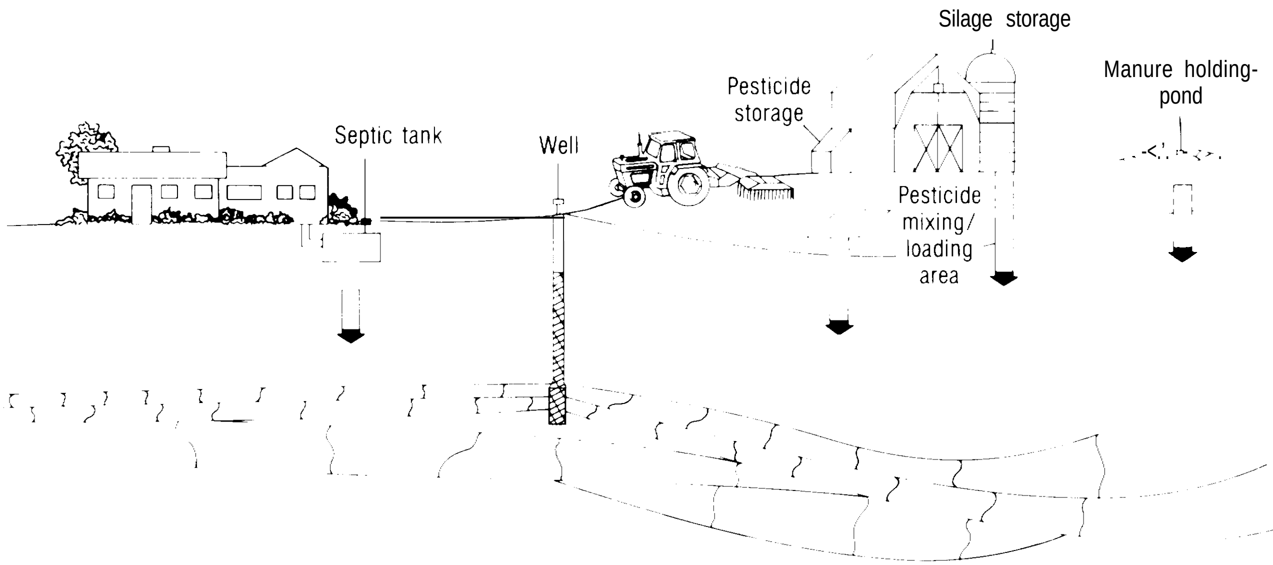
- improved agrichemical handling to reduce groundwater contamination from farmstead or dealership point sources;
- improved agrichemical efficacy and application to reduce nonpoint-source contamination;
- agrichemical use reduction; and
- incorporating nonchemical nutrient and pest management practices into farming systems.

Further opportunities are available through improved crop, soil, and water management techniques that reduce agrichemical requirements or potential for leaching. Management practices within each of these categories can be implemented as individual practices or as components of integrated farming systems.

Point-Source Controls

Reducing or eliminating point sources of agrichemical contamination is perhaps the least disruptive groundwater protection strategy. Common-sense approaches and simple, low-cost technologies to reduce and prevent agrichemical spills and other

Figure 1-2—Potential Farmstead Point-Source Routes of Contamination



A number of pathways may exist at the farmstead for point-source contamination of groundwater by pesticides and nitrate. Mismanagement of agrichemicals, especially near water wells, can result in groundwater contamination even by chemicals unlikely to leach through soils.

SOURCE: Office of Technology Assessment, 1990.

point-source losses on farmsteads and at dealerships could help prevent groundwater contamination (figure 1-2). For example, areas where agrichemicals are stored, mixed, and loaded, and where containers are rinsed, commonly are located close to wells, posing the risk of direct introduction of contaminants into groundwater.

Feedlots, manure stockpiles, and poorly designed treatment and storage lagoons are other potential point sources of environmental pollution. Improved storage, handling, and treatment techniques can reduce potential groundwater contamination from livestock wastes. Improved management can be combined with techniques to re-use livestock wastes. In addition to appropriate agronomic use of manure and other nutrient-bearing wastes, opportunities lie in comporting, biogas generation, thermochemical conversion, and fiber recovery technologies,

The Farmstead Assessment Program under development in several States, is designed to identify potential farmstead sources of groundwater contamination, and to educate farmers about management practices to prevent groundwater contamination. Further effort could promote development and adoption of such practices, and also could increase awareness of the variety of potential farmstead sources of groundwater contamination.

Nonpoint Sources

Only a small percentage of applied agricultural pesticides reach the desired target (e.g., insect), implying that substantial amounts may be distributed in the environment through a variety of pathways. Thus, improved agrichemical efficacy, application equipment, and methods for delivery of the pesticide could contribute to protecting groundwater and other environmental media (atmosphere, surface waters) and provide cost savings from waste reduction.

Agrichemical application timed to meet crop needs more closely may reduce agrichemical use without reducing expected yield. Pest scouting also can result in fewer or more pest-specific chemical applications. Avoiding agrichemical applications during weather conditions conducive to leaching offers another opportunity to reduce potential groundwater contamination. These approaches require regular monitoring of soil water, crop nutrients, and pest populations, and improved weather prediction capabilities.

A variety of pest-control techniques are not heavily reliant on agrichemicals. These include crop rotations to break pest cycles, cultivation methods that disrupt weed lifecycles, and use of natural pest predators. Nutrient management approaches that may reduce the need for commercial fertilizers include use of manures and legume-based crop rotations. However, mismanagement of such approaches also may create conditions for groundwater contamination.

Improved Agrichemical Efficacy and Application

Chemicals that are more pest-specific or potentially less toxic to non-target organisms (e.g., some natural toxins) offer potential for reducing adverse impacts, as do pest-specific application methods such as the use of pheromone baits to lure insects to an insecticide. Effective use of these approaches requires knowledge of chemical properties and pest lifecycles and sensitivities.

Changes in pesticide formulations can improve chemical efficiency such that desired results are achieved with less active ingredient applied per acre. However, this poses significant challenges to developers of pesticide application equipment. Little advantage is gained in developing and using products with greater efficacy if the smaller amounts applied per acre do not arrive at the target pest. Thus, improved precision delivery systems should accompany efforts to enhance the intrinsic activity of pesticides with new formulations. In addition to improvements in application accuracy, technology is needed to permit variable amounts of agrichemicals to be applied within a single field to account for inherent variations in soil nutrients and pest populations.

Recognition of these inherent variations is critical to improved application schemes. For example, it is important to understand how certain natural processes affect the availability of plant-usable nitrogen in determinin g appropriate fertilizer application rates. Failure to account for both natural and external sources of nitrogen can lead to excess fertilizer application and increased potential for nitrogen loss from the cropping system. Practitioners must be able to manipulate a broad array of data in determining fertilizer application rates; computers may become valuable tools in making such determinations.

Fertilizers that provide nitrogen to crops in a time-release fashion and vitrification inhibitors offer opportunities to enhance fertilizer efficacy. Numerous advantages have been claimed for slow-release fertilizers, however, these products are expensive and benefits have not been substantiated in economically viable, productive cropping systems. The environmental effects of slow-release fertilizers also need investigation, since potential exists for these materials to continue releasing nitrogen in the absence of plant growth (e.g., after harvest).

Reducing nitrification in soils may offer environmental as well as economic benefits. Positive yield responses to vitrification inhibitors have been demonstrated in the field, generally under conditions where formation of nitrate would have promoted nitrogen loss via leaching or denitrification.

Agrichemical Use Reduction

Additional opportunities exist to reduce nonpoint-source contamination of groundwater through reduced agrichemical use. The most promising of these are based on understanding of whole farm systems, broad knowledge of agroecosystem dynamics, considerable management effort, and a willingness on the part of farmers to use agrichemicals more carefully, more selectively, or not at all.

More selective use of agrichemicals requires consideration of whether the goals of use are economically optimal. For example, weed-free fields may not be an economically optimal goal. Identifying thresholds of weed growth that can be tolerated without significantly compromising soil nutrient content, soil moisture content, or crop yields may enable farmers to reduce herbicide and fertilizer applications.

Timing of agrichemical applications is critical to use reduction. Premature application of pesticides or fertilizer can increase the loss of the chemicals to the environment, thereby necessitating subsequent applications to achieve the desired effect. Decision aids such as models to predict pest intensities and calculate crop losses and economic injury associated with various pest intensities, can improve the basis for determiningg rates and timing of application.

Some systems integrate nonchemical practices to reduce agrichemical requirements. Commonly these ‘‘low-input’ systems draw on nutrient management and pest control practices used prior to the chemical era, and may require more inputs of information, management skills, or labor than conventional systems.

For example, Integrated Pest Management (IPM), a systems approach to pest control that draws from new and traditional methodologies, demands knowledge of agroecosystem dynamics. It assumes that a threshold level exists below which pest control is not economically practical; and that integration of chemical and nonchemical methods is possible. Pest scouting-employing visual inspection, pheromone traps, or other counting or collection methods-is used to identify and monitor pest infestations, If action is deemed necessary, a control method is chosen from a suite of techniques ranging from traditional cultivation or crop rotation practices to chemical applications. IPM programs have resulted in significant decreases in pesticide use in several crops.

Nonchemical Practices

Many producers, sensitive to public concern over agrichemicals on foods and in the environment, and aware of a clientele willing to pay more for food grown without chemical inputs, exclusively employ nonchemical practices. Examples include legume-based crop rotations; timing of planting and harvest to minimize opportunities for pest infestations or to break pest cycles; and biological pest control. Biological pest control may involve introductions of pest predators, rearing and periodic release of natural pest enemies or parasites, or conservation of those extant in the agroecosystem.

Crop rotation was a common practice in early U.S. agriculture that declined with expanded use of chemical fertilizers and pest-control compounds and availability of high-yielding crop varieties. Crop rotation and associated crop diversity may retard pest buildup by creating conditions that hinder development of pest populations and enhance the soil-nutrient content. Certain crops may provide additional benefits in rotation (e.g., nitrogen-fixing legume crops can provide nitrogen for following crops).

Managing Farming Systems

Other choices farmers make in managing crops, soils, and water offer additional opportunities to reduce external inputs in agroecosystems without significantly affecting production. Integrating management of *all* factors in agricultural production—crops, soil, water, nutrients, and pest controls-may provide the greatest promise for reducing adverse environmental impacts.

Crop, Soil, and Water Management—Some crops and production practices in certain regions require intensive agrichemical inputs because of incompatibilities between crop needs and predominant soil type and climate. Growing a particular crop in the most suitable environment for that crop, where fewer inputs are needed to sustain production, makes intuitive sense.

Crop cultivar improvements have accounted for 50 percent of overall yield increases in U.S. agriculture. Current areas of crop breeding research that may directly or indirectly affect agrichemical use include: pest tolerance, herbicide resistance, and nitrogen self-efficiency. Genetic engineering research has focused on introducing genes that may enhance tolerance to drought or pests, or provide nitrogen self-sufficiency. However, no guarantee exists that development of such cultivars would not create new problems, such as inadvertent transfer of tolerance or resistance to pest species. Public concern over introduction of genetically engineered or manipulated organisms may constrain development of such new cultivars.

Cropping patterns and tillage practices may also directly affect intensity of agrichemical use, uptake by plants, erodability and other attributes of soils, and movement of water and agrichemicals within soils. All of these factors can mitigate or promote agrichemical movement to surface water or leaching to groundwater. However, the interactive effects of various practices can be extremely complex, making it difficult to determine environmental impacts of management decisions.

Proper water management maintains soil moisture at levels sufficient for crop growth, but below those promoting deep leaching of agrichemicals. Producers rely on weather predictions to avoid application prior to heavy rainfalls or, under dry conditions, to apply agrichemicals when a light rain may facilitate plant uptake.

Irrigation offers risks and opportunities with respect to groundwater quality. Attributes of irrigation systems that may affect agrichemical contamination of groundwater include: scheduling, timing, rates, drainage, and type of systems (e.g., sprinkler, drip, furrow). Uniformity of distribution is of major importance, since uneven distribution across a field may result in overapplication and thus promote deep percolation of water and solutes. Advances in irrigation technology focus on enhancing uniformity of distribution and increasing water use efficiency.

Chemigation-applying agrichemicals with water through an irrigation system-may have potential to reduce groundwater contamination by agrichemicals. Through effective control of the amount of water applied and selection of proper agrichemical formulations, a chemical can be deposited either on foliage or the soil surface or distributed to a desired soil depth. However, under certain conditions, such as heavy precipitation following chemigation, these techniques have been shown to promote leaching of chemicals.

Integrated Farm Management Systems—Crop, soil, water, nutrient, and pest management clearly should be integrated to achieve the broad goal of protecting multiple and interlinked environmental resources (soil, surface water, groundwater, and atmosphere) without significantly compromising productivity.

One way of integrating these considerations is through development of packages of 'Best Management Practices' (BMPs). BMPs were originally designed to meet conservation and quality goals for a specific resource. The BMP concept may now have to be expanded as concerns broaden to include multiple environmental media and cross-media pollution.

The Soil Conservation Service (SCS) has developed an approach to integrate BMPs, called Resource Management Systems (RMSs). RMSs are coordinated sets of management practices that address multiple resource concerns. Some land-grant universities also are conducting research and demonstration on integrated farm systems with funding from the Low-Input/Sustainable Agriculture program of the U.S. Department of Agriculture (USDA).

FARMER DECISIONMAKING

Adoption of management practices and systems to reduce groundwater contamination by agrichemicals ultimately depends on decisions made by individual farmers. Information delivery and technical assistance programs to reduce groundwater contamination will be more effective if they are based on an understanding of factors influencing producers' decisions and address producers' constraints to technology adoption.

Factors Influencing Decisionmaking

Programs to reduce agrichemical contamination of groundwater stand better chances of being effective if they are built on a good understanding of the farm-level constraints, institutional and economic policies, and structural trends that influence producers' decisionmaking. Farmers' decisions on agrichemical use and groundwater protection will be based on fundamental objectives for farming. Although other personal, social, and environmental factors influence objective setting, economic factors define what is financially possible for farmers, often forcing them to focus on the short-term. Thus, economic factors can prevent producers from taking risks, making the most economically efficient decisions over a longer term, investing in natural resource protection measures, or adopting certain technologies.

Because individual producers have been slow to adopt relatively simple, highly profitable technologies (e.g., hybrid corn), voluntary adoption of more complex farming practices to reduce groundwater contamination is likely to require considerable time. The adoption process is likely to be further slowed if institutional programs (e.g., commodity support programs) and information sources generate conflicting incentives and messages.

Economic and structural trends in the agricultural sector (increasing numbers of large farms, increase in contract farming, and more vertical integration in agriculture) will also influence producers' decisions and affect their capacity to respond to groundwater contamination concerns. These trends are likely to affect economies of scale, financial constraints, actual and perceived risks, and producers' available time and willingness to learn about and adopt new farming practices or systems.

Decisionmaking To Protect Groundwater

Producers are more likely to adopt farming practices that: 1) have clear, documented advantages over other practices (e.g., lower costs, higher crop yields); 2) are compatible with their current practices and previous investments; 3) are easy to implement; 4) are capable of being observed or demonstrated; and 5) are capable of being adopted gradually or incrementally. The four approaches to reducing agrichemical contamination differ with respect to these characteristics.

The first two technology categories, *agrichemical management to reduce point-source contamination* and *improved efficacy and application management to reduce nonpoint-source contamination,* assume continued reliance on agrichemicals as the principal means of providing crop nutrients and controlling pests. These approaches are likely to be compatible with most current farming systems relying on agrichemicals.

The latter two alternative farming practice approaches, *agrichemical use reduction* and *nonchemical practices,* assume a conscious move away from conventional agrichemical use and require an increased understanding of interactions among nutrient, pest, crop, soil, and water management practices. These approaches will be important components of a groundwater protection strategy, but they may be perceived as risky, and are more complex and less compatible with most current agricultural operations than the first two approaches. Thus, the majority of farmers currently relying on agrichemicals would be expected to adopt the first two approaches much more quickly than the latter two.

Convincing a majority of producers to invest in unfamiliar nonchemical farming practices is likely to require much more information than currently exists. Producers also will need time, and possibly technical assistance and other incentives to plan, learn about, and gain experience with new practices during transition periods.

Information Sources for Decisionmaking

The people who will be most directly affected by groundwater protection policies for agriculture are people who work and live on farms. Recent and emerging survey literature on farmers' concerns and policy preferences related to agrichemicals and groundwater quality provide non-generalizable insights into farmer attitudes about groundwater quality in areas where the media has given the issue greater attention (i.e., the Midwest).

Farmers represented in these surveys show acute awareness of agrichemical groundwater contamination, and are concerned about the health implications. The majority would like viable reduced-use or nonchemical alternatives, but believe that pesticides remain their best current pest and disease control method. Most also indicate that they have already reduced agrichemical use as much as they profitably can, and prefer voluntary to regulatory approaches to reducing agrichemical contamination of groundwater.

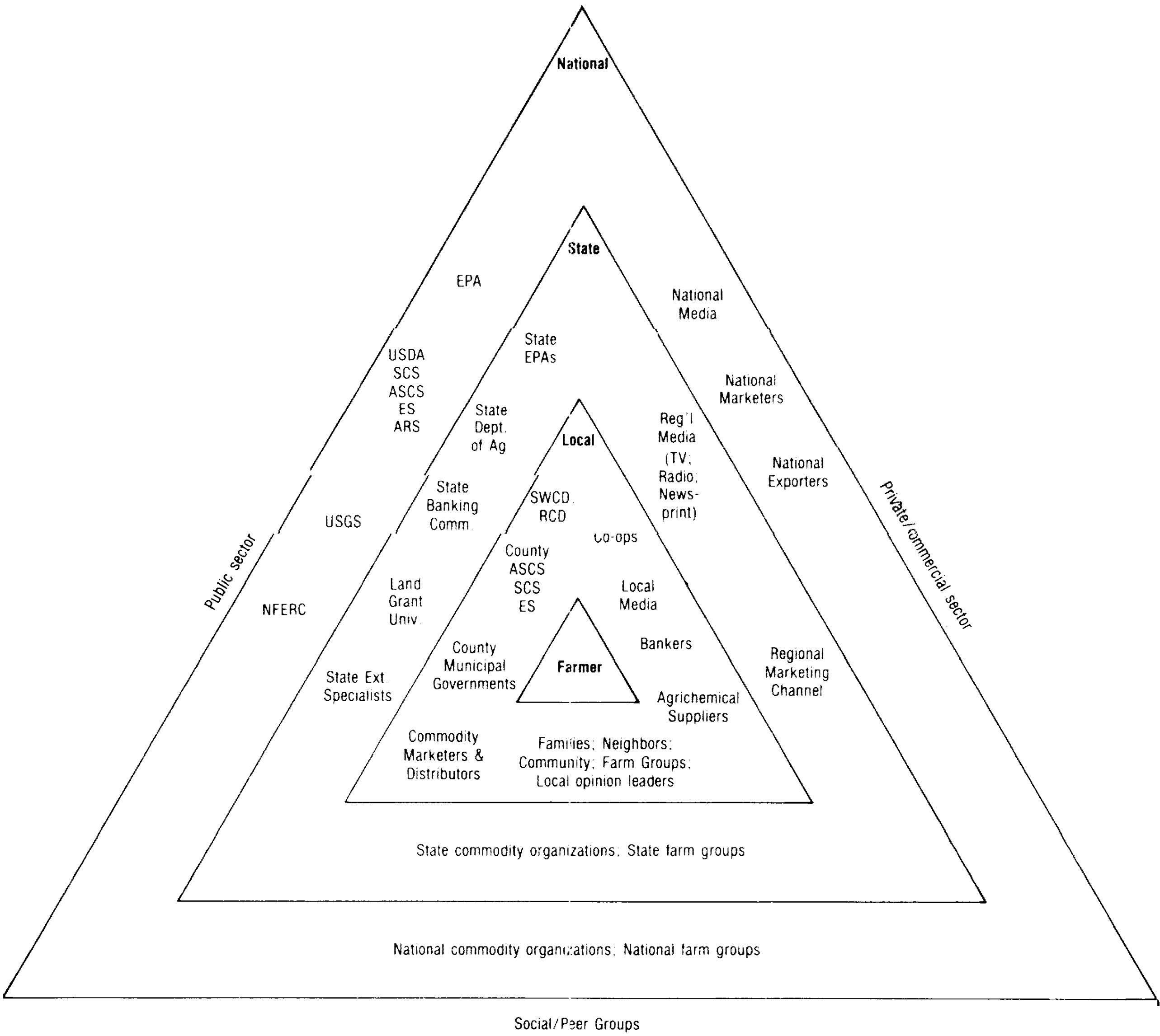
Photo credit: State of Florida ***Department of Environmental Regulation***

When contaminated drinking water wells are closed, water must be obtained from other sources such as surface water supplies, new well systems tapping different groundwater supplies, connections to water distribution systems, or water transported in from other areas.

A variety of information is needed to assist producers in reducing agrichemical contamination, beginning with data on agrichemical contaminant levels in local groundwater. Producers also need site-specific economic and agronomic information on proposed farm practice changes and assistance in keeping record of the types, amounts, and locations of agrichemicals used. Data-gathering and information delivery will be critical components of most technical assistance programs.

Farmers' sources of information include public agencies and private-sector sources such as agrichemical manufacturers, dealerships, farm cooperatives, agricultural magazines and advertising, and one another (figure 1-3), Farmers interested in use-reduction and nonchemical practices note a scarcity of information on these approaches. Such farmers have had to seek information from other experienced farmers, and these ''farmer-to-farmer networks' are playing important roles in disseminating information on more complex farming system changes. Farmer networks conduct on-farm experimentation, information gathering, and information dissemina-

Figure 1-3-Sources of Information and Advice to Farmers



Sources of information for, and thus of influence on, farmer decisionmaking are numerous and some may be providing conflicting advice. Examples of influential groups affecting farmer decisionmaking include public agencies, private-sector groups, and social or peer groups at local, State, and National levels.

SOURCE: Office of Technology Assessment, 1990.

tion through educational programs and field demonstrations. Some land-grant universities have established formal relationships with farmer networks, and their complementary efforts will facilitate broader dissemination of information and advice on a wider range of farming practices.

Commercial firms advise private applicators on recommended agrichemical types and application rates. They also could sell advisory services such as soil testing, pest scouting, and crop monitoring to reduce agrichemical use while maintaining profitability. However, it is not in the interest of an agrichemical supplier to provide advice to *reduce* agrichemical use. Moreover, current industry trends (declining numbers of dealerships, an increasingly competitive business environment, and increased regulatory requirements) make it difficult for agrichemical suppliers to offer new services.

However, advisory firms and independent crop consultants not associated with agrichemical sales can provide services without many of these problems, and are playing a substantial role in providing technical assistance to farmers. Some States have implemented licensing programs for crop advisors and consultants that facilitate farmers' access to reliable services. The public sector could assist the private sector in design, development, and delivery of advisory services by providing agronomic and economic information on feasibility of reduced agrichemical applications, and offering training programs for employees and education and licensing programs for advisors.

Public-sector sources of information and technical assistance for farmers include: 1) Federal agencies with local offices; 2) State organizations, primarily the Cooperative Extension Service (CES) based at the State land-grant university; and 3) local agencies and organizations, such as soil and water conservation districts and local conservation committees (see figure 1-5 later). These organizations play important roles in encouraging farm practice changes to reduce groundwater contamination.

District conservationists employed by USDA's *Soil Conservation Service (SCS)* help producers develop soil and water conservation plans and arrange for cost-share funding for implementation of conservation practices. USDA's *Agricultural Stabilization and Conservation Service (ASCS)* provides financial assistance to farmers by administering Federal agricultural program payments, including SCS cost-share payments for implementing conservation practices. Its pilot cost-share project, the "Integrated Crop Management" program, aims to achieve a 20 percent reduction in agrichemical use among participating farmers by improving their agrichemical management practices.

Information and assistance from State and local agencies complement Federal Government assistance and can predispose farmers to implement certain production and conservation practices. The State *Cooperative Extension Service (CES)* based at State land-grant universities plays the most important role in information delivery and assistance to farmers. CESs respond primarily to State needs but can also respond to regional and national priorities. Specific CES activities related to agrichemical management and groundwater quality include pesticide applicator training, recommendations on pesticide and fertilizer application rates, soil testing services, and water quality education programs.

State Departments of Agriculture (DOAs) also play important roles in managing agrichemical use within their borders, because they are the lead agencies in most States and territories for pesticide programs. DOAs can expand or restrict the State's range of pesticide uses by granting experimental or conditional permits for nonregistered pesticides and by restricting the use of pesticide materials. DOAs also administer pesticide applicator certification programs and some departments offer programs that help farmers try new agricultural practices.

Soil Conservation Districts are special-purpose units of government that plan and coordinate local soil and water conservation programs. They are important interfaces between Federal policy directives and local implementation efforts, and they have devoted a major share of their workload to helping farmers meet conservation compliance requirements of the 1985 Food Security Act. If additional cross-compliance provisions related to groundwater quality are authorized (e.g., agrichemical management plans), conservation districts will likely play key roles in program implementation.

County Governments and Local Conservation Committees also play a role in providing technical assistance to farmers through county extension funding. A wide variety of local boards, committees, or commissions help set priorities for extension and agricultural conservation programs. Local boards may have a high degree of influence on the assistance programs available to farmers and on the kinds of conservation practices that are supported technically and financially.

Public-Sector Financial Assistance To Improve Decisionmaking

Possible sources of public financial assistance to States for groundwater protection practices include: Federal grants; State general revenues; and a variety of ''Alternative Financing Mechanisms' (AFMs), such as user fees, permit fees, pollution discharge fees, environmental taxes, bonds, revolving loan finds, and compliance penalties. AFMs have become common sources of State capital and revenue for specific environmental activities.

As Federal contributions to States' environmental programs have declined in the last 10 years, many

States' general revenues have remained stable or declined. Since State officials do not foresee substantial increases in AFM funds, they believe that environmental protection demands will have to be met through increases in general revenues. Thus, increases in taxes may be needed to implement new State-level groundwater protection programs.

Public-Sector Coordination To Improve Decisionmaking

Producers or landowners who seek assistance for comprehensive resource management face difficulties in bridging the separate "turfs' created by different agencies and their programs and in evaluating conflicting messages from public agencies. If producers hear consistent messages from public, private, and informal information sources regarding the importance of proper agrichemical use and environmental protection in agriculture, they maybe likely to implement practices that protect groundwater. Just as producers need to consider all relevant resource concerns in making farm or ranch management decisions, State and local governments need to develop mechanisms to review, prioritize, and coordinate their efforts. Whenever possible, public-sector assistance should also support development of private-sector capacity to provide information and assistance.

TAKING A STRATEGIC APPROACH TO REDUCING AGRICHEMICAL CONTAMINATION OF GROUNDWATER

Agriculture is a national, strategic resource, and actions that severely reduce its productive capacity are clearly adverse to U.S. interests. Agriculture also is characterized by significant natural and farm diversity: no technological "black box' exists that can be universally adopted to solve agrichemical contamination of groundwater,

Agrichemical losses to the environment also are lost farmer investments-wasted resources (figure 1-4). Reducing agrichemical waste or contamination of groundwater likely will require a combination of new or modified programs involving education, incentives, technical assistance, technology research and development, and regulation to encourage changes in farming systems.

The question is, what should be changed? Uncertainties about the extent, meaning, and causes of groundwater contamination imply that policy approaches to reducing agrichemical waste or contamination of groundwater must be designed for high levels of uncertainty. Further, in some cases it may be decades before noticeable results—improvements in groundwater quality-can be achieved, due to the lag time of chemicals already applied and the time required to develop and encourage adoption of practices to minimize groundwater contamination.

Policies developed to deal with agrichemical contamination of groundwater need to consider how the changes that these policies may foster in U.S. agriculture will fit into the larger picture of environmental and economic change taking place in this country. Policymakers can try to strike a balance in addressing the groundwater contamination issue using a two-tiered strategic approach: focusing on the roles and goals of relevant institutions, and then on the actions of those institutions.

STRATEGY: Define and Evaluate Roles, Goals, and Relationships of Relevant Organizations

As currently structured, Federal and State agricultural policies and programs provide insufficient information or incentives for farmers to change their management strategies significantly and, in fact, some tend to encourage heavy chemical use. Development and adoption of improved agrichemical management or less chemical-intensive methods of production ultimately may depend on new institutional arrangements for policy formation and implementation, and their integration at local, State, and National levels.

Options relevant to this institution-oriented strategy begin with goal setting and fall into several additional broad categories. These include:

- clarification of agency roles in groundwater protection;
- coordination of intra- and inter-agency efforts to protect groundwater at (and between) Federal and State levels;
- provision of a congressional framework for integrating agricultural and environmental concerns in legislative debate and action; and
- removal of legislative and jurisdictional constraints to an integrated Federal response to the need for groundwater protection.

Congress, USDA, and the agricultural community in general, have not developed clear-cut agricultural goals or stated priorities for agricultural research. The oft-stated mission of agriculture-' 'to provide an ample supply of nutritious food for the consumer at a reasonable cost with a fair return to the farmer within an agricultural system that is sustainable in perpetuity ''-contains many unquantifiable terms. What is ''ample, " "reasonable," or "fair?" How much soil erosion or groundwater contamination can be tolerated by a sustainable system?

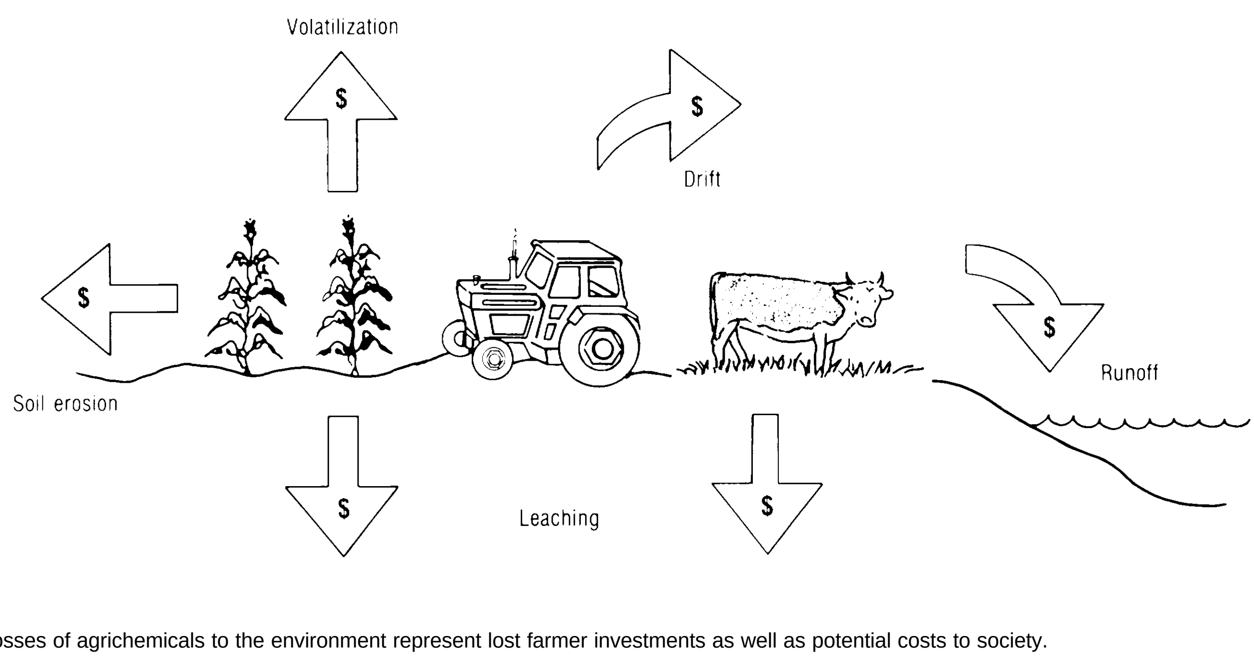
How a variety of issues relating to agriculture and the environment are handled may depend on congressional and Federal agency ability to set well-defined, achievable goals for U.S. agriculture and the environment; and on how well the roles and responsibilities of various agencies are defined in light of these goals. Agency efforts to achieve congressionally determined goals may be most effective if they are integrated into a comprehensive package such that groundwater protection is coordinated with other environmental and agricultural goals.

Several factors work against such an approach. The present committee structure of Congress does not easily handle agricultural bills containing environmental protection provisions, nor is there a central congressional arena for debating a comprehensive national environmental policy. At present, water quality concerns are addressed by a number of distinct pieces of legislation that have not been integrated into a coordinated set of statutes.

Moreover, a wide range of organizations at all levels of government confront issues and develop policy relating to agriculture and the environment (figure 1-5). Historical precedents, inadequate coordination among and within agencies (Federal and State), and confusion over roles, responsibilities, and leadership among and within agricultural and environmental agencies, hamper comprehensive approaches to groundwater protection. For example, a socially, economically, and administratively optimal mix of voluntary, regulatory, and cross-compliance approaches to nonpoint-source pollution control has yet to be determined (box 1-D).

These problems could be addressed in a variety of ways. A Joint Committee or other (temporary) congressional forum could debate goals for agriculture and the environment and review Federal roles in agriculture and environmental protection. Better coordination of Federal agency activities could be realized if the roles, responsibilities, and activities of each relevant agency were clearly specified in a special format such as a ''management matrix. '

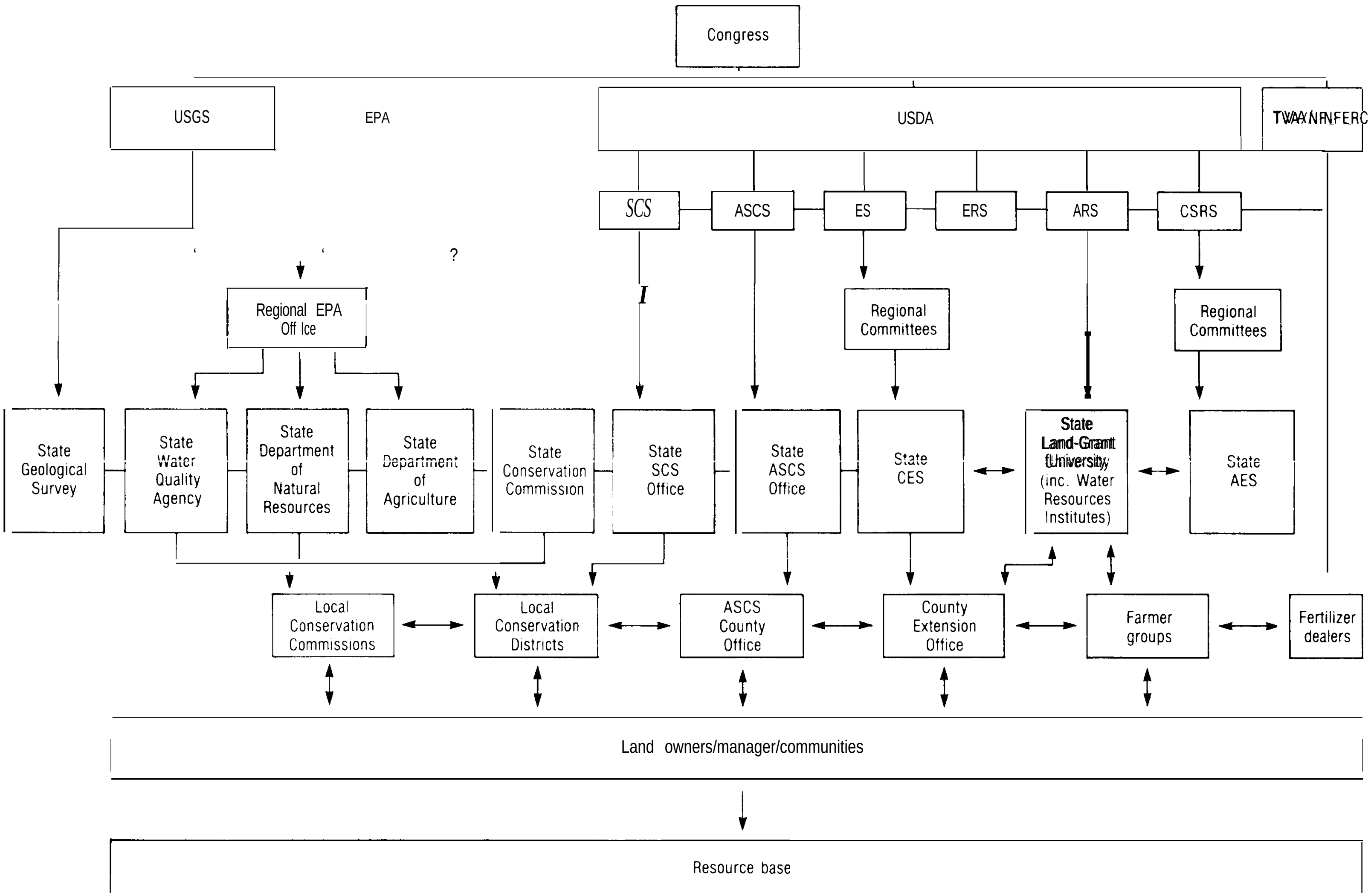
Figure 1-4-Lost Agrichemicals Are Wasted Resources



Losses of agrichemicals to the environment represent lost farmer investments as well as potential costs to society.

SOURCE: Office of Technology Assessment, 1990.

Figure 1-5—Major Federal, State, and Local Organizations Influencing Farmer Decisionmaking



Myriad organizations develop and implement policy related to agrichemicals and groundwater—to agriculture and the environment. The subsequent multiplicity of actors, actions, viewpoints, and approaches make it difficult to generalize-on current or potential roles, evaluating extent of success, or defining lines of coordination and cooperation.

SOURCE: Adapted from National Association of Conservation Districts, “Proposed Strategy for Protecting surface end Groundwater From Agricultural Activities,” June 1989.

Box l-D—Aspects of Agrichemical Use and Regulation Fostering Agrichemical Mismanagement

- The primary current means of encouraging proper use of most agrichemicals is through providing labeling information and applicators' voluntary compliance with label directions.
- Proper agrichemical management is extremely difficult to monitor and enforce, because agrichemicals are applied over wide-ranging areas and often in isolated situations.
- Accurate information on agrichemical mismanagement is difficult to obtain, because agrichemical applicators may not recognize or are not likely to admit that they are mismanaging agrichemicals.
- Current Federal regulatory authority to ensure minimum standards of applicator competence cannot be applied to fertilizer application nor to general-use pesticide application in most cases; regulatory authority can be applied only to applicators of restricted-use pesticides (RUPs), but EPA-designated RUPs constitute only a fraction of the volume of pesticides used in agriculture (less than 20 percent in 1987).
- The two most prevalent agrichemical contaminants of groundwater are nitrate and atrazine, an herbicide which had been classified for general-use through January 1990; groundwater contamination by these two agrichemicals reflects their greater capacity to leach through soils but may also reflect widespread mismanagement which could be addressed through more rigorous applicator certification and training requirements.
- At least one-half of all agrichemicals in agriculture are applied by private RUP applicators; however, testing and training requirements for private applicators vary widely among States, often being less rigorous than commercial applicator requirements; of the 10 highest ranking States in terms of agrichemical use, only 7 required testing or training for private applicators in 1986.
- One-third to one-half of all agrichemicals in agriculture are applied by commercial applicators, whose testing and training requirements vary widely by State; of the 10 highest ranking States in terms of agnchemical use, all required testing (as mandated by Federal law) but only 1 required training for commercial applicators in 1986.
- Commercial employees of agrichemical dealerships also manage agrichemical storage, handling, and disposal facilities, which are significant potential point sources of groundwater contamination; however, it is difficult to assess the extent of commercial facilities' contributions to groundwater contamination, because no national data exist on the number, locations, and condition of commercial agrichemical facilities, including those which are currently or no longer in operation.
- States do not document or report the numbers of noncertified RUP applicators, who must be under the direct supervision of a certified applicator; however, EPA estimates that noncertified RUP applicators constitute at least half of all agricultural RUP applicators (an estimated 1.2 million noncertified applicators in 1988).
- States typically do not provide special programs for certified RUP applicators on training and supervising noncertified applicators; because the definition of ''direct supervision' has been controversial and open to interpretation, it is difficult to monitor and enforce the extent and quality of supervision of noncertified applicators.
- Private, certified RUP applicators are not legally required to supervise noncertified farmworkers applying general-use pesticides; inadequate communication between certified and noncertified applicators, short terms of employment, and lack of familiarity with equipment are factors which increase chances of agrichemical mismanagement by noncertified applicators.

Congress could also recognize or establish lead-role responsibilities for various agencies, or ask for the development of an interagency proposal addressing groundwater protection in agriculture. Improved oversight of activities within agencies such as USDA could be fostered by activity "tracking systems' and by making a person or office accountable for coordination of agency activities related to agriculture and the environment.

Much confusion also exists over apportionment of roles between Federal and State Governments. Historically, agricultural programs have been largely generated at the Federal level, and environmental programs at the State level. Environmental protection increasingly became a Federal concern during the 1970s and 1980s, but EPA lacks the staffing and funds to guide States in implementing federally mandated groundwater protection strategies. Thus, a patchwork of laws and regulations has evolved across the Nation. These problems might be addressed through evaluation of State plans by relevant Federal agencies, and/or centralization of State planning for farmlands (through a program analogous to Coastal Zone Management).

To further improve Federal response to groundwater protection issues, agency jurisdictions and legislative authorities could be adjusted such that information collection, research and outreach programs address hydrogeologically defined "agroecoregions' rather than political boundaries. Increasing EPA's legislative authority and flexibility and providing the National Fertilizer and Environmental Research Center with greater funding autonomy and clear national authority could also enhance the Federal role in groundwater protection.

Losses of applied agrichemicals and excess energy use are economically and environmentally undesirable. Improving agrichemical management may be an appropriate goal for short-term policymaking. Actions to reduce such "waste" could have beneficial effects on farm income and environmental quality. Congress could establish an Agricultural Waste-Reduction Initiative as an organizing principle for identifying goals for U.S. agriculture and the environment. Efforts could be applied nationally or directed specifically to hydrogeologically vulnerable ''target' areas.

STRATEGY: Build the Knowledge Base To Support Improved Decisionmaking

The availability and adoption of technologies—products and practices-that reduce loss of agrichemicals to the environment will require substantial and long-term investments. A basic prerequisite to appropriate technology development is identification of critical site/agrichemical combinations. This requires systematic procedures for monitoring, sampling, and testing, and for data collection, management, and display.

Congress could create the basis for improved groundwater protection policies by accelerating data-collection efforts as well as digitization of data, so that interagency data sharing is facilitated. A national database on agrichemical use could, for example, fill an important information gap and help policymakers assess the environmental and economic impacts of changes in agricultural policies and practices. Techniques such as computer modeling can facilitate analysis of agrichemical use patterns and other parameters relevant to groundwater contamination potential. Improved and expanded use of geographic information systems (GIS) could provide a rapid means to assess where efforts might have the greatest beneficial impact, or whether proposed policy options have potential to solve problems. A comprehensive approach could be taken to provide an "open architecture" GIS—accommodating data and users from a variety of agencies. This could facilitate integration of national-level databases.

New investments are also likely to be needed in agricultural research. The decade of the 1990s will be characterized by broadening concerns for food safety and the environment in addition to traditional production concerns. Addressing these issues will pose a significant challenge to the agricultural research system, requiring an effective national strategy and potentially demanding advances in science and technology of unprecedented scale and scope. Whether the present system, which traditionally was narrowly focused on production, fragmented among several agencies, and unevenly funded at the State level, can meet this challenge is under question. The following are probably all needed to meet the challenges of the 1990s:

- a broadened focus for basic research in agriculture;
- adequate funding for applied research to address site-specific environmental problems;
- more emphasis on systems-oriented, interdisciplinary research to address a spectrum of environmental concerns arising from agricultural practices;
- improved interagency coordination of research efforts;
- stronger linkages between basic and applied research (and between public and private research efforts); and
- new mechanisms to enhance development and adoption of agricultural products and practices with the potential to protect groundwater.

Some of these needs could be addressed by directing and coordinating federally funded basic research to improve understanding of agroecosystem components and processes. Such a research initiative (implemented by USDA or jointly by several Federal agencies) could provide the means for developing research priorities, protocols, and methodologies that are broadly applicable to agroecoregions. Data collection, modeling, and GIS development efforts could, however, be directed preferentially to highly vulnerable areas.

Tracking mechanisms to identify extant research efforts with relevance to groundwater protection could be developed as a first step in planning and prioritizing research and determining funding needs.

Research coordination at the public level and a close working relationship between basic and applied scientists could be fostered by ''coordination bodies' and specific directives to Federal agencies to work closely with State land-grant universities in research and development efforts.

The present agricultural research system operates with fundamental constraints to interdisciplinary, collaborative efforts. Collaboration between individuals in the agricultural and social sciences is especially rare. Congress could establish means to identify and remove the constraints to interdisciplinary research, and direct Federal agencies to develop mechanisms for encouraging collaborative research, as well as adaptive research focusing on agroecological site conditions and on the socioeconomic factors influencing technology adoption.

If farmers are to meet resource protection goals (local or national) the traditional research and extension system may need to expand in other ways as well. In particular, the system could support and benefit from farmers to a greater degree than it does currently. Farmers may require help with recordkeeping on agrichemical use, long-term planning for resource protection, comparative economic analyses of agrichemical-based and alternative practices, and with site-specific implementation of chosen practices, In turn, farmer-based experiential learning could be tapped more fully by providing for better communication between farmers and researchers. In this way farmers' specific needs could also become known to researchers.

Congress could assess current mechanisms for incorporating farmer input into technology development, and encourage the role of farmers in implementing waste-reduction and other groundwater protection goals. Public-sector support for farmers who are trying to improve nutrient and pest management could be enhanced through better coordination of Federal, State, and local education, demonstration, groundwater monitoring, and financial support programs. Some mechanisms already exist to effect broad-based coordination of public-sector efforts, and these could be assessed for their potential to help producers integrate resource management concerns. Sources of additional advisory support to farmers might be found and encouraged in the private sector.

STRATEGY: Redirect Federal Agricultural Programs To Remove Disincentives and Create Incentives for Groundwater Protection

Agricultural policy reflects a complex web of programs governing commodity production, risk management, and resource conservation. Commodity programs, for example, help buffer farmers from market price fluctuations. These programs, intended to help ensure an orderly, adequate, and steady supply of agricultural products, strongly influence farmer decisions as to crop choice, agrichemical use, and farming practices.

Critics of these programs argue that allocating huge payment outlays to encourage the production of a small number of agrichemical-intensive crops has led to surpluses of these crops, encouraged their production in hydrogeologically unsuitable areas, discouraged farmers from diversifying production or from using crop rotations, increased farmer dependence on Federal payments, and reduced the ability of U.S. agriculture to compete in world markets. Alternatives to current Federal farm programs are being debated; these range from adjustments within the general framework of current price and income supports to elimination of Federal farm payments based on production output.

Increased cropping flexibility coupled with incentives to grow crops suitable to site and climatic conditions, could alleviate the need for some agrichemicals, and encourage beneficial cropping patterns (e.g., rotations) in some areas. A national commodity program based on environmental stewardship, or adjustments to extant programs to require rotations incorporating nitrogen-fixing or other beneficial crops could provide a means to achieve these goals. Other program adjustments could be made to remove incentives for intense agrichemical use on non-setaside lands.

Risk reduction or economic security programs (farm credit programs, crop insurance, disaster assistance, and marketing programs) in some cases deter farmers from taking action to protect groundwater resources, and some may actually encourage agrichemical-intensive practices in regions of marginal suitability. Similarly, marketing-order programs that originated before refrigeration and modern transportation may serve to encourage or protect environmentally inappropriate agricultural production in some areas.

Such programs could be reviewed and modified to better seine groundwater protection goals. For example, access to certain subsidies and payments could be made contingent upon approved nutrient and pest management plans. Obsolete marketing orders that are counterproductive to resource protection could be terminated.

The cross-compliance and voluntary cost-share conservation components of Federal farm programs could also be reoriented to better serve as groundwater protection tools. An enhanced cost-share program could integrate multiple environmental concerns. States could be encouraged to expand their cost-sharing programs with Federal grants specified for that purpose.

Some farm-credit mechanisms that could provide innovative ways to protect hydrogeologically vulnerable areas may be underused. For example, property easements, involving a transfer of certain use rights of private property, can be based on conservation as well as other values. Congress could reorient the loan restructuring program to encourage farmers to exchange conservation easements having groundwater protection benefits for partial debt forgiveness.

The Conservation Reserve Program provides farmers a ‘‘rental’ payment for planting designated highly erodible croplands into grasses, trees, or other vegetative cover, that cannot be grazed, harvested, or used for other commercial purposes for at least 10 years. This program could be expanded to include (and its contract terms extended in) hydrogeologically vulnerable and aquifer recharge areas.

STRATEGY: Foster a National Effort To Reduce Agrichemical Mismanagement and Waste

Currently, no national guidelines for EPA's and USDA's Pesticide Applicator Training program exist, and the quality of training programs varies greatly by State. Inconsistency in applicator certification requirements and training programs results in highly variable levels of management skills among agrichemical applicators, implying a high potential for agrichemical mismanagement. This represents a serious deficiency in the national effort to assure that agrichemicals are applied properly across the Nation. Congress could strengthen the national commitment to reducing agrichemical mismanagement and waste through options addressing applicator certification, training, and support services.

Because EPA does not maintain a regularly updated national overview of State pesticide applicator certification and training programs, it is difficult to assess how well applicator certification and training programs address environmental concerns relevant to each State. Congress could address this problem by commissioning a national assessment of such programs; and by authorizing EPA to maintain a regularly updated national overview of State pesticide programs and their applicator certification and training requirements, as well as a national database on pesticide applicators and agrichemical dealerships. Expanded certification and training requirements, along with increased Federal subsidies to enhance States' applicator training and certification programs, could also help reduce agrichemical mismanagement, waste and potential groundwater degradation problems.

LOOKING IN THE LONGER TERM

What action(s) Congress opts to take to protect the Nation's groundwater from agrichemicals may depend as much on how it chooses to approach the problem as on the state of science and technology. For example, groundwater contamination could be viewed simply as an additional target of environmental concern (along with surface water) and extant conservation programs could be modularly expanded to include groundwater protection provisions, or to increase the priority already given to such provisions. Groundwater contamination also could be considered an outcome of farm programs that create disincentives for farmers to protect the environment. Strategies for dealing with the problem could then involve program modifications to reduce or remove disincentives and provide incentives for conservation.

A broader approach than either of these is to view groundwater contamination as one of many symptoms of a need to integrate environmental protection into agricultural policy as a whole. Historically, agricultural policies and programs have placed major emphasis on increasing production. However, in the future, protecting environmental and public health could be considered as important as enhancing agricultural production. The tone is set for increased legislative and executive attention to agriculture's impact on the environment.

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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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 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.

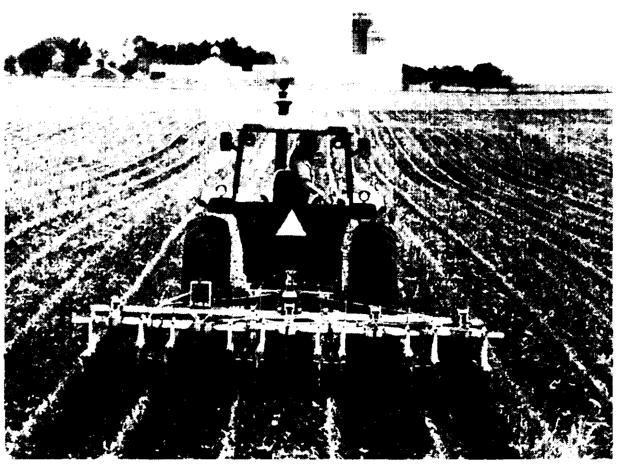


Photo credit: U.S. Department of Agriculture, Agricultural Research Service

Ridge tillage can reduce agrichemical use.

Given the high level of public concern about groundwater contamin ation 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 conlamination 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

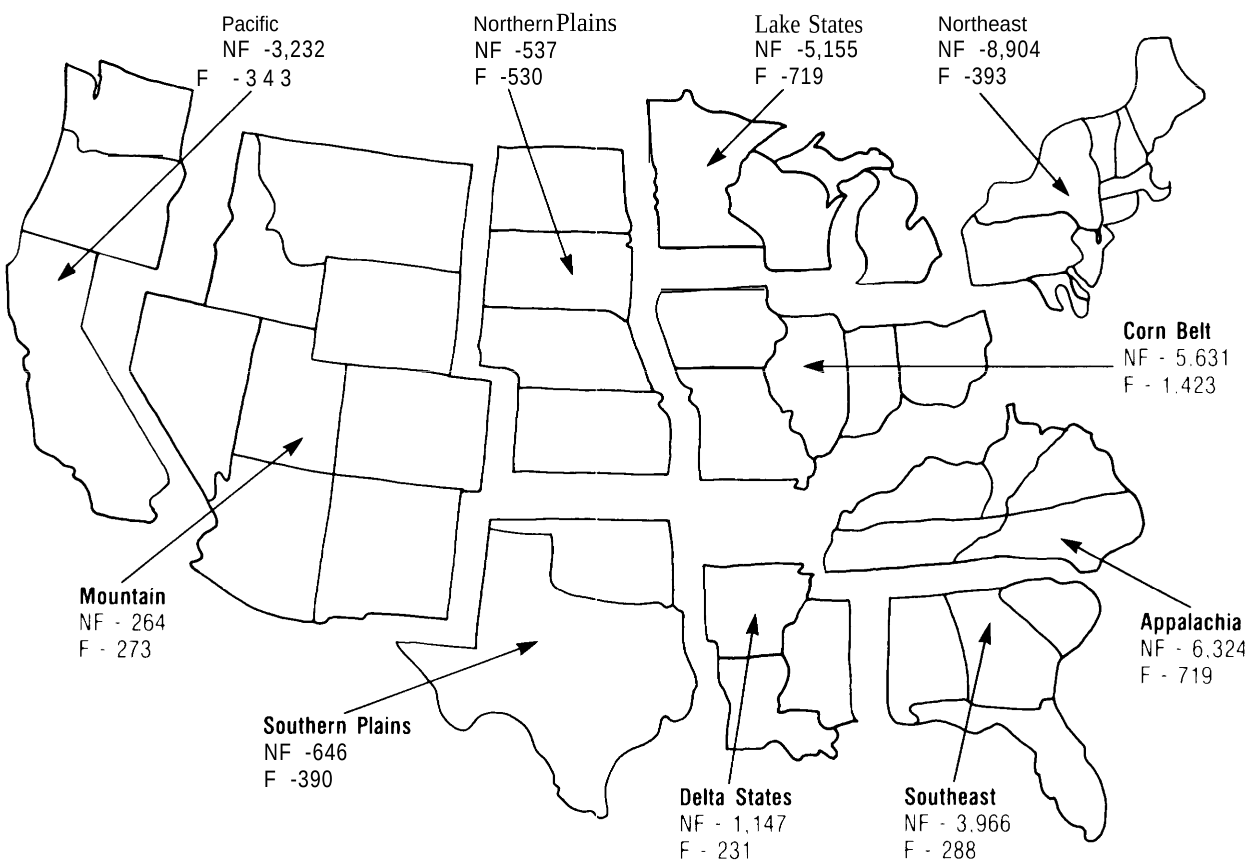
SOURCE: Adapted from F.R. Hall, "improving Pesticide Management Practices," contractor report prepared for the Office of Technoiogy Assessment (Springfield, VA: National Technical information Service, November 1989).

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.

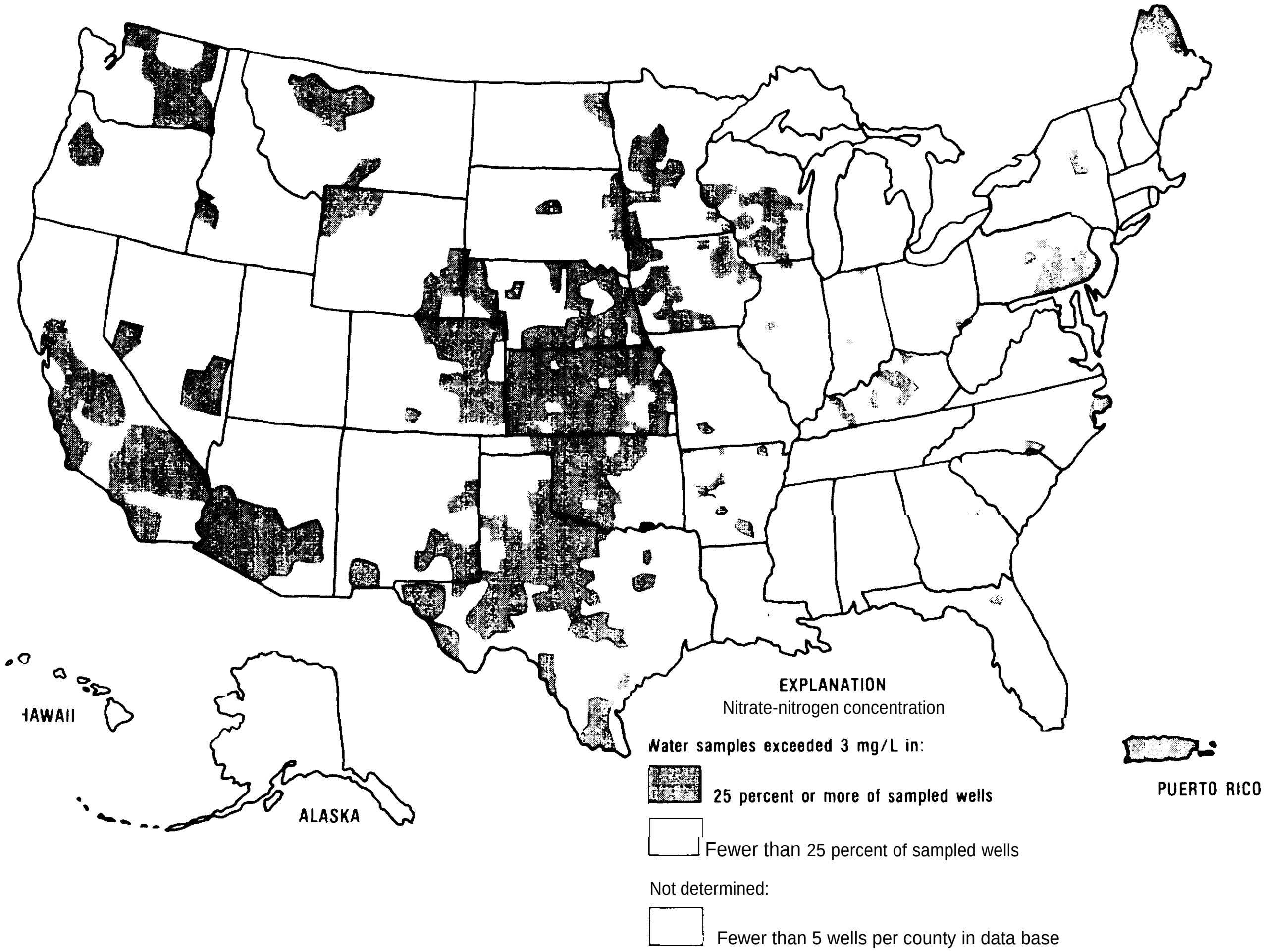
One part per million is equivalent to 1 second in 12 days while 1 part per billion is equivalent to 1 second in 32 years; beyond these, 1 part per trillion is equivalent to 1 second in 32,000 years. Alternatively, the unit ppm can be described as the equivalent of a one-inch square postage stamp in an 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, back-siphoning 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):

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[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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Chapter 3

Contamination of the Hydrogeological System: A Primer

CHAPTER HIGHLIGHTS

- Movement of chemicals is directly linked to water movement, over and through the soil.
- Natural factors affecting potential for agrichemical contamination of groundwater are complex, interactive, and not enough is known about them to specify solutions for most locations.
- Diffuse sites and diverse modes of entry, and multiple agrichemical transport mechanisms render agrichemical contamination of groundwater true nonpoint source pollution.
- Natural factors associated with suspected groundwater vulnerability are widespread and support national concern. Federal and State data collection and information management activities to identify and understand these natural factors are underway, but national-level efforts to synthesize this information to assist decisionmaking are still evolving.
- Long periods of time elapse between changes in surface activities and impacts on groundwater contamination, and contamination is extremely costly to reverse, such that prevention is preferable to redemption.
- Reduction of agrichemical contamination of groundwater requires that the entire agroecosystem be managed to minimize waste and leaching*

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Contamination of the Hydrogeological System: A Primer

INTRODUCTION

Groundwater has represented a vast and seemingly inexhaustible resource for years, and has become an indispensable source of freshwater. Even until the 1970s, the soil was believed to be a' 'living filter' preventing groundwater contamination from chemicals applied to the land (74). Today, however, a growing body of information tells us that agrichemicals (pesticides and nitrate) have moved through the soil cover to contaminate groundwater. Contaminated well-water in many U.S. agricultural areas is evidence that groundwater is ultimately affected by man's aboveground activities. Clearly, environmental contamination from agrichemicals requires a three-dimensional view of agriculture and its impacts rather than the two-dimensional view held by many in the past,

Three categories of factors largely determine the potential for agrichemical leaching to groundwater:

1. natural characteristics of the site of agrichemical use that affect leaching of water and thus transport of agrichemicals,
2. nature and extent of human modification to those natural characteristics that may affect leaching patterns, and
3. characteristics of the agrichemicals used that determine their environmental fate.

To understand how the problem originated and how it might be solved requires a basic understanding of how water moves through the atmosphere, over the land surface, and below the ground-the hydrologic cycle.

Groundwater and the Hydrologic Cycle

The hydrologic cycle begins with the evaporation of water from oceans and other open bodies of water, vegetation, and land surfaces (figure 3-l). The moisture from evaporation forms clouds, and falls back onto the Earth's *surface* as rain or snow. When it rains, some of the rainfall is taken up by vegetation, some returns to the atmosphere by evaporation and through transpiration by plants, and some water runs off the land to lakes and rivers and on to the sea.

Part of the rainfall falling directly on the land or collected in surface water bodies seeps downward through the Earth's surface. Water moves through the interconnected spaces among individual particles of soils and geologic materials, along cracks and fissures in these materials, or through openings where worms have burrowed or roots have decayed. These spaces may become temporarily saturated with water after a heavy rain, but near the surface, in the ''vadose zone,''[2] open spaces normally contain air as well as water. With increased depth, water fills all available pore space in the Earth's sediments and rock formations. This fully saturated zone is where groundwater is stored; the upper surface of this saturated zone defines the water table (figure 3-2).

Although groundwater is ubiquitous, only certain geologic formations (aquifers) have an extractable quantity of water sufficient for human use. Aquifers may reach hundreds of feet in thickness and may extend laterally for hundreds of miles. The Ogallala aquifer, for example, underlies parts of eight Great Plains States (6,18) and is vital to agriculture over a large region. *Other* groundwater aquifers are thin and of small areal extent and, thus, only a few wells can draw from them. The smallest aquifers—perched water tables—sit on small impermeable layers of geologic material above the region's general water table (figure 3-3).

Water moves continuously below the Earth's surface, much as surface water flows from higher regions towards the sea. Many aquifers contribute to surface water bodies, such as springs, wetlands, rivers, and lakes, and others flow directly into the ocean. Some deep aquifers, however, contain 'fossil water' sequestered under the soil thousands of years ago.

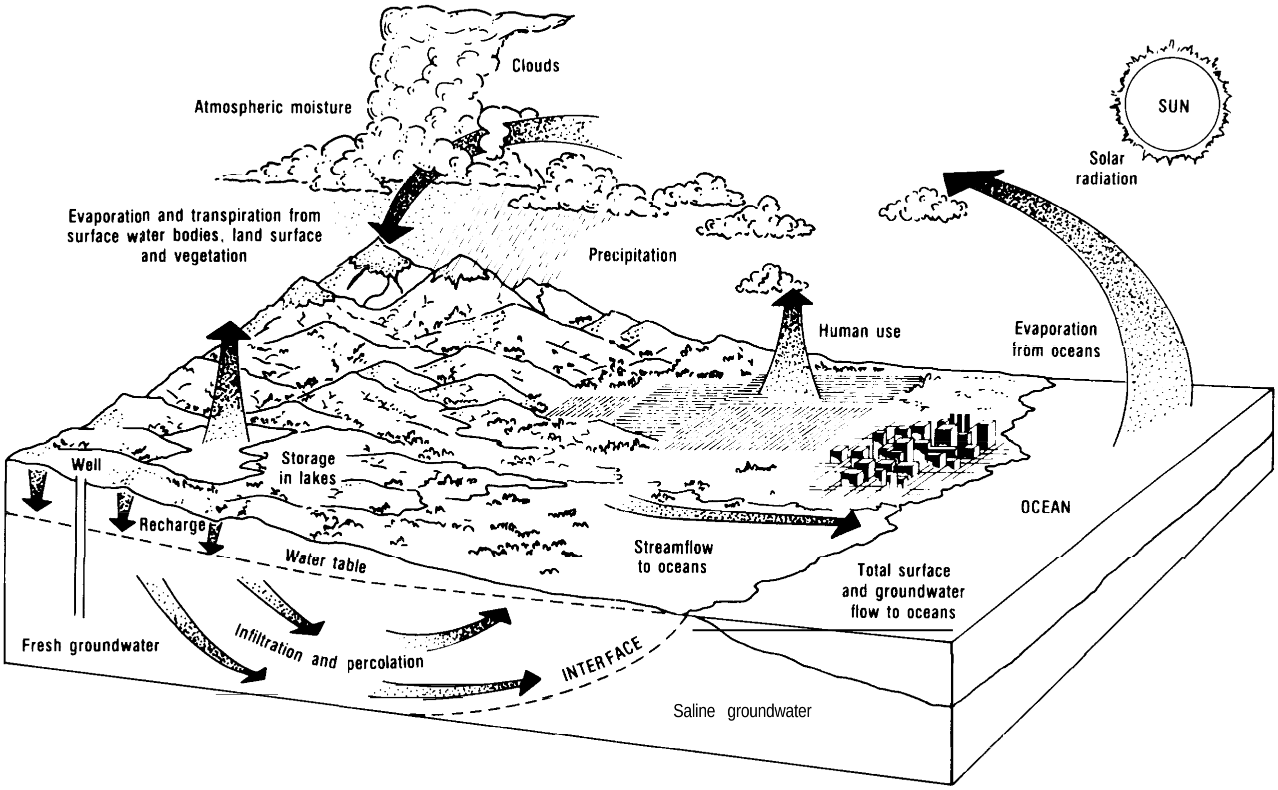
Contamination of the Hydrogeologic System

Water reaches the groundwater table through two primary natural pathways in the course of the

[1]Contamination here refers t. the measurable presence of an agrichemical or its breakdown products, and does not necessarily imply the existence or absence of a threat to human health or the environment.

[2]This zone also may be referred to as the unsaturated zone or the zone of aeration.

Figure 3-1—Hydrologic Cycle



SOURCE: Adapted from B.J. Skinner and S.C. Porter, ***The Dynamic Earth (New York, NY:*** John Wiley& Sons, 1989).

hydrologic cycle: direct leaching through soils and rock formations, and via recharge from surface waters. Although the waters leaching through farmlands to groundwater may pickup agrichemical and natural contaminants as they move through the system, contaminants also may derive from atmospheric deposition or contaminated surface waters.

Atmospheric Deposition

Agrichemicals can be transported and dispersed in the atmosphere, eventually returning to lands and surface waters. With spraying from airplanes, in particular, pesticides aimed at a specific field are likely to drift beyond its boundaries and settle on distant land areas, lakes, and streams.

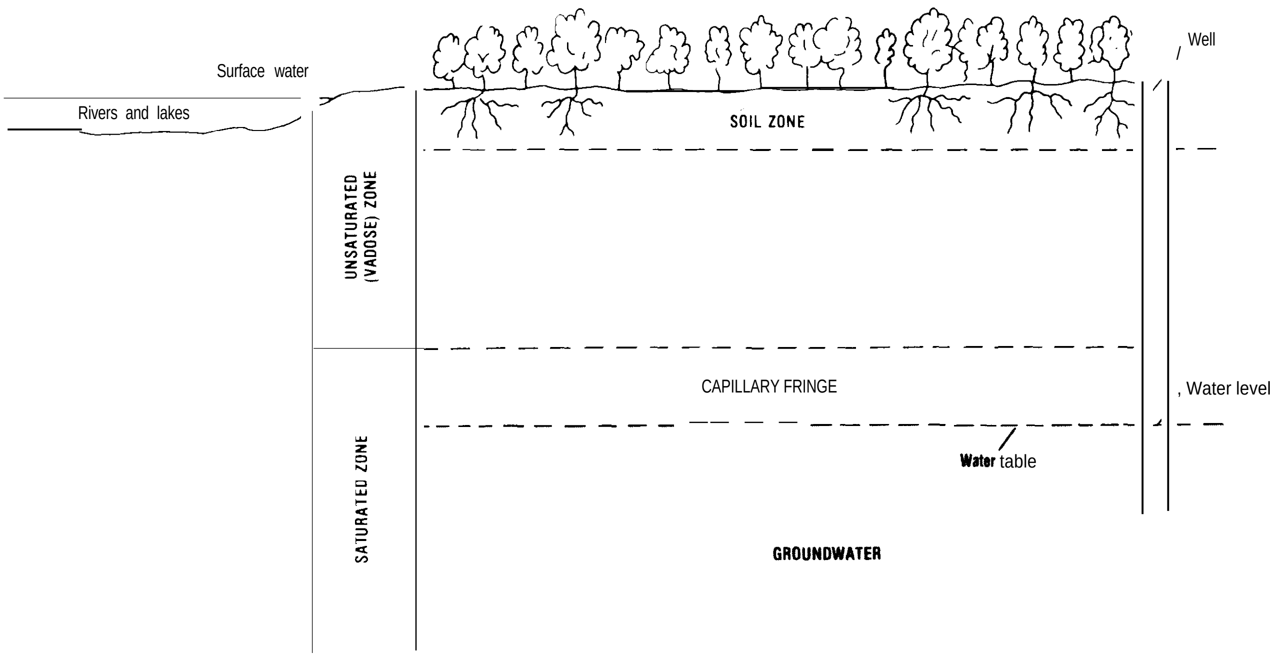
Contamin ation of rainfall has been documented for certain organochlorinated pesticides. Studies show that the pesticide toxaphene (now banned by the Environmental Protection Agency (EPA)) was carried long distances from its use site and deposited through rainfall in concentrations high enough to damage fisheries (1 1). Similarly, in a pilot study of atmospheric dispersal of pesticides in the Northeastern United States, rainwater samples were analyzed for 19 commonly used pesticides and 11 were found in detectable levels (62).

The detected compounds showed strong seasonal variation consistent with application times and chemical stability and, thus, are thought to have originated mostly from local sources (62). However, wind also can transport agrichemical particles and vapors hundreds or thousands of miles before they fall back to Earth. In 1980, an insecticide used to control boll weevils in cotton fields in the Southern United States was discovered in fish in the waters of Lake Superior. The global scope of atmospheric transport became apparent when insecticides used in Asia and southern Europe appeared in Arctic and Antarctic waters.

Recharge by Contaminated Surface Waters

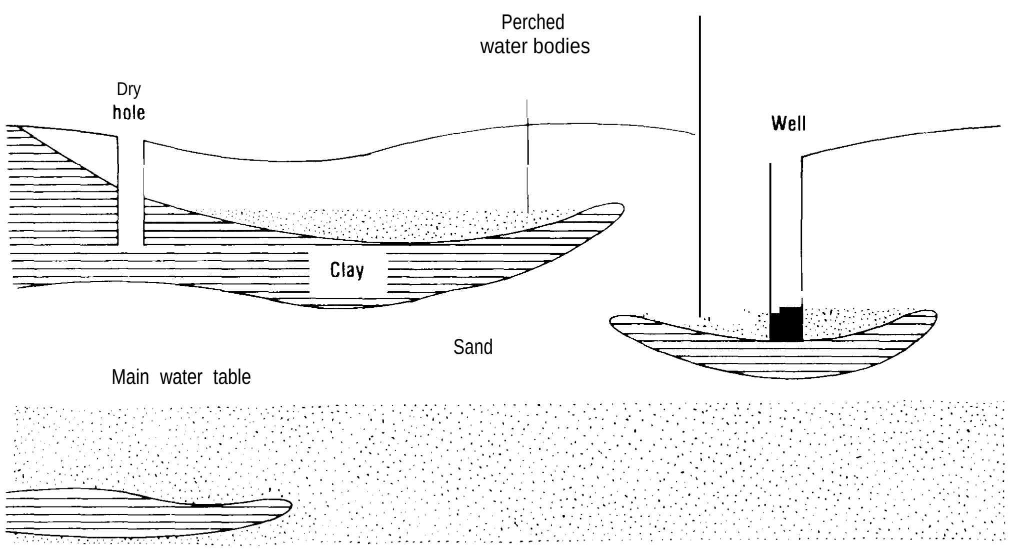
Readily soluble agrichemicals maybe carried off fields with runoff. Some agrichemicals have a tendency to attach themselves to certain soil parti-

Figure 3-2—Zones of Subsurface Water



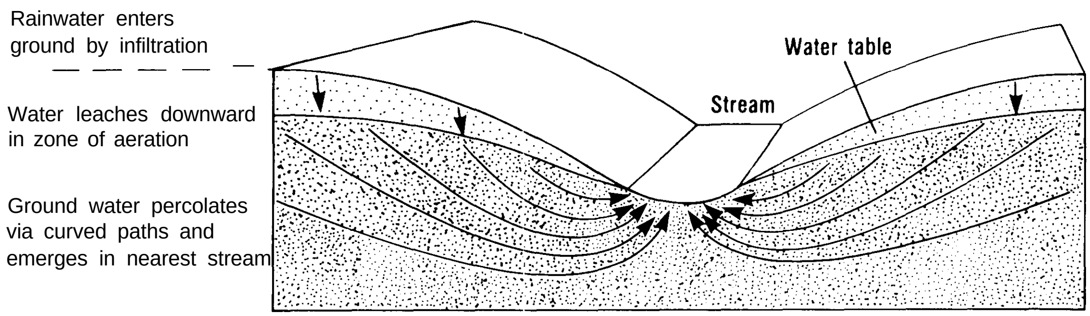
SOURCE: Adapted from R. C. Heath, ***Ground- Wafer Regions of the United States,*** Geological Survey Water-Supply Paper No. 2242 (Washington, DC: U.S. Government Printing Office, 1984).

Figure 3-3-Perched Water Tables in Relation to the Main Water Table

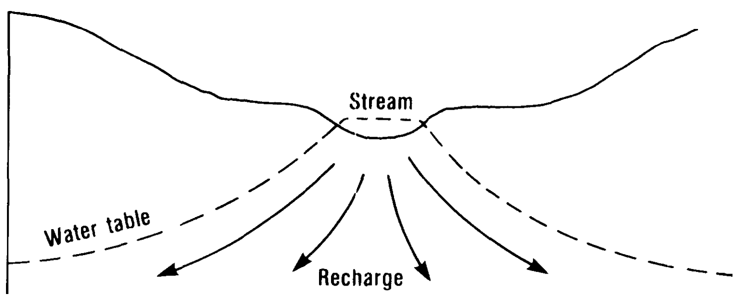


SOURCE: B.J. Skinner and S.C. Porter, ***The Dynamic Earth (New*** York, NY: John Wiley& Sons, 1989).

Figure 3-4-Surface Water and Groundwater Relationships



A. Generalized movement of groundwater in uniformly permeable **rock** in a humid region, or during high precipitation conditions in an arid/semiarid region



B. Generalized movement of groundwater in uniformly permeable rock in arid/semiarid regions-or during long-lasting drought in humid regions

SOURCE: **B.J.** Skinner and **S.C.** Porter, ***The Dynamic Earth (New York, NY:*** John Wiley& Sons, 1989).

cles; the impact of raindrops can erode soils and associated agrichemicals from the field. In such cases, agrichemicals may end up in surface water bodies. From there, agrichemicals or their breakdown products may leach into groundwater.

Groundwater and surface waters are closely linked, with the flow of one to the other depending on the relative altitudes of the surface water and the groundwater table (figures 3-4a and b). For example, in humid regions, the flow of groundwater generally is toward surface water bodies because the groundwater table in the surrounding land is higher than the surface water body. In arid/semiarid regions, however, the flow direction is reversed because the altitude of streams tends to be higher than the groundwater table (75,18,66). Under conditions of abnormally high rainfall in arid/semiarid regions or abnormally low rainfall in humid regions, the predominant direction of water flow may change accordingly. Thus, in any region of the country, potential exists for climatic factors to promote recharge of groundwater by surface waters. In addition, pumping of high-capacity municipal wells can draw surface water into the aquifer.

The absence of oxygen below the water table precludes most reactions that degrade contaminants in the vadose zone (40). Contaminants that reach and move with groundwater are therefore likely to remain chemically intact for long periods.

Once contaminants reach groundwater they may spread laterally to a greater extent than they may have in the vadose zone. In certain instances, a large aquifer may be encountered through which contaminants can disperse regionally (e.g., Ogallala aquifer) (25). While it might be years before contaminants reach the deeper parts of a very thick aquifer, deep groundwater may act as a long-term reservoir for contaminants. Thus, contaminants in groundwater

Photo credit: U.S. Fish and Wildlife Service-L. Childers

Groundwater and surface water, such as the wetlands shown here, are intimately connected. Contamination of groundwater can therefore result in contamination of surface-water bodies, and vice versa

may be discharged to a stream decades, or centuries, after percolating rainwater introduced pollutants in the first place (86).

Natural Factors Affecting Leaching of Agrichemicals to Groundwater

The potential for agrichemicals to leach directly through soils and rock to groundwater depends on numerous factors. Natural site characteristics can enhance or reduce the potential for a given agrichemical to leach and to contaminate groundwater. Local topography and landforms can favor surface runoff over downward soil seepage or vice versa. Vegetation and climatic parameters (temperature, precipitation, air movement, and solar radiation levels) affect the environmental fate of contaminants as well (14). Roots and sunlight can interact directly with the contaminant (e.g., photochemical degradation of chemicals exposed to sunlight, root uptake of nutrients and pesticides); vegetation and climate also have impacts on soil properties. Other variables such as the depth to the water table, characteristics of the unsaturated zone, and the presence and distribution of low-permeability layers also can affect contaminated water flow. Pesticide degradation may occur via one or a combination of several biological and chemical pathways, and the operative pathways may vary from site to site (58).

Certain soils may have direct physical or chemical interactions with agrichemicals. Some chemical reactions, relating to the presence or absence of oxygen or to the hydrolysis of a chemical, may serve to detoxify contaminants in the soil. Sometimes, though, the pesticide breakdown products may be more toxic than the parent compound (14).

Topography and the Soil Surface

Topography of the land and the roughness of the soil surface can affect the movement and fate of agrichemicals applied to agricultural lands. Sloping agricultural lands tend to be more prone to water erosion than are flat lands. On flatter agricultural lands, water erosion is less of a problem and the likelihood for infiltration of the agrichemical-bearing water into the soil and into groundwater may be enhanced. On flat land, wind is likely to be the agent that erodes soil and carries agrichemicals from agricultural lands. Strong winds can remove fine soil particles and lightweight organic matter from dry soils. These airborne materials may end up in distant water bodies; any attached agrichernicals may ultimately move into the groundwater. Rougher soil surfaces, such as those produced by leaving crop stubble on the field, tend to reduce runoff and thus hold agrichemicals and soil particles on site, affording time for agrichemical degradation.

Some pesticides will break down when exposed to direct sunlight, a process called photochemical degradation. The longer pesticides are exposed to sunlight, the more likely it is that photosensitive chemicals will break down. Topography obviously affects length of exposure to sunlight (e.g., north-v. south-facing slopes); it also affects soil temperature and microbiota, which in turn affect pesticide degradation.

Vegetation

The presence and type of vegetation-forests, grasslands, or agricultural crops—strongly affect the movement of water and water-borne solutes within the vadose zone. Crops such as alfalfa with roots up to 20 feet deep and high water demand, and sunflowers and safflowers with roots penetrating to at least 6 feet, have impacts far different from those of shallow-rooted crops with lower water demand. Agrichemicals are less likely to pass beyond deep-rooted crops to contaminate groundwater than to travel beyond the much shallower root zone of crops like corn (17,64). Once agrichemicals pass the root zone there is little to stop them from moving downward to the groundwater.

The closer the spacing between individual plants the less potential there is for soil erosion and the inadvertent movement of agrichemicals to off-site locations and potential groundwater contamination. Close-grown crops such as grasses or small grains, are more likely to intercept raindrops and shield the soil from wind than widely spaced crops such as corn, soybeans, or cotton. Moreover, the denser the root system the less likely it is that soluble nutrients will pass the root zone and move into groundwater. This is particularly true when the nutrients are applied at that time during the growth period when the plants have the most demand for them. Those areas having the longest growing seasons provide for the maximum nutrient uptake.

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

USDA researchers take groundwater samples from a test site next to a cornfield in Beltsville, Maryland. Groundwater will be tested for pesticides in a study on the effects of different tillage methods on pesticide movement.

When annual crop plants die, nutrient and water uptake by the plants ceases, thus providing a period when water, agrichemicals remaining in the soil, and nutrients from decomposition of crop residue can move downward. Some nutrients may be sequestered by soil organic matter; others are subject to leaching and may contaminate groundwater. Consequently, the removal or harvest of annual crops and its timing plays an important role in the fate of agrichemicals (64).

Water Table

The movement of water into and through the soil is very complex, and there are seasonal and regional variations in the amount of water that enters the soil and eventually recharges groundwater (25,57). The amount of recharge, depth to the water table, and fluctuations in depth to water table vary with climate, soils, topography, and geology.

The water table tends to be shallower and more readily recharged in the Eastern United States where precipitation normally exceeds evaporation, than in the arid/semi-arid regions of the Western United States, where the reverse is true. Streams supplied by water sources originating in distant mountains are for the most part the only significant source of groundwater recharge in some arid regions of the Western United States (75). With little rainfall over long periods of time, the groundwater table in arid/semiarid regions may be as much as 1,500 feet below the land's surface (6).

In humid regions, the likelihood of contaminating groundwater with agrichemicals is higher than in dry regions where water is scarce, because of the shorter distance between the land surface and the groundwater table. Longer transit time in dry regions than in humid areas may afford greater opportunity for the natural breakdown of pesticides. However, for those pesticides requiring moisture for degradation, this condition may lead to a persistence in the soil.

The water table fluctuates seasonally, typically rising during the winter and early spring rains, and falling during drier months. Under drought conditions, the water table will continue to fall. Streams and ponds that once served as outlets for groundwater may begin to dry up as their waters follow the falling water table. In normal times, the water table may rise to the plant root zone during the "spring flush' '-when snows melt and rains are more frequent or intense-minimizing potentially mediating soil effects, Spring also tends to be the period of heaviest plant nutrient application.

Soil Characteristics

Soil characteristics are determined by the interaction of soil-forming factors such as the soil's geologic parent material, the climate under which the soil formed, its topographic position, the nature of the vegetative cover, the kinds and abundance of soil organisms, and the amount of time the soil has been forming. The resulting soil properties in turn have a direct influence on how rapidly or slowly agrichemicals move through the soil into groundwater. Therefore, in a country as large as the United States where significant variation exists in soil, geology, climate, and topography, it is natural to expect large variations in soil properties vertically and horizontally in different areas. It would be necessary to have site-specific data on the soil type to indicate soil structure, mineralogy, chemistry, and texture before making detailed predictions on the potential for contaminating groundwater with agrichemicals.

Soils exist in a water-saturated or unsaturated state. Plants growing in ponds and marshes have their roots in water-saturated soils. Most agricultural crops, however, grow on unsaturated soils comprising the top few feet of the vadose zone. The soil factors that affect leaching and degradation processes through unsaturated soils include organic carbon, clay and moisture content, pH, temperature, texture and structure, nutrient status, and microbial activity (14).

Physical and Chemical Soil Characteristics—The *texture* of soil relates to the size and shape of its constituents, and extent of particle aggregation (56), all of which affect the volume of air or water a soil can hold or transmit. Soil texture exerts substantial control over the movement of water and associated agrichemicals.

Soils have many open spaces between constituent particles that can hold and transmit water. This open space in a soil is called *porosity.* However, if the open spaces or pores are not interconnected, water cannot flow through the soil rapidly. Such soils are said to lack *permeability* even though they are porous. Clean sand (sands containing little silt or clay or other fine-grained materials) and gravel soils are porous and permeable but as the content of fine silt and clay particles increases, the pores become plugged and the rate at which water moves through such soils decreases. Therefore, it is important to know how porous a soil is, how large the pores are, and to what degree the pores are interconnected before predicting the fate of agrichemicals applied to that soil.

Some of the best agricultural soils are called loams, i.e., those containing about 5 to 25 percent clay with approximately equal parts of silt and sand constituting the remainder. Such soils commonly remain well-aerated throughout the year and drain effectively. Loam soils are better than either coarse-grained soils or fine-grained, poorly drained soils in faltering out and arresting downward percolating contaminants (45).

Pore size is an important characteristic to consider when evaluating the likely movement of contaminated water. A thin film of water is held tightly on the mineral particles making up soil by forces of molecular attraction. This film of water (adsorbed water) does not behave like the water in the center of large pores. The adsorbed water will not flow out of a soil's pores as will the water in the center of a large pore (absorbed water). Consequently, a soil composed of fine-grained materials may have a high porosity and the pores may be interconnected, but because the pores are so small most of the water is adsorbed and little will be able to flow through the soil (66). Such soils give farmers problems bemuse they are slow to dry out, waterlog easily, are difficult to cultivate, and do not crumble but form clods (53). The oxygen content of the soil can be reduced in such situations to the point where plants are adversely affected.

Soil particles tend to be spherical in the large grain sizes (e.g., sand) but more plate-like in the freer fractions (e.g., clay). Fine clay particles can be arranged in two general forms, one like a deck of cards and the other like a house-of-cards. The adsorbed water is continuous between parallel clay particles and, therefore, essentially is immobile. Little pore space exists in the "deck-of-cards" arrangement. The house-of-cards clay arrangement has a high porosity and may have interconnected pores, but because the clay sheets are so small, the layer of adsorbed water on each sheet overlaps with that of adjacent sheets, also restricting water flow. Clay-rich soils and rocks thus transmit water poorly and, therefore, retard agrichemical movement into groundwater.

Clay *minerals* have other important properties for retarding the movement of certain agrichemicals, heavy metals (toxic constituents of sewage sludge containing industrial wastes), and bacteria into groundwater. Many U.S. soils contain several common types of clay minerals that can trap fertilizer nutrients on their outer surfaces as well as between mineral layers. The clays can incorporate nutrients important to plants such as potassium, calcium, or magnesium, hold them in an exchangeable form, and release them later to plant roots or the soil solution. The movement of nutrients to and from clay surfaces is called ''ion exchange. '

Some pesticides and heavy metals also can be trapped by appropriate kinds of clay minerals. In addition, some bacteria that might originate in sewage sludge, manure, or even dead farm animals can be filtered out of soil water or groundwater and trapped by clays and even fine-grained sands (66). Viruses, being much smaller than bacteria, are not easily faltered out but their properties are such that they are likely to adhere to clay mineral surfaces.

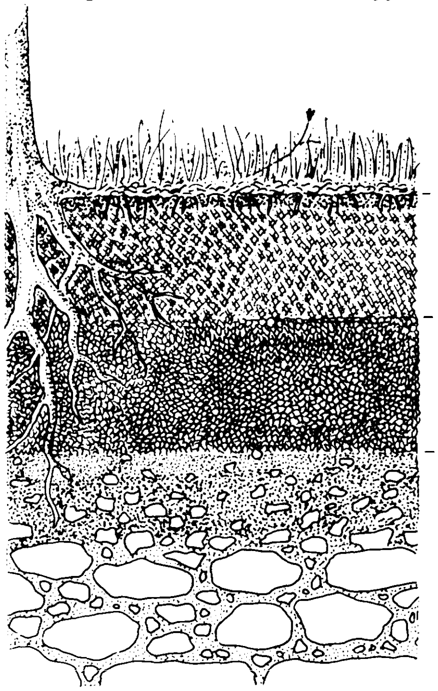
Another important component of soils is the humus that gives the uppermost part of soils their dark color (figure 3-5). Humus is a breakdown product of plant and animal *organic matter* and, like clays, has the ability to filter out and capture bacteria and many chemical contaminants. Organic matter can hold water, heavy metals, and some organic chemicals and it promotes the retention of soluble plant nutrients that otherwise would tend to leach downward with percolating waters. Pesticide adsorption in soils in many studies has been found to correlate with the soil organic-matter content (14).

Soil organic matter plays a key role in successful agriculture, imparting benefits to soils that, for the most part, cannot be obtained by merely adding chemicals. Soil organic matter promotes soil particle aggregation, which in turn improves soil tilth and soil percolation (74). Thus, soil organic matter relates directly to the capacity of the soil to hold air and moisture, and promote more extensive, deeper crop root systems. The latter is important in the overall water use efficiency of the crop.

Further, organic matter ultimately is biologically degraded to release the ''macronutrients' (nitrogen, potassium, and phosphorus) most essential to plant growth. The main natural source of nitrogen for plant growth is soil organic matter, however, most of the nitrogen is unavailable to plants until it is converted to ammonia and nitrate by microorganisms. Soil organic matter also helps control potassium supply for plant growth. As soil reservoirs of available potassium are depleted, they are replenished by potassium released from organic residues, fertilizer, living organisms, and soil minerals (47).

The *mineral part of soils* ordinarily contains about 400 to 6,000 lb. per acre foot of nitrogen in the plow layer. Somewhat lesser amounts are found in subsoils (3). Nitrate levels in range and wheat fallow soils of central and south central Nebraska were estimated up to 150 pounds per acre foot at depths of 30 to 40 feet. These high natural volumes of nitrate exceed the amount applied as fertilizer in the State,

Figure 3-5—Horizons of a Typical Soil Profile



SOURCE: B.J. Skinner and S.C. Porter, *The Dynamic Earth (New York, NY:* John Wiley & Sons, 1989).

and constitute a considerable threat to groundwater should they leach (13).

Soil inorganic matter may contain from 15 to 80 percent of the total soil phosphorus, an important plant nutrient (3). Mycorrhizal fungi are active in collecting phosphorus for plant use. As the phosphorus is slowly released during weathering of certain soil minerals, it is moved to plant roots by the fungi (76).

Characterizing the amounts and types of clay minerals, organic matter, and other soil components is complex, yet such information is fundamental to assessing the fate of commercial fertilizers, pesticides, and the heavy metals in sewage sludge that might be applied to agricultural land. Increased regional and soil series data are needed.

Biological Characteristics

Biological agents also affect the movement of water and water-borne substances within the vadose zone. Organic compounds break down most readily within the uppermost ‘‘bioactive” soil layers, although microbial populations are present and can be significant in deeper unsaturated zones (58). The soils most reactive with agrichemicals possess substantial water-holding and ion-exchange capacities, an open physical structure, and thriving populations of beneficial bacteria, fungi, and invertebrates (figure 3-6).

However, burrowing animals and decaying plant roots may create vertical ‘‘macropores’ that permit the rapid passage of water (41,55). Rapid, channeled flow, as opposed to dispersed, slow seepage leaves less room for soil reactions to cleanse water physically or chemically, and increases the potential for the movement of soil nutrients and other contaminants into groundwater.

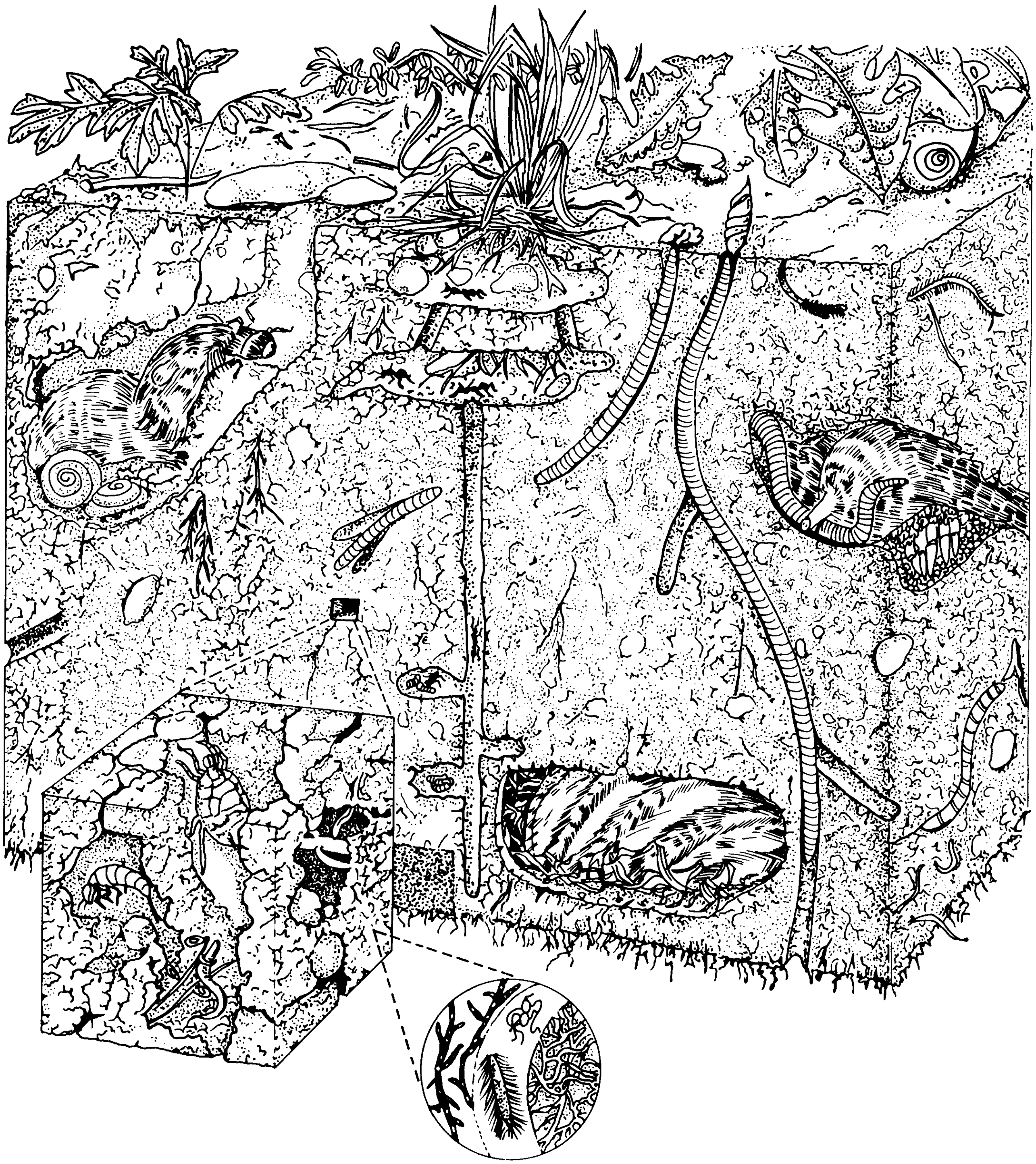
Microorganisms-Most soil microorganisms are microscopic or barely visible to the naked eye. Soil microorganisms (bacteria, fungi, actinomycetes, and protozoa) serve a critical function in that they metabolize extant organic matter to release the nutrients essential for plant growth. Microbial decomposition of organic matter also releases elements not used directly as plant nutrients. Some of these elements may be converted to gaseous form (e.g., carbon dioxide and nitrous oxides). By such conversions, microorganisms in part regulate the chemistry of the Earth’s surface and atmosphere.

Microorganisms comprise the sole or chief natural means for converting organic forms of nitrogen, sulfur, phosphorus, and other elements to plant-available forms. In the final stages of biochemical decomposition of organic matter, nutrients are recycled, humus forms, and soil particle aggregation is fostered (21). Any actions or agrichemicals deleterious to these microbial processes ultimately would have adverse consequences on crops.

Potential groundwater pollutants can be degraded (converted to a non-toxic form) or created by biological agents. Certain “nitrifying” soil microbes convert organic compounds of nitrogen into nitrate useful to plants and potentially available for leaching to groundwater. In the absence of high levels of commercial nitrogen fertilizers, the rate at which microorganisms convert nitrogen to products useful to plants largely determines the rate of plant growth. Leaching of microbially produced nitrate-not of fertilizer nitrate-is thought by some British scientists to be the primary source of nitrate detected in some of their water supplies (l).

Further, soil microorganisms are responsible for decomposing a wide array of synthetic organic chemicals in agricultural soils and water, including

Figure 3-6—Microfauna and Macrofauna Open Conduits and Create Pore Spaces in Soils



SOURCE: P.H. Raven, R.F. Evert, and S.E. Eichhorn, *Biology of Plants* (New York, NY: Worth Publishers, Inc., 1986).

pesticides, industrial wastes, and precipitated air pollutants, converting them to inorganic products. The breakdown process may lead to detoxification of toxic chemicals, the formation of short- or long-lived toxicants, or the synthesis of nontoxic products. Scientists have investigated only a few of the multitude of chemicals to determine what breakdown products are formed when microorganisms encounter chemicals in natural systems (2).

Soil Invertebrates and Vertebrates-*Most soils are* inhabited by a diversity of life forms. The soil biota includes, in addition to numerous microbes, a wide variety of invertebrate animals and a few vertebrates. Some of these larger soil invertebrates such as earthworms, ants, other soil insects, and land snails and slugs are important to agrichemical leaching or degradation processes. Small mammals are the dominant vertebrate animals found below ground, but some amphibians, reptiles, and even a few birds live at least a part of their lives within soils.

Soil "macro-organisms" often modify and enhance the soil by their activities, carrying out the early stages of the physical and chemical decomposition of all types of organic debris in or on the soil. They are vital to the formation and maintenance of the natural soil system and perform functions essential for plant growth. Annually, earthworms in one hectare of land can produce as much as 500 metric tons of castings, the soil material passing through their gut. The castings are enriched in nutrients compared to the adjacent soil: 5 times as much nitrogen, 7 times as much phosphorus, 11 times as much potassium, 3 times as much magnesium, and 2 times as much calcium (61). Before the widespread availability of commercial fertilizers, nutrients recycled by the biota were recognized as a major component of soil fertility and so soil biology ranked high among the agricultural sciences. In recent decades, however, there has been much less emphasis on soil biology as increased soil fertility has been achieved through use of commercial fertilizers.

Despite the lack of quantitative data on the impact of farming practices on invertebrates in most U.S. soils, some qualitative information does exist. The situation is not the same for soil vertebrates, which include such animals as moles, gophers, mice, other burrowing mammals, and some reptiles and amphibians. Even though some people worry that agrichemicals may harm beneficial soil invertebrates, the activities of soil vertebrates are commonly and narrowly viewed as negative: for example, making burrows in which farm machinery can become entrapped, consuming valuable grain or forage, or providing pathways for agrichemicals to reach the groundwater table. Some studies of soil vertebrates suggest that they may also have beneficial impacts, such as breaking up hardpan a foot or more below the surface, thus improving drainage and increasing rooting depth. Unfortunately, such ecological studies typically are conducted on virgin land and are difficult to relate to agricultural lands (63).

No economically feasible substitutes exist for the significant functions of organic matter and soil biota, so their maintenance in croplands and rangelands is critical. Soil invertebrates and microorganisms assist in breaking down plant remains, producing new organic compounds that promote good soil structure, and convert soil nutrients to forms usable by plants. Microbes also break down pesticides and other toxic chemicals. Without the soil biota, the organic matter from plant residues and manure would be of little use. Consequently, care is needed to assure that agrichemicals moving through the soil and groundwater do not adversely affect the soil biota.

Characteristics of Underlying Geological Materials

In situations where soils lie directly over bedrock it is generally easier to predict the likelihood for agrichemical leaching to underlying aquifers than in instances where unconsolidated sediments separate the soil from the bedrock. In this latter situation, the characteristics of the intervening materials play an important role in determiningg the fate of agrichemicals.

Bedrock Characteristics

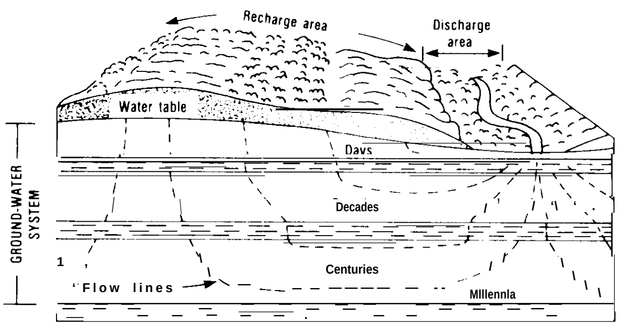
Accumulations of unconsolidated materials and various kinds of bedrock may lie beneath the soil surface. Whatever its name and origin, it is largely the chemical and physical nature of bedrock that governs water flow and pollutant dispersal. Even though the permeability of some types of bedrock is very low (table 3-1; figure 3-7), most types of bedrock are criss-crossed with hairline cracks and fractures, and larger cracks or "joints" provide pathways through which water can flow. *Some* rocks like sandstones and conglomerates may be highly permeable even where joints are scarce.

Table 3-l—Estimated Permeability of Typical Geologic Materials in Illinois

Geologic material	Flow rate	Comments
Clean sand and gravel	100 ft/yr	May be highly permeable
Fine sand and silty sand	1 ft/yr -100 ft/yr	—
Silt (loess, colluvium, etc.)	10 ft/yr -1 ft/10 yr	.
Gravelly till, less than 10% clay	1 ft/yr -1 ft/100 yr	Often contains gravel/sand lenses or zones
Till, less than 25% clay	1 ft/10 yr -1 ft/1 ,000 yr	
Clayey tills, greater than 25% day	1 ft/100 yr -1 ft/10,000 yr	Often contains gravel/sand lenses or zones
Sandstone	10 ft/yr	—
Cemented fine sandstone	10 ft/yr -1 ft/100 yr	Frequently fractured
Fractured rock	10 ft/yr	May be extremely permeable
Shale	1ft/100 yr -1 ft/1,000,000 yr	Often fractured
Dense limestone/dolomite (unfractured)	1ft/1000 yr -1ft/1,000,000 yr	—

SOURCE: Adapted from R.C. Berg, J.P. Kempton, and K. CartWright, "Potential for Contamination of Shallow Aquifers in Illinois," Illinois State Geological Survey, 1984.

Figure 3-7-General Direction and Rate of Groundwater Movement



SOURCE: R.M. Wailer, "Groundwater and the Rural Homeowner, " (Reston, VA: U.S. Geological Survey, 1988),

Generally, fractures and joints in bedrock become less common with increasing depth and groundwater movement and storage volume decreases. At least one-half of all groundwater, including most of the usable groundwater, occurs within the upper 2,500 feet of the land's surface (66).

Bedrock commonly shows evidence of distortion and folding and faulting. The variation of bedrock types and properties, and the different geologic structures present beneath the land's surface, all affect the flow of water and, hence, complicate predictions of contaminant movement in surface and groundwater. Groundwater follows an erratic path rather than a straight, vertical line and contaminants may be carried considerable horizontal distances away from the original site of surface application. Where water encounters solution cavities and channels in an area of carbonate bedrock, it may move rapidly downward as if through an open well. Without detailed subsurface geological data, it is nearly impossible to predict precisely where groundwater and its pollutants are likely to move or accumulate in the subsurface.

Solution Cavities in Carbonate **Rocks**

Limestone, dolomite, and marble are common rocks that can dissolve slowly as water comes in contact with them. Over centuries, rainwater and groundwater can dissolve a considerable volume of these rocks leaving behind a variety of solution features (cf: 66). Regions where limestone is common at, or very near, the land surface and where solution of this rock is at an advanced stage, are characterized by sinkholes, caves, and streams that seem to disappear into the ground. These features typfiy what geologists call karst topography.

If agrichemicals are used in karst regions there is high probability that groundwater will be contaminated. Once such chemicals move into the groundwater in such a setting, they can move rapidly over large distances diluting to lower concentrations or causing contamination in unexpected places. Wells in karst regions, therefore, are highly susceptible to contamination from agricultural activities.

In certain cases, limestone karst topography is buried far below the land surface. Overlying sediments may have low permeabilities and consequently downward moving agrichemicals may not reach the water-filled limestone cavities. In such cases, well-water pumped from the limestone aquifer may be uncontaminated, However, in cases where the limestone beds are tilted and crop out at the land surface, the entire aquifer may become contaminated as agrichemical-laden groundwater flows laterally from its shallow to its deepest parts. Wells miles from the source of contamination can be adversely affected. Thus, groundwater contamination that begins as a local problem can, under certain conditions, become regional in nature.

Unconsolidated Materials

Unconsolidated materials commonly underlie soils in many parts of the United States. For example, extensive unconsolidated glacial deposits separate the soil from bedrock across much of the farmlands of the northern part of the United States from Montana to Maine. These and other unconsolidated materials affect how slowly or quickly contaminated water will reach groundwater in confined and unconfined aquifers. Geologists can assist with assessing the subsurface character of these sediments where concerns exist about agrichemical contamination of subsurface waters.

Unconsolidated sediments deposited along streams and rivers (alluvium) can cover bedrock and can vary greatly in thickness. Similarly, sediments that move downhill and accumulate at the foot of slopes (colluvium) also can cover bedrock to varying depths. Other unconsolidated material form in place from weathering of underlying bedrock. These types of sediments can vary in composition vertically and laterally over short distances, thus directly affecting the downward flow of water.

The porosity and permeability of the unconsolidated materials relate to the sediment's source material, the degree of weathering, whether or not the unconsolidated material has been transported, and the mode of transportation. Where unconsolidated materials are thick, porous and permeable, they commonly are filled with water in their lower parts if rainfall is sufficient, and they are used as unconfined aquifers by farmers and others. Of course, where they have a high degree of porosity and permeability and underlie agricultural sites, they are likely to be contaminated easily where agrichemicals are applied to the land surface.

Glacial Geology and US. Midwest Agriculture

Glaciers moving south from what today is Canada once covered large parts of the United States from Montana to Maine and as far south as southern Illinois (figure 3-8). The last glaciers melted or retreated about 10,000 years ago leaving behind a variety of sediments of varying thicknesses, filling in old river valleys and giving the land a much smoother topography than before. Today, rivers have cut through these glacial sediments in some places but much of the flat land of this region still has a glacial sediment cover.

This glaciated region—nearly one-quarter the area of the lower 48 States--contains 40 percent of the U.S. population and some of the best agricultural land in the world, including the "Corn Belt. " This also is the region of the United States where the application of agrichemicals is highest.

The geology of the glacial deposits is complicated because the sediments had different origins; the composition of this sedimentary veneer varies laterally and vertically. Some of the sediments were deposited directly by moving ice and are clay rich and relatively impermeable (glacial tills). These till deposits are likely to contain intermixed sand, cobbles, and boulders. Trapped beneath tills in some localities are the compressed remains of forests and other vegetation that may assist in agrichemical breakdown. Some sediments were derived from glacial melt-water and consist of permeable, clean sands and gravels. Still other deposits are composed of the fine silts from stream valleys blown across the land during dry periods (loess).

Each of these sediment types transmits water at a different rate. Wind-blown loess deposits, for example, drain more slowly than gravels and sands but much more rapidly than clay-rich tills. Consequently, knowledge of the origin, distribution, and composition of these glacial sediments vertically and horizontally is key to understanding where agrichemical-bearing water from agricultural operations may have potential to reach groundwater.

Aquifer Configuration

Below the groundwater table, pores of the rocks and sediments are filled with water. However, this does not imply necessarily that the water is available to a well in sufficient amounts to satisfy human needs (an aquifer). For example, a completely saturated fine-grained sediment or rock would yield water to a well too slowly to be considered an aquifer. (Many mines exist below the groundwater table but because the tunnels are in rock having little permeability, the mines stay quite dry and have few water problems.) Therefore, downward-moving water containing agrichemical contaminants could in fact contaminate groundwater but not necessarily an aquifer.

Figure 3-8-Extent of Pleistocene Continental Glaciation in the United States

SOURCE: Adapted from R.E. Snead, *World Atlas of Geomorphic Features* (Huntingdon, NY: R.E. Kreiger Publishing Co., Inc., 1980).

Aquifers are classified as being "unconfined' or ''confined. ' Unconfined aquifers are those in which the water table is the top of the aquifer. A confined aquifer (or artesian aquifer) is separated from the groundwater table above by a layer of relatively impermeable sediment or rock and is sealed at its base by another layer of materials having low permeability. The water in the aquifer is under pressure and, therefore, rises above the top of the aquifer in a well. A greater potential for agrichemical contamination of well-water exists in unconfined aquifers than in confined aquifers that may have relatively small recharge areas.

Putting It All Back Together

The hydrogeologic cycle is a complex system of interactive components and processes, driven by the Sun and modified by local variations in climate, topography, vegetation, soils and bedrock, and human activity. Groundwater problems and solutions, therefore, cannot be addressed without reference to the atmosphere, surface waters, the soils and bedrock that overlie and contain groundwater, and human activity at the Earth's surface.

Changes affecting any one component of the hydrological cycle are likely to be felt by other components, or throughout the system. Over the long term, changes in regional climates affect how rocks weather and, hence, influence soil development and soil thickness. Soils, in turn, help determine what kinds of agriculture are possible in a region, and the extent to which agricultural activities and different cropping and tillage systems might affect groundwater.

Because water on and below the ground's surface is part of the same integrated system, what happens to groundwater, through human use, ultimately affects water resources on the land's surface and vice versa. Due to changes in rainfall patterns and agricultural activities, infiltration rates may vary over time in a given area, leading to fluctuations in aquifer levels (groundwater storage), and affecting the dynamics of surface and groundwater exchange, and sometimes water quality.

Because of the many different factors that affect groundwater storage and quality, groundwater management poses complex challenges. In assessing known or potential groundwater quality problems, all components of the hydrologic cycle as well as man's ability to modify them should be taken into account.

HUMAN MODIFICATIONS OF THE HYDROGEOLOGIC SYSTEM

Agriculture, by definition, continually modifies the landscape and its vegetative cover throughout the year and over the years. Application of chemicals to agricultural fields is but one possible source of groundwater and surface water contamination problems related to agriculture. Two additional pathways exist for agrichemicals to reach groundwater, both related to changing the nature of the hydrogeological system itself. The first way is through openings in the soil or exposed bedrock that circumvent soil filtration processes (preferred pathways), and the second way is through land-use practices that change the groundwater/surface water relationships.

Humans have dug and drilled holes in the ground for many purposes over time, inadvertently providing pathways for agrichemicals to reach groundwater. These include, for instance, water-wells, drill holes for mineral exploration, seismic shot-holes, test drilling for foundations, injection wells, tile-drainage wells, missile silos, and mines. On a much smaller scale, plant roots and burrowing animals may create vertical charnels allowing for rapid infiltration of water.

Similarly, land-use changes also can affect the flow of surface water and groundwater thereby moving agrichemicals to unwanted sites. For example, changing dry-land agriculture to irrigated (and perhaps chemigated) agriculture, construction of ponds for groundwater recharge, construction of dams and reservoirs, and channeling and diking streams can cause such changes. The following section describes a few of these land-use examples and relates them to possible movement of agrichemicals beneath the land surface.

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

Since climate affects pest outbreaks, weather balloons are released near the Mexico-U.S. border to study migratory behavior of can and cotton pests. Better information on pest populations can help farmers be more selective on when and where to apply pesticides.

Preferred Pathways

Water will flow along the path of least resistance. Even though a soil maybe fine-grained and have low permeability, if it is pierced by small, natural channels (macropores) or larger manmade conduits (megamacropores), water contaminated with agrichemicals can move rapidly through these toward the groundwater table rather than slowly through the soil matrix where most contaminants are trapped or broken down. Although the amount of agrichemicals moving downward through such openings may be small for any single opening, the total that can be moved during a growing season could significantly and adversely affect water quality.

The most common natural macropores derive from earthworm channels, decayed plant roots, or cracks from soil drying. Freezing and thawing will collapse some of these conduits. Nevertheless, during the warm spring and summer months, agrichemical contaminated water can move easily downward. Similarly, the burrows of larger vertebrate animals provide pathways deep into the soil. Such conduits will not extend below the groundwater table unless the water table rises.

Megamacropores can be natural, such as sinkholes where the land's surface has collapsed into underground caves eroded from carbonate rocks ("solution cavities"), or manmade conduits like abandoned wells and drill holes. The latter may be several inches to several feet in diameter, while sinkholes may be hundreds of feet across.

Poorly constructed water-wells can lead to groundwater contamination problems. Water-wells having continuous steel casing from the land surface down into the aquifer can eliminate the possibility of degrading the drinking-water source with contaminated water from shallower aquifers. Completion of such wells so that contaminated surface runoff cannot enter the well head is essential to keep agrichemicals from contaminating the well-water. If active or abandoned wells are only partly cased or if casings corrode or crack, a potential will exist for contaminants to reach the well's aquifer.

Abandoned Drill Holes and Wells

Drilling holes in the ground for oil, water, mineral exploration, foundation testing, and other uses has been a common practice in the United States for many years. The first productive oil well was completed in Titusville, Pennsylvania in 1859 (66), but water-wells predated oil exploration by many years. Only recently have States developed regulations about the proper sealing of abandoned wells and other such holes. Quantitative data on the number of wells and drill holes is sparse and the number of improperly sealed abandoned holes in each State probably will never be known.

Minnesota is one State where some quantitative information exists, although estimates are based on extrapolation of certain field sites. The Minnesota Department of Health (MDH) estimates that some 700,000 to 1.2 million abandoned water-wells in Minnesota have a potential to endanger groundwater quality (88). Today, Minnesota has roughly 500,000 producing water-wells, and some 10,000 new water-wells are drilled annually. By a conservative estimate, about 10 percent of these are replacement wells. Therefore, at least 1,000 additional water-wells are abandoned each year. At the present rate of sealing (2,500 in 1988 at an average cost of $500 each), the MDH estimates that it will take 480 years to seal already abandoned wells. If 1,000 additional water-wells are abandoned each year, sealing the combined backlog of abandoned wells will take 800 years.

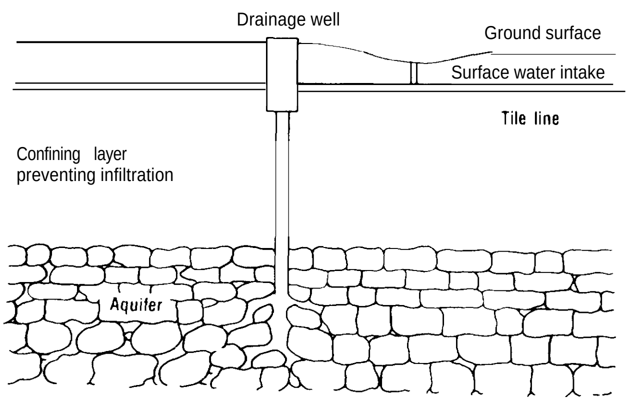
Minnesota is not an oil- or gas-producing State, so the number of abandoned wells there probably is far below the total number of wells and exploratory drill holes and seismic shot-holes scattered over States such as Texas and Oklahoma. Some abandoned wells and holes may have collapsed so that they no longer present avenues through which agrichemicals might move to contaminate groundwater. Further, water flowing down the walls of an open hole through the unsaturated zone are subject to strong withdrawal into the unsaturated zone. Contaminants, therefore, may not reach the water table if the contaminated supply of water is small (5). Yet other abandoned holes and wells probably are still open and may present a serious threat to States' groundwater resources.

Agricultural Drainage Wells

Agricultural drainage wells are structures designed expressly to provide access to underground strata for disposal of water drained from saturated soils or from irrigation systems. Farmland drainage, the primary agricultural water management and farm reclamation activity in this country, occurred throughout the last century, peaking in the 1930s (74). Nearly 75 percent (77 million acres) of the cropland on which wetness is a dominant constraint on production (105 million acres; (77)) have manmade surface or subsurface drainage systems (79). There are indications that many of the drainage systems constructed in the early 1900s, particularly in the Midwest, are now obsolete and in need of repair; in their current state, they promote leaching (74).

Drainage outflows can be directed through drainage wells and sinkholes into subsurface strata (figure 3-9). If outflow waters are directed into sinkholes for disposal, the relatively rapid movement of groundwater through karst may provide relatively rapid dilution of the soluble chemicals carried, However, in areas with fractured bedrock or slow-moving groundwater, chemicals may remain concentrated in the subsurface.

Figure 3-9-Schematic Diagram of Agricultural Drainage Well



SOURCE: Adapted from Iowa Department of Natural Resources, Environmental Protection Commission, *Iowa Groundwater Protection Strategy, 1987*

Drainage outflows and irrigation tailwaters commonly carry agrichemicals and naturally occurring soluble soil minerals, such as nitrate and selenium into surface- and groundwaters (see box 3-A). Unless properly processed or diluted, concentrations of natural and introduced chemicals can contaminate groundwater or aquifers posing environmental and health hazards.

Changing Groundwater/Surface-Water Relationships

Certain human activities can alter the natural relationship of surface waters and groundwater and, hence, how easily and in which directions contaminants are likely to move. Some common examples include darn construction, stream diversion, drainage and irrigation, and over-pumping of water-wells. These can either promote contamination, or dilute groundwater contaminated from *other sources.*

Dam Construction and Stream Diversion

Construction of a dam can greatly reduce the natural rate and volume of groundwater recharge downstream of the dam. Consequently, the groundwater table may drop to such an extent that contaminated surface- water bodies disappear as they drain into the falling groundwater table. Conversely, the water reservoir that forms behind the dam can raise the area's water table bringing the groundwater table close to or above the land surface. In such cases, the near-surface and surface water can pick up agrichemicals as contaminants. Previously contaminated groundwater may also be diluted.

Streams sometimes are diverted from their natural channels to new charnels to irrigate farmland, to divert water around developments, or to redirect water to water-poor areas. The groundwater impacts along the old charnel are similar to those that occur downstream of a new dam, and those along the diversion channel will parallel those occurring behind the dam.

Irrigation

Used on some 55 million acres of U.S. crops (75), irrigation is essential for crop production in arid areas, will increase crop yield or quality every year in semiarid areas, and ensures consistent crop yield and quality in subhumid and humid areas. However, irrigation has the potential to hasten leaching of applied and natural chemicals if excessive deep percolation occurs.

Irrigation systems commonly are established on agricultural lands with excessive soil drainage where they provide water for leaching. Irrigation water may release naturally occurring water contaminants including nitrate from certain mineral-bearing formations, Leaching of naturally occurring nitrate has been documented in several areas in the Great Plains and the Southwest (73).

In arid parts of Western States rainfall may not be sufficient to leach excessive soil salts below the root zone, requiring periodic ''soil flushing' with large amounts of water to allow continued agricultural production. This will also transport chemicals other than salts into the deeper soil profiles and potentially to groundwater. In arid areas where the contaminated ''outflow'' waters from soil flushing are directed into surface waters, they can seep directly below the water table to recharge groundwater (box 3-A).

Over-pumping Water-wells

When water is pumped from a well the water table is drawn down in the area adjacent to the well forming what is called a "cone of depression. ' The size of the cone of depression and how quickly the depression disappears after pumping ceases depends on the rate of water withdrawal from the well and the permeability of the surrounding rocks or sediments. If the cone of depression becomes large enough it can change the slope of the groundwater table. In

Box 3-A-Groundwater Contamination From Natural Sources: Kesterson National Wildlife Refuge

Kesterson National Wildlife Refuge was established from ponds built in 1971 for disposal of agricultural drainage water and also to provide wildlife habitat. Agricultural drainage water became the only source of inflow to the ponds by 1981, and by 1982 problems were first observed. Large-mouth bass and striped bass and carp disappeared from the ponds. In 1983, investigations of declining waterbird births showed deformities in embryos that were blamed on selenium (22,23,49).

Irrigated agriculture depends on the flushing of salts that accumulate in the rooting zone in order to maintain productivity; tailgaters thus have high salt content. Normally, the oceans are the ultimate sink for dissolved salts, however, depending on the drainage system these waters may or may not reach the ocean and drainage into contained basins may create a highly saline water body (e.g., Salton Sea, Dead Sea, Great Salt Lake).

Generally, trace elements (e.g., arsenic, selenium, molybdenum) are not contained in tailwaters, however, the soils in the San Joaquin contain naturally elevated levels of selenium and the hydrologic conditions promoted the movement of soluble selenium into irrigation tailwaters. The damage has been attributed to a combination of factors, including: 1) the high soluble-selenium content of soils, 2) increased irrigation development and installation of subsurface drains, and 3) lack of understanding of the potential adverse impacts from the method of disposal (49). Irrigated agriculture can clearly create adverse offsite effects over time. Irrigation management then must include adequate treatment and disposal plans for tailwaters.

A survey of 20 sites conducted by the Department of the Interior in Western States shows that at least four (Stillwater Wildlife Management Area, NV; Salton Sea, CA; Kendrick Reclamation Project, WY; Middle Green River Basin, UT) show potential trace-metal levels (boron, arsenic, molybdenum, and selenium) similar to those at Kesterson (22,49).

Technical options for remediation of the Kesterson refuge have been examined, including:

- transport and disposal of drainage water (ocean disposal, and deep-well injection);
- source control (retirement of land from irrigation, irrigation management, evaporation ponds); and
- water treatment (desalinization, chemical and biological removal of contaminants) (49).

The Bureau of Reclamation, the Fish and Wildlife Service, and the California Department of Fish and Game have developed a plan to offset the loss of the nearly 1,283 acres of wetlands destroyed. The plan calls for acquisition and management of 23,000 acres in the San Joaquin Drainage Basin to replenish the wetland acreage. Water needed to maintain the wetland will come from the Bureau's Central Valley Project (27).

some cases contaminated water from another well can flow downslope along the cone of depression of the uncontaminated well, degrading its water supply (figure 3-10). Each water-well produces its own cone of depression and where many wells exist, their intersecting cones of depression create complicated patterns in the surface of the groundwater table and affect normal flow patterns. In such cases, a properly maintained and constructed farm well still may become contaminated with agrichemicals even if none percolate downward directly from farm operations.

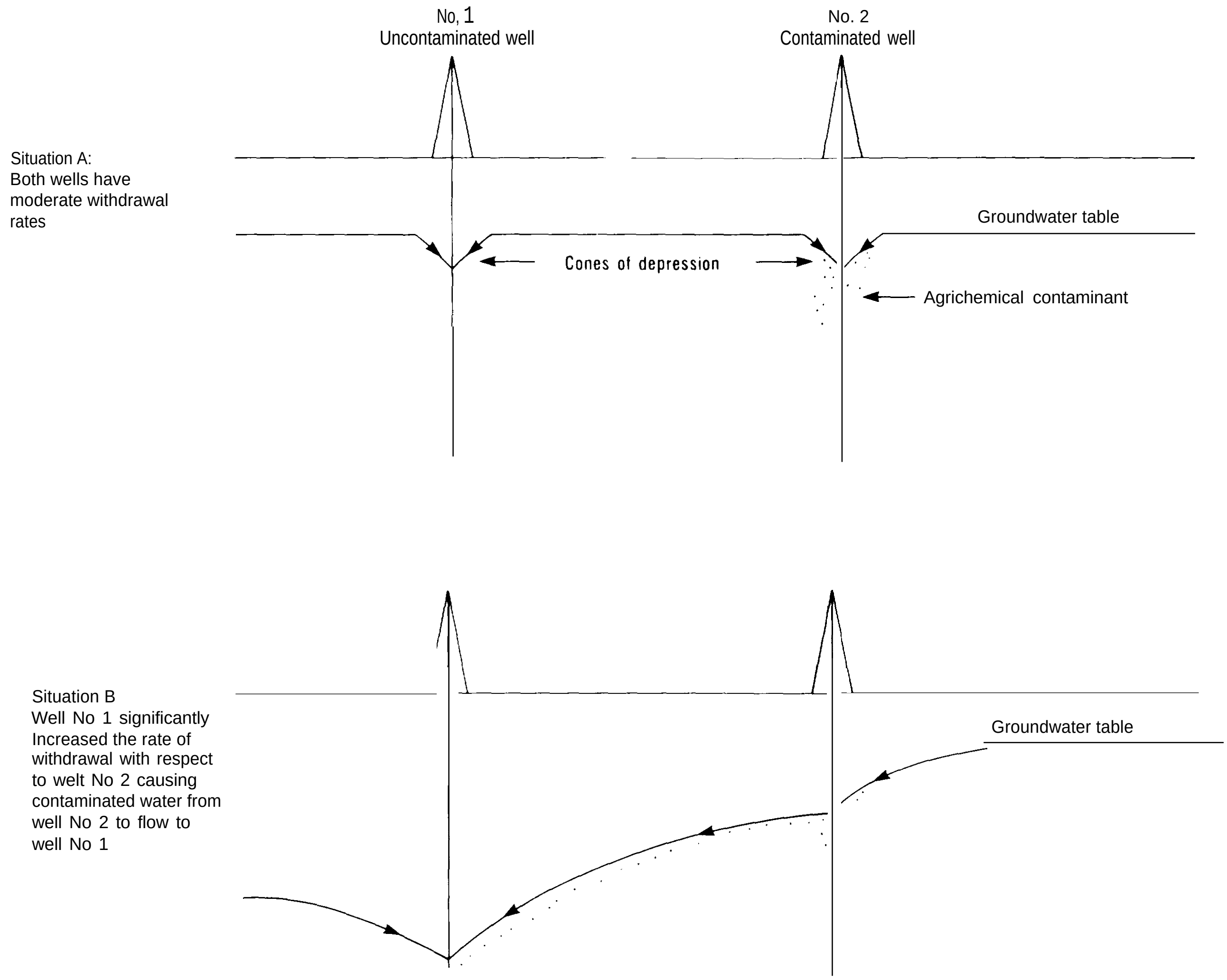
AGRICHEMICAL CHARACTERISTICS RELATED TO LEACHING

Characteristics of agrichemicals may be as important as site hydrogeological characteristics in predicting groundwater contamination potential. Agrichemicals vary in chemical structure, behavior and stability and, hence, in the extent to which they volatize into the air, are taken up by plants, disperse through the soil, degrade through chemical, biochemical, or photochemical action, or remain available for leaching through the soil (28).

Determining the probable fate of an agrichemical (it's "partitioning" among a variety of sequestration and degradation processes) is a complex process, but determination of certain key chemical characteristics helps scientists make such analyses (see table 3-2). In general, however, agrichemicals that are mobile and persistent, if used in hydrogeologically sensitive areas in sufficient quantities, have the highest probability of leaching to groundwater (16). Nitrate and certain pesticides have these characteristics (table 3-3).

Some studies suggest that nitrate might be used as a ''mwker' for potential vulnerability to pesticide

Figure 3-10-Cones of Depression Resulting From Water Withdrawal May Result in Contamination of Water Supplies Near Non-contaminated, Well-constructed Wells



SOURCE: Office of Technology Assessment, 1990.

contamination, although no study has shown a clear one-to-one link between the presence of nitrate contamination and pesticide contamination. In areas of Nebraska, at least, occurrence of high nitrate concentrations has been shown to be correlated with triazine-herbicide concentrations (71 ,84). Likewise, LeMasters and Doyle (38) found a significant association between wells in Wisconsin containing greater than 10 ppm nitrate and detectable levels of pesticides. However, the same researchers did not find a quantitative relationship between pesticide concentrations and nitrate concentrations. Similarly, the correlation was very weak in one two-county area of Iowa (39). Thus, in areas where herbicides are known to be used, nitrate might serve as an inexpensive test to identify areas potentially contaminated by herbicides (84), but more extensive data are needed for a broader correlation analysis.

Table 3-2—Some Chemical and Mineralogical Factors Commonly Considered When Assessing a Pesticide's Behavior and Ability To Leach[a] From Agricultural Lands

Volubility in water The amount of pesticide that will dissolve in water in part will relate to the pH of the water (pH is a measure of acidity).

Half-life/persistence: The time needed in the field for 50 percent of the pesticide molecules to degrade.

Stability in wafer The degree to which a pesticide resists hydrolysis (breakdown in water).

Volatility from the soil: A measure of how easily a liquid pesticide applied to the soil is able to change to a gas.

Octanol-water partition coefficient A laboratory test to determine the preference a pesticide has for fats versus water.

Photolysis The breakdown process of a pesticide when exposed to sunlight.

Ability to ionize: Whether the pesticide behaves as a cation (+), anion (-), zwitter ion (+ and -), or is neutral at various pH values in water.

Nature and amount of soil organic matter The biological breakdown products in a soil's A horizon (uppermost layer of a soil).

Clay mineralogy of the soil and underlying geological materials: The nature of the fine-grained minerals, some of which can bind pesticides tightly.

[a]Ability to leach (leachability) refers to the following pesticide property: when used in a normal agricultural manner under conditions conducive to movement, the pesticide moves down through the soil in quantities sufficient to be detected in nearby wells of proper construction.

SOURCES: D. Gustafson, "1989 Ground Water Ubiquity Score: A Simple Method for Assessing Pesticide Leachability," Journal *of Environmental Toxicological Chemistry,* pp. 339-357, unpublished paper; A. Moye, pesticide chemist, personal communication, December 1989.

A mobile agrichemical tends to move in the water phase without tightly adhering to soil. A pesticide would be considered mobile if its soil/water partition coefficient is 1 in a soil with 1 percent organic carbon (15). Pesticides vary widely in mobility. The pesticide paraquat, for example, is attracted to clay surfaces where it is held tightly whereas pesticides like picloram are repelled by the clay surfaces and can move freely through the soil (53). Atrazine, one of the most widely used agricultural pesticides, is only weakly held by the soil (30), and has appeared in the groundwater of at least 13 States (82).

Volubility can also affect a pesticide's mobility and fate. Highly soluble pesticides are more likely to be mobile and can move long distances with the natural flow of surface or groundwater. Plants can capture water-soluble pesticides along with soil moisture, potentially sequestering them in plant tissues. Pesticides that are not degraded by the plants may be re-released to the environment through crop residues remaining after harvest (14).

Table 3-3-Pesticides With High Potential for Leaching to Groundwater

Acifluorfen	Disulfoton
Alachlor	Diuron
Aldicarb	EDB
Aldicarb sulfone	Endrin
Aldicarb sulfoxide	ETU
Ametryn	Fenamiphos
Atrazine	Fluometuron
Baygon	Heptachlor
Bentazon	Heptachlor epoxide
Bromacil	Hexachlorobenzene
Butylate	Hexazinone
Carbaryl	Methomyl
Carbofuran	Methoxychlor
Carboxin	Metolachlor
Chloramben	Metribuzin
Chlordane-alpha	Nitrate/nitrite
Chlordane-gamma	Oxamyl
Chlorothalonil	Picloram
Cyanazine	Prometon
2,4-D	Pronamide
Dalapon	Propachlor
DBCP	Propazine
Diazinon	Propham
Dicamba	Simazine
1,2-Dichloropropane	2,4,5-T
cis-1 ,3-Dichloropropene	Tebuthiuron
tram-l ,3- Dichloropropene	Terbacil
Dieldrin	Terbufos
Dinoseb	2,4,5-TP
Diphenamid	Trifluralin

[a]Priority pesticides included in the EPA National Pesticide Survey of Drinking Water Wells, which includes testing for over 100 pesticides (general use, restricted use, or banned) or their breakdown products.

SOURCE: U.S. Environmental Protection Agency, "Pesticide Included in the EPA National Pesticide Survey," Apr. 14, 1988.

A persistent pesticide tends to degrade very slowly in the soil-water matrix. A pesticide with a soil-degradation half-life of 100 days would be considered persistent. Certain pesticides, such as DDT, can persist unchanged for long periods of time in the soil, and will accumulate over time if used regularly.

All else being equal, if agrichemicals resistant to degradation and only weakly interactive with soil particles are applied to widely-spaced, shallow-rooted row crops, where the water table is near the surface, there is great potential for groundwater contamination. If the same chemical is used on close-grown crops with deeply penetrating roots, the underlying aquifer may not be affected, particularly if it is confined. Chemicals that are more easily degraded in, or retained by soil materials, have less potential to reach groundwater than persistent chemicals that interact poorly with the soil.

SUMMARY AND POLICY IMPLICATIONS

Groundwater is one of the key components of the global hydrogeological cycle, as well as being an important resource. Whether pure or contaminated, groundwater can reside in some aquifers for thousands of years. Still, groundwater discharge (e.g., at surface springs, or into lakes, rivers, or the ocean) and recharge through rainfall eventually cycles water, and any contaminants it may hold, through most aquifers (14), Because groundwater recycles so slowly, over decades, centuries, or even millennia, and because the aquifers in which groundwater is contained lack the cleansing mechanisms of surface watersheds, a degraded aquifer may not recover at all in human time frame, The surest way of protecting groundwater is to prevent contamination at the source.

In areas characterized by many different soils and rocks it is extremely difficult to predict where, or how fast water-soluble pollutants will spread once they are underground and out of sight (40). Predicting the patterns of contaminant dispersal below the water table can be nearly impossible, particularly in geologically complex regions. Understanding the hydrogeology of a site is integral to determining the potential for leaching agrichemicals to groundwater (box 3-B), and therefore is imperative in identifying technologies that may reduce potential contamination.

Because of its close link to surface conditions and activities, groundwater must be considered a part of any agroecosystem. Agrichemical contaminants can invade groundwater as a result of a farmer's agrichemical handling or agricultural management practices, changes in land uses, or through poorly constructed or abandoned manmade holes or wells. Whether agrichemical contamination actually occurs depends on a large number of interactive physical, chemical, and biological factors. A systems approach to mitigate or eliminate such problems today is essential.

Different agricultural chemicals move through the environment at different rates. In some cases, low levels of detection may simply represent the forward edge of a contamination pulse that is working its way through the soil profile (35). Without expanded research efforts on the fate and transport of these chemicals, we will not know if these low levels indicate that there is nothing to worry about, or that the worst is just now coming (54). Clearly, repeated sampling of each aquifer, and testing for every agrichemical, would be impractical. Systematic procedures for monitoring, sampling, testing, and for data collection and management are necessary to identify critical site/agrichemical combinations (33).

Improving Data Collection and Management for Groundwater Protection

Numerous Federal agencies collect natural resource and land-use information relevant to prediction of potential agrichemical contamination of groundwater. An evaluation of the data collection, management, and coordination systems within Federal agencies is beyond the scope of this assessment. However, prediction of potential vulnerability, design of site-specific agricultural practices to mitigate that potential, and implementation of programs to reduce adverse impacts of agricultural practices will require extensive, detailed data and comprehensive, readily accessible information derived from that data.

It would clearly be advantageous for agricultural and groundwater scientists and policymakers to have access to relevant databases, including:

- climate data (National Oceanic and Atmospheric Administration and Agricultural Experiment Stations);
- topographical, hydrological, and aquifer mapping data (USGS);
- surface water quality and associated data (EPA; USGS);
- soil data (USDA/SCS);
- cropping patterns data (USDA/ASCS);
- nitrogen use data (TVA/NFERC);
- pesticide use data (USDA/NASS, USDA/ERS, EPA, and Resources for the Future);
- groundwater quality monitoring data (EPA, USGS); and
- data on hydrogeological vulnerability (USDA/ERS).

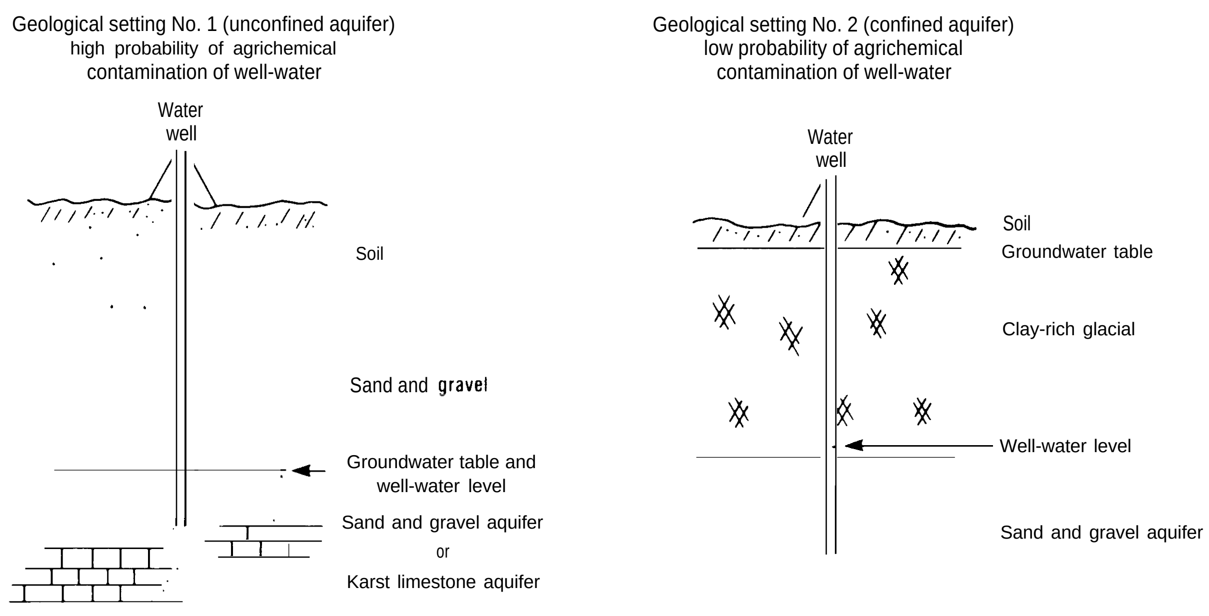
Other data not currently available in national-level databases, such as extent of tillage patterns or distribution of and waste production from livestock confinement facilities, would also improve decision-making.

Box 3-B—Using Hydrogeologic Information To Predict Sites Vulnerable to Groundwater Contamination: Minnesota's Groundwater Contamination Experience

Recent baseline field and laboratory research by Minnesota's Departments of Health and Agriculture (36,37) illustrates how hydrogeological information can be put to use in making a first approximation of the nature and magnitude of agrichemical contamination of groundwater resources. Researchers tested well water in two different settings: 1) where coarse-grained soils overlie either sands and gravels or limestone bedrock having well-developed solution channels and cavities, conditions thought to promote movement of contaminants to groundwater; and 2) where clay-rich glacial tills overlie sand/gravel aquifers, conditions thought to retard movement of contaminants to groundwater. Depth to bedrock generally was 25 feet or less in most wells but in some it was 50 feet. Most samples were taken intentionally from wells in geological setting number one, therefore the percentage of wells found contaminated with agrichemicals probably is higher than if samples had been taken randomly from both settings.

The assumption that "confined aquifers" underlying the clay-rich tills would be less likely to show contamination from agrichemicals than the groundwater in shallow, karst limestone environments and/or overlain only by coarse-grained soils and glacial sands and gravels (''unconfined aquifers") seems borne out by the field and laboratory work. The researchers found that, in general, pesticide contamination was higher in private wells than in public wells. The former normally are shallower and nearer to fields where pesticides are applied than wells used for public water supplies.

Pesticide contamination was common in the karst limestone region of southeastern Minnesota; most contaminated wells were not associated with obvious point sources of pollution. The fewest detections of aquifer contamination occurred where a thick layer of clay-rich till or other fine-grained materials separate surface contaminants fkom the aquifer.



SOURCE: Office of Technology Assessment, 1990.

Also playing important roles in whether a particular well showed contamination were the contamination source, the properties of the agrichemicals, local agrichemical practices, and well construction. These factors varied from well to well. However, the local hydrogeology seems to have played a lead role. Such determinations are likely to be repeated as further data on other sites become available.

Data Adequacy for Prediction of Agrichemical Contamination of Groundwater

Producing maps and developing three-dimensional displays to show where agrichemical contamination of aquifers is likely to occur in the absence of detailed data on soils, unconsolidated sediments, bedrock geology, and subsurface waters can lead to incorrect interpretations. It seems clear that the synthesis of such information is critical for assessment of where and when possible adverse impacts from agrichemicals might affect groundwater resources. Increased State and Federal activities in producing and presenting information depicting the Earth in three dimensions is highly important to understanding the nature of agriculture's impact on groundwater quality.

Status of Major Hydrogeologic Data Collection Efforts-The natural earth materials-soils, unconsolidated sediments, and bedrock-that contain groundwater are sometimes referred to as the "container" for groundwater. Characteristics of this container will determine the groundwater's direction of flow, its chemical purity, its residence time in the Earth, and a host of other variables. Therefore, it is important to know the status of the information base that currently exists to describe the "container." Data on topography, soils, and bedrock geology are fairly comprehensive, but detailed knowledge of the intervening unconsolidated sediments is less certain. Additional data continuously are being gathered at the State and Federal level to add to this knowledge base, but as yet may not exist in a published form. Synthesis of the major databases described below is starting to occur, but certain gaps still need to be filled.

Soils—The Soil Conservation Service has long striven to develop detailed maps of soils, topography, other site characteristics, especially as they relate to capability to support conventional agriculture. Today, soil maps for most States have been compiled. Soil data for some States have been digitized to allow for computer manipulation, and the other States are moving in that direction (figure 3-1 1). Digitized soil databases include SOILS-5 and SOILS-6 that describe soil characteristics and suitability for uses such as cropping, woodlot management, and certain types of development. SCS databases also include the progressively freer-scale Soil Geographic Data Bases, including National Soil Geography database (NATSGO) of soils data related to the major land resource areas (1 :7,500,000 scale), State Soil Geographic database (STATSGO) for ''general' soils mapping (1:250,000 scale), and Soil Survey Geographic database (SSURGO) presenting detailed soils data (1:15,840 to 1:31,680 scale) (8).

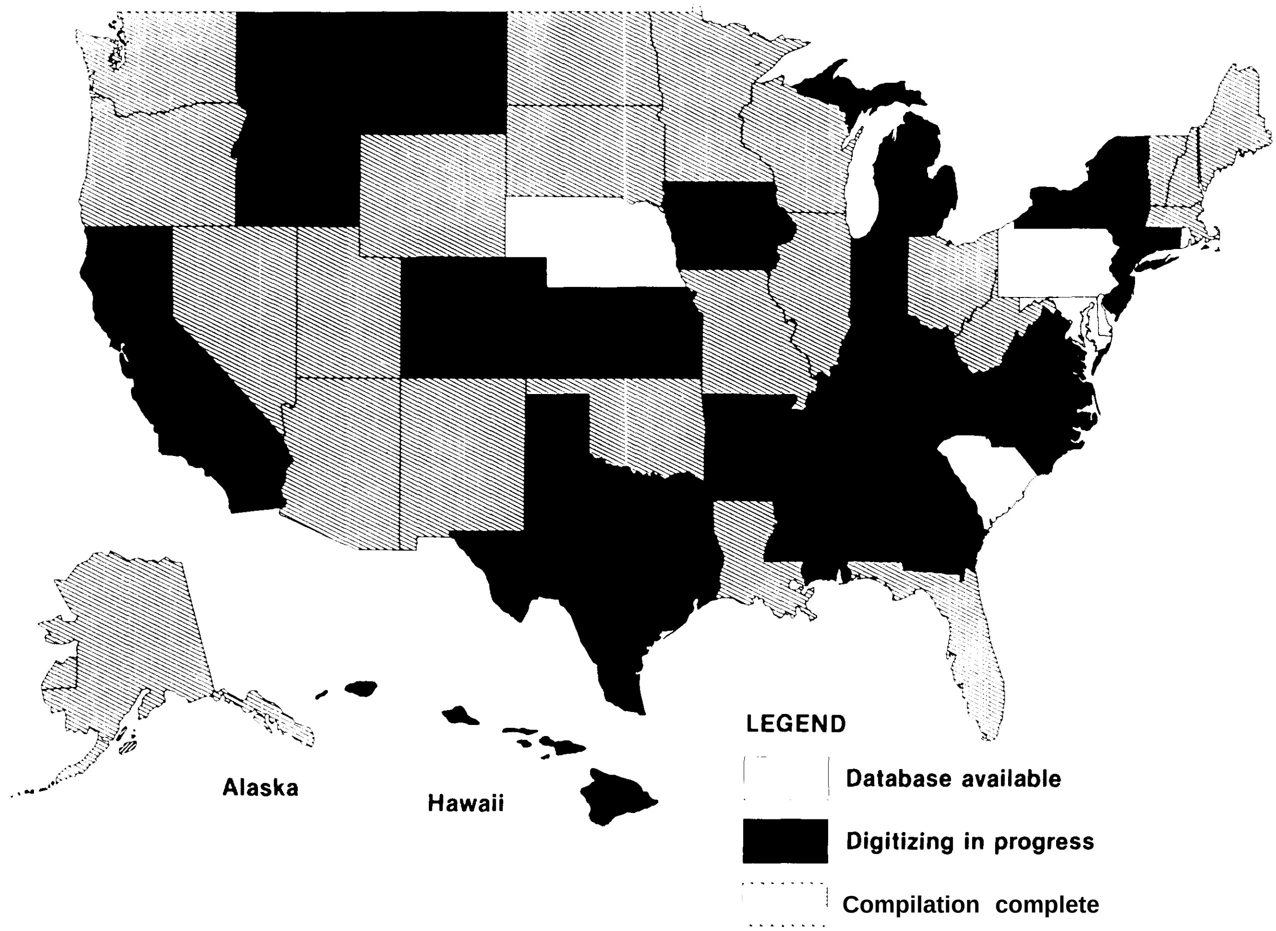
Geology ***and Topography-Each*** of the 50 States has produced a map showing the bedrock geology. The oldest State map is Ohio's, published in 1920; most other States have published maps produced between 1970 and 1980. A provisional bedrock geological map was prepared for Puerto Rico in 1964; few other U.S.-afffiated islands have been mapped. Most of these maps were published at a scale of 1:500,000; some at 1:100,000; Wisconsin and Nebraska at 1: 1,000,000; and Alaska at 1 :2,500,000. Even though some of these maps are old, detailed related information is continually collected and evaluated by each of the State geological surveys as well as the USGS (85).

Topographic maps are important to geological mapping and all aspects of land-use evaluation or planning. The Defense Mapping Agency will, in 1990, complete and publish the last 7½ minute scale topographic maps for all States except Alaska. Alaska is completely mapped in 15-minute quadrangles and, at this time, no plans to map at the 7½ minute scale have been made (85).

Unconsolidated Materials—Even though local soil and geologic maps showing the hard, subsurface bedrock may exist, little is known in detail of the makeup of the unconsolidated sediments lying between soil and bedrock in many States. This hinders efforts to collate information and predict vulnerable sites. Illinois is a notable exception. The Illinois State Geological Survey has developed maps showing the thickness of unconsolidated glacial sediments throughout the State (figure 3-12), and detailed lithological and mineralogical data exist for many glacial deposits there. Data are sufficient over much of this area to permit detailed, three-dimensional analyses of variations of the glacial lithologies. With this information at hand, Illinois is in the position to make reasonably sound estimates of where its groundwater and its aquifers might be vulnerable to agrichemical contamination.

The U.S. Geological Survey (USGS) is preparing a map based on data assembled from 850 sources that will show the extent, thickness, and gross lithology of glacial deposits in 28 glaciated States east of the Rockies (70). The map combines soil

Figure 3-n-Status of State Soil Geographic Databases

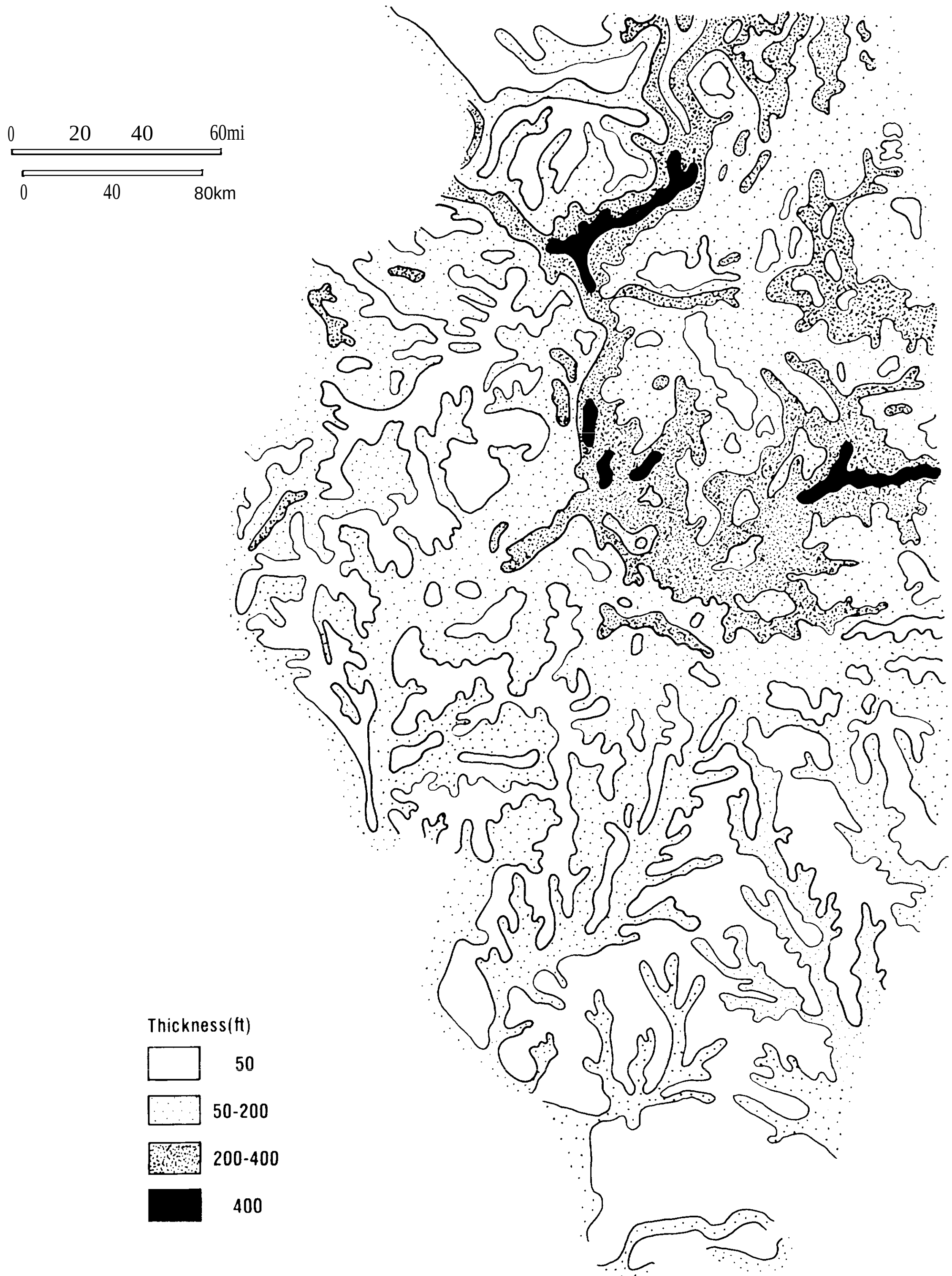


SOURCES: Adapted from U.S. Department of Agriculture, Soil Conservation Service, "Status of State Soil Geographic Databases (STATSGO)," map compiled using automated map construction with the FOCAS equipment, National Cartographic Center, Fort Worth, TX, revised November 1989; D. Goss, soil scientist, National Water Quality Technology Development Staff, South National Technical Center, Soil Conservation Sergvice, U.S. Department of Agriculture, personal communication, February, 1990.

data, glacial sediment data, and subsurface bedrock geological data into a three-dimensional geological picture, but published in a two-dimensional map called a ''stacked map. " Such three-dimensional depictions are useful for analysis of where potential agrichemical groundwater problems might exist. This new map will show for the first time the general nature of the glacial sediments covering this large region (69). The map shows that the thickness of the glacial deposits is 50 feet or less over much of the region but that broad areas exist that have at least 200 feet of sediment; in some cases, thicknesses may reach 1,000 feet or more. The thickest section of glacial sediments (1,200 feet) occurs in the lower peninsular of Michigan (68). Acceleration and expansion of efforts to produce maps showing information on unconsolidated sediments in greater detail is integral to predicting the fate of agrichemicals applied to the land, and to assuring that groundwater contamination is minimized.

Water Quality-EPA and USGS maintain water quality databases. EPA's REACH file is a digitized, graphical database of surface water attributes covering three-quarters of a million miles of the Nation's rivers, streams, lakes, bays, and estuaries. It was designed primarily to analyze pollutant movement in surface water bodies, and would require considerable expansion to include movement in groundwater. Associated with the REACH files are the EPA and USGS Water Quality Databases, which include

Figure 3-12—Thickness of Pleistocene Deposits in Illinois



SOURCE: R.C. Berg, J.P. Kempton, and K. Cartwright, "Potential for Contamination of Shallow Aquifers in Illinois," Illinois State Geological Survey, Circular No. 532, 1984.

Photo credit: U.S. Geological Survey

U.S. Geological Survey personnel have routinely collected groundwater data on water levels, total dissolved solids, and many inorganic chemicals in monitoring wells throughout the country. However, information has not been **collected** routinely on organic substances and other key chemical parameters.

approximately 40 million observations of chemical and natural attributes.

The USGS has a recently developed National Water Quality Assessment Program designed to assess water quality on a regional watershed/aquifer basis through joint monitoring of surface- and groundwater. The information collected includes: 1) source of agrichemicals, 2) rate of loading, and 3) where and how they are moving. Seven 2-year pilot studies based on the initial program proposal are nearing completion, and followup monitoring is planned to occur in 5 years. Further, the data collection program is based on drainage systems, not political boundaries. A pilot study just completed in Kansas and Nebraska provides a common data set for both States, and indicates that some agrichemicals are moving from Nebraska into Kansas surface waters (31). Full implementation of the Program would involve work at about 120 aquifer systems and river basins nationwide, covering about 80 percent of the water currently used in the United States.

Aquifers-The USGS also has had a Regional Aquifer-System Analysis (RASA) Program, in operation since 1978, to study the 28 major regional U.S. aquifer systems USGS has identified. To date, 14 studies have been completed (42). Objectives of the RASA programs are to ''define the regional hydrology and geology, and to establish a framework for background information-geologic, hydrologic, and geochemical-that can be used for assessment of local and regional groundwater resources" (83,42). The RASA studies use computer simulation to assist in the understanding of groundwater flow patterns, recharge and discharge characteristics, and effects of development on aquifer systems. The Program already has helped improve the matching of geologic and hydrologic data at State boundaries, and has developed numerous groundwater flow-models for regional use (83).

Integrated Natural Resource Information Databases—By congressional mandate, the SCS maintains a comprehensive survey of agricultural and related natural resources on 1.5 billion acres of non-Federal rural lands. Surveys have been conducted six times in the past 30 years, including the extensively detailed 1982 National Resources Inventory (NRI). The 1982 NRI consists of data collected from roughly 1 million individually inspected locations. Attributes evaluated included nearly 200 variables, such as land use and cover, conservation needs and practices, and irrigation water source. The NRI sample points (inspected locations) also are directly linked to the SOILS-5 databases described above (44). Because the data on multiple attributes were collected simultaneously for each sample point, this database allows analysis of associations between specific land use and resource conditions, whereas combined use of non-integrated databases using data generalized to an area (e.g., county) cannot.

Status of Agrichemical Use Data-Collection Efforts-Groundwater contamination potential is based on the combination of natural factors and type and intensity of agrichemical use or livestock waste application. While NRI data is collected to evaluate soil conservation efforts, no comparable information gathering process currently exists related to other resource conservation concerns (e.g., agrichemical losses to the atmosphere and groundwater) (19).

As a result of special appropriations in 1964, ERS provided a great deal of information on pesticide and fertilizer use from the mid-1960s up until the early 1970s, in order to provide a basis for determining costs and benefits of pesticides and to determine trends in pesticide use. However, the U.S. Government has drastically reduced its surveys of pesticide-use patterns in the last nine years: published information for the early 1980s is sparse and published pesticide-use data for the mid-1980s is almost nonexistent. Resources for the Future, a nongovernmental organization, has developed a national pesticide use database by compiling State- and county-level use data, but these data are based on average use estimates (26). Hence, we now have less specific knowledge of how farmers and other pesticide users are actually using materials than in the 1960s and 1970s (87).

USDA's Water Quality Program Plan developed in response to the President's Water Quality Initiative identifies the need for comprehensive national data on agricultural chemical use, related farming practices, and the links with the agroecosystem to assist Federal and State governments to ''assess the benefits, costs, and other effects of current agricultural practices and to evaluate consequences of alternative policies and practices for reducing any adverse effects of agricultural production on water quality" (78).

The Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS) are charged with the design of a continuous cycle of national surveys. The NASS plans to collect data on farm use of pesticides and certain other chemicals, and type of production practices. Farm survey efforts will cover field crops in major producing States as well as a range of vegetables in five large producing States (9). Statistical analyses are to be conducted by NASS and results summarized and disseminated by ERS. The first pilot test of this survey process is planned for a single crop in 1990 and will be expanded over a 3- to 4-year period to cover the other major commodities (78).

Rationalization of Data Collection and Management

Although many pertinent databases exist, in most cases they were created autonomously to address different fundamental questions. This hinders their use in predicting potential groundwater or aquifer vulnerability to agrichemical contamination. Myriad natural resource, land-use, and agrichemical-use factors combine to determine vulnerability to groundwater contamination, however, preliminary identification of regions exhibiting high association with agrichemical contamination of groundwater can be made.

Congress could direct USDA to correlate agrichemical-use data contained in the planned NASS Agrichemical-Use **Survey and the National Agricultural Census with EPA and USGS data on identified groundwater contamination problems to identify areas or regions with high apparent vulnerability to groundwater contamination.** Regions showing a high correlation between incidence of agrichemical contamination and intensity or type of agrichemical use could be designated target areas for intensified monitoring, and hydrogeologic research efforts. As data and data integration procedures improve, definition of highly vulnerable region can be refined.

Baseline information on current nutrient and pest management practices and continued information on changing agricultural practices will help policymakers assess the impacts of policy changes on groundwater quality, agricultural productivity, and the farm economy. Understanding of how and where the chemicals with greatest contamination potential are being used could assist in identifying pest control or nutrient problems that are in the greatest need of research and extension of alternate products or practices. Without such a clear link, research and extension may remain focused on issues unrelated to groundwater protection and associated environmental issues,

Although established, many extant natural resource databases are not readily accessible for users outside each agency, and may be of unusable format for integrated or geographically specific analyses. Moreover, no clearly defined Federal commitment has been made for provision of multi-use, national-scale maps and related geographic information for public and private users (50). Provision of information derived from these data probably would be of more use to agriculture and water quality decision-makers than the raw data.

Most legislation has dealt with parts of the total hydrogeologic system; only in the last several years have studies of how agrichemicals move through the larger environment been initiated. EPA is organized to address different components rather than the total ecosystem; its offices address air or water or groundwater rather than attempting to follow movement of particular contaminants through the entire environment. USDA and TVA have historically focused on the effect of agrichemicals on crop growth. Thus, they have studied the movement of these chemicals from site of application through the plant root zone, which usually is considered to be 6 feet deep (20). USGS traditionally has focused on movement of contaminants within the saturated zone, from the groundwater table down (60). Little research by these agencies has focused on the movement of contaminants between the root zone and the saturated zone. A Memorandum of Understanding between USGS and USDA has defined relative responsibilities of these agencies regarding such research, but few cooperative efforts have been initiated (54). Were this separation of research and data collection focus to continue, it would impede development of agricultural practices to reduce agrichemical contamination of groundwater in vulnerable areas, and would likely result in duplication of effort.

For example, a group of hydrologists might create a database that includes information on the movement of herbicides through the soil profile. They might measure parameters relevant to the chemistry and physics of chemical transport through the soil, but as hydrologists they may need to consult with soil scientists, and cropping system specialists to include measurements describing influences of tillage practice or crop types, information that would be critical to an agronomist trying to develop new cultural practices to minimize the movement of an herbicide out of the root zone (54). Preliminary consultation with potential database users could save substantial money and effort by adding measurements of a few extra attributes to the database.

Further, only some of the databases have been automated (entered into a computerized data management system), or "digitized" (entered into a spatial or geographically registered database in generic format) to allow ready transmission to users, easy manipulation of data for different decisionmaking efforts, or integration of different data sets to allow for more comprehensive analysis. In addition, the systems of information search and retrieval (manual or computerized) commonly are unique to each database system. Consequently, many data have been collected relevant to groundwater protection, but much is inaccessible or of unusable format for scientists from other agencies. Efforts are underway to define data-entry protocols and standard formats such that future databases might be more integrable (cf: 82,48).

Congress could undertake a number of mutually beneficial options to rationalize natural resource data collection and management efforts. Such efforts might include:

- accelerating extant hydrogeologic and agricultural land-use data collection efforts (e.g., SCS soils surveys, USGS RASA analyses);
- initiating additional data collection efforts to ensure comprehensive provision of information (e.g., used and abandoned well locations, State-level groundwater monitoring);
- accelerating digitization of data already collected by Federal agencies;
- mandating digital storage of all new, relevant land-use and natural resource attribute data collected by the Federal agencies; and
- requiring regular data updating, maintenance of databases, and cost-effective provision of data to users.

Furthermore, in order to ensure that the necessary information is collected for accurate Federal, State, and local decisionmaking to reduce agrichemical contamination of groundwater, Congress could encourage establishment of an interagency Technical Information Integration Group[3] that will determine what data is necessary, what data is available, who might collect data not presently available, and how data might be integrated to support non-technical decisionmakers and how data might be shared among public user groups.

Although the efforts listed above could be undertaken simultaneously and immediately, the costs of data collection and digitization can be enormous. Many data collected thus far are available only "manually," on maps or in tables, and thus must be transferred into computerized databases. Digitizing data is an expensive process. For example, the SCS estimates the cost of updating and digitizing soils data for the Nation at $200 million (72). Therefore, Congress might initially require the General Ac-

[3] A Technical Integration Group (TIG) is an interagency organizational structure designed to promote coordination and standardization at a technical level. At present, the only extant TIG is a three-tiered structure sponsored by the USGS including technical and administrative representatives of several Federal agencies, States, and academic research organizations. The tiers include four Strategy Teams comprised of researchers in certain topical areas, the Technical Integration Group of technical program managers, and a Headquarters Team of research administrators with authority to allocate research resources (59) [Ragone, personal communication Mar. 1990].

counting Office or a Federal interagency group (e.g., the Technical Information Integration Group) to evaluate the status and needs of data collection and management efforts specifically related to agrichemical contamination of groundwater, and to recommend specific steps to achieve a comprehensive, integrated system in the most cost-effective manner.

Coordination of Data Collection and Storage—Most Federal agencies have means to internally coordinate the information collected by that organization. Other systems have been developed to coordinate data acquisition and sharing of certain types of information. For example, the U.S. Geological Survey coordinates water resources data acquisition and data sharing activities among Federal organizations through its Office of Water Data Coordination (42). Coordination is accomplished among Federal agencies through a Federal Interagency Advisory Committee on Water Data and between Federal agencies and the States and private sector through a non-Federal Advisory Committee on Water Data for Public Use. While of immense use to those seeking specific information, such systems do little to improve integration of different types of data (e.g., integrating water data with soils and vegetation data) without specifications describing data detail, content, and accuracy.

Congress could require the creation of a coordinated database network, to ensure that the relevant agencies develop rational interfaces between extant databases and follow standardized data entry, format, and search protocols. **Alter**natively, Congress could aggregate all of the relevant databases into a single national database clearinghouse.[4] The Federal Interagency Coordinating Committee on Digital Cartography (FICCDC), was established in 1983 by the Office of Management and Budget (OMB) to facilitate coordination of 30 participating Federal agencies' digital information system activities and geographic information system activities and to establish standards for production of digital cartographic data (24). However, FICCDC has no authority to require that Federal agencies follow data protocols.

Further, the FICCDC has focused on thematic data collection, for example by recommending that the Soil Conservation Service be the lead agency on collection and management of digital soils information. It was not structured to assist in development of integrated databases, nor to coordinate data collection and management among Federal agencies and State and local information management systems or users (43). Any data management system also will need to be designed to accept data 'uploaded' from regions and States that likely will be collecting more detailed data related to crops, cropping systems, and hydrogeologic vulnerability than national efforts. Such a system would have capacity to aggregate information "upwards" to evaluate national trends and needs, providing a more accurate national picture than a random sample of a few points, as well as allowing resolution "down" to the local decisionmaking scale.

If all national-level natural resource and relevant land-use databases were transferable to a centralized organization, standardization of protocols and coordination among Federal, State, local, and private users might be simplified. Each Federal agency could maintain its own system, following formats for specific sets of environmental information set by the clearinghouse, but would periodically move their data to the clearinghouse.

However, some agencies may resist changing their own systems to accommodate outside users. Further, agencies may be reluctant to house all of their information within a separate organization, especially if it is part of an established agency.

If Congress wishes to focus solely on groundwater and agricultural production, the central database clearinghouse might be located within the Soil Conservation Service or at the National Agricultural Library. But if Congress prefers to address database integration for a broader array of agricultural/environmental issues, it may be preferable to create a separate office for environmental data acquisition, integration, and management (54). Such an office could be established with a ''neutral' data collection agency (e.g., USGS), within a central governmental unit such as the Council on Environmental Quality, or as a new part of the Department of Environmental Protection. Wherever located, the agency components of the system could remain

[4] A variation on this concept would be the creation of a ''universal computer search program.'' Rather than learning the computer language or search protocol of each database, or wait until the information is transferred to a national clearinghouse, individual inquirers could access an interactive search program that would ask them a series of questions. On the basis of the answers, the program would ''dial-out' to the appropriate databases and retrieve the relevant information (54).

housed within the agencies, but the central office would provide the integrating structure and mandate.

Coordinating Agroecosystem Simulation Modeling

Data are collected and managed to help make decisions. A working model of the world—whether a formal computer paradigm or an informal set of assumptions—is used when decisions are made.

In the case of groundwater management, as well as other environmental issues, the number of variables and parameters of concern are so numerous and the interactions between these factors so complex that there is an increasing reliance on computer models[5] (cf: 52). Computer modelers, in turn, are discovering that environmental modeling has become a large and complex undertaking. Consequently, discussions are underway regarding the development of "modular modeling. ' Individual researchers and teams develop the particular models for which they have interest and expertise, but build the "input" and "output" components of their models according to agreed upon standards so that other scientists can incorporate models without having to repeat work that has already been done by others.

For example, one scientist could develop a model of nitrogen movement through the soil, another could develop a model of how plants absorb nitrogen from the soil, another could develop a model on nitrogen volatilization, and yet another could develop a model of how nitrogen leaches through the soil profile to groundwater. Left as individual projects, these models would not be able to help answer questions on how to balance nitrogen fertilizer applications so as to ensure healthy plant growth while protecting groundwater resources. However, if the models are developed according to agreed on standards, an integration team could concentrate on the interactions of the models and put them together into a comprehensive nitrogen management model.

Congress could require that the U.S. Department of **Agriculture, perhaps jointly with other agencies, evaluate current simulation modeling efforts related to the environmental fate of agrichemicals.** Based upon this analysis, a Technical Agroecosystem Modeling Integration Group (TAMIG) could be established to coordinate research and development of computer simulation models related to the environmental fate of agrichemicals in farming systems. Such a TAMIG should include the technical program managers from relevant Federal agencies undertaking such modeling efforts (e.g., USDA, EPA), State government and academic specialists, and might include members of the environmental and agricultural research community.

One goal of such a group might be to ensure development of simulation models that can be generalized, through agreed upon means, to allow prediction of environmental fate on sites with different hydrogeology or agricultural systems. Another goal might be to coordinate development of detailed simulation models of certain parts of hydrogeologic systems (e.g., the Pesticide Root Zone Model developed by EPA or the Groundwater Loading Effects of Agricultural Management Systems model developed by USDA/ARS) so that they may be "hooked" to simulation models of other parts of hydrogeologic systems to allow more comprehensive analysis. USDA/ARS has used this approach in developing NTRM, a Soil-Crop Simulation Model for Nitrogen, Tillage, and Crop-Residue Management (65).

Developing Geographic Information Systems

Geographic Information Systems (GISs) are computer-based technologies including hardware, software, and graphics capabilities. More than automated mapping systems, GIS can encode, analyze, and display the natural and built environment in multiple ''layers' that are geographically registered to unique locations on the Earth's surface. Results of GIS analyses can be described in reports, tables, and most importantly, in maps at any scale.

Relationships between data can be used to depict complex variables such as hydrogeologic vulnerability to agrichemical contamination as well as spatial displays of component simple variables such as average depth to water table. Further, GISs are capable of displaying "option" variables, such as the percentage of lands eligible for the Conservation Reserve land-retirement program that coincide with areas containing hydrogeologically vulnerable cropland. By using GIS, the decisionmaker can alter

[5] For detailed discussion of groundwater models, see National Research Council, Water Science and Technology Bored, Committee on Ground Water Modeling Assessment, *Ground Water Models: Scientific and Regulatory placations* (Washington DC: National Academy Press, 1990).

variable components and test the impacts of decision alternatives before enacting new provisions. Given adequate and reliable data, and a sufficient understanding of the pertinent variables and their interactions, GISs provide a rapid means to assess where efforts might be allocated to have the greatest beneficial impact, or whether proposed policy options have potential to solve problems.

Databases and Systems

The first requirement for a GIS is spatially coordinated, geographically registered, digitized data: data transferred **into a** computer so that it is electronically associated with known geographic coordinates (unique locations on the Earth's surface). Then, using those coordinated layers, other geographic information can be added and attributes or characteristics of those geographically referenced locations can be described by the computer in graphic colors, textures, and shapes as well as numbers. For example, a county might have attributes including 1990 population, amount of agrichemicals used in a year, or wheat production in bushels per acre. A well shown as a point on the map may have attributes including depth to bedrock, nitrate concentration, or yield of water in gallons per minute. A stream shown as a curved line at a particular location may have a known flow rate, sediment loading at certain times, or average numbers of bass.

Some of the most important databases for assessing potential groundwater vulnerability to agrichemical contamination are digitized soil and geologic data at National, State, and local levels. SCS is in the process of digitizing soil surveys; however, digitizing all soils data, collected at the county level, for the Nation will cost nearly $200 million. This estimate includes $100 million for updating, recompiling, and establishing the geographic referencing system for soil survey data, and $100 million for digitizing (72).

Dearth of Federal funding has led a number of States to proceed with digitization on their own; however, some are not using the protocols proposed by SCS or USGS so that State-level 'pieces' are not likely to be easily assembled into a national system (54). On the other hand, EPA has moved to provide digital surface-water networks—another important data layer—based on USGS hydrography data at a relatively detailed, but still national scope. How and whether this database, known as the ''Reach File, '' together with associated Water Quality Assessment data and systems will be freely available for GIS users outside the agency is not yet clear (43).

Approaches to using GIS to describe vulnerability of surface- and groundwater should:

- Integrate gee-referenced overlays of natural resource information such as geology, subsurface hydrology, and terrain from USGS; soils from SCS; and surface hydrography from USGS and EPA.
- Incorporate agricultural land use variables for agricultural vulnerability assessments, including cropland and individual crops and cropping systems, vegetative cover, climate, pesticide and chemical use, and irrigation practices.
- Incorporate derived variables such as: 1) meaningful hydrogeological units, *2)* watershed units based on elevation and terrain data, and 3) surface stream and river networks that route water-borne contaminants through watersheds (this information should include associated water quality information including well and water samples, and the location of water intake sites for community water supplies).
- Develop or use existing GIS capabilities to manage and display the information, including maps of hydrogeologic parameters of particular concern to groundwater management.
- Identify needed information and databases that do not yet exist (54,43).

GIS Users

GIS for surface- and groundwater assessments have been developed and used for some time by certain Federal agencies, such as USGS, private organizations concerned with natural resources such as the newly established National Center for Resource Innovations, many State agencies, and some Agricultural Experiment Stations and Land Grant Universities such as Minnesota (7).

USDA, EPA, and others are showing increasing interest in these systems and have included proposed uses of such systems in their planning documents (cf: 78). A survey of Federal organizations using or intending to use GISs found at least 37 used GIS in 1988, 20 plan to have an operational GIS by 1990, and 10 others have developed policies related to GIS (24). For example, the NASS is planning to develop a GIS to support USDA's water quality program plan. The proposed system will link nationwide data and statistical information on agricultural productivity, cropping practices, land use, agrichemical use, physical attributes of the land and surrounding watersheds, climate and water quality (9).

Perhaps the greatest need for GIS development, however, lies at the local level where detailed information is most extensive. A 1985 survey conducted by the American Farmland Trust found that approximately 22,000 non-metropolitan rural governments have authority to allocate 1.5 billion acres of non-Federal rural lands and resources in 3,041 counties, 16,000 townships, 6,000 natural resources special district governments. Only 25 of these governments had operating GISs (4). That number is rapidly increasing; today it is estimated that approximately 1,000 urban and rural local governments use GISs.

Current Programs for GIS Support and Delivery

To assist with GIS research and development, the National Science Foundation recently established the National Center for Geographic Information and Analysis to: 1) serve as a clearinghouse on GIS research, teaching, and application; 2) promote use of GIS analysis and train users; and 3) study the legal, social, and institutional aspects of GIS (12). To assist with GIS technology delivery to primarily non-technical local, regional, and national decisionmakers, Congress has funded the National Center for Resource Innovations (NCRI). NCRI is a consortium of regionally distributed GIS technology transfer centers whose objectives include: 1) encouraging the use of established specifications and standards for data development, quality, and applications; 2) coordinating technical assistance from public resource specialists in interpretation and use of information in GIS systems; 3) developing training programs; 4) delivering GIS technology research; 5) supporting and identifying needed GIS development in the applications and decisionmaking environments; and 6) developing GIS into education tools for public decisionmakers and the public.

Approaches to GIS Assessment of Groundwater Vulnerability to Agricultural Land Uses

Two key impediments exist to GIS development for non-technical decisionmakers concerned with water quality protection at all levels of government. These are: 1) lack of needed data; and 2) difficulty integrating information from many sources at scales suitable for local, regional, and national assessments.

Congress could mandate development of interagency GISs for management of groundwater protection.[6] A first focus could be on completing and digitizing soil survey maps developed by the Soil Conservation Service. This should be extended to all data sets identified as important for water quality assessment and protection. To assist with this, data sets developed outside Federal agencies might be encouraged to meet specifications and standards established by agencies with lead responsibility for collecting and interpreting the data. Such an effort could be coordinated through current OMB/FICCDC efforts to ensure orderly GIS development within Federal agencies, or could be assigned to a concomitantly expanded Council on Environmental Quality. Development of such a system also could be handled through a centralized Office of Environmental Data Acquisition, Integration, and Management mentioned earlier.

A comprehensive and carefully developed approach to provide an "open architecture" GIS—allowing users to combine databases with new data and add models as well as interpret interrelationships-could eventually lead to integration of national-level databases into geographic information of specified accuracy and scientifically supportable applications (43). By being "open," such a "core" GIS could allow incorporation of decision support, and expert systems to provide a powerful and accessible information management system. Such a system could also be developed to allow regional and local levels of detail to be added together with regionally appropriate factors including local climate, cropping systems, chemical use, location of livestock confinement facilities, watershed characteristics, and other regionally specific factors. A core GIS might provide a model for local systems and could assist in integrating national-level databases, Geographic Information Systems, and expert systems into powerful information management and decision-aid systems. These, in turn, could foster development and integration of voluntary, incentives-based, and regulatory systems to protect groundwater (54).

[6] Digitized databases also can support development of computerized farm decisionmaking aids, such as ''expert systems' (see ch. 5).

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Chapter 4

Technologies To Improve Nutrient and Pest Management

CHAPTER HIGHLIGHTS

- U.S. agriculture has become highly specialized and is unevenly distributed across the country. Potential for agrichemical contamination of groundwater probably is strongly associated with certain farming systems, and with intensity of use in those systems.
- A variety of technological opportunities exist for reducing agrichemical contamination of groundwater within the general categories of: 1) improved point source controls, 2) improved agrichemical efficacy and application, 3) agrichemical use reduction, and 4) nonchemical alternatives. Farming systems designed to reduce the potential for agrichemical contamination of groundwater are likely to use a combination of technologies within these categories.
- Nutrients must be added to any cropping system intended to remain productive; however, the source and amount of nitrogen (the plant nutrient of concern to groundwater contamination) added may vary widely. Because nitrogen is part of a natural cycle, reducing loss of nitrogen as nitrate from soil systems through careful management is the primary means of reducing nitrate contamination of groundwater.
- Control of agricultural pests may be accomplished through chemical or nonchemical (biological and cultural) means, with varying and largely uncertain effects on productivity of farming systems. However, these technologies generally are not mutually exclusive such that, while chemical controls will likely continue to be an important element of pest control systems, managing whole farming systems to reduce potential for infestations and implementing of least potentially hazardous techniques can aid in pest control without unacceptable loss of yield or income.
- Although technologies related to use and management of nutrients and pesticides clearly are relevant to reducing the potential for agrichemical contamination of groundwater, these elements of a farming system cannot be separated from consideration of crop, soil, and water management components of farming. All interact, and thus in combination have potential to reduce potential agrichemical contamination of groundwater.
- Ultimately, the quality of and attention to management of a farming system is the most important factor in enhancing the efficacy of external inputs, and reducing waste in agricultural production. "Integrated farm management" decisionmaking will form the basis of successful systems.

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Chapter 4

Technologies To Improve Nutrient and Pest Management

INTRODUCTION

The agricultural sector has provided food, clothing, and shelter for the increasing U.S. population as well as contributed to global food security. This increased productivity has resulted from significant scientific research and application of improved technology ranging from the development and use of agrichemicals to current trends in biotechnology research and development. Advances in plant breeding using germplasm from native and exotic species have contributed to yield enhancement and stress tolerance of major crop plants, Similarly, research on pest-control methods and irrigation developments have made significant contributions. However, increasing concern exists that the costs of these advances may be greater than expected, particularly with respect to potential adverse effects on the environment and thus on future productivity of the land (8).

Many agricultural production approaches seem to have been developed without consideration of the fundamental linkages among components of the agroecosystem (73), often neglecting potential interactions or transformations within the agroecosystem. It is difficult, if not impossible, to account for all of the natural site characteristics and agricultural practices (agrichemical application rates and methods, tillage and surface shaping, cropping arrangements) that interact to determine groundwater vulnerability at a given site. However, certain patterns have emerged in groundwater contamination, which suggest that packages of agricultural and site-specific parameters strongly influence groundwater vulnerability. For example, atrazine, a nonvolatile and widely used herbicide, has been shown to leach at variable rates depending on the soil, geology, and agricultural practices of different regions. Leaching was less prevalent in silty clay and clay loam (nonirrigated) soils in Pennsylvania than in irrigated permeable soils in Nebraska (87).

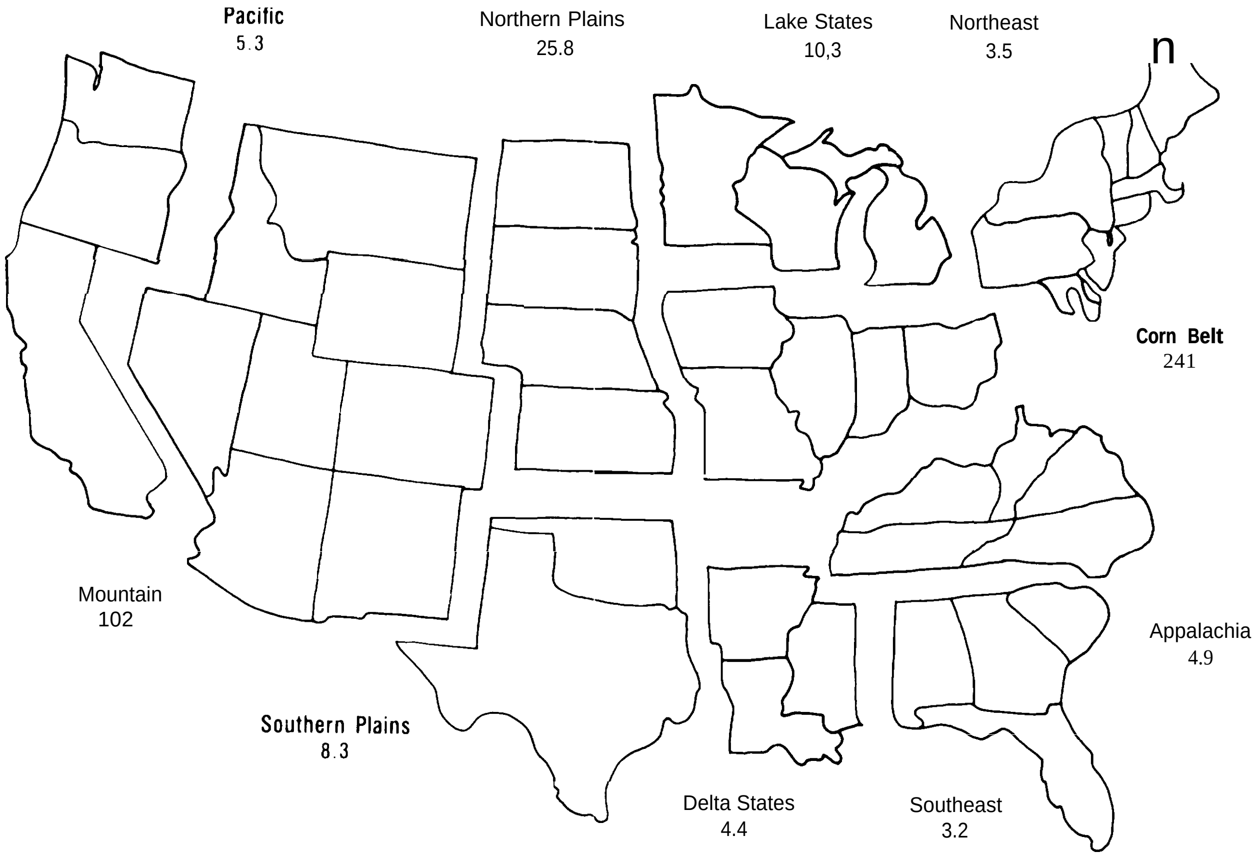
Ultimately, the quality of management maybe the factor of greatest importance in reducing the potential for agrichemical contamination of groundwater from agricultural production practices. Irrespective of the nutrient source, overapplication may occur in the absence of proper soil-testing and application methods. Similarly, inappropriate timing of application or unsuitable application methods may easily offset any environmental benefits that might be realized from reducing pesticide applications.

Agricultural production often depends on manipulation of numerous agroecosystem components and application of a broad variety of technologies. An agroecosystem refers to the blend of biological and physiochemical features (e.g., soil, water, nutrients) as they are modified by agronomic practices (e.g., tillage and cropping systems, and agrichemical inputs). The interactions of these local features give rise to highly diverse site conditions such that no two agroecosystems are identical. Similarly, farming systems are diverse in terms of crops, cropping patterns, and management systems (figure 4-1; box 4-A). Given the variability of agroecosystems and farming systems, effective approaches to reduce groundwater contamination from agricultural practices will need to be flexible and equally diverse. For example, cover crops may offer a mechanism for uptake of residual soil nitrate in humid regions; however, in dry regions where nitrate leaching potential is less, this practice may only create a soil moisture deficit for subsequent crops.

In addition to nutrient and pest management practices, potential for agrichemical contamination of groundwater may also be influenced by crop, water, and soil management practices. Cropping pattern and cultivar choice may directly affect the need for agrichemical use. For example, legume-based crop rotation systems may provide nitrogen for subsequent or interplanted crops as well as interrupting development of pest populations. Irrigation scheduling designed to reduce deep percolation may concurrently reduce chemical movement. Tillage systems (e.g., no-till v. conventional) may have a profound effect on agrichemical needs, and on the rate, timing, and method of agrichemical application.

The suite of farm management decisions are not made in isolation, rather they interrelate to such an extent that whole farm management becomes an integrated approach to managing the agroecosystem. Opportunities to reduce the potential for agrichemi-

Figure 4-l—Percentages of Cropland Used for Crops by Region, 1989



SOURCE: Adapted from U.S. Department of Agriculture, Economic Research Service, "Cropland," *Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report,* AR-16, September 1989.

cal contamination of groundwater arising from agronomic practices center largely on:

- improved point-source controls (e.g., mixing, loading, storage, and disposal practices);
- improved agrichemical efficacy and application (e.g., selective chemicals, enhanced efficiency in application equipment);
- agrichemical use reduction; and
- use of nonchemical practices (e.g., biological pest control, crop rotation, cultivation).

Improved point-source controls focus on management practices and physical facilities for agrichemical storage, mixing, loading, and residue disposal, and on livestock-waste management. Agrichemical spills and leaks at commercial facilities have been responsible for numerous detections of chemicals in groundwater (74). Certain on-farm agrichemical handling practices present similar, if smaller scale, threats to groundwater. Frequent handling of large volumes of chemicals at mixing and loading sites increases the risk of groundwater contamination at these points. Point-source contamination also may involve direct conduits of agrichemical entry into groundwater, such as abandoned wells, sinkholes in karst areas, or back-siphoning during mixing.

Improved agrichemical efficacy and application may involve using more selective chemicals, improving rate and timing of agrichemical applications, and using improved application methods or equipment. Agrichemical efficacy has increased over the last several decades, allowing significant reduction in the amount of active ingredient applied per acre. However, little advantage is gained in using more effective products if they do not arrive at the target. Recent trends toward lower application rates of pesticides and plant nutrients require more application precision than was necessary even a decade ago (73,60).

Box 4-A—Regional Diversity of U.S. Agriculture and Agrichemical Use

Approximately **50** percent of all cropland under cultivation in **1989** ***was*** located in the Corn Belt and Northern Plains States. These States encompass a large land area devoted to crop production and include Iowa and Illinois, the two States ranked highest in volumes of fertilizer and pesticides used (62). The Corn Belt also is the only area to expand its regional share of the nation's cropland during the 1980s (227), probably due to uneven distribution of land idled under Federal conservation programs.

Certain characteristics of agricultural production regions have implications for the degree of agrichemical use. Areas with longer growing seasons, and areas that do not experience significant cold winter seasons or other conditions conducive to pest eradication are more likely to maintain pest populations, For example, crop production in the warm, humid Southeast tends to require relatively larger amounts of pesticides than crop production in the Northern United States (62).

The relative amounts and locations of land devoted to different types of crops also influence overall agrichemical use. Corn, for example, requires comparatively larger amounts of agrichemical inputs per acre than other field crops; thus corn acreage accounts for the greatest percentage of fertilizer and pesticide use (228,62). Most U.S. cropland acreage is used for production of wheat, corn, soybeans, cotton, rice, and feed grains such as sorghum, barley, and oats. In 1989, these crops were grown on 75 percent of the 342 million acres of U.S. cropland under cultivation (227,228). (See tables 4-1 and 4-2.)

Each year, USDA estimates the proportion of acreage treated with commercial fertilizers for corn, cotton, soybeans, wheat, rice, and potatoes. Average nutrient application rates also are estimated. Overall, an estimated 20,5 million tons of plant nutrients were applied in the 1988-89 crop year (228). U.S. agricultural producers use an estimated 661 million pounds of pesticide active ingredient annually (62).

Table 4-1—U.S. Fertilizer Application Rates (pounds per acre)

Year	Corn			Wheat			Soybeans			Cotton		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1965	75	50	48	31	30	35	10	32	39	81	55	57
1970	112	71	72	39	30	36	14	37	51	75	55	57
1975	105	58	67	46	35	35	15	40	53	78	50	55
1980	130	66	86	58	39	40	17	46	70	72	46	46
1985	140	60	84	60	35	36	15	43	72	80	46	52
1988	137	63	85	64	37	52	22	48	79	78	42	39

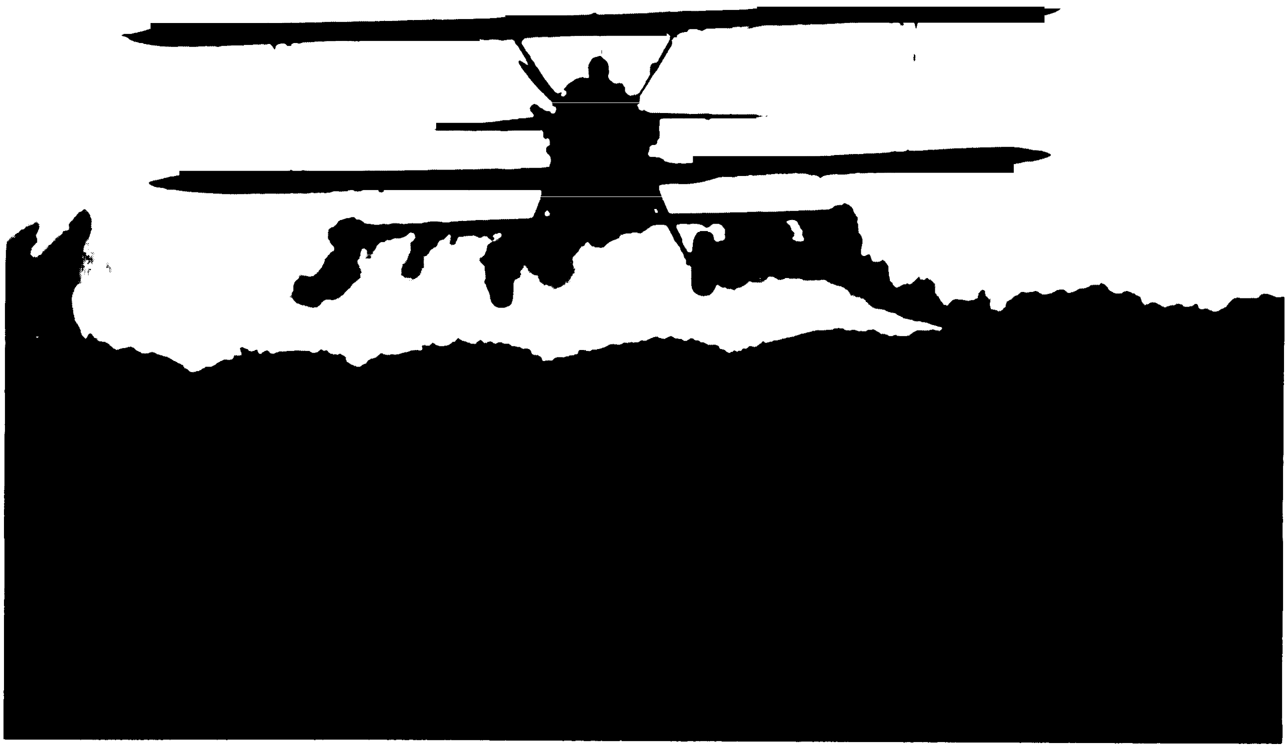
SOURCE: U.S. Department of Agriculture, Economic Research Service, ***Agricultural Resources: Inputs, Situation and Outlook***, AR-15 (Washington, DC: U.S. Government Printing Office, August 1989),

Table 4-2—Projected Pesticide Use on Major U.S. Field Crops, 1989

Crops	June 1 Acres	Herbicides	Insecticides	Fungicides
	Million	Million pounds		
Row:				
Corn	72.8	219	27.1	0.06
Cotton	10.5	16	15.6	0.16
Grain/sorghum	11.9	11	1.9	0.0
Peanuts	1.7	6	1.3	6.19
Soybeans	61.3	108	9.5	0.06
Tobacco	0.7	1	2.7	0.35
Subtotal	158.9	361	58.1	6.82
Small grains:				
Barley & oats	21.4	5	0.2	0.0
Rice	2.8	12	0.5	0.07
Wheat	76.7	16	2.2	0.88
Subtotal	100.9	33	2.9	0.95
Total	259.8	394	61.0	7.77
1988 total	243.4	372	59.7	7.56

NOTE: June 1 planted acreage for the 10 major field crops increased from 243 million acres in 1988 to 260 million. The area planted to corn, grain sorghum, soybeans, tobacco, and wheat went up whilecotton, barley, oats, and rice declined. Peanuts remained constant,

SOURCE: U.S. Departmentof Agriculture, Economic ResearchService, ***Agricultural Resources: Inputs, Situation and Outlook***, AR-15 (Washington, DC: U.S. Government Printing Office, August 1989).



credit: vironmental tec ency—Charles 'Rea

Only 1 to *2* percent of pesticides used in agriculture are estimated to reach the target pest; the remainder of the volume applied is lost to the environment, and represents a financial loss to the farmer. These losses can be reduced by improving the efficacy of chemicals and of application equipment and methods.

Appropriate timing and placement of agrichemical applications may facilitate their uptake and use by plants or affect their effectiveness against pests and, thus, reduce potential for loss via leaching, volatilization, or other environmental pathways. Similarly, improvements in application methods may allow achievement of a desired yield response with fewer agrichemical inputs. For example, rather than applying an insecticide to an entire field or farm, pheromone baits may be used to lure insects into a few insecticide-treated areas.

Agrichemical use reduction may involve using a variety of techniques, including more efficacious agrichemicals and application methods, cropping patterns that break pest cycles, crop cultivars with greater resistance to pest infestations, and improved management of agrichemical inputs. In addition to these approaches, establishing and understanding of pest tolerance levels (i.e., pest-free fields may not be economically optimal) may contribute to reduced agrichemical use. Adaptive research to establish agrichemical application rates and procedures for site-specific use might identify reduced agrichemical doses under certain conditions while maintaining economic yields.

Nonchemical practices to control pests and supply plant nutrients may be used exclusively (e.g., organic farming[1]), in preference to agrichemical use

[1]Organic farming was defined by USDA as a production system that avoids or largely excludes the use of synthetic fertilizers, pesticides, and other farm chemicals. Organic systems tend to rely on such inputs as crop residues, green- and livestock manures, legumes, crop rotations, mechanical cultivation and biological pest control to supply plant nutrients and control pest populations (218).

(e.g., low chemical input farming), or in combination with agrichemical use (e.g., integrated pest management). Farming practices that do not rely on agrichemical inputs can be productive; however comparative economic analysis is lacking (136). These production systems commonly depend on crop rotations, biological pest control, nutrients from livestock waste or green manures, and greater management attention.

Management practices within each of these categories can be implemented as individual Best Management Practices, or as components of integrated farming systems. Development of comprehensive agrichemical management systems or whole farming systems" could provide the basis for addressing pest and nutrient management in a coordinated fashion that minimizes adverse environmental impacts. Systems approaches designed to operate in concert with existing natural processes are likely to result in decreased agrichemical needs.

Current on-farm management activities that are linked to agrichemical use and thus affect the potential for agrichemical contamination of groundwater fall into four general categories: nutrient management, pest management, crop management, and soil and water management. Opportunities to reduce agrichemical losses to groundwater exist within each of these categories, and while singly their contributions to resource protection may be small, collectively they may offer significant benefits.

Agricultural researchers have provided U.S. farmers with a wide array of technologies that, when implemented properly, can help minimize groundwater contamination by agrichemicals. Some of these technologies are in operation on farms today; some familiar ones from the past are being re-adopted. Others need modernization or are undergoing research and testing, and still others remain conceptual. What their combined impacts may be is not yet known. What is known today, though, is that "old' and ''new" technologies are less likely to be viewed separately in the environmental setting of the farm than in the past. The view today increasingly is one that recognizes farming activities as part of the overall environment: the agroecosystem.

This view recognizes the importance of working within the framework of the hydrologic and other natural cycles if groundwater contamination from agrichemicals is to be prevented. This systems approach is evidenced by current efforts such as *Integrated* Pest Management, *Integrated* Farm Management Systems, *Integrated* Crop Management, and the Farmstead Assessment program. It is within these systematic approaches that new technologies will find their role. It is unlikely that one particular technological "black box" will be found to solve the agrichemical/groundwater contamination problem.

"Good housekeeping, " involving careful storage, handling, and use of agrichemicals, can play an important role today, and already is doing so on many farms. Farmers are conscious of the large role economics plays in their survival and, therefore, minimizing waste of important agrichemicals makes good sense. Additional opportunities exist to find new uses for old ''wastes,' like manure and sludge, which can turn these from wastes to resources.

Central to the successful application of technologies is the understanding that the physical situation changes from one farm site to another, e.g., soils, geology, and topography. Because of this, technologies, packages of technologies, or systems involving technologies have to be adapted to the local conditions at the farm site. Finally, whatever approach is used ultimately rests with the farmer.

NUTRIENT MANAGEMENT

Addition of nutrients to a cropping system is an accepted axiom of agricultural production. Agricultural products, whether plant or animal, remove nutrients from the land on which they are produced. For example, corn production in the United States is estimated to remove nearly 5.7 billion pounds of nitrogen annually. Hawaii exports 2,200 tons of potassium each year in its pineapple crop alone (212), Even well-maintained organic farms that carefully collect and return crop residues and livestock wastes to the soil do not replace all of the soil nutrients without external inputs or through rapid weathering of soil minerals.

Nutrients also are removed through a number of other natural processes, including erosion, leaching, and volatilization. If the nutrient supply is not replenished, soil fertility decreases. Management practices attempt to avoid limiting crop growth by ensuring that sufficient nutrients exist in the soil, or are applied, and that excessive nutrient losses to other media do not result.

Box 4-B—Phosphorus and Potassium: Potential for Movement to Groundwater

Unlike nitrogen, which has a relatively short residual activity in soils, phosphorus tends to accumulate in soils in relatively insoluble inorganic forms. Thus, phosphorus fertilization leads to increased soil phosphorus levels over time. In many intensively managed soils, particularly where high-value crops such as vegetables are grown, phosphorus levels have become quite high.

Phosphorus buildup is of practical significance. Only a very small amount of fertilizer phosphorus is lost from soils if erosion is controlled. Even these small amounts, however, can be significant and can accelerate surface water eutrophication. This avenue of loss can be minimized through proper erosion control.

Although some phosphorus may be lost by movement into groundwater through leaching, the amounts generally are insignificant from both agronomic and waterquality standpoints. However, significant phosphorus may enter groundwater where the water table is high or approaches the plow layer. Similarly, flooding may provide anaerobic conditions in soils, and in such cases phosphorus concentrations can be fairly large in effluent from tile drains and can be a groundwater pollutant.

Like phosphorus, potassium from fertilizers can accumulate in soils over time. Soils in humid areas of the United States are inherently low in potassium, so yields can be enhanced by potassium application. Many soils in the more arid regions contain adequate potassium levels (72). Thus, as with any input, care is needed to ensure that potassium is applied only on soils with low natural potassium levels. Potassium fertilizer does not appear to be a source of pollution for surface or groundwater.

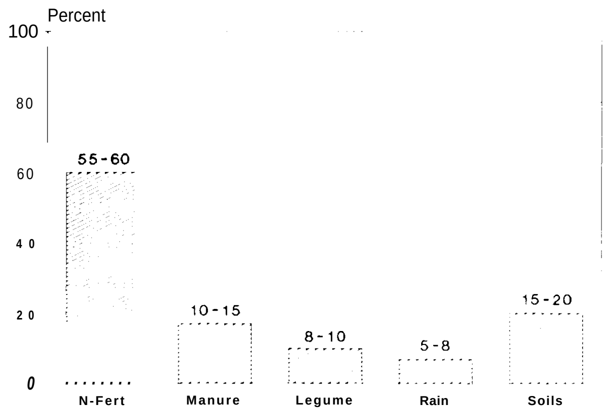
Plants require carbon, oxygen, hydrogen, nitrogen, phosphorous, potassium, calcium, magnesium, chlorine, ‘and sulfur in relatively large quantities (and another six elements—iron, manganese, boron, zinc, copper, and molybdenum-in small amounts). The frost three elements are freely available in the atmosphere and the latter four are common in temperate soils; thus, nitrogen, potassium, and phosphorus are the most commonly added nutrients. Although plants may take up ammonium (NH_4, the predominant nitrogen uptake form is nitrate (NO_3), which is relatively mobile in the soil environment. Because of this mobility, nitrogen (N) availability is most often the limiting nutrient factor for plant growth and the most common agrichemical contaminant found in groundwater. The chemical properties of phosphorus (P) and potassium (K) generally restrict their movement through the soil profile (box 4-B), although phosphorous loading of surficial waters can be a significant problem in certain areas (110).

Whether soil nutrient replacement is accomplished by addition of organic (e.g., manures) or commercial fertilizers is an individual’s choice, but agriculture has to replace what it has taken from the soil in order to maintain long-term crop production. Early agriculture depended on soil- and atmosphere-derived nutrients and plant and animal residues to maintain soil fertility. Legume-based systems were introduced to increase available nitrogen in cropping systems. Natural weathering produces new soil and releases additional nutrients, but the process is slow and does not keep pace with modern agricultural needs. Today, genetically improved, high-yielding crop varieties require much higher nutrient levels than are naturally available in the soil, and most U.S. croplands are managed to sustain high yields, normally requiring frequent nutrient inputs (208).

Nutrient sources have gradually become more sophisticated, shifting from livestock manures to concentrated single-element particulate formulations and to complete fertilizer combinations. Commercial fertilizers are the main source of resupply of the soil nutrients needed for continued agricultural production (figure 4-2). A broad variety of commercial fertilizer formulations exist, including granules, liquids, and gaseous forms, each requiring a specific application technology. Most forms either are applied on the soil surface or are subsurface injected, although some liquid nutrient formulations have been developed for foliar application and *chemigation* systems. The cost of fertilizing is increasing because production is highly energy-intensive, especially for nitrogen fertilizers (figure 4-3).

Limestone, gypsum, dolomite, greensand (glauconite), rock phosphate, and granite are common rocks that, when ground to a fine particle size, also can be added to cropland soils to provide calcium, magnesium, potassium, and phosphorus. These freely ground, less soluble natural materials were the basic inorganic soil nutrient inputs prior to industrial

Figure 4-2--Sources of Nitrogen in the Environment



Nitrogen for crop production may be derived from a variety of sources, however, commercial fertilizers comprise the main source of resupply of the soil nutrients.

SOURCE: Environmental Protection Commission, Iowa Department of Natural Resources, *Iowa Groundwater Protection* Strategy, 1987.

synthesis of commercial fertilizers and usually are not included in the category "commercial fertilizers.

Nitrogen Cycle

Nitrogen in the soil and available for plant growth is derived from atmospheric dinitrogen (N_2). This chemically unreactive nitrogen is circulated from the atmosphere through the soil and living organisms through various processes that comprise the nitrogen cycle (figure 4-4).

Nitrogen additions to the soil maybe the result of several processes, biological or industrial dinitrogen fixation, lightning fixation, and ammonification. *Biological dinitrogen fixation,* conversion of atmospheric nitrogen to ammonia (NH_3), is carried out by microorganisms, either free-living or in symbiotic associations with other organisms. *Industrial nitrogen fixation,* which produces ammonia through a natural gas and petroleum-based process, is currently the major source of nitrogen fertilizers. A small amount of nitrogen may be freed into the soil through the process of *lightning fixation. Ammonification is the* decomposition of soil organic matter (i.e., dead animals, plants, microbes, and manures) by soil microbes to ammonium ions (NH_4).

Soil transformations of ammonium yield nitrite[2] and nitrate. Oxidation of ammonium to nitrite and **nitrate** is carried out by several bacterial species in the process of *nitrification.* Although nitrate is the primary nitrogen form taken up by plants, under acidic soil conditions with low populations of vitrifying bacteria, plants may take up nitrogen in the ammonium form.

Nitrogen is returned to the atmosphere from the soil through the activities of denitrifying bacteria. *Denitrification* is the anaerobic conversion of soil nitrate to the volatile forms of nitrogen. Plants may release small amounts of these nitrogenous forms to the atmosphere as well, particularly under high fertilizer application regimes (18 1).

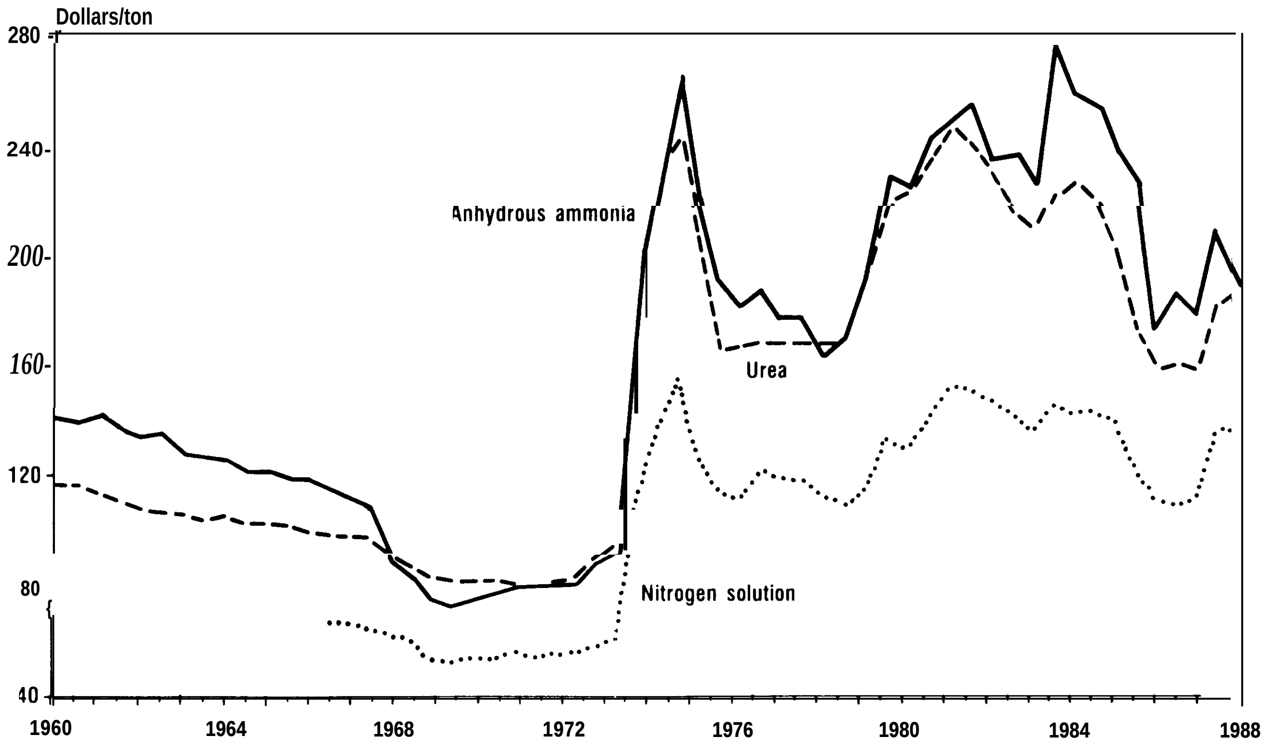
The nitrogen cycle processes of greatest importance to agriculture are those that yield inorganic forms of nitrogen. The processes by which organic nitrogen is converted to inorganic forms is referred to as *mineralization* (ammonification and nitrification). *Immobilization is the* sequestering of applied or extant plant-available nitrogen in organic matter. Uncertainties regarding rates of immobilization and mineralization complicate estimation of the amount of nitrogen that will become available to plants during a cropping season.

Three categories of processes control nitrogen availability to a growing crop: 1) direct physical or chemical effects (e.g., nitrate leaching and ammonia volatilization); 2) direct biological effects (e.g., dinitrogen fixation, mineralization); and 3) indirect biological effects (e.g., immobilization) (42). These processes are highly dependent on specific agroecosystem traits such as microbial populations, soil organic matter content, and soil moisture, and on the agronomic practices that affect these traits. The first category is of primary concern relative to the potential for nitrate contamination of groundwater, while the latter two categories are indirectly linked to nitrate leaching potential since they mediate soil nitrate levels.

Leaching is a natural pathway within the nitrogen cycle and nitrate is a naturally occurring form of nitrogen in water bodies. Nitrate, mineralized from soil organic matter and dissolved in water, leaches from the root zone of even unfertilized lands. Nitrate concentrations in groundwater vary with amount and timing of rainfall; soil composition, permeability, and porosity; time of year; vegetation management; and other site-specific factors. Measurements of

[2]The nitrite form of nitrogen is highly toxic to plants and is rapidly converted by bacterial action to the nitrate form.

Figure 4-3-Average Farm Prices of Selected Nitrogen Fertilizers



SOURCE: H. Vroomen, U.S. Department of Agriculture, Economic Research Service, *Fertilizer Use and PriceStatistics, 1960-1988,* Statistical Bulletin No. *780* (Washington, DC: U.S. Government Printing Office, 1989).

nitrate concentration in water may provide little understanding of the nitrate loss from a specific field (86).

The concentration of nitrate in groundwater is controlled by either the rate of nitrate addition to a constant flow of water or the rate of water flow through a region where nitrate is steadily becoming available. The nitrate concentration in the soil water of unfertilized grasslands and fields commonly is negligible, but may reach 3 ppm. It varies with the rate of nitrate mineralization from soil organic matter and with the rate of water percolation through the soil.

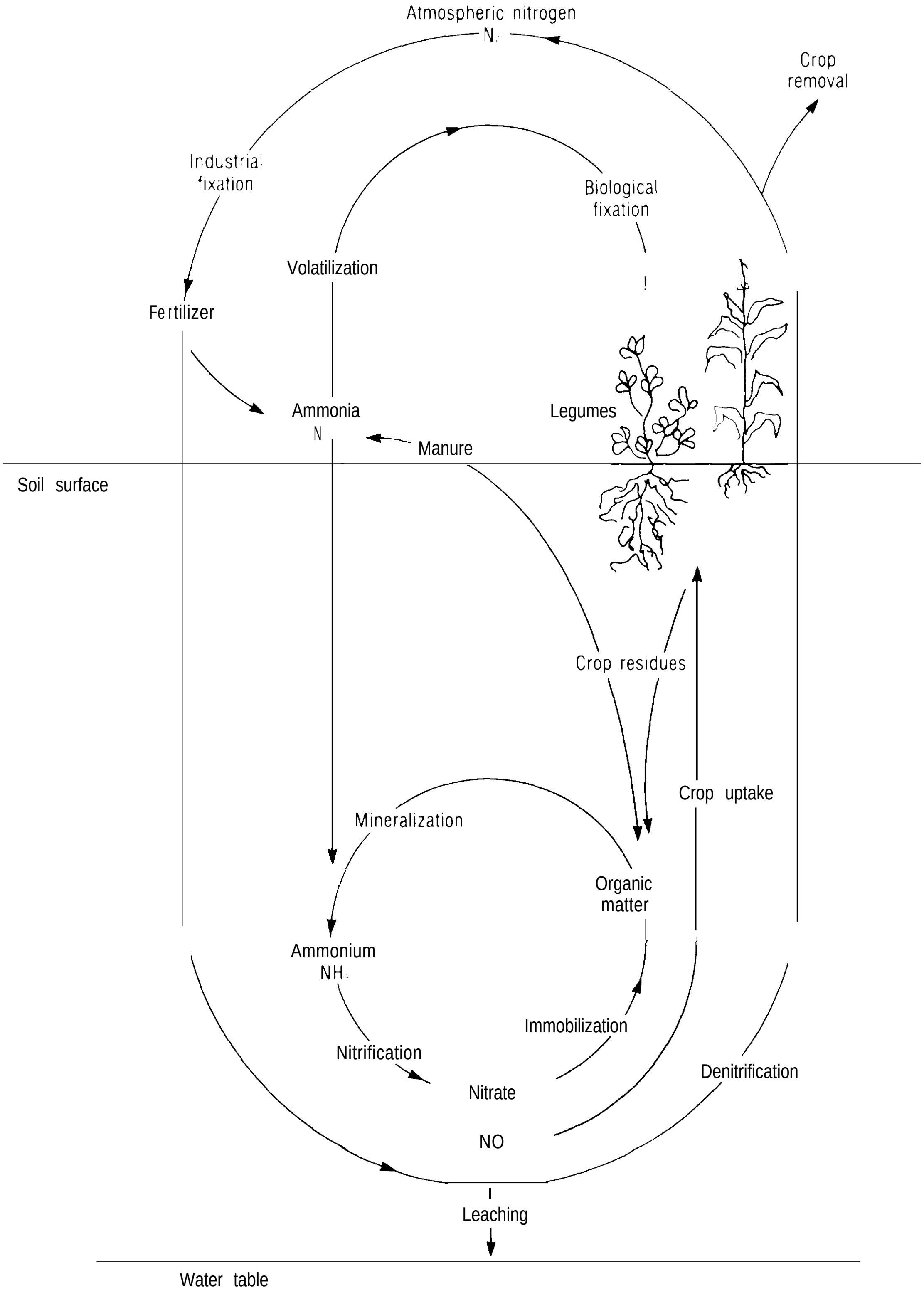
Thus, nitrate losses from cropland maybe visualized as integrated fluxes, i.e., rate of nitrate movement from the root zone per land area per unit of time. Viewed in this manner, in temperate lands, unfertilized native grasslands and agricultural fields lose about 20 lbs N/acre/year on average (range 5 to 40) as nitrate (86). How closely nitrate fluxes through cropland approach this value depends on a number of factors. Fertilized cropping systems lose on average from 22 lbs N/acre/year (rainfed systems) to **50** lbs N/acre/year (irrigated systems). These rates of loss are in part intrinsic to the nitrogen cycle and cannot foreseeable be eliminated. Given the natural flux, as well as the propensity for nitrate to arrive in groundwater from numerous sources, it seems likely that farmers will have difficulty meeting **a** strict groundwaterquality standard of 10 mg/1 in all areas (120).

Nitrogen Sources and Formulations

A variety of amendments are applied to Us. cropland annually to provide nutrients for crop production, including commercial fertilizers, manures, and sewage sludge, slurry, and wastewater. Commercial fertilizers comprise the greatest part of these additions with an estimated 20.5 million tons applied in the crop year 1988-89 (228).

Commercial fertilizers generally are synthesized or manufactured through various industrial processes and contain one or more of the essential plant nutrients (54). These include important soluble compounds of nitrogen, phosphorus, and potassium. Because commercial fertilizers are highly soluble

Figure 4-4—Nitrogen Cycle



SOURCE: Pennsylvania State University, College of Agriculture, "Groundwater and Agriculture In Pennsylvania," Circular 341 (College Station, PA: Pennsylvania State University, 1998).

Box 4-C—Summary of Best Management Practices for Controlling Potential Contamination of Surface and Groundwater From Fertilizers

- *soil* testing to determine soil nutrient content and appropriate fertilization and liming regimes;
- spring fertilizer applications in regions with wet soils, humid climates, and high infiltration;
- split applications may reduce potential losses by up to 30 percent compared to single applications;
- level terraces as a mechanism to reduce nitrate losses in runoff in areas with low vulnerability to nitrate leaching, contour farming is recommended in humid regions with high vulnerability to contamination;
- drainage control to reduce nitrate losses in wet and irrigated areas; to include wise irrigation management to prevent leaching losses;
- slow release nitrogen fertilizers;
- crop rotations, no-till, and conservation tillage to reduce surface losses of nitrogen;
- soil incorporation of broadcast fertilize
- level terraces as a phosphorus control measure;
- rotation grazing, crop rotation, cover crops, and conservation tillage to reduce phosphorus losses as compared to continuous grazing or conventional tillage; and
- sedimentation basins and flow control in irrigation systems to reduce phosphorus losses.

SOURCE: North Carolina State University, Agricultural Extension Service, Biological and Agricultural Engineering Department, *Best Management Practices for Agricultural Nonpoint Source Control, II: Commercial Fertilizer* (Raleigh, NC: North Carolina State University, n.d.).

and concentrated, concern exists that they may have certain long-term adverse impacts on soils, soil biota, water supplies, and other parts of the natural resource base (box 4-C).

Commercial Nitrogen Fertilizer

A variety of nitrogen-containing fertilizer compounds exist; however, only a few are used widely—the "conventional nitrogen fertilizers." These include anhydrous ammonia, urea, ammonium nitrate, urea-ammonium nitrate solution, ammonium sulfate, monoammonium phosphate, and diammonium phosphate (152). Anhydrous ammonia, nitrogen solutions, and urea account for 40, 20, and 15 percent of U.S. fertilizer use, respectively (77). Formulations vary from gaseous (anhydrous ammonia) to granule to liquid, with each formulation requiring a specific application technology.

The rate of application of nitrogen to croplands can influence the amount of nitrate leaving fields via subsurface waters or drain tiles. As progressive increments of nitrogen become less efficient in increasing crop growth, the amount available for runoff or leaching increases.

Most nitrogen removed by surface runoff is organic nitrogen associated with sediment. Even though it is possible to lose significant amounts of fertilizer nitrogen in surface runoff, this accounts for only a small proportion of nitrogen lost from soils or applied fertilizer nitrogen (127).

The amounts of fertilizer nitrogen either lost to, or found in transit to, groundwater are quite variable. The partitioning[3] of nitrogen in the environment is highly dependent on climatic and soil factors as well as amendment type and application method. For example, under anaerobic soil conditions (e.g, waterlogged soils) denitrification is favored and gaseous losses of nitrogen to the atmosphere are likely to occur. The problem of nitrate leaching to groundwater is greater in humid or irrigated areas as compared to dryland cultivation systems. Nitrogen fertilizer use on irrigated sandy soils shows a high correlation with nitrate-contaminated aquifers (192, 170).

Slow-Release Fertilizers-Slow-release fertilizers provide nitrogen to crops in a time-release fashion in contrast to the more rapid release action of conventional fertilizers. They operate in one of four general ways: 1) employing a physical barrier to control the escape of water-soluble materials containing ammonia or nitrate into soil; 2) possessing reduced water-solubility properties and containing plant-usable nitrogen (e.g., metal ammonium phosphates); 3) possessing low water-volubility and releasing plant-available nitrogen during chemical

[3]Partitioning refers t. the apportionment of nitrogen within the nitrogen cycle. Of greatest agronomic interest is what part of the applied nitrogen remains within the soil in a form usable by plants or in organic forms that may be released as nitrate through mineralization.

or biological decomposition (e.g., ureaforms and oxamides); and 4) having high water-volubility but a chemical structure that allows materials to decompose gradually and release plant available nitrogen (e.g., guanylurea salts). The nitrogen release rates and nitrogen transformations in the soil may be further modified by the addition of a nitrification or urease inhibitor.

Coatings, encapsulations, and matrixes are used as physical barriers to slow nitrogen release. Coatings may be impermeable or semipermeable. Impermeable coatings either may have tiny holes to allow release or may depend on abrasion or chemical or biological action to release nitrogen. Semipermeable coatings depend on an influx of water to rupture or distend the coating sufficiently to release the nitrogen. Most commercially important coatings are waxes, polymers, and sulfur. Most uncoated varieties have low volubility and only decompose to release plant-available nitrogen after going into solution. This dissolution rate is affected by size of particle, particle hardness, and degree of water volubility.

Slow-release materials may generate a more desirable apportionment of nitrogen among plant parts than faster acting nitrogen sources (82). Yield response seems to be comparable between the two nitrogen sources, although less nitrogen is accumulated by the plant when slow-release materials are used. This effect may be beneficial if the nitrogen remains available for subsequent crops; however, it also may represent a potential source of nitrate available for movement to groundwater.

Numerous advantages have been claimed for slow-release fertilizers, including: reduced seed, seedling, and leaf burn damage from heavy concentrations of fertilizer salts; improved crop quality; reduced disease infestation; reduced stalk breakage, improved seasonal nitrogen distribution; increased residual value of applied nitrogen; improved economy of use (e.g., single as opposed to multiple applications); and improved storage and handling properties (81).

Agronomic constraints to using slow-release fertilizers arise largely from their high cost and varying rates of nutrient release. For example, while a certain slow-release fertilizer may be appropriate to the nitrogen accumulation pattern of one specific crop it may not confer similar benefits to another crop or a cultivar with a different accumulation pattern. However, for high-value crops, or crops where split applications are problematic, slow-release fertilizers may offer sufficient advantage to offset certain of these constraints. Use of slow-release materials is growing for high-value crops or those grown under special conditions that hinder conventional fertilization techniques (e.g., crops grown using mulch in highly permeable soils and high rainfall, such as strawberries; and under conditions where vitrification/ denitrification is highly likely, such as in rice paddies) (81). Increased understanding of nitrogen uptake and use by plants may aid in identification of specific crops and cropping situations where slow-release nitrogen sources may be valuable.

The environmental effects of slow-release fertilizers, however, have not been assessed. For example, these materials may continue to release their nitrogen to soil in the absence of plant growth (e.g., after harvest), This could result in the production and leaching of nitrate during winter and early spring (83).

Nitrification Inhibitors—When applied nitrogen is converted to nitrate more rapidly than plants can accumulate it, nitrate leaching potential is increased. Nitrification inhibitors retard this bacterial oxidation of ammonium to nitrate. Additionally, in order to be agronomically desirable, vitrification inhibitors should be as mobile as ammonium in the soil, remain effective over 1 to 2 weeks, be compatible with fertilizers, and lack toxicity to higher plants, soil microorganisms, and humans (82).

Vitrification inhibitors are effective at reducing nitrate losses and thus could have a large potential market. Identification of cropping systems in which nitrification inhibitors would be valuable could promote adoption of vitrification inhibitors as a nitrogen management tool. Similarly, increased fertilizer costs relative to the economic benefit derived from their use could improve the cost-effectiveness of nitrification inhibitors (82).

It may be desirable to reduce nitrification in soils for environmental reasons as well. Products of nitrification (nitrite and nitrate) may create a variety of undesirable effects, including: 1) seedling damage from nitrite accumulation in soil, 2) nitrate leaching out of plant root zone, and 3) increase in subsoil acidity. Research efforts that correlate nitrate loss rates with nitrification-inhibitor use under various climatic conditions and cropping systems are needed.

Use of a nitrification inhibitor to maintain midseason applications of ammonium nitrogen in the plant root system may be beneficial. On the other hand, such research may reveal that the short-term benefits derived by reducing nitrogen loss during the growing season may be offset in part by increased loss of nitrogen during the fall and winter. This is because vitrification inhibitor use often results in temporary storage of nitrogen in microbial tissue; this nitrogen may be released to the soil after crop harvest (83).

It is difficult to predict where use of a vitrification inhibitor will be beneficial. However, positive yield responses to vitrification inhibitors have been demonstrated in the field, generally under conditions where formation of nitrate would have promoted nitrogen loss via leaching or denitrification (e.g., in warm, high-rainfall areas with permeable soils; soils abnormally wet in the spring; irrigated, aerobic soils; and paddies). The utility of nitrification inhibitors seems highly likely under certain cropping situations, for example, in direct-seeded rice systems where starter fertilizer is added with seed and conditions are conducive to nitrification (81,82).

Manure

Manure is a mixture of feed residues, microorganisms, and metabolic products. Generally 40 to 60 percent of manure nitrogen is in an organic form that is rapidly decomposed. During this decomposition process, ammonium salts are formed and ammonium is emitted until the process ceases (81).

Although the nutrient content of manures maybe substantial (table 4-3), nitrogen content and nitrogen release rates may be highly variable. Under certain conditions an estimated 50 percent of the nitrogen is volatilized prior to field application, and 50 percent of that applied is not recovered by plants during the season of application, although estimates on the amounts lost to the atmosphere vary widely (81). Nitrogen and phosphorus accumulate in the root zone if manure applications greatly exceed crop nutrient requirements (135,122,168) and may **be** subject to leaching. The fraction of nutrients in the soil that actually leach, volatilize, denitrify, or are taken up by crops for typical livestock and crop production systems needs to be determined through further research.

Under proper manure application rates, crop yields that equal or exceed those from commercial fertilizers have usually been observed (table 4-4) (124). Yields with manure are often sustained for several more years after manure application than after commercial fertilizer application due to the slower release of residual nutrients from manures (1 14,1 13). This effect may lead to nitrogen remaining in the soil after harvest and thus increase potential for nitrate leaching to groundwater under humid conditions.

A method to determine proper manure application rates based on nitrogen content was developed by the U.S. Department of Agriculture, Agricultural Research Service (63). Technical guides to proper manure application and accurate soil analyses can be obtained from the Extension Service in most States or from commercial laboratories. These technical guides take into account the slow release rates of organic nitrogen in manure. Recommended manure application rates per 100 pounds of available nitrogen are shown in table 4-5. Application rates are highest in the first year and then drop in future years as mineralization releases nitrogen from the extant soil organic matter.

With proper management, manure application results in increased yields. However, excessive application rates generally do not increase yields appreciably, may increase soil nitrate levels (167, 124,247), and may even reduce the proportion of applied nutrients accumulated by the crop. For example, Bermuda grass took up 74 percent of the nitrogen in manure when applied at rates meeting plant nitrogen needs. However at application rates four times the recommended rate, plant uptake was only 33 percent of the nitrogen applied (197).

Clearly, manure represents a potentially significant nitrogen source for agricultural production. However, numerous constraints exist to improved and more widespread use of manure as a nutrient source. The energy and labor costs associated with improved collection and storage practices may be prohibitive particularly for large confinement operations. Distance to potential markets and high transportation costs create additional economic constraints to such recycling. Although this problem may be partially overcome in livestock operations that also produce feed, excessive manure production relative to nearby soil-loading capacity may pose constraints to on-farm recycling.

Opportunities have been examined for developing regional livestock waste processing facilities to reduce the potential for nonpoint source pollution

Table 4-3-Estimated U.S. Livestock and Poultry Manure Voided and Nutrient (N,P,K) Content[a]

Species	No. animals 1,000 head	Manure dry weight	Nutrients N	P	K
		Million tons/year			
Cattle inventory (January 1989)					
Beef cows and heifers	33,669	44.917	1.776	0.476	1.097
Cattle on feed	9,408	11.813	0.467	0.125	0.288
Stock on pasture	46,190	39.872	1.576	0.422	0.974
Dairy cows and heifers	10,217	29.088	1,091	0.228	0.703
Hogs and pigs inventory (December 1988)	55,299	15.542	0.734	0.456	0.734
Sheep inventory (January 1989)	10,802	1.762	0.065	0.013	0.052
Poultry inventory					
Laying hens (December 1986)	280,500	3.276	0.174	0.061	0.063
Turkeys (1988)	138,300	4.543	0.235	0.087	0.091
Broilers (1988)	951,900	7.644	0.382	0.104	0.139

[a]This information was developed using the 1988 American Society of Agricultural Engineers Manure Production data and characteristics.
[b]Includes sheep and lambs on range/pasture and on feed.

SOURCE: J.M. Sweeten, "Improving Livestock Management Practices To Reduce Nutrient Contamination of Groundwater," OTA commissioned paper, 1989.

Table 4-4--Crop Yields From Feedlot Manure Application Bushland, Texas, 1969-80

Manure treatment	Number of years Applied	Recovery	Average yields, lbs/acre/year Sorghum grain 1969-73	Corn 1975, 1977,1979	Wheat 1976, 1978,1980
0	11	0	4,490	8,350	1,400
0 (id.;..:.-.-:::;.'::::	11	0	6,440	13,390	4,050
0 (N,P,K)	11	0	6,410	13,560	4,290
10	11	0	6,640	13,920	3,430
30	11	0	6,490	13,400	4,530
60	5	6	6,360	14,340	4,000
120	5	6	5,120	13,950	4,260
240	3	8	900	15,260	4,330
240	1	10	330	12,100	2,810

SOURCE: J.M. Sweeten, "Improving Livestock Management Practices To Reduce Nutrient Contamination of Groundwater," OTA commissioned paper, 1989.

from storage or inappropriate disposal of animal wastes. Marketable products that might be generated from anaerobic digestion of livestock wastes include: energy from methane production, liquid slurry to be used as a fertilizer, and livestock bedding materials (46),

Sludge and Wastewater

Sludge is an accumulation of the solids generated from wastewater treatment. Septage is a sludge produced from the individual home on-site treatment system using a septic tank and drainfield. Forty-one percent of sewage sludge now goes to municipal landfills and 21 percent to incinerators with no recovery of the nutrient components. Growing levels of sludge production in the United States (4 million tons in 1970 to 7 million tons in 1987) coupled with declining availability of disposal sites clearly indicate that alternative disposal methods are needed (80). Increasing application of wastewater treatment products on agricultural land has been suggested as a major alternative to other disposal methods (215).

Sludge application to agricultural and forest land has received increased research attention; studies indicate the potential for nutrient recycling in these systems. While land application allows for recycling of nutrients contained in sludge, it also provides the opportunity for introducing undesirable components into an agricultural system (table 4-6). Further, the

Table 4-5-Dry Tons of Manure Needed To Supply 100 Pounds of Available Nitrogen of the Cropping Year

	Nitrogen content of manure, percent dry basis					
	1.0	1.5	2.0	2.5	3.0	4.0
Years manure is applied	Tons of dry manure/100 lb nitrogen					
1	22.2	11.6	7.0	4.6	3.1	1.4
2	15.6	9.0	5.8	3.9	2.8	1.4
3	12.7	7.7	5.1	3.6	2.6	1.4
4	11.0	6.9	4.7	3.4	2.5	1.3
5	9.8	6.3	4.4	3.2	2.4	1.3
10	6.9	4.9	3.7	2.8	2.2	1.3
15	5.6	4.2	3.3	2.6	2.0	1.2

SOURCE: C.B. Gilbertson, F.A. Norstadt, A.C. Mathers, R.F. Holt, A.P. Barnett, T.M. McCalla, C.A. Onstad, R.A. Young, L.A. Christensen, and D.L. VanDyne, U.S. Department of Agriculture, Agricultural Research Service, *Animal Waste Utilization on Cropland and Pastureland: A Manual for Evaluating Agronomic and Environmental Effects*, URR 6 (Washington, DC: U.S. Government Printing Office, 1979), *In:* Sweeten, J. M., 1989.

Table 4-6-Average Concentrations of Heavy Metals in Grain From Six Wheat Cultivars Grown With Three Fertilizer Treatments at Mesa, Arizona in 1983

	Cadmium	Zinc	Copper	Lead	Nickel
Fertilizer treatment			mg kg-1		
Suggested N, P, K from commercial fertilizer	0.4	31.6	10.6	1.4	10.5
Sewage sludge to provide suggested N with no additional fertilizer	0.6	45.3	12.0	4.5	22.4
N, P, K from commercial fertilizer equal to sewage sludge	0.5	34.8	11.5	1.6	14.9

SOURCE: A.D. Day and R.K. Thompson, "Fertilizing Wheat With Dried Sludge," *BioCycle*, pp. 30-32, September 1986, *In: Moore,* J.A., 1989.

nutrient content of waste byproducts can be quite variable depending on factors such as the type of raw material and treatment process (191) (table 4-7).

Land spreading of sludge on agricultural lands now accounts for only 15 percent of the total produced, but this method is growing rapidly. Maryland now land applies at least 90 percent of the sludge generated in the State. Concerns over negative aspects of land application (i.e., odors, toxic heavy metals, disease vectors, surficial and groundwater contamination) have caused some communities to delay or cease land application operations. Pathogen reduction processes are required in sludge treatment before land application to protect public health. Lag times between spreading and harvest, and access limitations, also are required for certain crops to protect the food chain. Additional support to evaluate and monitor receiver systems and provide expanded educational programs could foster improved use of sludge in agriculture.

While research on the fate, availability, and pathways of sludge constituents in the soil-plant system is still expanding, a procedure has been developed to determine agronomic loading rates. Calculation of the annual and total loading rates (site life) of a heavy metal to a site can be determined knowing the application rate and characteristics of the sludge.

Studies of the potential of forest ecosystems to assimilate nutrients from liquid-sludge applications have been very promising. Overall positive aspects of silvicultural sludge application include:

- low risk of food chain contamination since forest crops are generally nonedible,
- positive vegetative growth response to applications resulting in improved wildlife habitat and nutritional quality of forage plants,
- sequestering and removal of undesirable elements such as heavy metals,
- reduced likelihood of surface runoff due to high permeability of forest soils, and
- reduced potential for human contact with sludge applications due to the distance of application sites from population centers (80).

Studies indicate sludge application to forestlands to be economically and technologically feasible. However, the variability of nutrient cycling among

Table 4-7—Total N, P, and K Concentrations in Selected Waste Materials

Waste material	N	P	K
Solid or semisolid: [a]			
Composted/shredded refuse	0.57-1 .30	0.08-0.26	0.27-0.98
Waste food fiber	2.00	0.01	0.36
Paper mill sludge	0.15-2.33	0.16-0.50	0.44-0.85
Citric acid production wastes	0.51 -4.13	0.06-0.29	0.01-0.19
Tomato processing wastes	2.33	0.29	0.28
Municipal sewage sludge	‹0.1 -17.6	‹0.10-14.30	0.02-2.64
Liquids: [b]			
Municipal wastewater	16-37	7-13	14-22
Whey	1500	500	1820
Vegetable and fruit processing wastes	19-318	4-91	—

[a]Expressed on adry-weight basis.
[b]Expressed on a wet-weight basis (commonly called suspended solids).

SOURCE: L.F. Sommers and P.M. Giordano, "Use of Nitrogen From Agricultural, Industrial, and Municipal Wastes," ***Nitrogen in Crop Production*** (Madison, WI: ASA-CSSA-SSSA, 1984), pp. 207-220.

different forest ecosystems requires that site-specific application rates be determined to generate forest growth benefits in an environmentally sound manner (80).

Comporting is a popular pretreatment process that uses sewage sludge and produces an acceptable product. Several examples exist of large comporting operations producing and marketing the product to lawn and garden and agricultural markets. Comporting sludge with an organic material yields a nearly odorless humuslike material that is free of enteric pathogens. This product can be used as a soil amendment and is a minor source of plant nutrients (table 4-8) (217). Composted materials have a variety of uses, including applications for agronomic crops, land reclamation efforts, nursery operations, and turf grass production. These materials applied at equivalent fertilizer nutrient rates may generate higher yields due to the associated improvements in soil physical properties.

Irrigation with wastewater offers another recycling mechanism. Field experiments show that nearly 67 percent of applied nitrogen is assimilated by corn under a wastewater irrigation regime as compared to 58 percent of applied N from ammonium nitrate. This implies that greater efficiency is achieved under the wastewater regime. However, another study on nitrogen assimilation by grasses showed no appreciable difference between waste-

Table 4-8-Composition of Nutrients and Heavy Metals in a Washington, DC, Area Composted Sewage Sludge

Nutrient components as percent of total:	
Nitrogen	<1.50/0
Phosphorus	<2.0%
Potassium	4.2%
iron	<4.0%
Heavy metal concentration in parts per million:	
Zinc	1,250.0
Copper	500.0
Cadmium	12.5
Nickel	200.0
Lead	500.0
Mercury	5.0

SOURCE: U.S. Department of Agriculture, Use of Sewage ***Sludge Compost for Soil Improvement and Plant Growth,*** Agricultural Reviews and Manuals, ARM-NE-6, 1979, *In*: Moore, J.A., 1989.

water or conventional fertilizer application regimes (191).

Opportunities exist to increase the use of wastewater treatment products in an agricultural setting. However, concerns over the addition of undesirable sludge components (i,e., heavy metals, pathogens, etc.) to agricultural systems require consideration. In addition, further information is needed on the fate of organic and inorganic nitrogen after field application of wastes to improve management practices and determination of appropriate application rates of wastewater treatment products.

Fertilizer Application Rates

Fertilizer application-rate information commonly is obtained from local agriculture agency offices and field personnel. Land-grant universities in each state have developed "Official Fertilizer Recommendations" that are made available to the public through the Cooperative Extension Service and maybe used by all segments of agriculture. These recommendations are used by private soil-testing laboratories and producers in developing fertilizer application rates. Recommendations are in a continuing state of review and may be revised as new information becomes available.

Fertilizer application rates are determined based on crop nitrogen requirements and nitrogen-use efficiencies, yield goal, level of available soil nitrogen, fertilizer replacement values for nutrients in manure, legume or irrigation water inputs, cultural practices, and other variables. Plant-available soil nitrogen is composed of newly applied sources, residual nitrate in the profile, and that mineralized from soil organic matter. Rational fertilizer application regimes incorporate this information to arrive at appropriate application rates.

Soil- and tissue-testing methods exist to quantify residual soil nitrate, nitrogen derived from soil organic matter, and nitrogen levels in plant tissues. This information can be used to help determine fertilizer needs. Complex interactions among the variables governing the availability of soil nitrogen to plants make accurate determination of efficient application rates difficult.

Numerous factors affect the accuracy and use of soil testing in determiningg fertilizer need. The lack of a generally accepted index for mineralization means that an accurate picture of the quantity and release rate of nitrogen during the cropping season may not be obtained through soil testing.

The currently used residual nitrate test identifies how much nitrate is contained in the soil. However, it measures only nitrate present at the time of sampling, and thus is less useful in areas where nitrate may be removed before plant uptake as a result of leaching or denitrification (19). The spring nitrate test currently under evaluation may be applicable for humid regions; evidence is now available to support use of the late spring soil nitrogen test in Iowa (101). This test measures residual nitrate and also estimates nitrate that may be released during the growing season.

Failure to account for all of the various sources of' nitrogen as fertilizer application rates are determined can lead to overapplication and increased potential for nitrogen loss from the cropping system (161). Computer modeling may become a valuable tool in determining fertilization schemes. To obtain maximum economic yield and optimum fertilizer-use efficiency, and to minimize potential impacts on the environment, a practitioner must be able to accurately manipulate a broad array of data in making fertilizer application rate decisions. The capability of computers in such a setting could facilitate this process (box 4-D) (194, 183).

Nitrogen Use Efficiency

Nitrogen use efficiency describes the extent to which nitrogen is taken up by crops relative to the amount remaining in the soil or lost to the environment. Thus, improving nitrogen-use efficiency has potential to reduce amounts available for leaching and loss to groundwater. One approach to improving nitrogen use efficiency is to control vitrification. Nitrification of ammonium-producing substances (e.g., fertilizers, animal manures, crop residues) converts the relatively immobile ammonia to the mobile form of nitrate. Further action by denitrifying bacteria may convert nitrate to gaseous forms that are lost to the atmosphere. Vitrification may be controlled by:

- slowing the rate at which fertilizer materials dissolve in the soil environment,
- slowing the rate at which fertilizer releases N to the soil solution,
- timing applications to match plant uptake patterns and thus compete more effectively with the nitrifying bacteria, and
- using nitrification inhibitors (81).

Recovery of fertilizer nitrogen in the above-ground portions of grain crops seldom exceeds 50 percent at recommended application rates and is often lower (19,152) (table 4-9); these figures vary however, based on site characteristics. The remaining nitrogen may be volatilized (denitriffied), immobilized in microbial tissue and nitrogenous constituents of soil organic matter, stored as nitrate in the soil profile, or lost via erosion or leaching to groundwater. The partitioning of fertilizer N among these fates varies with soil, cultural, and management conditions. Nitrogen use efficiency also may be affected by nitrogen application practices, primarily application rate, timing, and placement (77).

Realistic Yield Goals

Yield goals should be based on the productive capacity of the agroecosystem and the crop nitrogen need. However, yield goals commonly contain a subjective value that is incorporated into the fertilizer application decision—an individual's desire to achieve maximum yield. Overapplication of nutrients commonly is attributed to an overestimation of the productive capacity of the cropped area.

Fertilizer application rates based on highest yield year(s) may in fact be inappropriate given the numerous variables responsible for crop growth (152). Realistic yield goals are developed by averaging production over past cropping years (generally 5 years) with the addition of no more than five percent to that value (191). Further, this value should be calculated on a field-by-field basis to account for the inherent heterogeneity of the agroecosystem.

Box 4-D—Modeling as a Tool for Predicting Nitrogen Contamination Potential From Agricultural Practices

Manipulation of a broad range of data is necessary in order to identify the potential for nitrate movement to groundwater from agricultural activities. Computer modeling has been instrumental in illustrating agrichemical movement through the soil profile and current effort is substantial in this field of diagnostic modeling. The following examples describe a number of models that are helping identify the groundwater vulnerability and the fate of agrichemicals in the soil environment.

AGNPS-Agricultural NonPoint Source-single event, cell-based model that simulates sediment and nutrient transport from agricultural watersheds.

DRASTIC---empirical standardized system for evaluating groundwater pollution potential by using hydrogeologic settings; the seven parameters estimated by the NWWA to be most significant in controlling pollution potential are: 1) Depth to water table, 2) net Recharge, 3) Aquifer material, 4) Soil, 5) Topography, 6) Impact of the vadose zone, and 7) Conductivity of the aquifer.

EPIC—Erosion Productivity Impact Calculator-a model to determine the relation between soil erosion and soil productivity; capable of simulating periods greater than 50 years; incorporates hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and plant environment control.

GLEAMS-Groundwater Loading Effects of Agricultural Management Systems-developed to evalute the effects of agricultural management systems on the movement of agricultural chemicals in and through the root zone for field-size areas.

LEACHMN-Leaching Estimates and Chemistry Model Nitrogen-process-based model of water and N movement, transformations, plant uptake, and N reactions in the unsaturated zone,

NITWAT-Nitrogen and Water Management-developed especially for corn on sandy soils; evaluates N transformations and transport in relation to crop growth under certain weather and irrigation conditions.

NLEAP-Nitrate Leaching and Economic Analysis Package-computer application package developed to estimate potential nitrate leaching from agricultural areas and project impacts on associate aquifers.

NTRM-Nitrogen Tillage and Residue Management—model with emphasis on management of nitrogen sources at the soil surface in conventional and reduced till systems. N transformations and transport are detailed using the NCSOIL submodel with active and passive N pools.

RZWQM-Root Zone Water Quality Management—in development; will compare alternative management practices and their potential for groundwater contamination; comprehensive model includes macropore flow and N cycle description; expert systems approach.

SOURCE: J.W.B. Stewart, R.F. Follett, and C.V. Cole, "Lntegrationof Organic Matter and Soil Fertility Concepts Into Management Decisions,' Soil *Fertility and Organic Matter as Critical Components of Production Systems* (Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 1987).

Soil Testing

Soil testing is used to diagnose the soil nutrient content prior to planting to determine fertilizer need. Plant available nitrogen may be derived from two soil pools: 1) mineral nitrogen, and 2) nitrogen mineralized from soil organic matter. While characterization of mineral nitrogen is a relatively simple procedure, quantification of mineralizable nitrogen is more difficult (152). Tests that measure phosphorus, potassium, and mineral nitrogen (i.e., nitrate) levels in soils are well-established laboratory procedures. Testing to assess potential mineralizable nitrogen may require laboratory or field incubation and chemical extraction and thus are more costly and time consuming. Many laboratories use previous farm management records to account for mineralizable nitrogen in making nitrogen application rate recommendations (152).

Most laboratories conduct chemical extraction of soils and correlate the results with various soil types to provide a basis for determiningg fertilizer application rates to provide optimum nutrient availability to the crop. These studies correlate soil nitrogen content, application rate, and plant yield to establish the validity of soil tests in the area where they are used (194).

The correlative approach is time consuming and expensive and depends on an assessment of actual and potentially available nutrients prior to planting. Further, it is so specific to crop, soil type, and cultivation technique that transferring recommendations to other settings is inappropriate. An alterna-

Table 4-9-Recovery of Fertilizer Nitrogen by Corn in the Application Year and Following Year

N rate lb N/acre	Percent recovered Plant	soil	Total	Recovery in soil in following year percent
Goodhue Co.:				
67	51	32	83	5
134	40	34	74	7
Waseca co.:				
89	42	37	81	1
178	35	44	79	1

SOURCE: G.W. Randall, "Who's Responsible for Nitrates in Groundwater," presented at 1986 Soils, Fertilizer, and Agricultural Pesticides Short Course, Dec. 9, 1986, Minneapolis, MN.

tive to the correlative approach is the maintenance concept, whereby fertilizer recommendations are based on the amount expected to be taken up by the crop and exported by harvest.

Periodic in-field soil tests would allow farmers to account for seasonal changes in the amounts of available plant nutrients-for example, nitrate levels are highly variable throughout the year as a result of mineralization, immobilization, denitrification, leaching processes, and changes in soil moisture, temperature, and organic matter level. Thus, depending on the timing of soil tests, an accurate picture of the soil's maeronutrient content may or may not be obtained. Proper testing techniques such as sampling at appropriate soil depth, accurate delineation of the management unit to be sampled (i.e., field), and determining the number of samples to be taken per management unit are critical to obtaining accurate soil test results (152).

As management changes affect the timing of cultivation and organic matter incorporation, it will be necessary to reevaluate existing soil tests for applicability under the new management system—requiring costly field experimentation to provide correlation data. This makes it all the more compelling to understand the processes involved in nitrogen transformations in soil (194). EPA has suggested that a joint USDA/EPA soil-testing program be undertaken in an effort to reduce the volume of nitrogen applied to U.S. cropland (69).

Tissue testing of crops for overall nitrogen and nitrate content offers another technique that may be used to determine nitrogen deficiency or sufficiency. Indices exist that identfy sufficiency, deficiency, and excessive nitrogen content for specific plant parts of numerous crops. Comparison of tissue test results with these values then provides information as to crop nitrogen need.

Correct timing of tissue tests and testing of correct plant part axe critical to obtaining a representative sample and thus accurate test results. Although tissue sampling techniques have not been examined as widely as those for soil tests, the number of samples should account for heterogeneity of soils and plant biology to obtain a representative sample for the management unit tested (152).

Fertilizer Replacement Value

Fertilizer replacement value (nitrogen credits or FRV) is a method to assess the N-supplying capability of a legume preceding growth of a nonlegume. Values represent the amount of manufactured nitrogen fertilizer that would be required to produce a corn yield equivalent to that following a legume under otherwise comparable test conditions (57,91). Legumes so evaluated are interpreted as replacing various amounts of fertilizer nitrogen for the frost nonlegume cropping season after legume plowdown. FRVs vary among and within cropping regions due to site-specific factors, crop species, and management methods. In many tests, the FRV for perennial legumes (e.g., alfalfa) is similar to the nitrogen fertilizer rates recommended for corn.

The FRV approach may be used to estimate the minimum amount of fertilizer nitrogen required by a nonlegume following a legume. One shortcoming of the approach is that the magnitude of the FRV estimated in a specific experiment depends strongly on the fertilizer-use efficiency of the nonlegume. Thus, this approach may not provide accurate assessment of the contribution of legume N to a succeeding crop. Recent studies involving radiolabeled N_{15} indicate that the FRV may in fact overestimate the ability of a legume to provide N to succeeding crops (86).

Timing of Fertilizer Application

Nutrient accumulation patterns vary among crops and even among cultivars, thus, timing nutrient application to coincide with greatest crop need provides an opportunity to reduce nutrient loss to the environment. Varying rates of nitrogen release from nutrient sources may complicate efforts to match nitrogen availability with maximum crop need. However, reduction in the time interval between application of fertilizers and time of maximum crop uptake may reduce the potential for leaching and denitrification losses (165,77).

A variety of fertilizer application regimes are practiced including fall, spring preplant, and split. Each regime generates slightly different benefits and all have differing potentials for nutrient contamination of groundwater. Multiple, small applications of fertilizer generally promote better plant uptake and thus reduce the potential for nitrate loss via leaching as compared to a single, large application. Fertigation (i.e., fertilizer application in irrigation water) may be particularly advantageous for multiple applications under certain irrigation regimes such as sprinkler systems that allow uniform water distribution (19).

In many regions it is common to apply fertilizers in the fall for subsequent spring crops. While this practice reduces the demands on a grower's time during spring planting season, it may create potential for denitrification and in some cases leaching losses. However, in dryer regions where leaching is unlikely this practice may not pose a potential hazard. Application techniques that may improve the efficacy of fall applications include use of a nitrification inhibitor and application after the soil reaches a critical temperature (i.e., 45° F) that inhibits nitrification of applied nitrogen.

Preplant applications, weeks before maximum uptake, are common for tall-growing crops like corn that can be damaged by application of fertilizers later in their growing season. Such practices clearly expose nitrate to the leaching potential of rainfall and irrigation prior to nutrient uptake by a crop (208).

Split applications generally entail a starter application of fertilizer with a subsequent application later in the growing season. This method is designed to reduce the amount of nitrogen remaining in the soil and available for nitrification and potential losses from the cropping system as well as to match nitrogen availability to the time of the crops' maximum nitrogen uptake requirements.

Application Technology

Fertilizers may be distributed before primary tillage, at planting time, and supplementally during the growing season. By far the majority of plant nutrients are applied to the soil for uptake by plant roots and are incorporated into root zone by tillage, direct injection, or leaching with rainfall or irrigation water (208). Dry or solid forms of urea and ammonium nitrate may be broadcast and high--pressure anhydrous ammonia is injected or "knifed" in to the soil. These forms comprise the greatest market share of applied fertilizer materials in the United States. Liquid fertilizer forms are also broadcast or dribbled on soil or plant surfaces. Spray applications are widespread in custom applications since they allow relatively rapid coverage over large areas (164).

A variety of methods exist for fertilizer application, including broadcast, injection, banding, in-row, side-dress, top-dress, and foliar. *Broadcast* applications entail distribution of fertilizer across an entire field surface. The fertilizer then may be mixed into the soil or left on the surface and allowed to move into the soil with moisture (rainfall or irrigation). Use of nonhomogeneous particles, however, may result in nonuniform distribution and thus over- or under-fertilization in parts of the field (152).

Injection application methods may be used with gaseous, liquid, or solid fertilizer materials. Gaseous and liquid forms generally are knifed into the soil, while solid forms may be placed in slots or furrows created by shanks or chisels. *Banding* of fertilizers may be done either at planting or after the crop has emerged. Solid fertilizer may be placed on the soil surface in strips between crops rows and liquid forms may be injected below and to either side of the seed. Fertilizer is applied during planting and directly next to the seed in *in-row* application. In-row application generally is used for starter fertilizers.

Side-dress applications are used to apply fertilizer to an established row crop, generally in a band beside the row. Either surface or injection application methods may be used in side-dressing of fertilizers. *Top-dress* fertilizer applications are liquid or solid forms broadcast over an established crop. *Foliar* applications of fertilizers involve spraying of liquid forms onto plant foliage or application through a sprinkler irrigation system (i.e., fertigation). Sprayed applications generally are taken up by plant leaves while uptake under irrigation applications may largely be through the plant roots.

An important consideration in fertilizer application is the placement of the fertilizer to avoid positional unavailability of the nutrient for the growing crop. Depth and location of fertilizer placement relative to the crop rhizosphere is critical in assuring maximum nutrient uptake. In areas where the soil surface dries out and retards root activity, placement must be deep enough to allow extraction by the roots (164).

Point injection of liquid fertilizers has the potential to reduce certain avenues of nitrogen loss and is useful in conventional and conservation tillage systems. Developed by Iowa State University, the spoked wheel applicator injects fertilizer solution about 4 to 5 inches below the soil surface and at about 8-inch intervals. This method of introducing nutrients nearly eliminates runoff potential, requires less horsepower than conventional equipment, and reduces disturbance to residue layer. This technology is compatible with postemergence application to crop, thus allowing improvement in timing of application to greatest crop nitrogen uptake. Further, it allows positioning of nitrogen in ridges for ridge-till systems, reducing problems of positional unavailability of nutrients. Although testing has demonstrated significant yield increases with this technology, additional work is needed to bring the applicator to market (55,183).

Precision application methods offer some potential for reducing overapplication of fertilizer materials to U.S. cropland. Soil nutrient content may be highly variable across a single field, thus fertilization schemes that seek to ensure adequate amounts to the least fertile segment of a given field easily may overfertilize other parts. Application methods that take into account the heterogeneity of soil nutrient content can reduce overfertilization. For example, a precision fertilizer application system is capable of taking 3,000 soil-nitrate tests per acre and adjusting application rates based on these tests (29). The user determines desired soil nitrate content and the applicator system tests the in-soil nitrate level and then applies the amount needed to meet the predetermined level. The number of nitrate tests the system is capable of performing can account for the heterogeneity of soil nitrogen level in a field.

PEST MANAGEMENT

Pesticide use has changed dramatically over the years, in terms of compounds used and amount of cropland treated. Some of these changes seem linked to environmental concerns (e.g., decline in organochlorine insecticides), while others may be the result of certain agricultural programs. Prior to World War II, agricultural pest control methods relied largely on tillage, crop rotation, and hand removal of pests. Available pest control chemicals were expensive and contained inorganic, highly toxic components (e.g., copper, lead, antimony, arsenic). Development of new pest control chemicals during World War II, and improvements in application technology, fostered a pest control approach that replaced older, more labor-intensive practices (254).

Phenoxy herbicides and organochlorine insecticides became popular pest control chemicals after World War II. However, in the mid- 1960s their use declined in favor of triazine and amide herbicides and carbamate and organophosphate insecticides. The 1970s witnessed an increase in herbicide use on major field crops, while insecticide use declined largely in response to lower doses associated with newly introduced pyrethroids. Pesticide use seemed to stabilize or even decline in some cases during the 1980s, perhaps as a response to acreage diversion programs (148).

Pesticides are applied to agricultural crops to reduce yield losses due to insects, diseases, and weeds that even today destroy almost one-third of all food crops (73). Pesticide use has risen roughly 1,900 percent in the 50-year period between 1930 and 1980 (73). The percentage of herbicide-treated cropland planted to corn, cotton, and wheat climbed from about 10 percent in 1952 to nearly 95 percent by 1980 (148).

Generally, pesticide applications are considered *effective if they* **achieve the** desired degree of pest control, and *economical if the* crop yield and quality response is above and beyond the cost of chemicals and their application. Opportunities may exist to reduce volumes of applied agrichemicals; develop safer effective compounds (box 4-E); and develop improved application methods that might address concerns over the potential adverse environmental effects of pesticide use (93).

Pesticides are broadly classified on the basis of the kinds of pests they control (e.g., insecticides, herbicides, fungicides, nematicides, rodenticides, and miticides). Chemicals used for defoliation, desiccation, soil fumigation, and plant-growth regulation also are classified as pesticides (79)(box 4-F). Most pesticides are organic chemicals; some are synthetic, others are of natural origin. Many contain chlorine, nitrogen, sulfur, or phosphorus that determine the toxicological impacts of the compounds,

Box 4-E—Biological Pesticides

Biopesticides are naturally occurring toxins and microorganisms that tend to be highly specific for a particular pest *(206),* Attributes of biopesticides include target specificity, low production costs, and biodegradability (22). Currently biopesticides comprise a small part of the overall market ($35 million); however, it is estimated that growth will increase rapidly (22).

Persistence of biopesticides is low; generally they are proteins that degrade quickly when exposed to the environment. This may be percieved as a drawback since multiple applications of biopesticides may be needed to control pest infestations relative to conventional chemicals. However, new techniques in packaging might address this feature (22).

Most biopesticides tend to be pest specific, which means that more than one agent maybe needed for multiple infestations. However, potential exists to combine agents into one delivery vector (22). Certain biopesticides are effective against more than one pest species. One such pesticide, an extract of the seeds of a tropical evergreen, the neem tree *(Azadirachta indica),* shows promise as an insecticide with little or no toxic effects to mammals and effectiveness against a number of pests that have resistance to other commercial chemical pesticides (97,89).

Biological herbicides have been developed that use soil bacteria and fungi to retard weed growth. A strain of ***Pseudomonas is*** being tested by Iowa State and Texas A&M Universities as a potential bioherbicide for downy brome (cheatgrass) in wheat. Applying the bacterium prior to planting may increase yields as much as 35 percent. The soil fungus *Gliocladium virens* may have some potential as a broad spectrum herbicide. The fungus was effective on 15 of the 16 weed species on which it was tested in University of California-Berkeley studies (1 37).

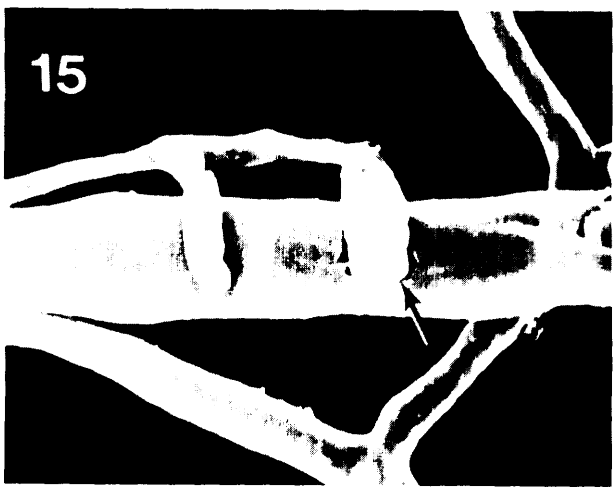


Photo credit: Colorado State University—Ralph Baker

Other biological control agents include fungal parasites prey on other soil fungi that are pathogenic to plants. Here, a photograph taken through a scanning electron microscope shows how the parasite penetrates its host.

Nearly 50,000 pesticide products are now registered with the U.S. Environmental Protection Agency (EPA) (62), although only a few are used extensively. The agricultural sector accounted for at least 75 percent of all pesticides applied in the United States in 1988 (236). Pesticide use on major crops has grown from 225 million pounds of active ingredient in 1964 to 558 million pounds in 1982, with greater herbicide use accounting for a significant part of this increase (148). Projected pesticide use for 1989 was 463 million pounds of active ingredient (228). This decrease from previous years may reflect a reduction in treated acres generated by acreage reduction programs (148) or a reduction in total amount applied as a result of the lower application rates allowed by newer pesticides (229).

Some 1,800 weed species cause an estimated 10 percent annual production loss in U.S. agriculture (valued at nearly $12 billion) (7), and farmers spend at least $8 billion annually for weed control. Herbicides comprise the greatest part of the pesticide market and account for most pesticide detections in groundwater to date.

Pest control practices may be initiated based on pest scouting—monitoring to determine existence of a pest problem. Depending on the type of pest identified, the organization of the production system, and the extent of infestation, various control approaches may be used. Additional monitoring of the pest population may be initiated if the extent of infestation is deemed to be below an economic threshhold.[4] If infestation is significant, pesticides

[4]Economic threshold is defined as the level at which the costs of control are equivalent to the benefits to be derived from control measures. This term also includes a subjective value-risk aversion of the producer-that makes the definition somewhat variable based on the individual.

Box 4-F—Plant Growth Regulators

Plant growth regulators (PGRs) are organic compounds that are applied to promote, inhibit, or otherwise modify plant physiological processes (21). Such compounds have been used on horticultural crops since the 1940s and have been applied to agronomic crops during the last 20 years (31). Their use on agronomic crops largely is limited to antilodging for cereals, maturation and yield enhancements in cotton, and enhancing sugar content of sugarcane (31). Major categories of effects of PGRs include:

- yield enhancement—inhibition of certain growth patterns may stimulate greater fruit set (e.g., mepiquat chloride used on cotton has been shown to increase cotton yields by 6 to 8 percent),
- conservation of energy or labor requirements-stimulation of uniform maturation allowing harvest in fewer passes,
- quality control—stimulation of ripening promoting uniform maturation, also applications postharvest to enhance product appearance,
- morphological control—through inhibition of certain growth patterns, application of PGRs may stimulate a preferred growth pattern (e.g., inhibition of flowering may stimulate increased vegetative growth giving rise to denser foliage, particularly important in ornamentals) (31).

At least 75 percent of the cotton grown in the United States is defoliated or dessicated annually using plant growth regulators. Other crops that commonly recieve dessication treatments to facilitate harvest include: soybeans, rice, potatoes, grain sorghum, sunflower, lentils, trefoil, dry beans, guar, and sugarcane. Many of these defoliants have been placed on EPA's Rebuttable Presumption Against Registration lists (31).

PGRs commonly are applied as foliar sprays. They must be retained on the plant surfaces in order to be effective, since the desired response depends on absorption of PGRs through the plant tissue and translocation to the appropriate reaction site (21). However, performance of these chemicals maybe affected by numerous factors internal and external to the plant. Lack of performance consistency has been noted in certain PGRs (31) and may be a symptom of such effects.

Research directions in PGRs are focused on increasing plant protein content, enhancing plant stress tolerance, promoting development of vegetative tissue, and mediating plant flowering (31). Disadvantages of some defoliants and dessicants include expense, unpleasant odors, explosive or flammable properties, and high mammalian toxicity. An increasingly important research area is the search for herbicide resistance. Protestants or safeners may be applied to a crop (usually seed) so that when herbicides are applied to the crop row only the non-protected plants are killed (214). Concern exists over this trend and the potential for accelerating herbicide use or promoting indiscriminate use.

may be used, requiring decisions on application method, timing, and rate of application. Alternative control measures (e.g., cultural or biological controls) may be used in lieu of or in conjunction with pesticides. All of these strategies are combined in the development of integrated pest management (lPM) programs (210,254).

Pest Scouting

A number of pest-scouting techniques exist, including visual inspection, pheromone traps, and other highly technical counting and collection methods. Once pest populations reach an economic threshhold level, pest control methods may be undertaken. In this way scouting can diminish the need for certain pesticide ''insurance" applications (73), however, some pests (e.g., diseases, nematodes) may not be easily scouted. Scouting also may identify pest problems that may otherwise have been unnoticed and thus result in increased pesticide use.

Scouting can help determine pest pressure and "hot spots," allowing selective application of a specific pesticide based on need (73). Farm scouts or pest consultants recommend correct pesticide application time to farmers based on accurate identification of a pest problem, stage of crop growth, weather forecasts, and other factors (73).

Pesticides

Although pesticides are credited with a high rate of food and fiber production at relatively low cost, increasing concern has been expressed since the 1960s over the potential hazards and long-term environmental impacts associated with their use. Despite these concerns, however, overall pesticide use has not decreased significantly.

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

Insect **traps loaded with pheromone are** used to estimate pest populations for integrated pest management. Here, a research entomologist observes the night flight pattern of a moth through infrared glasses.

The potential for groundwater contamination by pesticides depends on pesticidal properties (e.g., half-life, mobility), application method, physical and chemical soil properties, depth to groundwater, and amount of irrigation and precipitation (159). Impacts of pesticide use on the environment are determined by the transport of the chemicals; their persistence, degradation, and dissipation in the environment; and the hazards associated with pesticides and their metabolizes (figure 4-5). Pesticide use practices developed with these factors considered, thus, offer an opportunity to protect groundwater resources (254).

Improved efficacy of the newer pesticides has allowed reductions in total active ingredient applied per acre (figure 4-6); lower doses generally are achieved through increased pesticide toxicity. The capability for accurate delivery of such small amounts to the target pest, however, is questioned. For example, numerous researchers have estimated that only 1 to 2 percent of foliar-applied insecticides arrive at the target pest (71,156). However, the efficiency of any pesticide application will depend on a variety of factors, including: the method of application, weather conditions during application, equipment operating condition, time of year, crop type, volume of liquid used, pesticide formulation, and pest location and density. Further, the avenues for loss from the time of application to the point of contact with the active site in the target pest are numerous (figure 4-7). Additional improvements in intrinsic activity of pesticides may, in fact, be offset by inefficiencies in delivery mechanisms. Thus, despite complicating factors, it seems clear that improvement in delivery systems, then, may offer additional opportunities to enhance the intrinsic activity of pesticides (73).

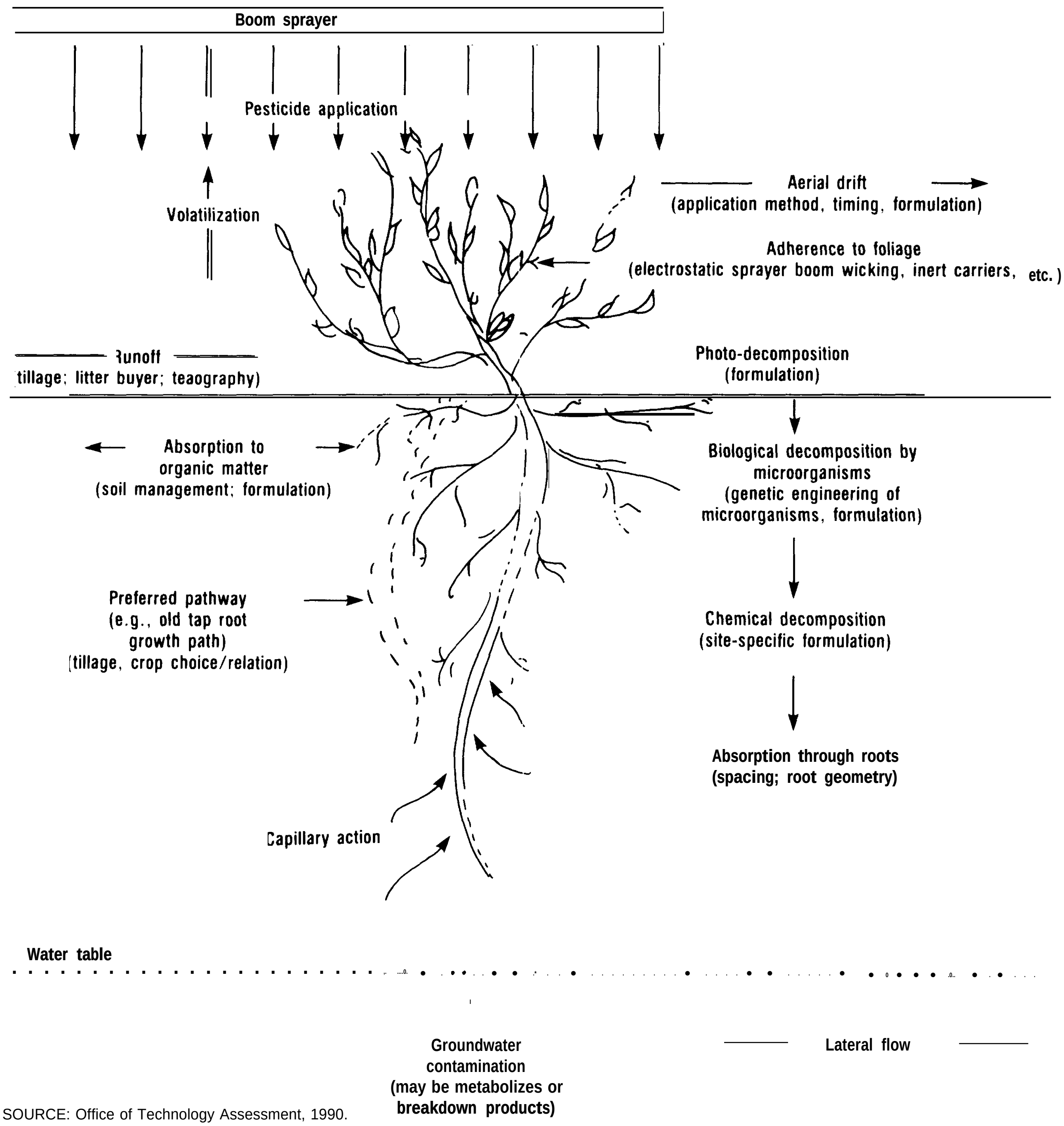
Concerns over the identified and potential harmful effects of pesticide chemicals in the environment has promulgated efforts to improve current use practices and identify alternative pest control approaches. Major research and development foci include:

- use reduction (e.g., fewer applications, lower levels of active ingredient);
- improved delivery systems (e.g., electrostatic sprayers, pheromone baits);
- environmentally more acceptable chemicals (e.g., biopesticides); and
- nonchemical approaches (e.g., cultural, genetic, or biological controls).

In addition to the current broad concern over environmental hazards of pesticide use, several other issues are associated with chemical pest control, including: 1) human exposure to pesticides (from the application process or where humans enter recently treated areas), 2) pest resistance, and 3) secondary pest outbreaks.

Pest Resistance—Resistance to a chemical may develop rapidly as pest life cycles may be short—some passing three or more generations in a single growing season. Within pest populations some individuals with genetic resistance to a chemical exist. As these individuals survive and reproduce, resistance is passed on to succeeding generations. Ultimately, a pesticide-resistant population devel-

Figure 4-5-Environmental Fate Pathways for Pesticides

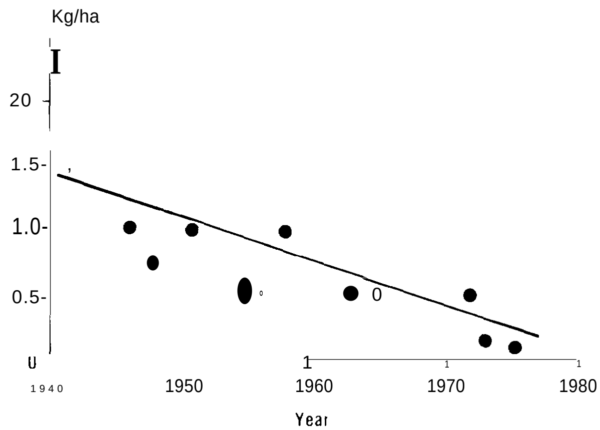


SOURCE: Office of Technology Assessment, 1990.

ops. For this reason, most pesticides have a finite effective life. For example, as of 1986, resistance had been reported in at least 447 species of ‘insects and mites, 100 species of plant pathogens, 48 weed species, 5 species of rodents, and 2 nematode species (61).

Effect on Nontarget Organisms and Secondary Pest Outbreaks—Pesticides generally are effective against a broad spectrum of plant-associated organisms of which only a fraction are considered pests. Thus, while a pesticide maybe applied to control a specific pest, it may also cause declines in beneficial

Figure 4-6-Evolution in Rate of Application of Insecticides



SOURCE: H. Geissbuhler, "Advances in Pesticide Science," International IUPAC Congress of Pesticide Chemistry (New York, NY: Pergamon Press, 1981).

populations. Such adverse effects on beneficial populations may create the conditions for secondary pest outbreaks. For example, continued use of a single herbicide or herbicide group may lead to prevalence of weed species not affected by the herbicide group (7). Also, natural control agents can be adversely affected by chemical applications directed toward the bona fide pest species. Secondary pest populations may then emerge as natural predator populations decline.

The effects of pesticides on soil fauna are highly complex, making generalizations difficult. Controlling variables include:

1. the abundance of biocidal compounds from various chemical families,
2. differences in persistence of pesticide compounds in the environment,
3. the diversity of invertebrate organisms in different soil communities,
4. metabolic products of different organisms that ingest pesticides,
5. chemical and physical heterogeneity of agroecosystems, and
6. the agricultural practices of pesticide users **(39).**

Where effects of pesticides in the soil environment have been observed and analyzed, the biotic responses are variable. Pesticides may affect soil fauna directly or indirectly; however, only certain organisms are adversely affected and some populations actually may increase. Certain pesticide residues may accumulate in the tissues of some soil organisms with no apparent ill effects, while certain sensitive species are killed from acute or chronic exposure. In almost all cases, the structures and functions of soil communities are modified by pesticide use (39),

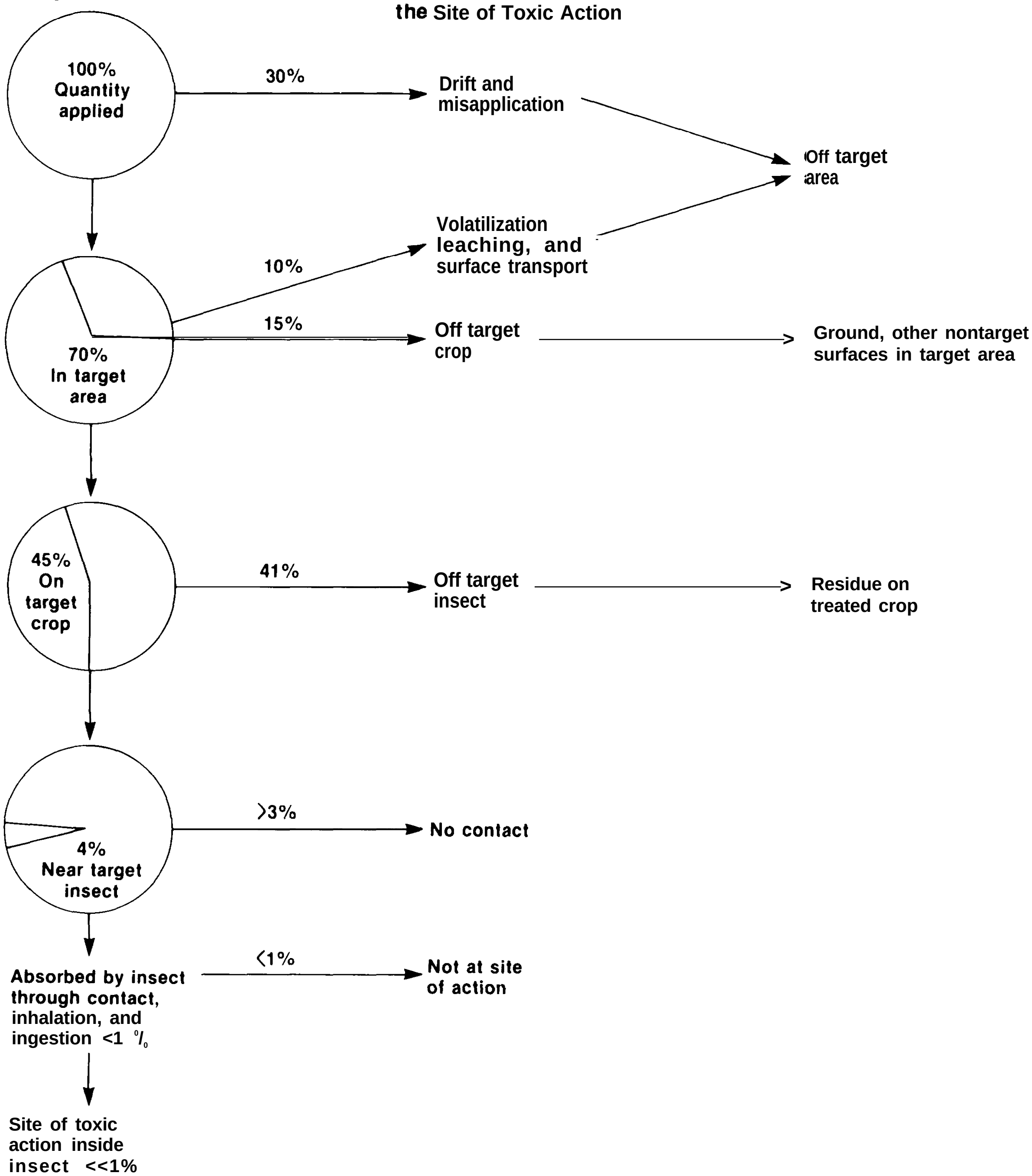
Inhibitions of microbial activity are most pronounced from fungicides and fumigants and suppression may remain for long periods. The impact may be so great that the natural balance among the resident soil microbial populations is upset and new organisms may become prominent. Moreover, certain nutrient cycles regulated by microorganisms are inhibited by fungicides and fumigants in such a way that significant adverse effects on plant growth and nutrition become evident. The lack of widespread concern for these antimicrobial agents is explained by the fact that they are not as widely used as insecticides and herbicides—the two major classes of pesticides (2).

Insecticides have received most attention in the past and are often acutely toxic as compared to other pesticides. These compounds may be applied directly to the soil for the control of soil-borne insects, or they may reach the soil from aerial drift or when previously treated plant residues are incorporated into the soil during cultivation.

While some soil microbial processes or populations may be inhibited by the presence of insecticides, the beneficial effects of insecticides in controlling insect pests argue for their use. Few instances of major suppressions of microbial activities in the field have been noted (2); however, further investigation of the links between pesticide use and modification of soil microbe populations seems warranted.

Herbicides are designed to control weed growth. Generally, small amounts of herbicide are used per unit of land area and the compounds are relatively selective for target plants, so little or no inhibition of other soil processes has been noted. In some instances, herbicides alter microbial activities, possibly because the suppression of target plant species may limit the availability of organic nutrients needed by microorganisms. These effects seem slight and have not raised questions over the use of particular chemicals (2). Herbicide use in no-till agriculture, however, is a matter of increasing

Figure 4-7-Typical Losses of Aerial Foliar Insecticide Application Between the Spray Nozzle and the Site of Toxic Action



SOURCE: R. Von Rumker, E.W. Lawless, and A.F. Meiners, "Production, Distribution, Use, and Environmental Impact Potential of Selected Pesticides," Environmental Protection Agency, Office of Pesticide programs, and Council on Environmental Quality, 1974.

concern because of the higher level of application associated with these cultivation systems (7). However, under certain reduced-tillage systems, these increases may be short-term; evidence exists showing that applications may drop significantly after 5 years (11 1).

Despite demonstrated problems with chemical pest-control approaches, numerous factors constrain use reduction (e.g., efficacy of alternative control methods, economic viability, practitioner risk perceptions). The demand for perfect cosmetic appearances of food by an affluent buying public may

Box 4-G—Pesticide Best Management Practices

Pesticide management practices that may reduce the amount of agrichemicals lost to the environment and potentially to groundwater include:

- following label instructions/documenting application practice and use patterns;
- application at the correct time per recommendations from scout/consultant;
- use of optimized approach rather than maximum label rate at the fill site; monitoring application so that tank is empty at end of the field to minimize waste being disposed of at fill-up site;
- use of small nurse tanks to dilute spray mixes remaining in pump and booms-spraying of this dilute mixture on way back to spray pads;
- tank rinsing with greatly diluted mixture to eliminate major point source contamination;
- calibration of application equipment (tagging yearly with calibration date);
- adjustment of spray volume and application rate by field, based on scouting information;
- following proper procedures for pesticide container disposal (on-farm demos by extension personnel);
- use of sound on-farm economic models to explore production/cost/crop loss relationships, thus diminishing tendency to insure, i.e., put it in the tank just to be sure;
- proper use of irrigation and better timing of sprays based on weather predictions to minimize movement through soil; and
- judicious management of pesticides based on selection, timing, dosage, and placement (ecological selectivity).

SOURCE: F.R. Hall, "Improving Pesticide Management Practices, " contractor report prepared for the Office of Technology Assessment (Springfield, VA: National Technical Information Service, August 1989).

contribute to continued pesticide use despite growing evidence of pest resistance, groundwater contamination, or adverse health impacts on farmworkers (73). Premium prices received for cosmetically appealing fruits and vegetables make it difficult to produce and market these foods profitably without chemicals (73).

It seems likely that despite intensified and accelerated research on nonchemical pest control methods, there probably will be continued need for some chemical pesticides in agricultural production. Analysts have suggested that agricultural pesticide use has modified agroecosystems sufficiently such that significant losses to pests occur when chemical use is discontinued (43). Despite this, potential exists to reduce some of the adverse impacts associated with pesticide use through improving agrichemical application methods, rate and timing, and developing of safer pest control compounds (box 4-G).

Formulation

The pesticide formulation provides for dispersion of the product in application media (e.g., water), product integrity/stability in storage, and ability of the pure pesticide to move through lipid barriers to the biological site of activity. Formulation may affect the release rate of the active ingredient, reduce volubility and leaching potential, and optimize dose transfer to target pests (73). Most of these properties affect the efficacy of foliar-applied pesticides. Increased attention is now being given to formulation chemistry with emphasis on increasing ability of product to move through waxy layers of leaf surfaces, thus increasing efficacy and pesticide retention on plant surfaces (60). Formulation chemistry has an overwhelming effect on pesticide efficacy relative to application technologies and physical properties of spray materials (60). While chemistry of a product may not change for years, formulation often changes.

Pesticides are formulated in several physical types: liquids (aqueous, oil, emulsifiable concentrates); solids (dust, wettable powders, granules, encapsulated products); and gases (fumigants). Progress has been made toward new formulations that enable additional products to be applied as liquid sprays (60). For example, active ingredients that are not easily diluted in water require specific formulation to allow mixing with water (60). The type of formulation depends on the chemical nature of the pesticide, target pest, and other pesticidal properties (60,208).

The density of granular products significantly affects pesticide performance and deposition, While granules have less drift potential, they require moisture to release the active ingredient to the soil.

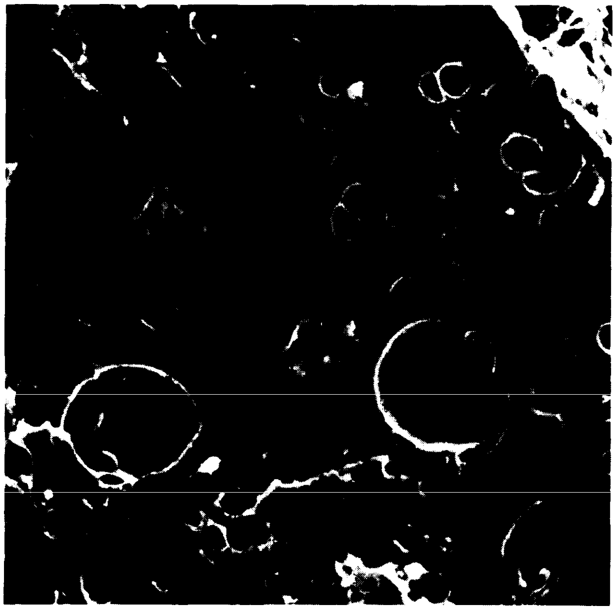


Photo credit: U.S. Department of Agriculture, Agricultural Research Service

Highly magnified granule of a starch-encapsulated herbicide shows pores through which herbicide is slowly released. Use of slow-release agrichemical formulations can reduce potential for high concentrations to **leach to** groundwater.

Thus, the release pattern is unlikely to be uniform because of variability in the carrier and soil. Opportunities also exist for improving application processes with existing equipment by improving formulations. For example, products that improve droplet size distribution of sprays may reduce the potential for pesticide drift from the application area (60). Liquid formulations, with a uniform state and higher quality control in manufacture, may increase uniformity of application (73). Controlled-release formulations (e.g., starch-encapsulated herbicides, ethylene vinyl acetate copolymers incorporated with pesticides) may reduce leaching potential in certain soils (73).

Formulation directly affects the physical properties of the final spray material and is an important factor in achieving accurate flow-rate measurements over a wide range of sprayer application rates (60). Similarly, if formulation fails to exploit the physical properties of a soil insecticide, delivery efficiency may be improved by application technology (72) and careful determination of application rates.

Pesticide Application Rates

Significant effort in terms of exhaustive field trials under varied climatic conditions goes into setting the recommended use rate for a pesticide-the level at which application is effective and meets environmental acceptability standards. Setting the application rate too low generates risk of product failure while setting it too high risks denial of approval by regulatory agencies (60), increases product cost, and lowers the flexibility in meeting food tolerance standards.

The trend toward reduction in active ingredient applied per acre has resulted in steadily declining application rates of insecticides from nearly 4.5 lb/acre (with carbaryl) to as low as 0.2 oz/acre with the new synthetic pyrethroids (73). However, these lower application rates generally indicate powerful active ingredients that may damage the crop if improperly applied. Small amounts of pesticides used per acre suggests that intrusion rates into surrounding environment would also be low. This suggestion, however, is complicated by the fact that off-target movement can vary widely depending on numerous variables, including crop type, soil factors, application system, rate and frequency of chemical application, and time of year. The capability to deliver small pesticide amounts effectively is questioned (71), suggesting that improvement in delivery systems should accompany efforts to enhance the intrinsic activity of pesticides.

Identification of pest tolerance levels for specific crops and cropping systems may offer another opportunity to reduce pesticide use. Weed-free fields, for example, may not be economically optimal. In a weed tolerance experiment conducted by ARS and Colorado State University, a one-sixth reduction in herbicide use had no effect on corn yields (cf: 103,137). These results suggest that reduction in chemical use may not necessarily result in depressed yields. Label-recommended application rates are developed on a nationwide basis; however, further work that identities what level of application produces economic yield could assist in revision of recommended application rates for specific sites and cropping situations.

Improved methods of delivering a pesticide to a selected target may affect application rates as well. Recently, the conventional practice of intermittently banding aldicarb granules along a row of trees (citrus) was replaced by a system based on sensing the trees with infrared photocells and then metering out the needed quantity of granules. Thus, the same pest control effect was achieved using significantly less material (73).

Pesticide Application Technology

The goal of pesticide application technology is to allow deposition of a precise amount of a formulated product on a specific target without exposing nontarget organisms to the pesticide (60). However, basic understanding of the complexities of agrichemical application technology has not kept pace with advancements in chemicals themselves or with public concerns for the environment (73). Chemicals that decompose readily and rapidly in the soil are of lesser concern than more persistent compounds that may be distributed broadly in the environment.

In general, costs of herbicides and insecticides have increased over the past 3 years, Pesticide manufacturing prices and dealer costs (e.g., liability insurance) have increased as well during this time period (table 4-10). This trend may create some incentive for producers to focus on more cost-effective applications of pesticides.

Since the early 1980s there have been numerous meetings and conferences focusing on agrichemical application technology and its role in determining the environmental fate of chemicals. The first national conference on the subject in 1985 concentrated on the hardware aspects of application technology and a following conference in 1988 focused on operator training and technology for improved operation of application equipment. However, few of the recommendations that emerged from these meetings have been followed (60).

While the efficiency of many application techniques is known to be low, the inherent variation of biological systems and a lack of significant research and development efforts hinder improvement. Lack of calibrated equipment is the number one problem for effective pesticide management-current equipment cannot easily deliver consistently lower pesticide rates with the necessary accuracy (73). Opportunities for improvement in application technology lie in permitting variable amounts of pesticide to be applied within a field (60) and in improving application accuracy. This may be done by improved calibration, mixing calculations, and monitoring equipment; equipment for incorporating pesticides that need to be mixed with the soil to proper soil depth; and education in the use of such equipment (60).

Table 4-10-U.S. Average Farm Retail Pesticide Prices

Pesticide[a]	1987	1988	1989
	Dollars per pound (active ingredient)		
Herbicides:			
Alachlor	4.84	5.10	5.40
Atrazine	2.20	2.28	2.7
Butylate	3.04	3.10	3.10
Cyanazine	4.63	4.78	5.03
Metolachlor	6.03	6.21	6.61
Trifluralin	6.3	6.45	6.60
2,4-D	2.44	2.53	2.60
Composite[b]	4.05	4.2	4.43
Insecticides:			
Carbaryl	3.9	4.06	4.07
Carbofuran	9.57	9.36	9.51
Chlorpyrifos	8.25	8.5	9.05
Fonofos	8.70	8.83	8.96
Methyl parathion	2.82	2.94	3.85
Phorate	6.59	6.68	6.85
Pyrethroids[d]	48.8	50.00	53.20
Terbufos	9.79	9.88	10.13
Composite[b]	10.25	10.57	10.88

[a]Derived from the April survey of farm supply dealers conducted by the NASS. USDA.
[b]Includes above materials and other major materials, not products registered in the last 2 to 3 years.
[c]Supplied by Fred Cooke, MS Agricultural Experiment station.
[d]Average of fenvalerate and permethrin prices based on 2.6 pounds of active ingredient per gallon.

SOURCE: U.S. Department of Agriculture, Economic Research Service, *Agricultural Resources: Inputs, Situation* and Outlook AR-15 (Washington, DC: U.S. Government Printing Office, August 1989), p. 26.

Pesticides commonly are only as effective as the application method (60). Changes in product packaging and formulation pose one of the greatest challenges to development of pesticide application equipment. Such formulation changes can affect the physical properties of the final pesticide material and thus affect the efficacy of the delivery mechanism. Pesticides used selectively to control specific pests without adversely affecting beneficial organisms may require highly precise application technology capable of delivering the compound at a rate small enough to avoid affecting beneficial organisms, yet large enough to control the pest.

Recent trends toward foliar-applied pesticides and lower application rates will require increased precision in application technology than was needed a decade ago. While these new trends have potential to decrease over application and to reduce contact of pesticides with the soil and thus soil water, the requirements for increased application precision

may exceed current application technology capability (60).

Simultaneous application of several pesticides (tank mixes) has increased dramatically, placing added requirements on pesticide application technology. This trend is particularly significant for injection sprayer systems because up to three different pesticides may be injected into the sprayer boom during application. Still other requirements are arising with the trend toward faster, lighter weight applicators that apply pesticides at low or ultra-low sprayer application rates and with less diluent (water) (60).

Pesticide application technology research and development started to increase in the 1960s and peaked in the 1970s. However, Federal and State research efforts have diminished significantly since that time with herbicide application technology effort alone decreasing from 11.1 scientist years to 2.5 between the years 1972 and 1982 (table 4-11). Similar trends are found in equipment development for insect and disease control (60).

Resources invested in development of application equipment are small relative to those invested in pesticide product development, which may range from $20 to $40 billion over 7 to 10 years (60). Advances in chemical technology have and continue to outdistance research and development of application technology. Causes for this condition include depressed equipment sales; lack of financial incentives for fundamental research by the application equipment industry; lack of basic information about the application process; and inadequate communication among users, manufacturers, and researchers (73). Only recently have some of the larger chemical companies tried to coordinate formulation development with application technology; much more effort is needed, however (60).

Currently ARS has the largest investment in application research effort. This is concentrated primarily in Texas, the Southwest, and Ohio. Development of agrichemical application equipment also is significant in the United Kingdom and some eastern European countries. Improved granule distribution equipment has been developed in France (60).

A few small companies, specialized to serve different market segments, are the major developers of pesticide application technology in the United States. Most large machinery manufacturers do not consider application equipment to be an important profit segment of the market but rather an essential complement to other product lines. For example, there are only two U.S. manufacturers of nozzles, valves, screens, and other hydraulic sprayer components (60). Herbicide application technology has lagged ever further behind that of insecticide and fungicide application technology, even though herbicides account for most pesticide use (71).

Table 4-n-Agricultural Engineering Research for Weed Control Equipment Development

Year	ARS	State	Total
	(SY)	(SY)	(SY)
1972			
1974	4.3	2.0	6.2
1977	2.9	1.5	4.4
1979	2.8	0.7	3.5
1982	1.7	0.8	2.5

SOURCE: C.G. McWhorter and M.R. Gebhardt (eds.), *Herbicide Application Technology* (Champaign, IL: Weed Science Society of America, 1988), p iii.

Despite relatively small investments in development of application technology, improvement has been made in overall accuracy of application equipment. Equipment designed to apply pesticides within plus or minus five percent of the recommended rate now exists. This constitutes a vast improvement over equipment used 40 years ago. Various pesticide applicator designs have been developed to increase uniformity of spray coverage, reduce drift, increase deposition at desired locations, and reduce volume of diluent-i.e., hydraulic sprayers, pneumatic sprayers, airblast devices, propeller-driven applicators, spinning cages, and spinning disks.

Certain application equipment development efforts are focusing on increasing the application accuracy by improving existing sprayer components. Although basic sprayer components have not changed, they are manufactured more accurately and have improved hydraulic components. Further, several new components designed to improve application efficiency are now available, many of them using modern electronics to control the application rate and to measure the amount applied per field or unit area. Most sprayers are now equipped with devices to agitate the spray mixture to ensure that the formulated pesticide stays in suspension (60).

Improved maintenance and calibration technology is the most significant short-range improvement that can be made to agrichemical application equipment, requiring no great amount of research but time for development. Some companies now offer kits to aid in calibration.

Technology and engineering concepts from other sciences and industries might be applicable to pesticide application technology; however, such interchange has been insufficient (71). Technology existing within the military and industrial manufacturing complex could be adapted for agricultural applications. For example, developing automatic guidance of sprayers and other equipment could improve efficacy of many products by eliminating skips and overlap. Improved flow rate measurements could also improve agrichemical application accuracy. Many small improvements, when aggregated, overall could have a significant beneficial effect on reducing agrichemical waste. Such an effort, however, may be quite difficult given the current state of the farm equipment industry (60).

Currently, three basic techniques exist for agrichemical application: ground-based, aerial, and chemigation (208). Ground-based and aerial pesticide applications generally are accomplished by spraying or wiping liquid formulations on plant surfaces or broadcasting pelletized forms. The majority of pesticides are applied as sprays with ground-based equipment using a hydraulic spray nozzle (208,60), although aerial application of agrichemicals is substantial (35 percent of all chemicals (73)).

Wicks, rollers, and other wiping devices offer the best available method for effectively eliminating application of herbicides onto the soil, but these application methods require sufficient weed growth to provide contact of foliage and stems with the topical application. Since weed growth is variable, several trips around the field may be necessary for control. However, this technology needs further development, especially if soil-applied (preemergence) herbicides are banned (60).

Electrostatic sprayer technology has been very successful in the commercial painting industry, but this technology has yet to show significant promise for agriculture—its greatest potential is for application of insecticides to plant foliage where coverage is very important for insect control. It may also be important technology as postemergence herbicide use increases (60).

The injection sprayer mixes formulated pesticides in the boom of the sprayer on the go during field

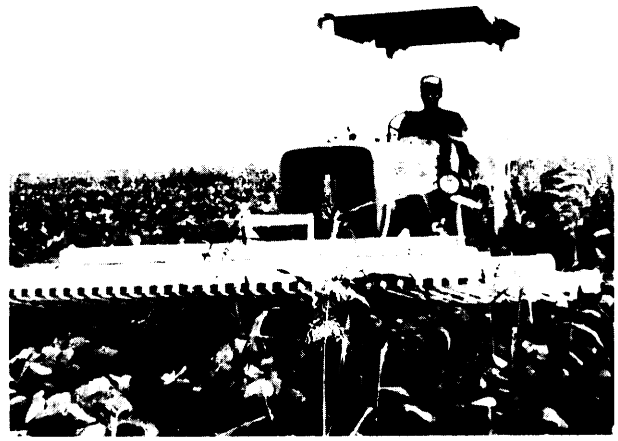


Photo credit: USDA Agricultural Research Service, Southern Weed Science Laboratory, Stoneville, ***Mississippi***

Herbicide application with rope-wick applicator.

Photo credit: USDA Agricultural Research Service, Southern Weed Science Laboratory, ***Stoneville, Mississippi***

Close-up of rope-wick applicator.

application, thus avoiding premixing and handling; the diluent is stored in a large tank on the sprayer. Only the pesticide actually applied is mixed into the spraying system-no residual material is left except what is contained in the boom. Direct injection of pesticides on the go should be evaluated for adoption by sprayer manufacturers. The technology is now commercially available (138,173) and offers an opportunity to reduce point source contamination from disposal of rinsate and mix-disposal problems.

Losses of agrichemicals during ground-based spraying operations may be reduced by shrouds or shields that reduce the effect of wind and other environmental conditions that may affect drift or evaporation. Such approaches may most directly affect air quality and ultimately water quality from atmospheric deposition.

In response to concern over environmental contamination from aerial application, the National Agricultural Aviation Association developed Operation SAFE (Self-regulating Application and Flight Efficiency). However, procedures for drift containment, waste disposal, rinsing, packaging, and container transfer/handling are needed to hold drift and environmental contamination to minimum under SAFE (73). Efficiency of aerial application could be increased by controlling the range of droplet size and developing pest-target-specific delivery devices (73).

Chemigation is the application of agrichemicals to crops through an irrigation system. The pesticide is mixed and distributed with water flowing through the irrigation system (208). It is a relatively new agrichemical application technology and is primarily used in conjunction with sprinkler irrigation systems. The concept of applying plant nutrients in irrigation water by dumping animal manure into irrigation canals likely arose hundreds of years ago; however, the basic concept of applying commercial fertilizer through sprinkler irrigation emerged only about 30 years ago. Now advances in irrigation system design and chemical injection equipment have produced technology for expanding chemigation to include all types of crop inputs (i.e., fertilizers and pesticides) (208).

Advances in chemigation technology may offer significant promise for reducing potential groundwater contamination by agrichemicals (223). Some examples include:

- wider use of advanced irrigation scheduling techniques,
- development and use of irrigation techniques that improve uniformity of distribution,
- development of agrichemical formulations particularly suited to chemigation,
- performance standards and reliability testing procedures for chemigation,
- backflow prevention systems (required by EPA), and
- exploitation of agrichemical application scheduling diversity offered by chemigation (208).

By controlling the amount of water applied and selecting a proper formulation, a chemical can be deposited either on foliage or the soil surface or distributed to a desired soil depth (208). However, chemigation techniques have been shown to promote leaching of chemicals under certain conditions such as wet years when heavy precipitation follows chemigation (223).

Application of agrichemicals via chemigation is subject to local, State, and Federal laws and regulations, labeling mandates, and guidelines by several professional societies. The American Society of Agricultural Engineers (ASAE) has described system components and presented an arrangement of these components comprising a functional system for minimizing potential environmental contamination and maximizing operator safety (ASAE Engineering Practice EP409). Combination of these efforts has resulted in broad consensus on appropriate, commercially available chemigation system components to achieve maximum practical prevention of chemical backflow into water sources (208).

Sprinkler irrigation systems, particularly center pivot and linear move systems, are ideal for chemigation because chemicals can be applied to foliage and soil-most insecticides and fungicides, many herbicides, and most growth regulators need to be applied to foliage. Chemigation via surface irrigation seems less desirable due to inherent difficulties in uniform water distribution. It is impractical and uneconomical with subirrigation systems (208).

Microirrigation systems with emitters or porous pipes are effective for chemigation of soluble nutrients and pesticides needing distribution through the soil; such systems with miniature sprinklers can chemigate soluble foliar-applied chemicals. However, small openings are a constraint for chemigation with microirrigation systems, limiting utility to soluble chemicals (208).

Advantages of chemigation relative to other agrichemical application approaches include:

1. increased uniformity of chemical application,
2. prescription application (timing and quantity),
3. easy chemical incorporation/activation,
4. reduced operator hazards, and
5. cost-effectiveness.

Under highly efficient chemigation systems potential exists to reduce agrichemical requirements for crop production, which could have a beneficial effect on groundwater quality. However, such systems also require a greater degree of management attention and further potential exists for backflow of chemicals into the water supply (208).

Timing of Pesticide Applications

Timing of pesticide applications is critical to the overall efficacy of use, Application during inappropriate weather or premature applications can release chemicals into the environment and yet not accomplish the desired pest control effect. Such circumstances may lead to the need for several applications to achieve pest control.

Timing, however, is problematic given the often narrow windows of opportunity for pesticide applications, particularly when such timing must also fit a custom applicator's schedule. Application equipment is costly and the trend toward purchasing the service of the custom applicator as opposed to owning and operating personal agrichemical application equipment may increase difficulties in timely agrichemical applications.

Use of economic injury levels and pheromone traps as decision aids to improve the timing of pesticide applications is a feature of improved management (95). Pest-prediction models (e.g., prognosis models, economic injury models, crop-loss models, prediction of pathogen or aphid intensities) may improve practitioners' ability to match timing of crop-protection measures with pest infestations.

Alternative Control Methods

Nonchemical pest control methods such as crop rotations, crop monitoring, use of resistant varieties, timing of planting and harvest, and biological controls were prevalent prior to World War II.

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

Insect parasites that colonize and develop within other insects are one type of biological control. Here, a parasitic wasp lays eggs in a tobacco budworm host.

Low-chemical-input producers use a number of these practices to control insect and weed populations today.

Cultural controls include a broad range of production practices that render the crop environment less favorable for the pest. Although widely used in the past, the more labor-intensive cultural controls were practiced less with the advent of the chemical era. Tillage and water management are effective cultural controls in the management of weeds. Tillage may also bury weed seeds. Further, increases in mortality in many insects that overwinter in the soil are likely to result from tillage practices. The destruction of crop residues may be important in the management of many pests, such as navel orangeworm in almond, late blight of potato, stem rot of rice, and pink bollworm and boll weevil in cotton. For these, compulsory plowdown dates exist in several regions as part of regional pest control programs.

Manipulation of planting and harvesting dates permit breaks in the development of pest populations in regions where pests develop throughout the year. Crop rotation can also be used to break the life cycles of many pest species. Applying fertilizer with the seed of annual crops or through drip-irrigation systems may also provide a measure of weed control, especially in contrast to broadcast applications.

Genetic controls include the traditional breeding of plant varieties resistant to pests and biotechnological approaches to conferring pest resistance in crop plants (see section on cultivar improvement). This second approach involves the introduction of genetic material that governs resistance characteristics such as toxin production. Genetic control may also be applied to the insect pest directly, for example, to create sterile organisms that will interrupt the natural pest population lifecycle. This method has been used to control screwworm in cattle, pink bollworm in cotton, and the Mediterranean fruit fly.

Mechanical control methods, common before the development of modern pesticides, are still used. Many crops require cultivation several times during the growing season. For example, soybeans in the Midwest receive more cultivation than corn largely due to the availability of long-lasting residual herbicides suitable for corn and not for soybeans, and to later planting time for soybeans (60,203).

Pheromones, viruses, bacteria, fungi, and bioengineered organisms have been touted as alternatives to conventional pesticides; however, their use is not widespread in part due to lengthy testing and registration procedures required under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (254).

Biological control is commonly considered the cornerstone of any integrated pest management (IPM) program. Often referred to as biocontrol, it is a biological approach to pest control that employs the use of natural enemies-predators, parasites, and disease-to reduce a pest population. This may involve the introduction of a natural enemy (classical biocontrol), rearing and periodic release of natural enemies (augmentative biocontrol), or conservation of a natural enemy extant in the agroecosystem (conservative biocontrol).

Augmentative and conservatory approaches to biological control often will require behavioral changes on the part of the practitioner. Because these methods rely on the acquisition and release of natural predators or conservation of those extant in the agroecosystem, respectively, such methods require an understanding of pest cycles, predator/prey relationships, and the biotic factors responsible for maintaining populations of beneficial organisms. Thus, to promote adoption of these techniques it is necessary to understand the factors that influence practitioner choice of pest-control methods, such as: 1) what the long-range goals are and what external factors affect how pest control methods are selected, and 2) what level and type of technical assistance will be needed and accepted by the practitioner.

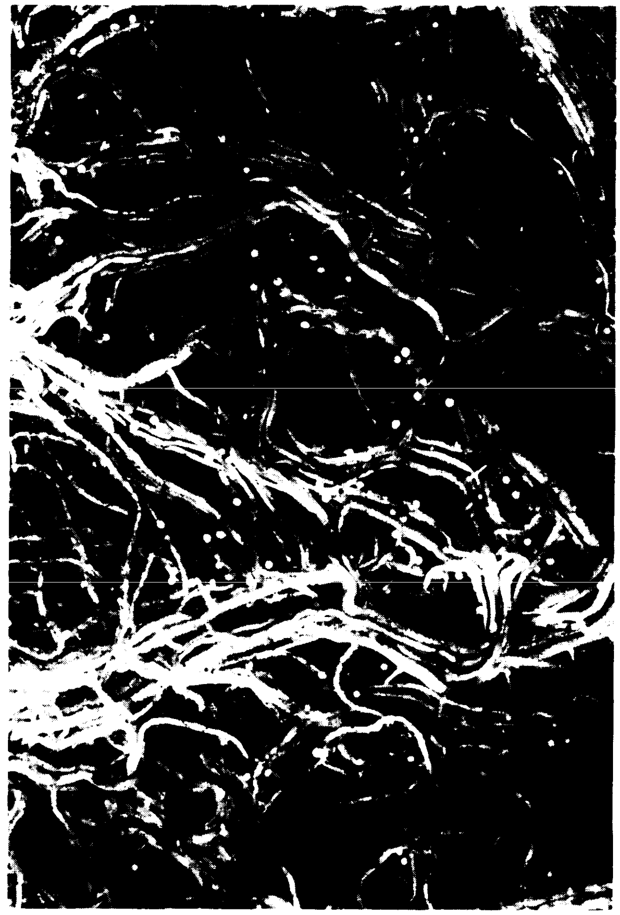


Photo credit: U.S. Department of Agruculture, Agricultural Research Service

Although commonly an agricultural pest, certain nematode species also are useful as commercial biological control agents. Augmenting or maintaining populations of beneficial nematodes has been shown to be an effective control measure for certain root weevils. Shown here are nematode cysts on plant roots.

Control of cottony-cushion scale on citrus in California was achieved by importation of the Vedalia lady beetle in 1888. Biological agents, primarily insects and plant pathogens, currently are applied to control as many as 100 weed species. Substantial control has been achieved for numerous weed species (e.g., klamath weed, prickly pear, lantana) (151). Additional examples of successful development and marketing of weed biocontrol agents include the use of *Collectotrichum gloeosporioides* on northern joint vetch and *Phytophthora* on stranglevine of citrus. Lack of funds for commercial development of biological control agents and biological pesticides, including bacteria, fungi, and viruses, has limited their availability and increased their price (96). Currently, 68 U.S. suppliers participate in a $25 million market in the global distribution of biological pest-control agents (92).

The narrow foundation of basic research may pose an obstacle to expeditious development of technologies to reduce environmental contamination b y agrichemicals. The agricultural research foundation could be expanded to emphasize the biological, ecological, and systems sciences to a much greater extent. These research areas, however, have received comparatively little attention and funding in public-sector programs. Research funding for Integrated Pest Management (IPM) programs, for example, has declined in the last ten years (254).

Another obstacle to the development of alternative pest control products is the high cost of commercializing new biological products, which discourages firms from expanding technologies available to farmers. Although the development costs of one of the frost commercial mycoherbicide (biological controls designed to combat fungal pathogens) was approximately $2 million as compared to nearly $30 million for development of a chemical herbicide (7), the marketing potential, stability, shelf life, and potential for mass production are issues of particular concern in commercializing a biological control agent, Costs of meeting regulatory requirements for registering new products and uncertainties as to whether or not products will be allowed to go on the market also may provide a disincentive to investment in new-product research. Even when products are placed on the market, uncertainty exists as to whether regulations will change, causing a product to be restricted or banned.

Specialized registration procedures for alternative pest control products (e.g., biological controls, fungi, viruses, and bacteria) might facilitate more rapid development and marketing of these products. Some allowances exempting certain aspects of registration for these products have already been made. For example, recently a nematicide developed from processed crustacean sheik received unconditional EPA approval (50). Although currently a small part of the market, such ‘‘pesticides’ present an alternative to certain traditional compounds (254). The specificity of such compounds means that the potential market is small in comparison to that of traditional compounds. Grants or tax incentives might promote development. Additional incentives for private development and marketing of innovative pest controls could promote this sector of the agrichemical industry. Additional research will likely be necessary to assess the potential for adverse impacts generated by use of nonchemical pest controls to the U.S. environment.

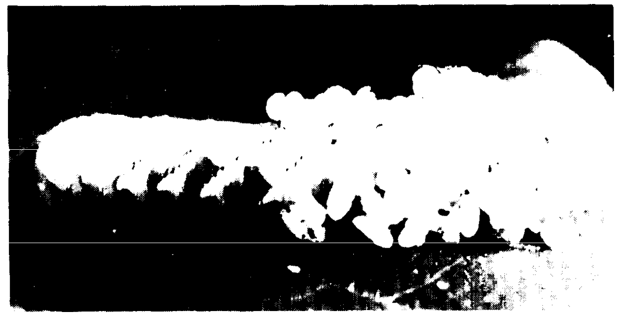


Photo credit: University of California-Riverside+Vancy E. Beckage

Parasitic wasp larvae have hatched and are feeding on this tobacco hornworm host. Use of natural predators may help control insect pests that cause billions of dollars of damage.

Integrated Pest Management

Integrated Pest Management (IPM) is a systems approach to pest control that is designed to provide benefits (economical, environmental) to the user and society. Where possible, IPM programs attempt to restructure an ecosystem to minimize the likelihood of pest damage. Programs are meant to be adaptive with a goal of improving program efficacy overtime. The broad goal is to maintain pest populations at near-harmless levels by reducing population fluctuation and to improve the predictability of control measures. IPM programs commonly are composed of a number of the pest control tactics discussed above.

The key concepts behind IPM are that:

- a threshhold population level exists, below which pest control is not economically practical;
- integration of chemical and natural methods of pest control is possible; and

- a sound understanding of the agroecosystem being managed is needed (including host, pests, natural enemies, competitors, alternate hosts, etc.) as pest populations interact with other ecosystem members.

The development of an IPM program requires thorough knowledge of the ecosystem being managed, the social and economic goals or reasons for its management, and the incentives and constraints imposed by social, economic, political, and regulatory rules and values. This knowledge comprises the framework within which an effective IPM program can be built. Thus, the system being managed and its specific needs are analyzed prior to design of the pest management strategy.

A common perception of IPM programs is that they represent a return to past, labor-intensive practices. While it is true that strategies may employ cultivation or crop-rotation practices that served to control pest populations in early U.S. agriculture, new techniques also are integral to modern-day IPM programs. Further, IPM does not mean the absence of chemical controls. Indeed, in certain instances chemical use may even increase under IPM. This effect sometimes may be attributed to recognition of a theretofore unnoticed pest population.

However, IPM programs have resulted in a significant decrease of pesticide use in several crops. These reductions in pesticide use occur because practitioners are trained to pay careful attention to the actual need for the pesticide, as well as its timing and application (254). For example, in an IPM program implemented in Egypt to control cotton leafworm, corn aphid, and three species of corn borers, the area that had to be treated with chemicals dropped from 692,000 to 22,000 acres within 5 years (43). IPM programs frequently are characterized by a combination of tactics designed to keep pest populations at a level below which economic injury would occur.

Growers may adopt IPM for a number of reasons. The most influential factor seems to be the potential for financial gain due to reduced inputs, increased production, or reduced pest damage (cf: 68,248). Recently, in response to public concern over pesticide residues in or on food, certain retailers have begun to advertise ''no detectable residues, ' with IPM being one of the marketing tools. The potential for entering new or premium-price marketing channels is causing some growers to reconsider their

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

A Mexican bean beetle-a major pest of snap- and soybeans-becomes a meal for the spined soldier-bug. Introducing, attracting, or maintaining populations of such natural predators in fields is one possible component of Integrated Pest Management systems. Increased understanding of plant-pest-predator-farming system interactions will allow for more efficient use of such biological controls in the future.

pesticide-use practices. For example, the New York State regulatory agency, at the request of growers and following guidelines being developed by the IPM program of Cornell University, is initiating a certification program for growers who produce crops using IPM practices (204). It seems likely that financial incentives or disincentives provided through government programs would have an impact on adoption of IPM and other low-input agricultural methods (254).

A crisis in pest control such as resistance to pesticides (cf: 33,66,96), loss of key pest control materials due to regulation (253), or severe secondary pest outbreaks may stimulate some producers to adopt IPM tactics. Environmental and on-farm health concerns were an important stimulus to IPM research, but they have typically contributed to adoption only because of some obvious problem or because of regulation resulting from a concern or problem (201). Growers rated protection of personal and public health and reduced environmental damage as the two least important incentives for adopting IPM in the national evaluation of extension IPM programs (163).

A number of constraints to IPM use have been identified in various studies (32,68). Obstacles fall into the following categories: technical, financial, educational, institutional, and social (246).

Technical Constraints-Insufficient development of IPM strategies and techniques such as monitoring guidelines, control action thresholds, biological controls, cultural controls, and host plant resistance for a wide variety of cropping systems comprise the primary technical obstacles. However, the technical constraints are regarded to be less important than other constraints (cf: 70,151). Simplification of IPM methodology may foster adoption of monitoring and sampling guidelines and control-action thresholds (5,33,65,96).

Financial Constraints-While IPM implementation commonly increases profits for adopters, there remains a perception that it does not offer the short-term economic advantages equal to those generated by conventional control, largely because of the additional labor costs from sampling and monitoring (157). The concept of purchasing the advice of private pest consultants and others providing IPM services still may be difficult to accept, particularly since costs are incurred in advance of pest problems, and even if no pest problem occurs (254).

Financial risk may be the most important obstacle to IPM adoption. Growers value pesticides for reducing production risk as well as contributing to profit. However, the more producers learn about pests in their fields and the likelihood of resultant damage, the more likely they are to make wise pesticide-application decisions. The value of IPM in terms of risk reduction may actually increase in relation to the grower's level of risk aversion (4).

Lack of funds for extension programs has been cited as a constraint to IPM adoption in numerous studies (cf: 58,202,248). Where such projects as the Federal extension pilot projects of the 1970s and State-supported IPM projects (e.g., California, Texas, and New York) have been initiated, enhanced IPM adoption can be documented. At present, most extension IPM activity occurs at the State level with a combination of State support and Federal formula funds. However, Federal funds have not increased during this decade, and the areas where major extension efforts are occurring are those with significant State contributions (254).

Educational Constraints-Implementation of IPM requires a complex set of methods, technologies, behaviors, and decisionmaking processes requiring intensive education of uses. However, it has been suggested that lack of education of IPM developers about the perceptions and needs of growers also comprises a significant obstacle (cf: 65,174). Such lack of understanding can lead to development of an inappropriate technology that is unlikely to be adopted (254).

Institutional Constraints-The structure and codes of regulatory, educational, and corporate or industrial institutions can influence the implementation and expansion of IPM programs. Lack of coordination, especially among organizations, personnel, and disciplines, may be particularly problematic (105,15 1).

Efforts to mandate or regulate IPM specifically have not been highly successful. For example, adoption of a mandated IPM program for lessees on State-owned land in California declined rapidly with the lack of enforcement (67). The cause was assessed as a lack of experience on the part of the State agency involved in addressing producer concern for risk (254),

Lack of interdisciplinary collaboration in IPM research, extension, and education has been suggested as a major constraint to more widespread use of IPM strategies (cf: 12,17,130). A tendency for research and education activities to be conducted within strongly discipline-oriented departmental units in land-grant universities has evolved in response to institutional pressures. Individual achievements rather than team accomplishments typically are rewarded (155), leading to the predominance of such efforts at the expense of multidisciplinary work. Programs leading to interdisciplinary, professional degrees rather than research degrees in plant health and pest management are few, and not well supported within higher education institutions (102).

Other organizational obstacles also exist, most notably cosmetic standards imposed by such agencies as the Federal Food and Drug Administration, USDA, and State departments of agriculture; corporations including processors, packers, and retailers; and commodity associations such as cooperatives and marketing orders (32,53). These quality standards have largely been imposed because of consumer demands, but also may be used as market regulating tools (254).

***Social Constraints*-The** rate at which adoption occurs and the ultimate level of adoption may be affected by many social factors including demographic attributes of the agricultural population, communication channels used by growers or managers, and growers' perceptions of the technology. Growers receive pest management information from a variety of sources and in this regard chemical controls may have a competitive advantage over IPM. A well-established infrastructure exists for pesticide supply and use and a high ratio of commercial representatives exists relative to private pest management consultants or extension IPM personnel (237,189).

Agrichemicals are seen as easy to use despite regulations on their use and application and associated increased costs. In addition, pesticides give nearly immediate reinforcement in terms of pest control. Thus, most growers have developed confidence in their use (32,96,245). Alternatively, IPM often requires additional labor or specific knowledge, and may take longer to realize benefits. Further, the concept of economic thresholds is perceived as risky by many growers (155). However, experience with IPM may change this risk perception (68).

Photo credit: ***United Nations-M.*** Tzovaras

Past plant breeding efforts have been highly successful in increasing productivity of crops such as wheat. Current efforts are now being directed towards developing crop varieties that are more suited to specific cropping situations or are able to withstand a number of environmental stresses (e.g., drought tolerance, pest tolerance). Such efforts may reduce agrichemical inputs that are needed to compensate for agricultural production in unfavorable environments.

CROP, SOIL, AND WATER MANAGEMENT

Management of the soil and water environment for crop production requires an understanding of the interaction of these cropping-system components, and of the suitability of the chosen crop(s) for the agroecosystem. Production of crops ill-suited to a given region may require more intensive external inputs, such as pesticides and fertilizers, to overcome the associated plant stress responses and to achieve acceptable yield levels. Productivity of current crops falls far short of their potential, largely because of production in unfavorable environments (16).

Soil- and water-management techniques offer a mechanism to adjust or modify the agroecosystem to enhance crop production and thus affect the requirements for external inputs. For example, soil-management practices designed to improve the friability and moisture-holding capacity of soils can facilitate crop root development. This in turn may improve the plants' nutrient extraction capability, thereby reducing the need for external nutrient inputs.

Crop Management

Crop management refers to the numerous decisions that most directly relate to the crop, including cropping pattern (e.g., rotation, intercropping) and

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

Maintaining a winter cover crop, interplanting one crop into another, and reduced tillage systems, involving leaving crop residue on the soil surface, may provide slow release of plant nutrients and promote nutrient "scavenging" from soils that otherwise might become available for leaching to groundwater. Conversely, some reduced tillage systems may require intensive use of herbicides and promote infiltration of water through the plant root zone. Care is needed to balance factors in designing farming systems.

crop or cultivar choice. Certain crop-management alternatives and techniques may complement or enhance nutrient and agrichemical management activities. Crop-management decisions may have direct impacts on agrichemical use and on how such compounds will behave and move through the agroecosystem. Crop choice alone has instant implications for the pesticide and fertilization regime a producer will use. For example, greater amounts of nitrogen fertilizers and pesticides are used to produce corn and cotton than are used to produce other crops (225,226). Similarly, certain cropping patterns such as a legume-based crop rotation may provide a mechanism to supply plant nutrients and break pest cycles for a subsequent crop and thus reduce agrichemical requirements.

Cropping Patterns

Successive planting of different crops in the same field--crop rotation—was a common practice in early U.S. agriculture. Practitioners maintained a diversified production system in order to provide livestock forage and various other crops. However, with expanded use of chemical fertilizers and pest control compounds and availability of high-yielding crop varieties, the practice of crop rotation declined in favor of continuous production of one or two crops (6).

Crop rotation and associated crop diversity may retard pest buildup by creating conditions that hinder development of pest populations and enhance the soil-nutrient content (162). Thus, such production systems tend to have lower agrichemical require-

Table 4-12-Common Crop Rotations Used on Land Producing Soybean-1988

Previous crop 1987	1986	AR	GA	IL	IN	1A	KY	IA	MN	MS	MO	NE	NC	OH	TN	Total area
		Million acres planted														
		3.25	0.9	8.8	4.3	7.95	0.98	1.8	4.9	2.4	4.3	2.4	1.47	3.9	1.4	48.75
		Percent														
soybean	Corn		7	7	16	6	18	10	7	1	17	12	9	24	8	10
soybean	Soybean	40	34	5	9	3	8	44	2	58	24	3	16	11	38	15
soybean	Other	13	7		2	1	2	7	3	18	7	2	4	8	6	4
Corn	Corn	nr	8	11	19	7	13	4	7	nr	6	17	4	7	4	8
Corn	soybean	1	4	61	41	74	34	nr	51	1	24	43	32	30	9	41
Corn	Other	nr	3	4	3	5	11	nr	6	nr	3	8	8	9	9	4
Wheat	Other	1	11	3	2	1	9	2	10	2	5	8	6	6	8	4
Rice	Soybean	17	nr	nr	nr	nr	nr	14	nr	4	nr	nr	nr	nr	nr	2
Rice	Other	5		nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr
Fallow[a]	Other	9	10	5	4	3	1	13	4	15	3	1	6	2	4	5
	Total	86	84	96	96	100	96	94	90	99	89	94	85	97	86	93

[a]Fallow includes land idled under farm Commodity program provisions.

NOTE: Entries made as nr indicate that data for that item was not reported.

SOURCE: U.S. Department of Agriculture, Economic Research Service, *Agricultural Resources: Inputs, Situation and Outlook,* AR-1 5 (Washington, DC: U.S. Government Printing Office, August 1989).

ments (136). Continuous cropping-planting the same crop on the same land in successive years-has the lowest degree of diversity and tends to be associated with intensive agrichemical use. More pesticides are needed to combat the pest populations that may develop in response to the consistent food source and field conditions. Such cropping systems may represent a greater potential for agrichemical contamination of groundwater in hydrogeologically vulnerable regions because of the higher levels of agrichemical input associated with continuous cropping.

Federal commodity programs have been said to discourage crop rotations and diversity (136). However, continuous cropping is not as widespread as this might suggest. Continuous cropping is most prevalent for cotton in the Southeast, corn on irrigated lands in Nebraska, winter wheat in Oklahoma and Texas, soybeans in Mississippi, and rice in California. In the major corn-producing states, 38 percent of the corn acreage was in rotation, while 26 percent was in continuous cropping during 1985-88 (228).

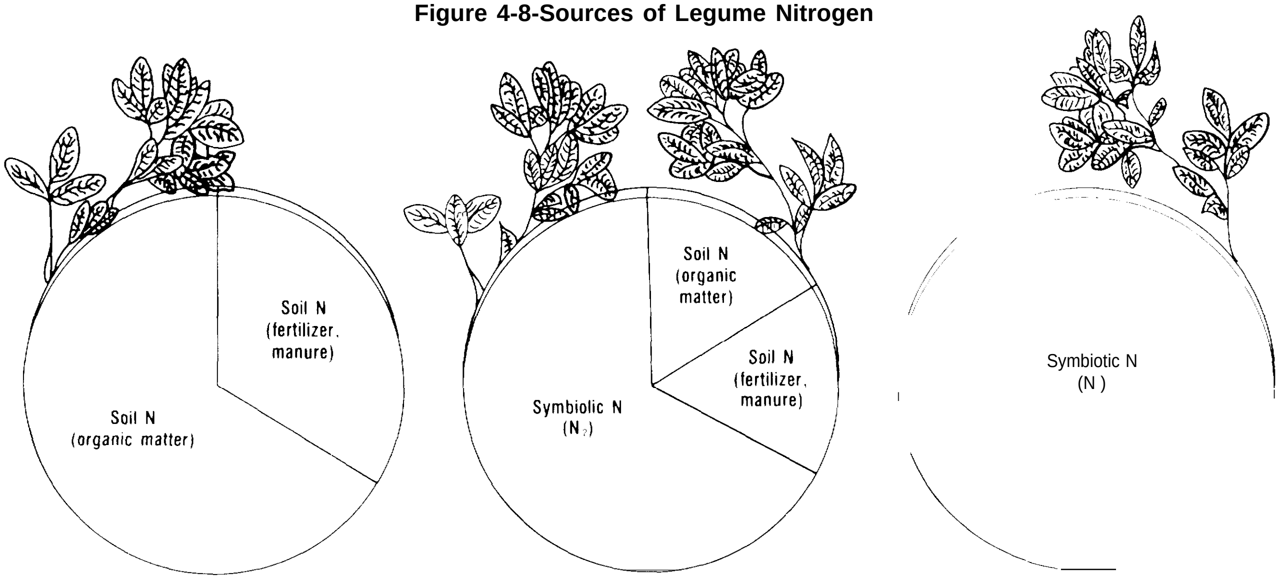
Nevertheless, most crop rotations commonly used by farmers in the United States do not lend a high degree of crop diversity (table 4-12). Although at least 80 percent of the cropland in most States is characterized by some form of crop rotation, in many States only two or three rotations are widely used (228).

Sod-based crop rotations are used to minimize wind and water erosion. They also can be used to provide some nitrogen for later crops. Total soil loss is greatly reduced, although soil conservation is not equally distributed over the rotation. On many soils, crop rotations favor higher yields and improved crop quality (212) largely from enhanced soil structure and composition, addition of nitrogen, and other rotation effects. Rotation effects refer to the enhanced yield commonly associated with crop rotation beyond what might be attained under a continuous cropping regime. Such effects are noted under legume- and nonlegume-based rotations and thus are not necessarily solely attributable to deposition of nitrogen (9,87,90). Improvements in soil structure and composition, moisture storage capacity, and organic content and reductions in pest infestations are likely factors contributing to rotation effects (136),

Cropping sequence influences the water content of surface soils, on a gravimetric and volumetric basis (1 17). The volumetric water content is significantly greater in the upper soil profile under a legume-based rotation as compared to a fertilizer-based system (41,171). While legume-based cropping systems may increase organic content of the soil, the improved soil texture and porosity associated with such systems may have a greater effect on the availability of soil water to plants (86).

Legume-based crop rotations have been long known to improve the yield of subsequent nonlegume crops (154). Legumes derive nitrogen from three principal sources: through commercial fertilizer or manure application; by mineralization of

Figure 4-8-Sources of Legume Nitrogen



SOURCE: C.C. Sheaffer, D.K. Barnes. and G.H. Heichel, "Annual Alfalfa in Crop Rotations," Station Bulletin 588-1989, Minnesota Agricultural Experiment Station, St. Paul, MN, 1989.

indigenous soil organic matter; and by symbiotic nitrogen fixation (figure 4-8). The role of atmospheric nitrogen (N_2 or dinitrogen) fixation by legumes as one factor in the yield improvement became known early in this century (56). Use of legumes as "green manures"[5] in U.S. cropping systems peaked in 1940, when an estimated 13.0 million acres (3.5 percent of harvested cropland) were planted (179). The knowledge that forage legumes were capable of fixing atmospheric nitrogen fostered the belief that nearly all legume nitrogen was derived from this process, despite evidence that soil nitrogen substituted for atmospheric nitrogen in legume nutrition (3). Thus, the fertilizer replacement value commonly was based on the nitrogen content of the biomass incorporated as a green manure (196,185), without regard to the possible legume uptake and recycling of soil nitrogen. A net enrichment or renewal of the soil resource by fixed nitrogen in legumes can only occur when the legume is grown and managed with attention to returning the above-ground plant material to the soil rather than exporting it as hay or grain (84,85).

Different hay and pasture legumes grown on a soil with the same initial nitrogen concentration in the profile derive different amounts of nitrogen from symbiosis (table 4-13). The amount of nitrogen fixed varies with species, growth stage, and inherent soil fertility and may be further influenced by crop management practices, life form (i.e., annual v. perennial), and environment. Factors that promote high rates and high seasonal totals of nitrogen fixation in legumes include:

- optimum mineral nutrition at a pH slightly below neutrality (pH 6.5 to 7.0),
- long growing season,
- low concentration of plant-available soil nitrogen,
- optimum water availability, and
- absence of insects or pathogens.

The amount of legume-fixed nitrogen made available to a nonlegume crop depends on plant, environmental, soil, and management factors. In an intercrop situation where the legume and nonlegume are grown concurrently, observations have indicated that some nitrogen transfer occurs, conferring a benefit to the nonlegume (86). The amount of nitrogen transferred seems to vary depending on the species intercropped. The method and mechanism of transfer are unclear, however.

Under a rotational cropping system, several factors determine whether the nitrogen returned to the cropping system is a net input or simply a return of

[5]Green manure refers t. plant materials, generally legumes, used as a nitrogen Source for crop growth. Plowing under of these crop residues promotes decomposition and release of inorganic nitrogen that is then available for crop uptake.

Table 4-13-Variation of Dinitrogen Fixation Capacity With Legume Species

Species	Nitrogen from symbioses by harvest[a]	Dry matter Yield (lbs/acre)
Hay and pasture legumes:		
Alfalfa[b]	63	6,809
Red clover[b]	65	6,230
Birdsfoot trefoil[b]	40	4,880
	Harvest *at grain maturity*	
Grain legumes:		
Soybean[c]	76	2,494
Soybean[d]	52	7,837

[a]Mean percent over three harvests.
[b]Established in soil with 3.7% organic matter and an initial nitrate concentration of 12ppm at the O- to 6-inch depth.
[c]Established in soil with 1.8% organic matter and an initial nitrate concentration of 12ppm at the O-to 8-inch depth.
[d]Established in soil with 4.8% organic matter and an initial nitrate concentration of 31ppm at the 0- to 8-inch depth.

SOURCE: G.H. Heichel, "Legumes as a Source of Nitrogen in Conservation Tillage Systems," The *Role of Legumes in Conservation Tillage Systems,* J.F. Power (cd.) (Ankeny, 1A: Soil Conservation Society, 1987), *In:* Heichel, G. H., 1989.

soil-derived nitrogen, temporarily sequestered in the legume crop. For example, under certain conditions only 40 percent of total accumulated nitrogen in soybeans is freed from atmospheric nitrogen. After harvesting the crop for grain, a net export of nitrogen from the cropping system is observed. Under different conditions the same crop may fix nearly 90 percent of total accumulated nitrogen and post-harvest soil conditions will show a net nitrogen input (86).

Legume-based rotations remain a significant part of agricultural production practices. Food and feed crop legumes are the nitrogen-fining species of the greatest agricultural importance in the United States and totaled at least 89.7 million acres in 1986 (220). However, the impact such systems have on nitrate contamination of groundwater has not been well studied. Nitrogen from legumes may appear in groundwater due to mineralization of the organic forms of plant nitrogen to nitrate in soil solution, and when precipitation or irrigation sufficiently exceeds evapotranspiration to allow water loss from the root zone. Nitrogen may be released from legumes by: 1) direct release from the nodules (20,1 12); 2) decomposition of dead roots or nodules; and 3) soil incorporation of legumes. Any of these situations in combination with a leaching event may increase the risk that legume nitrogen will appear in groundwater (180).

Although the circumstances that promote nitrogen loss from legumes to groundwater may be easily predicted, only meager experimental evidence exists for leaching of legume-derived nitrogen to groundwater in U.S. cropping systems. Available evidence is limited in interpretation because the sources of nitrate lost from the root zones of legumes have not been unambiguously identified by origin-e.g., nitrate from living or decomposing legumes, from mineralization of soil organic matter, from fertilizer, or from other origins (86).

Intercropping—Intercropping refers to a variety of cropping patterns including mixed intercropping, strip intercropping, and relay intercropping. *Mixed intercropping* describes the growing of two or more crops simultaneously with no distinct row arrangement, while *strip intercropping* implies a distinct row arrangement of the intercropped plants. ***Relay intercropping*** is the growing of two or more crops with the second crop planted into the frost crop a.tier it has reached maturity but is not yet at harvest stage. These cropping patterns are used commonly in tropical agriculture to provide a diversity of agricultural products, to discourage the spread of pests across a field, and to allow for greater exploitation of the soil profile and nutrients than monoculture systems (214).

Intercropping combinations that include a nitrogen-fixing species may offer the additional benefit of providing nitrogen to adjacent crop(s) and thus reduce the need for nitrogen fertilizer applications. Similarly, use of deep-rooted species, such as alfalfa, may offer a mechanism to draw nitrate up from the lower soil profile and thus make it available for nearby, shallower rooted crops (152). The highly mechanized agricultural practices common in the contiguous United States may pose a constraint to widespread use of intercropping techniques.

Conservation Plantings-Conservation plantings, such as contour cropping, have been designed to reduce soil erosion and and surface runoff. While erosion control may have been the impetus for development of these practices, they may also provide beneficial effects on groundwater quality when used in combination with new strategies such as inclusion of nitrate-scavenging crop varieties. For example, strip cropping using a deep-rooted crop as one of the components may offer some potential for reclaiming nitrate in the lower soil profile (alfalfa roots may reach nearly 3 feet in one cropping season). Further, as the alfalfa roots draw soil moisture and nitrate up the profile, the nutrient

Photo credit: University of California-Berkeley-M.A. Altien

Intercropping systems offer potential for reducing agrichemical needs. Incorporation of nitrogen fixing species as one component of the intercropping system may offer nutrient provision benefits to the adjacent crop. Other combinations may include "trap crops" that provide barriers to pest movement through a field.

becomes available to nearby or interplanted crops as well (190)

Certain conservation practices that have been promoted since the 1930s as methods to reduce soil erosion from wind and water also serve to increase soil moisture and are valuable tools for protecting water resources (23 1,230). Hedgerows, shelterbelts, and field border strips consist of fast-growing, resilient herbaceous and woody vegetation planted between fields to trap snow on fields or to prevent snow from collecting in vehicle travel lanes. These plantings provide soil moisture benefits for subsequent crops and may offer additional benefits by taking up excess nitrate. However, they are located commonly along field edges, fencerows and tractor paths and thus would only provide for nitrate uptake along field perimeters, Similarly, establishment of cover crops offer a mechanism to reduce nitrate losses to groundwater in regions of the country where rainfall exceeds evapotranspiration. Such crops may take up soil nitrate remaining from the cropping season and thus reduce the potential for leaching to groundwater (183,207).

Riparian zones consist of vegetation typically adapted to seasonal periods of submersion and drying out. Riparian zones may be planted along cultivated fields to help moderate the movement of sediment and adsorbed chemicals into riverine ecosystems. Agricultural nonpoint-source pollution could be minimized by the establishment of riparian border vegetation (184). Similarly, planting of such areas to deep-rooted crops can create an upward flux of soil moisture and thus ''scavenge' nitrate from the lower soil profile (190).

Grassed terraces and waterways offer some potential to improve agricultural land productivity (18,2 12). They serve as buffer areas to slow agricultural runoff and sediment flowing toward surficial water supplies, and to further provide soil stabilization. Terrace and waterway establishment, however, tends to be expensive and may require soil disturbance. Narrow-based terrace construction costs in Illinois are about $300 to $400 per acre (18). Further, maintenance may be required to control possible weed outbreaks.

However, conservation plantings also may have undesirable effects. They may compete with the crop for soil moisture and nutrients or constitute barriers to certain production practices (e.g., center-pivot irrigation systems) or use of large mechanical cultivators (213). Use of deep-rooted species as in conservation plantings may ameliorate competition for these resources in the upper soil profile under some conditions.

Cultivar Improvement

Fifty percent of the overall yield increases in U.S. agriculture have been attributed to the use of improved crops and cultivars (16,44). While past efforts sought to increase yields, currently research scientists are investigating potential avenues to reduce agrichemical losses to the environment through a variety of cultivar development techniques (e.g., conventional breeding, genetic engineering). Developing plant varieties that are more suited to various cropping environments, for example, may offer an opportunity to reduce agrichemical use. Similarly, a plant able to use nutrients more efficiently could require fewer fertilizer applications. Ongoing ARS adaptation activities include developing crop varieties with tolerance for various soil pH levels, salt accumulations, and water stress. Crops less subject to stress are more likely to survive minor pest infestations and other adverse conditions (loo).

Genetic engineering approaches to enhance crop productivity is of significant interest to seed, agrichemical, and biotechnology companies (59). Research has focused on introducing genes that may enhance stress tolerance (e.g., drought tolerance), pest tolerance (e.g., toxin production), and nitrogen self-sufficiency (e.g., introduction of nitrogen-fining genes). Successful manipulation of a number of crop plants has occurred already, and engineered varieties are expected to become available in this decade (59).

Genetically, plant resistance is conditioned by major- and minor-effect genes. Major-effect genes are easier to manipulate and have given dramatic results in laboratory experiments, however, their effectiveness commonly is less in the field. Generally, major-effect genes are more effective than minor-effect genes in heterogeneous cultivars such as certain wheat varieties developed in Iowa and Washington. Minor-effect genes seem to be more successful in the homogeneous cultivars common to Western mechanized agriculture (214). Current areas of crop improvement research that may have implications for agrichemical use include: pest resistance, herbicide resistance, nitrogen self-sufficiency, and enhanced nitrogen-use efficiency.

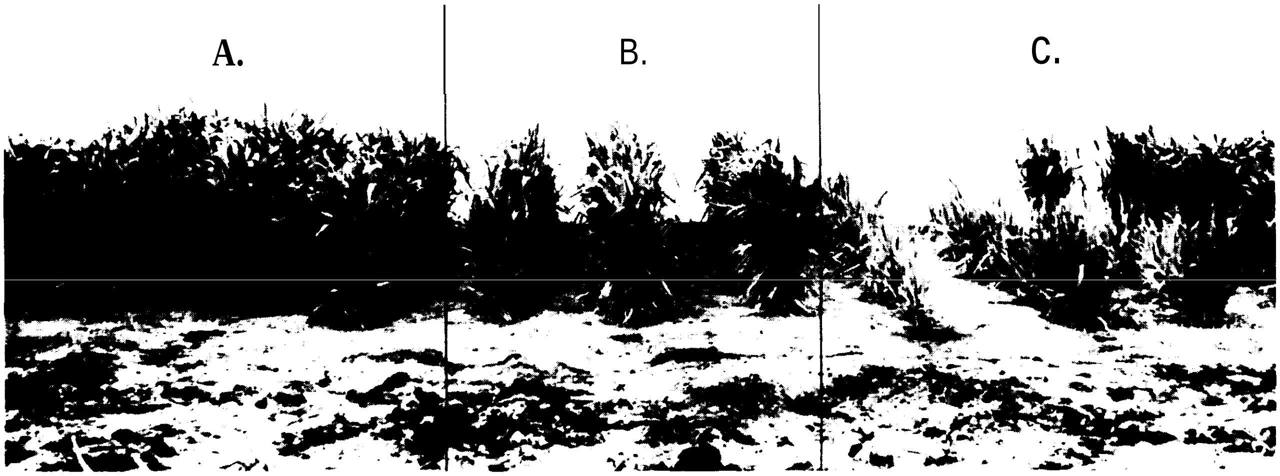
Pest ***Resistance—Advances in*** development of insect-resistant plants have to date been largely achieved through the use of a protein found in the bacterium *Bacillus thuringiensis* (B.t.). The protein is lethal to certain insects such as moths and butterfly larvae and some strains produce a protein toxic to beetle and fly larvae. Toxicity to other insects, animals, or humans has not been noted (59).

Field tests of tomato and tobacco plants with the B.t. gene have had positive results. In one study, tomato plants with the B.t. gene were not adversely affected under conditions that resulted in complete defoliation of plants without the gene (59).

Given the potential of this technology to reduce insecticide application, significant benefits to groundwater protection might be achieved if research were directed toward development of such resistance for high-use crop species. The expense of genetically engineered varities may pose a constraint to implementation. Further, concern exists over the possibility of development of pest resistance to the toxin.

Although plant diseases are the results of bacterial, viral, or fungal infections, research efforts have focused on developing resistance to viral infections. Success has been achieved in developing resistance to the tobacco mosaic virus through use of a gene responsible for inhibiting uncoating of the virus once inside the plant cell. Similar results have been demonstrated against alfalfa mosaic virus, cucumber mosaic virus, and potato X and Y viruses in tomatoes, tobacco, and potato. Greenhouse and field tests of tomatoes with the resistance gene showed no yield loss after viral inoculation as compared to 23 to 69 percent loss in untreated plants (59).

Development of resistance to fungal and bacterial infections has met with little success to date (59).



Wheat can be partially protected from the fungal disease "take-all" by treating seeds with Pseudomonas bacteria prior to planting. A = plot with no fungal infection; B = treated wheat in infected plot; C = untreated wheat in infected plot.

Billions of dollars in crop losses per year are attributed to fungal-caused disease and postharvest spoilage (209). Given the low efficacy of fungicides relative to other pesticides as well as the method of application (generally soil incorporation), investigation into developing resistant plants could have important implications for groundwater protection. EPA recently has proposed a ban on most uses of EBDC, a widely used fungicide, because of its potential carcinogenicity. One of the alternatives to EBDCs, chlorothalonil, has been detected in well water (147).

Herbicide Resistance—Research on developing herbicide resistance in crop plants largely has concentrated on broad-spectrum herbicides that exhibit low soil mobility and rapid biodegradation. It is suggested that such development might result in a shift in herbicide use to more environmentally safe compounds (59).

Engineering approaches currently focus on: 1) reducing sensitivity of plant to the herbicide, and 2) conferring detoxification capability to the plant (59). A certain herbicide may act by inhibiting activity of an enzyme essential to plant (weed or crop) life. To reduce sensitivity of the crop plant to this herbicide, a gene sequence might be introduced that would promote overproduction of the target enzyme or production of an herbicide-tolerant variant of the enzyme. Detoxification of an herbicide is achieved by introducing bacterial genes that produce enzymes that inactivate the herbicide. Resistance to certain herbicides has been achieved by the detoxfilcation and sensitivity reduction approaches (59).

However, concerns exist over the potential for conferring herbicide resistance to weed species. Concern also exists over the potential for increased herbicide use stemming from availability of this technology. Proponents of the technique argue that the compounds for which resistance would be developed would be more environmentally acceptable and effective and thus could result in reduced herbicide use (59).

Alternatively, certain plant-growth regulators (PGRs) are being investigated as a potential avenue for herbicide resistance. These protestants or safeners may be applied to a crop (usually seed) so that when herbicides are applied to the crop row only the nonprotected plants are killed (214).

Examination of chemical residues and breakdown products remains to be done for certain of the herbicides for which resistance may be developed. Currently, herbicide resistance research is being conducted for such crop species as soybean, cotton, corn, oilseed rape, and sugarbeet.

Nitrogen Self-Sufficiency-The transfer of nitrogen-fixing ability to crop plants has been suggested as an opportunity to reduce excess nitrogen in agricultural soils that may be available for leaching, potentially to groundwater. Nitrogen-fixing genes are found only in certain microorganisms (procaryotes) many of which are symbiotically associated with plant species. Research and development efforts have focused on development of methods to confer nitrogen-fixation capability to crop plants and thus create a more self-sufficient plant. To date, however, transfer of nitrogen fixation genes to plants (i.e., from procaryotes to eucaryotes) largely has been unsuccessful.

Legumes develop highly specific symbiotic associations with various species of *Rhizobium*. A specific strain of the bacterium will infect only certain groups of legumes—' 'cross-inoculation groups. ' It has been determined that certain proteins (lectins) are responsible for allowing the plant and bacterium to recognize each other and enter the symbiotic association. Research has been conducted on introducing the protein responsible for recognition from a plant in one inoculation group to a plant in another (pea to clover). Some success was observed in that the clover plant developed nodules, however, they exhibited abnormalities. Nonetheless, such results suggest that there may be potential for genetic engineering to modify the plant genome sufficiently to make symbiotic nitrogen fixation a possibility (116).

These technologies remain an ongoing research area and no guarantee exists that development of nitrogen-fining crop plants would reduce nitrate contamination of groundwater even if commercial fertilizer use is reduced. Some evidence exists for release of nitrogenous compounds from actively growing nitrogen-fixing species and thus potential for nitrate formation and movement to groundwater under leaching events (86). Further, the nitrogen-fixing process itself may operate at some cost to the host plant and how this may affect crop productivity is unclear.

Nitrogen Use Efficiency-The nitrogen use efficiency of a crop plant is a significant factor in making wise fertilizer application decisions. Nitrogen use efficiency describes the capability of a plant to take up and assimilate available nitrogen and this attribute may vary among species and even among cultivars of the same species. Increased efficiency then may be displayed either by: 1) increased crop yield and nitrogen uptake with equal or lesser amounts of applied fertilizer, or 2) equal crop yield and nitrogen uptake with lesser amounts of fertilizer (164). Crop breeding to select for greater nitrogen use efficiency may have the potential to reduce nutrient requirements; however, numerous environmental and management factors mediate observed nitrogen uptake, making such selection difficult. Nongenetic factors that affect nitrogen use efficiency include: 1) planting geometry and planting dates, 2) tillage and residue management, and 3) irrigation management (180).

Manipulation of genetic materials in order to improve nitrogen accumulation is currently an area of research. However, little success has been achieved to date. Estimates are that development is at least several decades away (214).

Soil Management

Agricultural productivity is clearly linked to the management of soil resources. Certain soil characteristics can be maintained to provide alternatives to purchased inputs and to reduce energy and labor requirements in crop production. For example, maintaining soil organic matter contributes to friability and "natural' nutrient content, facilitating cultivation and potentially reducing the need for external inputs. Thus, soil management practices may indirectly affect agrichemical use. However, the tillage system effects with the greatest importance to groundwater contamination largely center on how various systems affect water movement and nitrogen transformations in the soil.

Tillage practices most directly affect the soil properties that influence the movement of water in and through the soil (e.g., structure, organic matter content, soil microbial populations) and thus affect potential agrichemical movement. Under conventional tillage systems (i.e., moldboard plow) water tends to remain in the upper profile or move laterally, whereas under reduced tillage systems that promote moisture infiltration, deep percolation may be an enhanced pathway (207). Environmental variables such as intensity and duration of rainfall and soil composition further influence the depth and route of water movement. Similarly, different soil types respond differently to the wide variety of tillage systems, making only general conclusions possible (207).

Conservation or reduced tillage systems are any of a variety of noninversion types of tillage including mulch-till, ridge-till, and no-till. Under these systems, seedbed preparation and planting techniques leave protective amounts of residue mulch (e.g., corn stalks, wheat stubble) on the soil surface. Initially promoted as a mechanism to reduce soil erosion, reduced tillage also tends to produce soils with higher levels of organic matter and soil fauna.

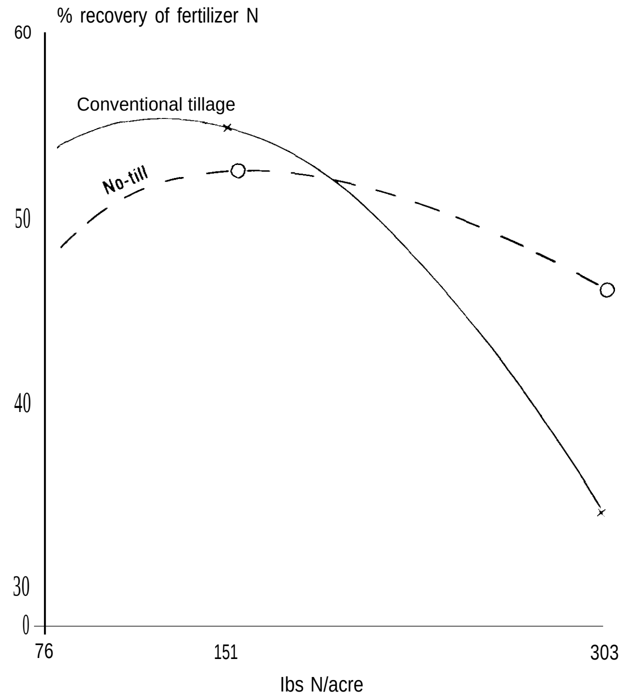
Because the soil is less disturbed by cultivation in reduced tillage systems, burrowing animals (insects, earthworms, etc.) may create extensive networks of charnels through which water may preferentially flow (27). One study estimated that twice as much water flowed out of the root zone under no-till as compared to conventional till. This effect was attributed to reduced evaporation and increased number of conduits from the surface through the soil profile (190). This condition may promote movement of agrichemicals to groundwater; however, data are limited (190,165).

Tillage systems may affect soil organic matter content significantly. Commonly, under conventional tillage systems where the soil is significantly disturbed, organic matter decreases through oxidation (212), whereas under reduced tillage systems surface residue accumulation and soil organic matter content may be quite high, Surface residue accumulations and increased soil organic matter content common under reduced tillage systems may increase the potential for immobilization of applied nitrogen. Evidence suggests that this effect may be due to low populations of the nitrifiying bacteria responsible for the conversion of organic nitrogen to nitrogen in the upper 15 cm of the reduced tillage soil profile (207). While this might represent an opportunity to retard vitrification and thus potential nitrate-leaching losses, the immobilized nitrogen also may be unavailable to the plant, potentially retarding its growth.

As tillage and cropping practices influence the physical soil properties, they also may affect the soil microorganism activity necessary for mineralization of organic nitrogen. Thus, these factors may be of great importance to crop nutrition and groundwater quality (41). However, strategies with which to manage organic nitrogen mineralization in relation to rainfall and crop nitrogen demand are lacking (86).

The additional reliance on herbicides for weed control in certain reduced tillage systems may exacerbate agrichemical loss to groundwater (12 1,27). However, field data vary widely, indicating that environmental parameters significantly influence the propensity for agrichemical movement. Some analysts report that reduced tillage systems require more herbicides only in the first few years, with

Figure 4-9—Recovery of Fertilizer N by No-Till and Conventionally Grown Corn



SOURCE: J.O. Legg, G. Stanford, and O.L. Bennett, "Utilization of Labeled-N Fertilizer by Silage Corn Under Conventional and No-Till Culture," ***Agronomy Journal***, vol. 71, 1979, pp. 1009-1015.

herbicide use declining as practitioners become familiar with the tillage techniques. Despite these concerns, most agronomists conclude that soil conservation benefits of conservation tillage outweigh potential groundwater quality impacts (1 11).

Tillage systems also may affect plant recovery of fertilizer (figure 4-9) and thus fertilization schemes. Reduced nitrogen efficiency associated with the various forms of reduced tillage systems initially seems more related to volatilization and immobilization of applied nitrogen fertilizer than vitrification and nitrate leaching. However, in moist cropping regions, ample opportunity may exist for mineralization of immobilized N, nitrification, and subsequently nitrate leaching (166).

Although injection of fertilizers may address this need to some extent, such application methods are problematic in reduced tillage systems because of maintained surface residues, A study in Indiana showed that under no-till conditions yields were greater when fertilizer was injected than when it was surface applied (164). Possible reasons for the lower yields from surface-applied fertilizers include volatilization, immobilization, or denitrification.

Fertilizer research over the last 30 years largely has focused on conventional tillage (primary tillage with a moldboard plow with various secondary tillage practices). Thus, fertilizer recommendations have been based on a crop management system that is much different from the various reduced tillage systems that are now gaining popularity (166).

Acreage under some form of conservation tillage rose from four million acres to 98 million acres between 1963 and 1986 (33 percent of total planted cropland). The highest use of conservation tillage is in the Corn Belt, totaling 34 percent of planted acres in 1988 (227). Although estimated acreage under conservation tillage has dropped by nearly 28 percent since 1986 (possibly due to acres idled under Federal acreage reduction programs in 1987 and 1988), adoption is expected to increase again. One SCS projection, assuming an improved farm economy in the 1990s, indicates that 63 to 82 percent of total planted cropland acreage could be in conservation tillage by the year 2010 (228). Clearly, research to identify the action and interactions of agrichemicals in reduced tillage systems is needed. Advance of reduced tillage systems requires new concepts of fertilizer and chemical placement, including significant changes in application techniques and new equipment (73).

Water Management

An important factor in attempting to prevent movement of agrichemicals into groundwater is proper management of water sources-natural and artificial-used in crop production. Water management practices in non-irrigated agricultural regions are closely related to soil management, and are designed to maintain soil moisture at levels sufficient to allow crop growth. Soil management techniques that promote maintenance of soil organic matter and increased water infiltration can contribute to enhanced soil moisture storage. In some areas, fallow seasons are necessary to allow for soil moisture recharge.

In humid regions, excessive water may pose a constraint to cultivation. Under these conditions, alternatives to reduce the flux of water and soluble agrichemicals below the crop root zone include cropping patterns to promote plant moisture uptake and installation of drainage systems. Drainage systems serve to remove excess moisture from the soil and numerous studies have focused on the relative amounts of agrichemicals contained in tile drains. Potential for contamination of groundwater largely may be related to drainage-water disposal practices and, to a lesser extent, to improperly functioning drainage systems (212). If drainage outflows are disposed of through agricultural drainage wells or sinkholes they may represent significant groundwater contamination potential (see ch. 3).

Weather prediction may play a significant role in overall water management approaches. Accurate and timely prediction of precipitation conditions could allow producers to adjust their agrichemical application plans accordingly. For example, under drought conditions, applied fertilizers remain unused by the crop and thus excess nitrogen is available for movement through the soil or to other media. Alternatively, agrichemicals applied prior to a major precipitation event maybe washed off plant surfaces, leach through the soil profile, or run off the land. Improved weather prediction capacity and dissemination of this information could assist producers' in making appropriate rate and timing decisions for agrichemical inputs.

Under irrigation systems additional opportunities exist to improve water management. Application of excessive quantities of irrigation water or nonuniform distribution of irrigation water can cause runoff or deep percolation of water and dissolved agrichemicals to groundwater (77). Most irrigation acreage expansion since 1945 has occurred with the installation of sprinkler irrigation systems in areas located over major groundwater aquifers. Nitrate and pesticide contamination of groundwater have been measured in several regions, with much of it likely due to agricultural practices. Significant potential for nitrate and pesticide contamination exists in many major U.S. groundwater areas. Vulnerable areas are concentrated in the humid, subhumid, and Central Great Plains regions, the same regions where sprinkler systems are the dominant mode of irrigation (208),

Sixty-eight percent of total groundwater withdrawal is applied to the land though various irrigation systems. Irrigated acreage is concentrated largely in the 17 western states (85 percent), the Mississippi Delta, Florida, and South Georgia (figure 4-10). Total U.S. irrigated acreage stabilized in the 1980's largely due to low farm commodity prices

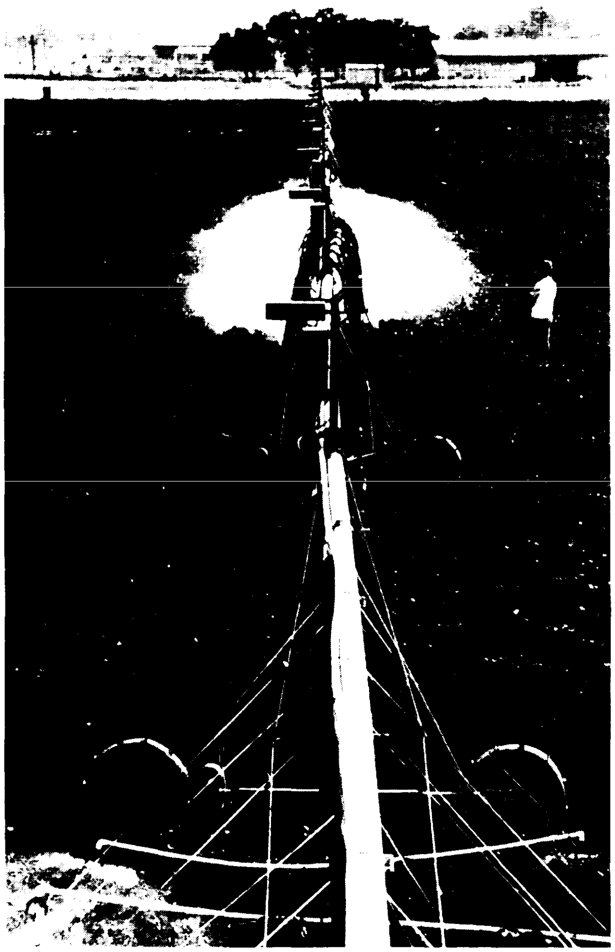


Photo credit: U.S. Department of Agriculture, Agricultural Research Service

Improving water-use efficiency in irrigated and "chemigated" agriculture can reduce the potential for agrichemical contamination of groundwater. Here, a laser-aligned, traveling trickle-irrigation system is being tested in California cotton fields.

and increasing irrigation costs, particularly energy-related expenses. Agricultural commodities produced using irrigation systems generated 30 percent of the total value of the U.S. market (78). Clearly, irrigated acreage plays a significant role in U.S. agricultural production (figure 4-1 1).

Attributes of irrigation systems that may affect agrichemical contamination of groundwater include scheduling, timing, rates, drainage, and system type (e.g., sprinkler, drip, furrow). Uniformity of distribution is a key factor of major importance when evaluating the potential for irrigation practices to promote groundwater contamination. Uneven distribution across a field may result in overapplication and thus promote deep percolation of water and contained solutes. Advances in irrigation technology such as the Low Energy Precision Application (LEPA) system enhance uniformity of distribution as well as increased water use efficiency. The LEPA system was developed by agricultural researchers in Texas and is designed to apply irrigation water and agrichemicals in small amounts and in precise locations to maximize the benefits to the crop. An economic comparison over 4 years of LEPA, drip, sprinkler, and furrow irrigation systems showed LEPA to be most profitable (139).

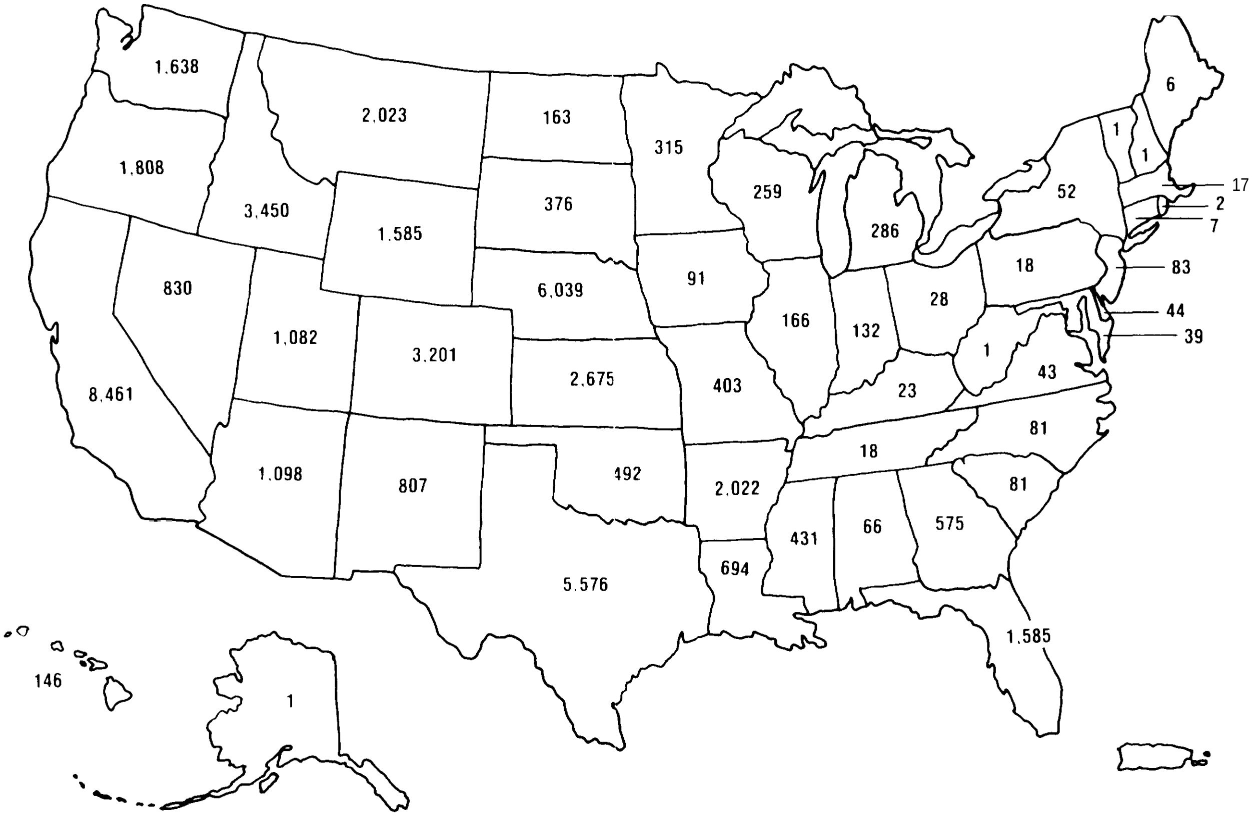
A mobile irrigation planting system (MIPS), developed by researchers at the Texas Agricultural Experiment Station, is an expansion on the LEPA system. The MIPS combines the capability for seed planting and irrigation, allowing growers to plant and irrigate with the same equipment (139). The system contains a facility for seed germination and gel coating for seed protection, a transfer and injection system, and a distribution and planting unit (cf: 115).

Proper scheduling and rate of irrigation can promote effective and efficient water use. Improper scheduling can lead to the application of too much or too little water. Overapplication of water may result in deep percolation or runoff of water and applied agrichemicals. While transit time for water to move from the soil surface to the groundwater table may range from a few days to centuries, excessive irrigation has a great potential to hasten this downward movement.

In the arid parts of the Western States where rainfall is not adequate to maintain an acceptable salt balance, irrigation may be used to flush salts below the crop root zone. Most irrigation practices include management practices for salinity control. Irrigation applied to promote deep percolation of surface salts may also transport other contaminants.

Four categories of irrigation systems are prevalent today: surface (use of gravity to distribute water), sprinkler (use of pressurized pipes to distribute water to sprinklers or nozzles for discharge through air to plants and soil), subirrigation (water supplied to crop root zone via capillary action by raising water table in soil using unlined surface channels or unpressurized underground pipes) and microirrigation (water distributed in closely spaced small-diameter pres-

Figure 4-10-Areas of Irrigated Land in the United States



SOURCE: U.S. Department of Agriculture, ***Agricultural Statistics*** (Washington, DC: U.S. Government Printing Office, 1986), p. 374, ***In:*** **Threadgill,** E. D., 1989.

stied conduits above, on, or below ground, with distribution from miniature sprinklers or emitters at low flow rates and pressures). The sprinkler system is the preferred type of irrigation system on most irrigated acreage added during the last few decades (208).

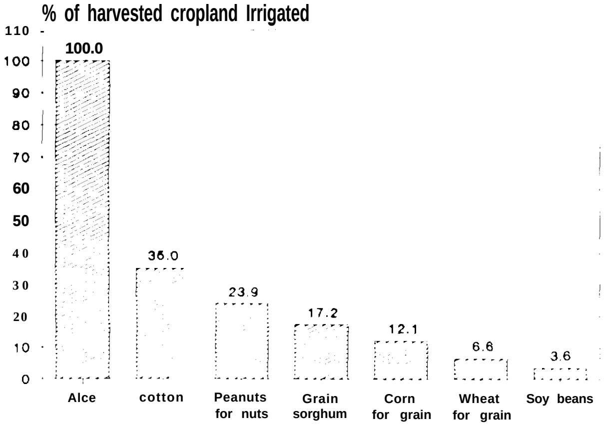
Costs of irrigation systems are quite variable, depending on system type, soil type, topography, field shape, and water source. Generally, capital costs are greatest for subirrigation systems and least for surface systems; sprinklers and microirrigation are intermediate. The reverse seems to be true for energy costs: surface systems are highest and subirrigation lowest. Although certain sprinkler systems may have high labor costs, irrigation systems such as microirrigation and center-pivot sprinkler systems lend themselves to automation, thus reducing labor requirements.

Potential effects of irrigation on agrichemical contamination of groundwater vary among the four categories of irrigation systems. Deep percolation of water below the root zone is more likely to occur with surface systems than with other types. Moreover, significant quantities of water applied in surface irrigation can run off the field and be discharged into surface water resources unless the water is contained or recycled into the irrigation system. This return flow or tailwater can transport chemicals from a variety of sources (e.g., directly added, picked up from the soil surface).

Sprinkler systems installed in areas with high slopes may promote runoff when improperly designed or operated. This runoff may contain chemicals from a variety of sources. Subirrigation systems frequently are designed to irrigate and provide drainage for the plant root zone. Although deep percolation should not be a problem in subirrigated areas, any drainage waters could potentially transport chemicals from the field into offsite drainage systems (208).

Quantity and timing of irrigation have direct impacts on the potential for movement of agrichem-

Figure 4-1 l—Percentage of Harvested Cropland Irrigated for Major Program Crops



SOURCE: U.S. Department of Agriculture, 1989 Agricultural ***Chartbook,*** Agricultural Handbook No. 684 (Washington, DC: U.S. Government Printing Office, March 1989).

icals through the soil profile. Excessive water can increase the amount and rate of percolation of a water-soluble pesticide through soil into groundwater, as well as runoff of trace residues (either dissolved in water or adsorbed to soil particles) (73,208).

Effective management of any irrigation system depends primarily on irrigation scheduling. Determinations of when to irrigate and the amount of water to apply are made almost daily during growing season. The decision of when to irrigate may need to be made in advance if the system requires movement, or additional labor, or is dependent on placing an order for the water. The amount of water to apply similarly is dependent on many factors, including soil type; stage of crop growth; precipitation since last irrigation, or predicted during next few days; and probable lapsed time before subsequent irrigation can be scheduled (208).

Three basic approaches exist for irrigation scheduling: 1) allowable soil-water depletion; 2) soil-water tension; and 3) allowable plant-water stress. Scheduling based on allowable soil-water depletion involves irrigation before predetermined limits for these criteria are reached (208). For example, the predetermined limit could be when 50 percent of the available water contained in the plant root-zone at field capacity has been depleted. Irrigation is applied to bring the soil moisture to field capacity, or another desired limit.

Soil water tension is defined as the force required for a plant root to extract moisture from the soil complex and varies with soil type and condition. Irrigation scheduling based on the soil-water tension approach is designed to supplement soil water before the plant roots can no longer effectively extract water. The amount of water to be applied is based on the relationship between soil-water tension and the soil-moisture depletion and is highly field specific.

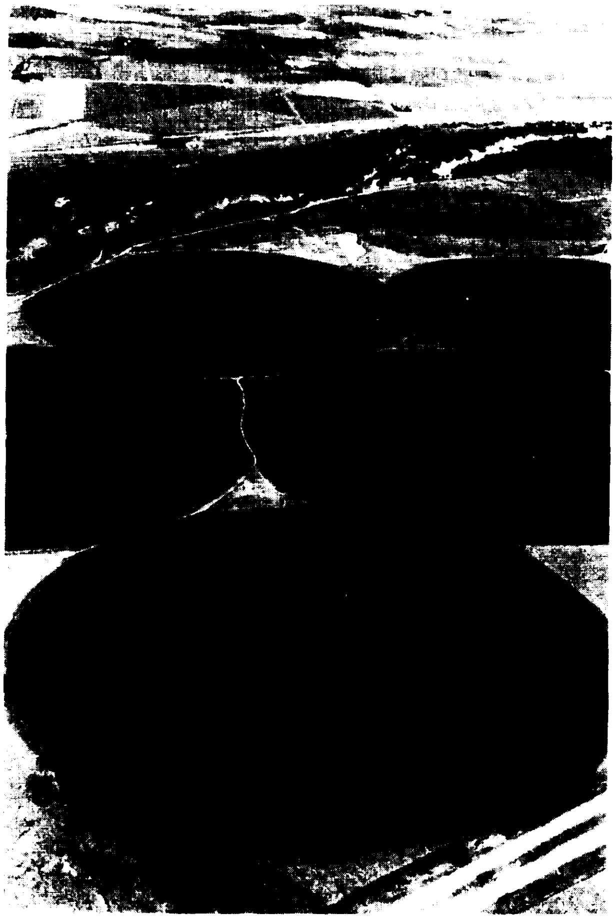
Irrigation based on plant-water stress involves measurement of the water stress in some part of the plant and irrigating before a critical limit is reached. This method only identifies when irrigation is needed and does not define the amount of water to be applied.

Several technologies exist to enhance imigation scheduling decisions. For example, soil-moisture measuring devices and automated microprocessor-based scheduling systems may improve irrigation timing and amount. Gypsum blocks set into the soil have been shown to be an effective mechanism for determining relative soil moisture. Use of such indicators can facilitate accurate determination of soil moisture needs and thus assist in appropriate irrigation scheduling decisions. Surge-flow and cablegation systems can lower potential for deep percolation and high-volume tailwater from surface irrigation systems (208).

Clearly, existing and emerging technologies may enhance the efficiency of irrigation practices. In particular, significant advances could be made by more widespread use of advanced irrigation scheduling techniques and the adoption of improved irrigation uniformity technologies. Consideration of weather patterns may also be important in scheduling decisions to avoid excessive percolation of water and contained solutes through the soil profile. This may be particularly true for irrigation scheduling or application that is not based on relative soil-moisture content,

WASTE MANAGEMENT

Agrichemical wastes arising from certain agricultural activities have been implicated as groundwater contaminants. Nitrate leaching from manure storage has been noted under feedlots in numerous studies (197). Pesticide contamination of well water also has been linked to inappropriate mixing and loading of pesticide application equipment near wells. Seepage



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wise irrigation management is critical in reducing agrichemical losses under such circumstances.

of effluents from livestock-feed silage have also been noted as groundwater contaminants.

Entry of these wastes into groundwater may represent point-source contamination. In many cases, however, leaching through soils has also been identified as a route of entry. Such agrichemical losses to the environment represent an economic loss to the practitioner. Thus, approaches that increase the efficacy of waste-management practices should provide economic benefits to producers as well as the environment.

Agrichemical Wastes

Pesticide and fertilizer spills and leaks at commercial facilities have been responsible for numerous detections of chemicals in groundwater (75). In some cases pesticide concentrations in soils and water around the pesticide mixing, loading, and equipment-cleaning areas of these facilities are close to formulation concentrations (76,145) (table 4-14). On-farm storage, mixing, and loading areas can present a similar, although smaller scale, threat to groundwater. For example, a typical pesticide field application rate is one to four pounds per acre. In terms of concentration, spilling 1/4 pound of a chemical in a 100 sq.ft. area around a well head is roughly equivalent to the application of 100 lbs per acre. Improper management of on-farm mixing and loading areas is believed to be a major factor causing farm well-water contamination that exceeds enforcement standards of alachlor and atrazine (48). Pesticide concentrations exceeding 50 micrograms per liter in well water suggests that mixing, loading, storage, and disposal sites are likely entry points (104).

Agrichemical Storage

Pesticide labels contain brief, explicit instructions for storage. Ideally, pesticide containers should be stored in a fire-resistant facility on a raised pallet or on a raised and drained concrete platform (99). Most farmers use existing buildings for pesticide storage, although the buildings have not necessarily been designed for that purpose. If these buildings have an earthen or wooden floor, spills or leaks present a groundwater contamination threat, particularly if they are located in areas of permeable soils and fractured bedrock, or near a well. Guidelines for safe storage facilities are available (cf: 40,125).[6]

Early-season buying incentives offered by agrichemical dealers tend to conflict with minimizing the amount of pesticides stored on-farm. On the other hand, minimal storage may represent a risk to a producer in the event of emergencies or poor weather windows. Opportunities to reduce agrichemical losses during storage lie in upgrading the quality of storage areas and educating users on storage hazards and economic benefits of planning for next year's production strategies (73).

[6]Detailed plans for a pesticide storage and mixing building are available from the Midwest Plan Service, Ames, IA 5~11.

Table 4-14--Contamination From Pesticide Mixing and Loading Areas

	Maximum concentrations detected		
	In pools and soils in loading and rinse areas	Groundwater in affected wells and seeps	Local background groundwater
Herbicides:		micrograms/liter	
Atrazine	70,000	65.0	No-0.65
Alachlor	270,000	145.0	No-1.30
Cyanizine	225,000	36.0	No-0.26
Metolachlor	270,000	50.0	No-0.80
Metribuzin	52,000	8.0	No
Trifluralin	(1,000+)	0.2	No
Insecticides:			
Carbofuran	(1,000+)	No	No
Fonofos	(1,000+)	1.3	No-0.3
Fumigants:			
EDB	10-100	1.0	No
1,2, dce	10-100	2.0	No
Carbon Tet	10-100	66.0	No
Chloroform	10-100	4.0	<1.0
		miligrams/liter	
Nitrate	137-480	18-41	
Nitrate-Nitrogen	30-105	4-9	

SOURCE: G. Hallberg, "Pesticide and Nitrate Concentrations From 8 Case Studies Where Groundwater Has Been Contaminated in the Vicinity of Farm-Chemical Supply Dealerships," *In*: Hall, F., 1989.

Agrichemical Mixing and Loading Areas

Pesticides and fertilizers commonly are loaded and mixed at the same location on the farm. Often the site is near a well for convenience in filling spray tanks (240), and many of these sites lack facilities for spill containment (60). The same site is sometimes used to rinse equipment after application. As a result, chemical residues can accumulate in soils and are available for leaching to groundwater (40). Concrete pads and water tight dikes can contain spills and allow recovery of the spilled chemical. If the concrete pad slopes to a collection basin, the same area can be used for rinsing application equipment (98). However, on-farm lagoons, catchment basins, or other surface storage containment may not be designed to prevent movement of spent material into water sources (60).

Pesticide losses during mixing and filling of tanks and hoppers offers much greater potential for contamination of surface and groundwater than losses during application. Back-siphoning from spray equipment into wells is a common cause of residues contaminating drinking water. Pumping equipment could be required to have antibackflow devices. Technology to prevent back-siphoning is already available; however, economic incentives or regulation may be needed to promote its use (73). While EPA regulations require back-siphoning equipment on chemigation wells, such regulations do not exist for other mixing and loading practices.

Thus, a need exists to improve technology and procedures for storage, handling, and mixing of pesticides and other agrichemicals. The potential for dilution and water recycling in pesticide mixing, loading, and disposal activities needs investigation (73). Additional commonsense strategies that may reduce the potential for well contamination from pesticide preparation include restricting mixing/storage of agricultural chemicals within 500 feet of a well, and continuous supervision of the sprayer/tank during filling operations (73).

Transfer Systems

Some systems for loading, transferring, and mixing pesticides eliminate the need to open containers and handle materials and thus may reduce the potential for spilled materials or rinse water to contaminate groundwater at this stage. Such systems meter and transfer chemicals from the shipping container to the mixing or application tanks and commonly rinse the emptied container (15). Individual farmers have developed a variety of ways to use couplings, valves, and hoses to transfer and mix chemicals in a closed system (175).

Pesticides packaged in premeasured, soluble bags that may be put directly into mixing tanks have some potential to reduce the possibility of spillage. Further, such packaging reduces human exposure during the mixing process. Similarly, returnable systems allow a producer to return the container and remaining pesticide mix to the dealer. Such systems are receiving increased interest and are a major emphasis of the National Agricultural Chemical Association's member companies (64). However, additional resources for research on suitable technologies for returnable systems as well as the potential for such systems to reduce agrichemical waste are needed to promote their development and use (73).

Disposal Practices

Three types of pesticide waste with potential to contaminate groundwater are produced on the farm: leftover pesticides, empty containers, and rinse water from washing equipment and containers. Some pesticides are listed as hazardous or acutely hazardous wastes in the Federal Resource Conservation and Recovery Act (RCRA). Many other pesticides not specifically listed in Federal and State laws are classified as hazardous because they exhibit hazardous characteristics identified in the laws (99,244).

Pesticides are packaged in a wide variety of containers of varying material composition, size and shape, creating problems for users in pouring, storage, rinsability after use, and disposal (73). Pesticide containers that seem empty generally contain chemical residues. For example, several ounces of some pesticide formulations can remain in an unrinsed 5-gallon container despite normal efforts to empty it (40). Some residues remain even after draining and rinsing (table 4-15). Triple-rinsed containers can be legally disposed of in sanitary landfills, but few landfills now accept them because of concern over liability. However, improper disposal of empty containers or excess unused pesticides can cause localized groundwater problem in disposal areas (73).

Rinse water from cleaning application equipment and containers also contains chemical residues. Rinse water includes solutions left after field spraying, water from washing the outside of the sprayer or spray tank, and spray left in booms and hoses. Rinse water should be sprayed on fields at the proper rate of application for the chemical; however, often it is simply dumped or disposed of on the ground (240). A number of facilities have been designed and tested for disposing of leftover pesticides and rinse water

Table 4-15-Pesticide Residues After Rinsing Containers

Active ingredient in the 1 oz. of liquid remaining in a 5-gallon container

Rinsing stage	Pesticide residue (grams)
After draining	14.2
After 1st rinse	0.2
After 2d rinse	0.003
After 3d rinse	0.00005

SOURCE: R. Doersch, J. Wedberg, C. Grau, and R. Flashinski, Pest *Management Principles for the Wisconsin Farmer,* 2d ed. (Madison, WI: University of Wisconsin—Extension, 1988), *In:* Jackson, G.W., et al., 1989

(235). These disposal systems might be feasible for use at commercial facilities, but there is a continuing need for inexpensive on-farm systems (240).

The most cost-effective approach to improving the situation is to minimize the amount of waste. Cost-effective waste effluent treatment systems could address this need to some extent. Some such systems have been developed (e.g., ICI Sentinel System) aided by Federal grants; however, this effort could be expanded to promote more rapid development of similar systems (73).

Livestock Wastes

Animal agriculture accounted for a significant part of the gross agricultural receipts in the United States in 1988, exceeding the contribution of crops ($80.2 billion **or 53** percent of the total) (197). However, livestock and poultry production operations can sometimes contribute to excess nutrients, salts, organic matter, and other constituents as contaminants of groundwater if manure and wastewater are not properly managed. Constituents in livestock and poultry manure that can cause groundwater contamination primarily include pathogenic organisms, nitrate, and ammonia. Presence of such constituents in livestock drinking water may adversely affect livestock health (34). Under special conditions other constituents such as potassium, sodium, chloride, and sulfate also may be leached and impair groundwater quality.

Certain livestock production practices may promote nutrient contamination of groundwater. Potential sources of groundwater contamination include open unpaved feedlots, runoff holding ponds, manure treatment and storage lagoons, manure stockpiles, and land application of manure and wastewater. Dead animal disposal and animal dipping-vats may contribute to localized groundwater contamina-

Photo credit: State of Florida Department of Environmental Regulation

Improper disposal of pesticide wastes and pesticide containers may pose significant hazards to groundwater quality. Pesticide containers that seem empty still may contain chemical residues and some residue may remain even after draining and rinsing.

tion. Manure accumulations around livestock watering locations, intermittent-use stock pens, and livestock-grazing operations that vary from sparse rangeland to intensive pastures may also influence surface and groundwater quality. In many cases the relationships between the practice and pollution potential have been identified. For these, technologies exist to reduce the potential adverse impacts of livestock production on groundwater resources.

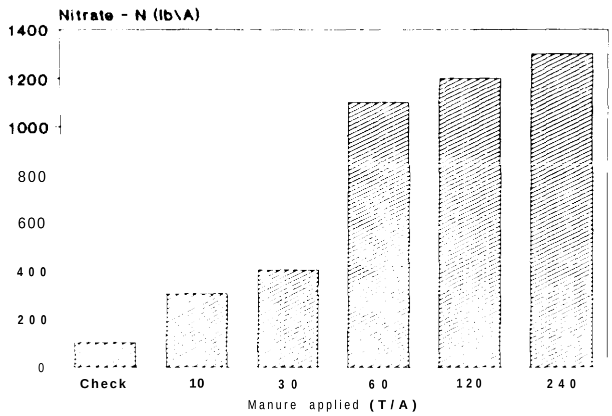
To prevent discharge to surface waters, livestock manure and wastewater may be collected, stored, and then land applied. However, application rates must be developed that account for the nitrogen content existing in the soil to avoid applying excessive amounts that may leach through the soil profile (figure 4-12). Under wastewater irrigation systems, application should be uniformly less than the soil-infiltration rate to prevent surface runoff. Further, manure and wastewater should be applied to soils at annual rates that match crop-yield goals and expected plant uptake of nutrients to assure that nutrients are used efficiently and that groundwater contamination is not likely.

Livestock and poultry manure generated from concentrated and confined animal feeding facilities may be a valuable resource for fertilizer, feedstuff, or fuel. Manure is widely used as an organic fertilizer in many areas. Certain types of manure also may receive limited use in specialized situations as a feedstuff, as a substrate for anaerobic digestion to produce biogas, or as a fuel for combustion/gasification for electric power generation. However, these latter uses return all or a part of the original manure fertilizer value as a residue that eventually is applied to land.

Overall, the general routes to groundwater contamination from livestock production operations are the same as those from other forms of agriculture: leaching, runoff, and direct infiltration. Animal production facilities and practices that create the potential for such mechanisms to operate include:

- intermittently occupied livestock facilities, continuous-confinement facilities, and manure stockpiles and storage bunkers;
- liquid-manure storage ponds or treatment lagoons and runoff collection channels;
- dead animal disposal pits;
- feed silos and grain-storage pits and stockpile; and
- land application of manures, livestock insecticide-application sites (spray pens and vats), and

Figure 4-12—Nitrate in Pullman Soil After Five Annual Applications of Manure



SOURCE: A.C. Mathers and B.A. Stewart, "Manure Effects on Crop Yields and Soil Properties," *Transactions of American Society of Agricultural Engineers, vol. 27, No. 4, 1984,* pp. 1022-1026.

disposal sites for insecticide containers and residues.

Indirect introduction of agrichemicals or nutrients into groundwater may occur in a number of ways. In addition to these, potential also exists for direct introduction of runoff or leachate through activities conducted in the vicinity of active or abandoned wells.

Manure Production and Distribution

Total U.S. manure production (dry basis) by all livestock and poultry species has been estimated at nearly 158 million tons annually. This amount contains some 6.5 million tons of nitrogen, nearly 2 million tons of phosphorus, and nearly 4 million tons of potassium (197). Direct losses via volatilization, leaching, and runoff are estimated to reduce the nutrient content of manure significantly.

Based on land-application values from a 1974 study of manure production, current economically recoverable manure production would supply an estimated 184 pounds of nitrogen/acre, 67 pounds of phosphorus/acre and 122 pounds of potassium/acre for nearly 15 million acres of U.S. cropland (238,197). However, according to estimates, "extensive" production of livestock on pastures and rangelands accounts for a large proportion of the manure produced. This manure recycles back through the soil and plant system but is largely uncollectible and is therefore 'unmanageable.' Extensive production systems account for about 88 percent of the total for beef cattle as well as sheep. For dairy cattle, as much as one-half or two-thirds of manure produced might be voided on pastures, depending on the types of production systems, season, climatic region, and herd size. However, as dairy operations increase in size the trend to total confinement is expected to continue (197).

Livestock concentrations in extensive systems may vary by two or three orders of magnitude from 10 to 5,000 pounds liveweight per acre, depending on climate, soils, topography, and management intensity. Accordingly, manure voided varies from no more than 0.5 to 7 dry tons per acre per year and nitrogen deposition ranges from approximately 1 to 500 pounds per acre per year for sparse rangelands and intensively grazed improved pastures, respectively (198). While nitrogen deposits may be a factor in sustaining forage production on more intensively grazed, improved pastureland, nutrient return may be almost inconsequential on more extensive rangeland.

For intensive animal-production systems (predominately in confinement), the predominant sources of voided manure seem to be dairy cattle, swine, beef feedlot cattle, broilers, turkeys, and laying hens. Figure 4-13 shows manure production and nitrogen concentration (as-voided basis) within intensive systems versus extensive livestock production systems as a function of animal density and spacing per unit liveweight.

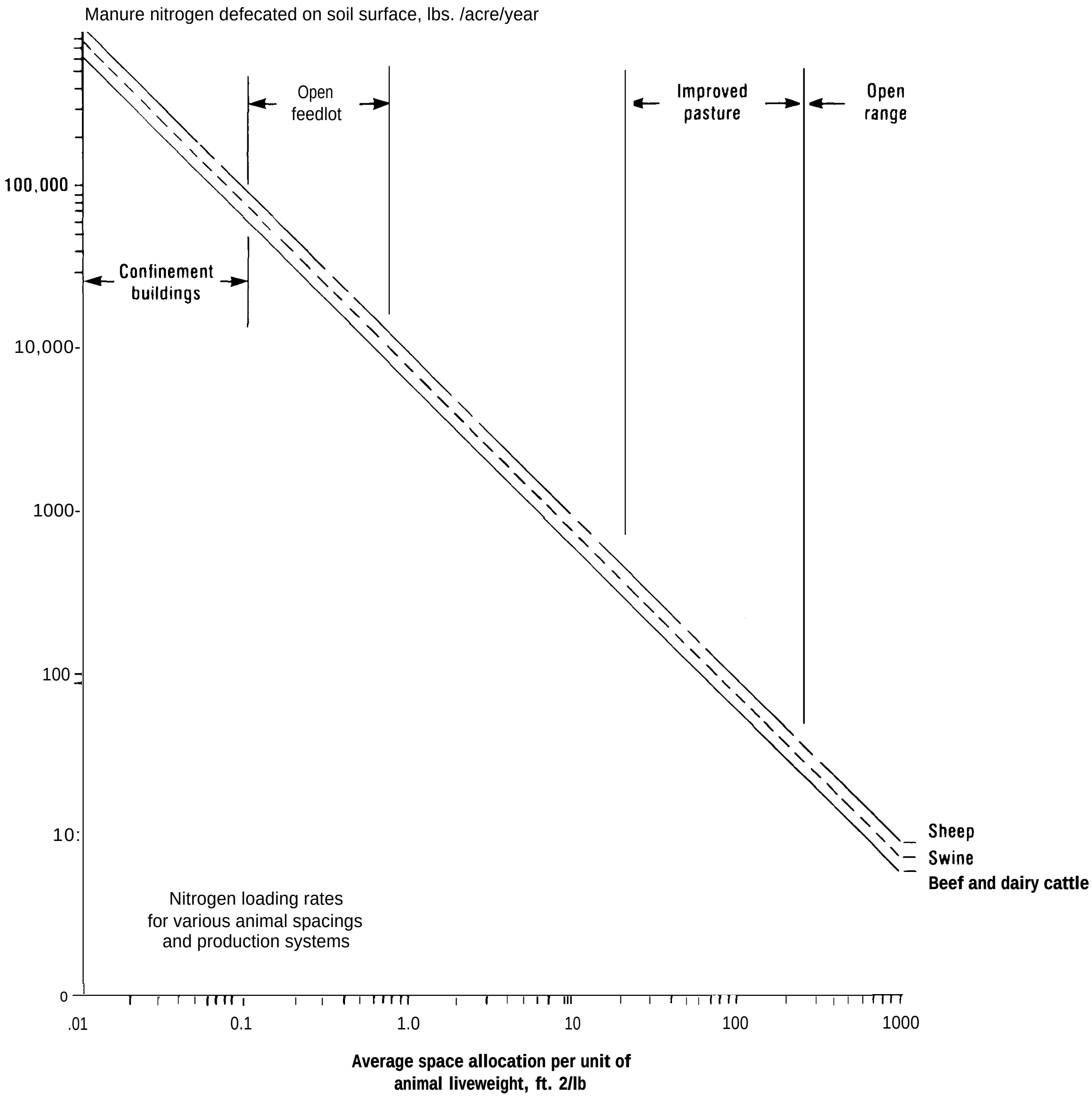
For purposes of water pollution control, intensive livestock production systems are defined in the EPA regulations for feedlots as:

> . . . animal feeding operations (where animals are) stabled or confined and fed or maintained for a total of 45 days or more in any 12 month period, and. . . crops, vegetation, forage growth or post harvest residues are not sustained in the normal growing season over any portion of the lot or facility. (234)

This definition covers many animal species, types of facility, animal densities, climate, and soils. It uses a single, visually determined criterion—absence of vegetation. Under such conditions, manure production and animal traffic are great enough and frequent enough to prevent germination or growth of forage. This condition implies that:

- crop uptake is not a pathway for nutrient removal, thus runoff, volatilization, and leaching pathways may be proportionately larger than from vegetated surfaces;

Figure 4-13-Average Amount of Manure Nitrogen Defecated per Unit Area as a Function of Animal Spacing



SOURCE: J.M. Sweeten and D.L. Redden, "Nonpoint Sources: State of the Art Overview," Transactions *of the* ASAE, vol. 21, No. 3, 1978, pp. 474-483.

- **runoff volume** is greater and time of concentration is shorter as compared to a vegetated surface; and
- a vegetation falter to slow and capture suspended sediments is lacking.

These conditions, which increase the potential for nutrient contamination of groundwater, may persist long after livestock are moved from the confinement area.

Livestock Waste Collection Trends

Certain aspects of livestock production practices have potential to influence groundwater quality because of the waste management practices with which they may be associated. Livestock operations are increasingly moving toward the use of confinement buildings and larger feeding facilities and away from labor-intensive manure-handling systems. In such confinement buildings there is increased use of manure flush systems or mechanical scrapers, which provide for manure collection as often as several times a day.

Flush, Lagoon Irrigation Systems—These sys- tems use large volumes of water to remove and transport manure from confinement areas. Lagoons or holding ponds are needed for storage and treatment of manure prior to land application. The effluent produced usually has considerable nitrogen content such that land application quantities are limited based on the soil or plant capacity to assimilate the amount applied. Solids concentrations, however, are low and volumes generally are sufficient to favor application by irrigation rather than hauling. Low, frequent, uniform applications are needed to avoid runoff and excessive nutrient leaching.

Mechanical Scrapers, Storage Pit, Tank-Wagon Transport Systems—These types of systems also are used to collect livestock manure from confinement buildings on a daily basis. Mechanical scrapers are used to remove the waste with minimal amounts of supplemental water. Consequently a much smaller storage structure is needed—generally concrete tanks or small earthen pits. The relatively high solids concentration make it convenient to use tank-wagons or trucks for direct transport to fields where application may be by surface spreading or soil injection. Due to the relatively high nutrient concentrations, much lower volumetric application rates per acre must be observed as compared with lagoon effluent.

Open Feedlots With Solids Collection and Run-off Control-open feedlots may be less likely to pose a potential hazard to groundwater quality in areas characterized by at least a 30-inch moisture deficit and moderate winters. Manure in solid form is scraped at intervals (weekly, annually) and stacked in pens or outside stockpiles prior to land application. Rainfall runoff is collected in runoff holding ponds and irrigated on croplands or pasture-lands. In dry climates, evaporation is the method often used for disposal of feedlot runoff.

Management Practices and Effects on Groundwater Contamination

Leaching from feedlot surfaces, stockpiled manure, and land-applied manure and effluent, and seepage from runoff holding ponds can potentially contaminate groundwater. General trends toward consolidation of ownership, more frequent manure collection, off-site marketing of solid manure, use of comporting to reduce volume, reduced application rates, and expansion of land ownership by feeding operations may reduce this potential. Land application of holding-pond effluent does not seem to be increasing, and installation of overflow water systems that reduce storage capacities of such holding ponds seems to be increasing.

Feedlot Surfaces—Research in several states, in arid and humid climates, has determined that an active feedlot surface develops a compacted manure/soil layer (2 to 4 inches thick) that provides an excellent moisture seal. This layer may reduce downward water movement significantly (129,128), thus restricting leaching of salts, nitrates, and ammonium into the subsoil and underlying groundwater (table 4-16) (186). The compacted, inter-facial layer is composed of bacterial cells, organic matter, degradation products, and soil particles.

The soil surface essentially self-seals if an anaerobic layer of compacted manure is left undisturbed above the manure/soil layer. This seal may retard the formation and leaching of nitrate in favor of denitrification (193,23). The best soil profile to retard nitrate and nitrite movement and retain salts near the surface was found to be a sand topsoil above a clay-loam subsoil (142).

Appropriate collection practices should be used to remove manure to avoid disrupting this surface-seal layer. Correct use of collection machines such as wheel loaders or elevating scrapers that leave the manure pack will maintain the residue layer and thus restrict leaching potential. This will result in collection of highest quality manure for crop fertilization or energy generation (199).

Measurements of groundwater quality under 80 cattle feedlots in the Ogallala Aquifer in the Texas High Plains indicated that about one-fourth had contributed to nitrate levels approaching or exceeding 10 ppm in the immediate vicinity of the feedlots. Seepage rates were estimated at 0.003 to 0.03 inches

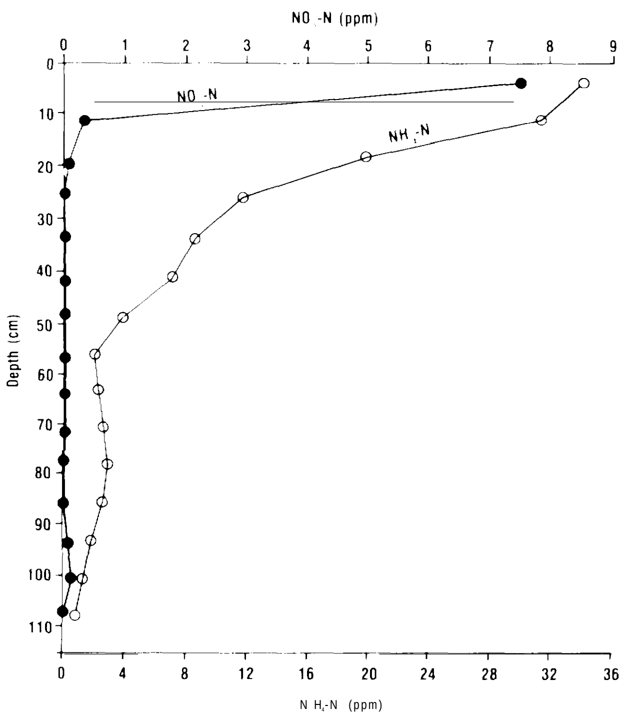
Table 4-16-Nitrate, Nitrite, and Ammonium-Nitrogen Concentrations Beneath Playa Used for Feedlot Runoff Collection (in ppm)

	Feedlot playa[a]			Non-feedlot playa[b]	
Depth (feet)	Nitrate	Ammonium	Nitrite	Nitrate	Nitrite
0	12.8	58.7	2.8	- -	- -
1	225.0	18.4	3.2	7.8	0.34
2	6.2	5.7	0.13	2.8	0.16
3	3.7	5.7	0.13	2.8	0.16
4	3.0	3.3	0.03	2.5	0.13
5	3.4	3.5	0.02		
6-13. : : : :: : : : : : : : :	0.3 -2.7	1.1 -2.8	0.02-0.12		

[a]Average of three center observationwells.
[b]Average Of two observation wells.

SOURCE: O.R. Lehman, B.A. Stewart, and A.C. Mathers, Seepage *of Feedyard Runoff Water Impounded in Playas,* MP-944 (College Station, TX: Texas Agricultural Experiment Station, Texas A&M University, 1970), *In:* sweeten, J. M.,-l 989.

Figure 4-14—Ammonia and Nitrate Present in a Feedlot Soil Profile



SOURCE: G.E. Schuman and TM. McCalla, "Beef Cattle Feedlots: Impact on Underlying Soil," ***Abstracts*** (Fort Collins, CO: Western Society of Soil Science, June 1975).

Photo credit: State of Florida Department of Environmental Regulation

Livestock wastes can be a significant source of nitrate having the potential to contaminate groundwater. **Commonly feedlots leach little through their hard-packed floors, but may contribute runoff to nearby surface waters or leach through to groundwater after abandonment.**

per hour under feedlot surfaces and playas used for runoff collection (13 1).

Concentrations of nitrate and ammonia decrease rapidly within the top foot of the feedlot soil layer (figure 4-14) (186). Soil-water samples taken at three feet beneath cattle feedlots showed concentrations of nitrate, phosphorus, and magnesium and total solids similar to concentrations found under adjacent cropland (1,49,186,36).

Feedlots that have been abandoned without manure removal may have greater potential for groundwater contamination (1 19) than active operations. Cropping abandoned feedlots to deep-rooted crops such as alfalfa may have some potential for capturing nitrates that have migrated through the soil profile (212).

Holding Ponds and Lagoons—Leaching from livestock waste-treatment lagoons and runoff holding ponds has also been studied by researchers for at least two decades. It has been determined that bacterial cells and fine organic matter generally clog soil pore-spaces along the bottom and sides of lagoons and holding ponds (14) creating a seal (37).

After several months of storage, soil coefficients of permeability of wastewater pond bottoms are generally one to three orders of magnitude lower than those of clean water ponds (177,108,13). Where the bottom and sides of manure storage ponds and lagoons have a moderate- to fine-textured soil the final permeability coefficient is usually reduced significantly (14). While infiltration time varies depending on soil type, it also is affected by the type of manure. For example, measurements taken of infiltration rates of swine and dairy slurry indicate that infiltration of swine slurry increases over time relative to dairy (figure 4-15).

Although livestock manure and wastewater provide beneficial self-sealing on the bottom and sides of lagoons and holding ponds, regulatory agencies further suggest that lagoons should be placed on relatively impermeable subsoils (45).

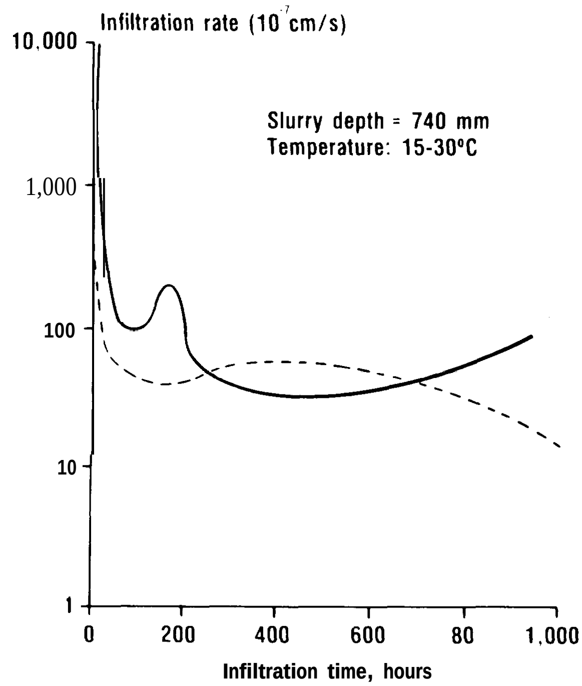
A study of the leaching of contaminants in feedyard runoff below a playa lake bottom indicated that nitrogen compounds did not move below 3 feet. At 2 feet and below the nitrate and nitrite concentrations were only slightly higher than for playas that did not receive feedyard runoff (109). A further study showed that nitrate concentrations decreased drastically within the top meter and that below one meter, nitrate concentrations were no more than 10 mg/1 nitrate-nitrogen (figure 4-16).

The potential for groundwater contamination is increased in arid regions when playa lake bottoms are excavated below the natural clay layer. An alternative is to stockpile the clay and reapply it to a compacted depth of one foot or more over the bottom and sides to serve as a clay liner (205).

Monitoring wells placed in the vicinity of livestock waste-treatment lagoons and holding ponds have been used to evaluate the distribution of groundwater contaminants caused by lagoon seepage (28,25, 187,176, 153). Nutrient or salt concentrations sometimes increase in shallow groundwater in the immediate vicinity of lagoons or holding ponds. However, these initial increases usually diminish after several months. These results are reasonably consistent with the observed reductions in permeability caused by self-sealing.

Researchers are working on new methods for locating and quantifying groundwater pollution near animal waste lagoons to replace expensive, time-consuming soil-sampling techniques. An above-

Figure 4-15-infiltration Rates for Swine and Dairy Manure Slurries Over Coarse Sand

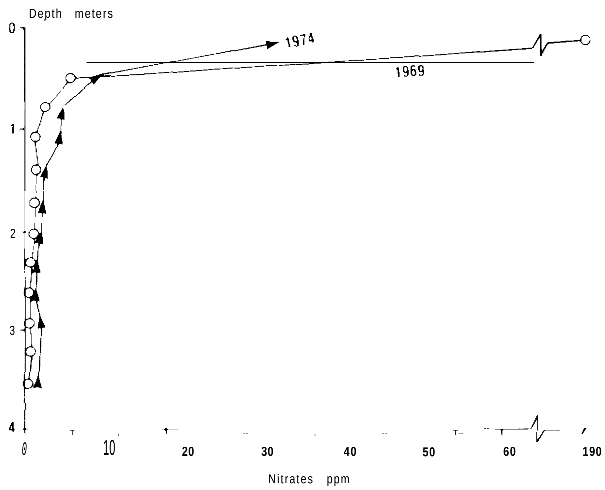


SOURCE: S.F. Barrington and P.J. Jutras, "Selecting Sites for Earthen Manure Reservoirs," *Agricultural* Waste *Utilization and Management*, Proceedings of the Fifth International Symposium on Agricultural Wastes, American Society of Agricultural Engineers, 1985, pp. 386-392.

ground electromagnetic (EM) sensor is used to detect conductivity plumes or gradients that suggest leakage of livestock waste materials from lagoons. Efforts are under way to correlate the relationship of specific EM signals and groundwater contamination to form the basis for determining groundwater pollution from waste lagoons (30).

U.S. Environmental Protection Agency (EPA) regulations for confined livestock and poultry operations deal with surface-water protection and do not include requirements for groundwater protection. Several States and local entities do have groundwater protection requirements. For example, the Texas Water Commission regulation that governs confined, concentrated livestock- and poultry-feeding operations considers groundwater protection for lagoons and holding ponds (205). The regulation requires that all wastewater-retention facilities be constructed of compacted, low-permeability soils (e.g., a clay or clay loam) at a minimum thickness of 12 inches.

Figure 4-1 6-Nitrates, Dry-Weight Basis Beneath Feedyard Playa



SOURCE: R.N. Clark, "Seepage Beneath Feedyard Runoff Catchments," ***Managing Livestock Wastes,*** Proceedings of the Third International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, MI, pp. 289295, 1975,

Livestock waste management techniques exist that may reduce the potential for groundwater contamination from livestock production practices. Further effort is needed to promote development and adoption of such practices. Areas of significant importance include:

- increased development of manure treatment and use technologies, particularly in relation to comporting, biogas generation, thermochemical conversion, fiber recovery, and marketing of such products (box 4-H);
- development and extension of economic guidance for land application of manures, to include soil testing to define appropriate application rates, and understanding of nutrient-release rates; and
- quantification of the magnitude of nutrient losses from lagoons, storage tanks, and land application as a function of design, operation, and climatic variables in order to develop nutrient management plans and nutrient mass balance models,

The design, location, and management of permanent and temporary livestock-waste storage facilities are factors that may contribute to or prevent well-water contamination by nitrate and bacteria (35). Storage and handling facilities will minimize leaching if they are constructed of concrete or other impermeable materials and properly managed. Management includes routine inspection and maintenance of above-ground systems to ensure that they do not rupture; filling facilities only according to design specifications; and applying the wastes so as not to exceed the nutrient uptake capacity of the application area (98).

Increasing the agronomic use of manure might be fostered through joint efforts among States, cities, industry, and agriculture to promote manure processing and use on public and private lands. Development of incentives for manure use in cropping systems, particularly in high manure-production areas, may offer opportunity to enhance agronomic use of this resource as opposed to treating it as a waste disposal problem (box 4-I).

Concomitant activities to increase awareness of the potential of manure as a groundwater contaminant might be achieved through revision of EPA effluent guidelines to include groundwater protection requirements. Federal and State programs that work toward cost-sharing or other economic incentives for livestock producers to adopt and implement water quality protection practices, particularly in areas where greatest vulnerability exists, could promote such adoption. Technical assistance (SCS), education (CES), and research (ARS) must be able to promote and support practitioner adoption and thus may require some enhancement. For example, demonstration livestock production operations in areas having a high or low groundwater-pollution potential could serve to disseminate information on appropriate best management practices that contain provisions for groundwater protection.

Silage

Corn, legumes, and grasses commonly are stored in moist, partially fermented conditions for use as livestock feed. When stored and compacted in silos and other facilities, these wet crops lose moisture, which drains out of the silo as effluent. Effluent production from silage varies with the material stored and its moisture and nitrogen content. Of these, moisture seems to be the most important factor affecting effluent production. Several studies have determined that materials stored at 65 percent moisture content or higher can produce effluent. For grass silage, the amount produced varies from a trickle at 75 percent moisture to 79 gallons per ton at 85 percent moisture (195). About three-quarters of the effluent is produced in the first 3 weeks of

Box 4-H—Natural Zeolites: Some Potential Applications in Agricultural Waste Management

Zeolites, a suite of porous fine-grained minerals found in certain near surface, sedimentary rocks, have special physical and chemical properties that could make them valuable to farmers in agricultural waste management.

Some 50 species of a certain group of natural minerals called zeolites have their atoms arranged so that they form hollow cages with tiny openings through which other ions or molecules of the right size can pass. Larger ions or molecules are screened out from the cages and channels of the zeolites. Because of these unique properties and behavior, zeolites are referred to as "molecular sieves, "

In addition, zeolites have the ability to hold various chemical elements (ions) loosely so that they can be exchanged for other chemical elements. This ion exchange property of zeolites, coupled with the unique properties of their porous structure, accounts for the interesting and potentially important usefulness of zeolites in agriculture. With steadily increasing knowledge of zeolites and their applications (158), today it seems evident that those minerals can play an increasingly important role in agriculture, especially in animal waste management.

Zedites could have an important role in animal waste management because they can adsorb ammonia from animal wastes (134). Zeolites have a potential for use to help minimize water pollution from agricultural runoff and to make animal manure easier to handle and to move from animal pens to agricultural plots.

Swine manure, for example, is malodorous and is composed of only about 10 percent solids (132), making it difficult and undesirable to handle. A zeolite-rich mudstone was used in a swine-raising activity in Japan to reduce the manure's offensive odor and to improve its handling, characteristics. The zeolite-treated manure proved suitable as a fertilizer for rice production (94).

Other work in Japan on large hog farms also illustrates the usefulness of zeolites (141). A zeolite filter composed of a granular zeolite, used to process contaminated water remaining after initial manure/water filtration, removed the ammonium ions and other microsubstances, and trapped many of the remaining suspended solids. Transparency of the effluent showed marked improvement after zeolite treatment and chemical and biological oxygen demand was significantly reduced.

Recently, Romanian researchers showed similar results to those of the Japanese (1 23). They used nonactivated, ground volcanic tuff containing 67 percent zeolite in a series of filters, each with a different zeolite size fraction ranging from 0.5 to 10 mm. The ammonia-nitrogen content decreased 91.3 percent and the nitrate content decreased 99 percent from the initial metallic screens through the final zeolite filter.

Such studies illustrate that zeolites can play an important role in animal waste management by trapping ammonia. Zeolites could be spread on the floors of animal enclosures to trap ammonia and reduce the odor and moisture content of manure. Similarly, zeolites could be placed in manure holding ponds and lagoons to trap ammonia. Periodic removal of the nitrogen-enriched zeolites could provide a fertilizer source for croplands.

Zeolite-amended diets, in the case of poultry, have been shown to reduce the moisture content of feces by 25 percent (249). Such moisture reduction could improve the potential for using poultry manure as a nutrient source. Swine fed a 5 percent zeolite diet produced more compact and less malodorous feces than control groups (243).

Mixing of ammonium-saturated zeolites with ground rock phosphate or other phosphorus-bearing minerals with low volubility enhances release of phosphorus in plant-available forms (10,24,106). Greenhouse experiments mixing ammonium-saturated zedites with ground rock phosphate in ratios of 3:1 to 4.5:1 show increased phosphorus uptake by plants and increased biomass production (10).

Mixing livestock manures with zeolites offers an opportunity for farmers to reduce potential nitrogen leaching through the soil profile, In addition, these materials offer a mechanism to improve soil fertility as well as promote release of phosphorus from soil matter. Zeo-agriculture success will depend on interdisciplinary approaches involving mineralogists, chemists, and agriculturalists. Thorough assessment of zeolite uses in animal waste management just as in other agricultural uses is strongly needed (149).

storage, although it can continue to flow for up to 3 months. The composition of the effluent varies with the material stored; it may be highly acidic and corrosive to steel and concrete (200).

Groundwater contaminated with silage effluent may have a disagreeable odor and show increased levels of acidity, ammonia, nitrate, and iron. Cases of water contamination from silage effluent have been documented. In one case, thousands of gallons of sweet-corn silage juices drained through a limestone sinkhole and contaminated wells a mile from the site (250,25 1).

Box 4-I—Best Management Practices for Controlling Potential Contamination of Surface and Groundwater From Animal Wastes

- Annual soil testing to determine nutrient content and evaluation of efficiency of nitrogen use in the production system.
- Nutrient analysis of the waste prior to application to match with crop requirements.
- Determination of application rates based on crop needs and soil reservoir.
- Timing of application to match maximum crop uptake such as spring or summer.
- Application by broadcast and incorporation or injection to avoid volatilization or loss in runoff.
- Installation of vegetative filter strips to control sediment and nutrient losses in feedlot and dairy runoff.
- Restrict access of animals to streams, lakes, and other impoundments and rotational grazing to maintain sufficient vegetative cover on pastureland.

SOURCE: North Carolina State University, Biological and Agricultural Engineering Department, *State of the Art Review of Best Management Practices for Agricultural Nonpoint Source Control,]: Animal Waste* (Raleigh, NC: North Carolina State University, August 1982).

Silage poses little pollution threat when it is harvested and stored properly (146). Improper handling can lead to significant effluent flow from storage facilities. Silage commonly is stored on uncovered ground or in structures not designed to contain silage juices (99). Silage storage facilities include vertical silos; trench silos; temporary stacks; and temporary, plastic storage-tubes; none of which were designed for groundwater protection. Collection of silage effluent in water retention structures such as clay- or plastic-lined ponds can reduce leaching potential.

Effluent production may be reduced by varying cutting and harvesting time, adding a silage preservative (e.g., formic acid), and adding moisture-absorbent materials to the silage as it is stored (252). Addition of absorbent materials has also been shown to raise nutrient value of the silage. Allowing materials to wilt in the field for 24 hours prior to storage has been shown to reduce moisture content by 10 percent and effluent production by as much as 100 percent (252).

RESEARCH APPROACHES IN AGRICULTURAL TECHNOLOGY DEVELOPMENT

Two concurrent thrusts for research and technology development are needed in taking a comprehensive approach to reducing groundwater contamination from agriculture. The first thrust addresses more immediate needs to improve agrichemical management and encompasses technology categories for point-source controls, efficient application management, and some agrichemical use reduction. This short-term thrust assumes that agrichemical use will remain the central feature of nutrient and pest management practices in U.S. agriculture. A second research thrust aims to increase farmers' technology options in the longer term and emphasizes technology categories for agrichemical use reduction and alternative practices. The long-term thrust assumes that farmers in the longer term will use ecological principles and biological methods as the central means to manage nutrients and pests in integrated farming systems.

These two research thrusts are not mutually exclusive, but they involve different research questions, emphasize different scientific disciplines, and are likely to use different linkages among basic and applied researchers, commercial fins, and agricultural producers. Moreover, the current agricultural research and delivery system will accommodate the short-term thrust much more easily than the long-term thrust, which requires more interdisciplinary research and greater integration of the biological, social, and agricultural sciences.

Because the current research and technology delivery system is more amenable to moving the short-term thrust forward, researchers and producers could focus on this thrust exclusively and fail to recognize the opportunity costs of neglecting long-term information and management needs. The agricultural research system is likely to need strong public support and incentives to advance the long-term research thrust rapidly enough to achieve sufficient knowlege that can be translated into feasible practices (box 4-J).

Box 4-J—Progression in Research and Development Efforts Needed To Minimize Agrichemical Contamination of Groundwater

R&D feature	Short-term thrust	Long-term thrust	
Study regions	Identify hydrogeologically vulnerable regions.	Identify agroecological regions with common natural resource and agricultural production characteristics.	
Regional characteristics	Determine extent of groundwater contamination and types and characteristics of contaminants.	Identify cross-media agrichemical management problems.	
Site-specific processes	Clarify agrichemical fate and transport to groundwater.	Identify agroecological processes **and interactions, and agricultural productions that affect agrichemical fate and transport.**	
Site-specific products	Develop agrichemical formulations that are less likely to leach in vulnerable sites, more efficient application equipment, and improved handling facilities.	**Develop improved agrichemicals, plant varieties, biopestiades, and other products that maintain or enhance beneficial ecological processes.**	
Site-specific practices	Development and adapt practices (e.g., BMPs) that prevent or reduce agrichemical transport to groundwater.	**Develop integrated agricultural systems that optimize beneficial** ecological processes, minimize adverse environmental impacts, reduce production costs, and maintain farm profitability.	**Mission** Maximize **Farmer Options**
Site-specific services	Increase information dissemination on groundwater vulnerability, appropriate agrichemical selection and management through existing information-transfer organizations (e.g., agricultural extension services, commercial firms, consulting services).	Increase information dissemination and education efforts on ecosystem processes; offer advisory and management services for improved multi-objective decisionmaking; adapt existing extension framework and develop new services to provide information and advisory or management services.	
Farmer decisionmaking assistance	**Facilitate agrichemical recordkeeping and use of realistic yield goals.**	Emphasize long-term farmland resource management planning to integrate agricultural production and natural resource protection.	
Assistance delivery	Emphasize commercial sector and traditional "top-down" delivery from researcher to farmer.	Facilitate commercial sector support of integrated decisionmaking at the site; encourage on-farm observation and experimentation.	

Components of the U.S. Agricultural Research System

Public- and private-sector agricultural researchers play key roles in developing agricultural technologies and management practices. Such research includes improving agrichemical products, developing individual or combined management practices, and designing integrated farm management systems that are less likely to contaminate groundwater with agrichemicals. The following discussion focuses on researchers' roles, opportunities, and constraints in developing environmentally related agricultural improvements.[7]

Federal Agricultural Research

Federal agricultural researchers work within the USDA Agricultural Research Service (ARS) as well as research divisions of the Economic Research Service (ERS) and the Soil Conservation Service (SCS) Technical Centers. Other Federal research groups conducting environmentally related agricultura1 research are EPA research laboratories, USGS research offices, and the Tennessee Valley Authority (TVA) National Fertilizer and Environmental Research Center (NFERC). Despite extensive Federal agricultural research, efforts have not been adequately coordinated and planned to ensure consistent research methodologies in the development

7 A previous OTA report has reviewed the United States agricultural research system, its organizational structure, roles of research participants, and planning and finding mechanisms (21 1); and a recent Special Report covers agricultural research and technology transfer policy issues for the 1990s (216).

of environmentally appropriate farm management practices (140).

State Agricultural Experiment Stations

State-employed agricultural researchers work in the land-grant universities and State Agricultural Experiment Stations (SAESs). SAES systems are composed of field sites, research farms, and laboratories that provide site-specific agronomic information based on a State's climate, soil, and water resource conditions.

Each SAES receives Federal formula (Hatch Act) funding for agricultural research through the USDA Cooperative State Research Service (CSRS). Individual researchers at many SAESs also receive Federal competitive grants for specific research projects, as well as grants from trade associations and commodity groups for applied research and product testing. Formula funds generally are directed toward basic and applied research that meets the needs of each State's producers and rural communities. Competitive grants, on the other hand, emphasize basic research in specific areas. Thus, formula funds are more likely to be directed toward development, testing, and dissemination of agricultural practices most suited to the State's hydrogeologic, climatic, and economic conditions than are competitive grant funds.

Investment in agricultural research to answer questions about impacts of agriculture on environmental quality varies widely from State to State. States that are most likely to provide timely, site-specific information on groundwater protection are those that allocate substantial amounts of State funding for this type of research.

Private-Sector Research

Agricultural researchers in the private sector apply basic research findings to the development of commercial products and production techniques. Commercial agricultural firms historically have relied on basic research results from the public sector to develop commercial crop production technologies. Public-sector research in the basic agricultural sciences, thus, has provided the technical foundation for commercial applied research. Since development and commercialization of technologies resulting from basic research may be lengthy (e.g., 10 to 20 years or more) (178), the breadth and depth of the basic research base in the public sector is a critical consideration for new technology development.

All components of the agricultural research system can contribute to the identification, testing, and adaptation of practices with potential to reduce agrichemical contamination of groundwater. Although a broad basic research base is needed, Federal and State governments also need to devote adequate funding to applied research that addresses the site-specific nature of environmental problems in agriculture. Many commercial agricultural technologies have been widely adopted because markets are large enough to support high-volume production, resulting in relatively low-cost products to farmers. However, market niches for innovative agricultural technologies designed to address specific environmental conditions may not be large enough to encourage commercial firms to develop these technologies. Such technologies also may be too expensive for farmers in environmentally sensitive areas to afford. Alternatively, if farmers in such areas cannot use certain comparatively low-cost inputs (e.g., some pesticides), they may be at a competitive disadvantage with farmers in other areas where agriculture-related environmental problems are fewer.

Best Management Practices

The agricultural Best Management Practice (BMP) concept originated with EPA programs established to reduce agricultural nonpoint-source pollution and has been expanded to mean individual methods designed to reduce adverse impacts on soil, surface water, or groundwater resources. Best management practices (BMPs) are defined in the Federal Water Pollution Control Act Amendments of 1976 as:

> . . . a practice or combination of practices that is determined by a State (or designated area-wide planning agency) after problem assessment, examination of alternative practices and appropriate public participation to be the most effective practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals (52).

When this definition was written, water quality was essentially synonymous with surface-water quality, thus in the course of BMP development considerations of other off-site impacts (e.g., effects on groundwater quality) largely were unexamined.

Partial solutions to environmental pollution problems in agriculture have involved the development

Box 4-K—Maximum Economic Yield

The Maximum Economic Yield (MEY) approach, developed and advocated by the Potash and Phosphate Institute and the Foundation for Agronomic Research, is based on more intensive cultivation of the higher quality land to generate equal or higher production on reduced acreage. An estimated 90 percent of the soil losses in the United States come from 10 percent of the cultivated land. These soil losses maybe largely due to cultivation of highly erosive lands, thus removing such lands from production is suggested as a mechanism to reducing U.S. soil erosion.

The MEY operates on the principle that early and rapid development of a denser crop canopy will reduce soil and nutrient losses due to runoff events. Higher yields above and below ground promote greater root proliferation leading to soil stabilization, increased soil moisture holding capacity, and enhanced soil infiltration rates. Greater leaf area established by the associated denser canopy reduces impact of precipitation on the soil surface. It has been suggested that such an environment might reduce the potential for contaminants to move through the soil profile, despite associated increases in agrichemical use. If the root mat developed under an MEY field is sufficiently dense, it may promote plant uptake of available nitrogen. However, this effect is also dependent on the nutrient accumulation patterns of the crop being grown as well as environmental parameters that affect leaching.

Best management practices for crops and nutrients are incorporated into the MEY concept that promotes such techniques for nitrogen management as split applications, cover crops to reclaim residual soil nitrate, soil testing to determine soil nutrient level, tissue testing, application of vitrification inhibitors, and accounting for nitrogen credits. Applied crop management practices include: conservation tillage, contour stripcropping, terracing, crop rotations, water and sediment control basins, and use of cover crops.

SOURCE: Potash and Phosphate Institute, *The Vital Role of Phosphorus in Our Environment,* Publication No. 11-87-A (Atlanta, GA: 1987).

of pollution-reducing BMPs by agricultural researchers in the public sector. BMPs have been used by SCS and State conservation agencies to control soil erosion and address nonpoint-source surface-water contamination. This approach included components that addressed: 1) structural controls such as terraces and buffer strips to control pollutant transport in runoff, 2) source controls that affect rates of agrichemical applications, 3) agronomic management affecting timing and placement of agrichemicals, and 4) integrated pest management (8). Private organizations have incorporated BMPs into agricultural managment schemes as well (box 4-K).

BMPs to protect surface waters from agricultural sources of contamination might include technologies and management practices that:

- maintain a soil cover (crop residues, canopy development, and/or rough surface) in order to reduce the impact of precipitation on the soil surface and to slow runoff velocity;
- increase soil permeability to enhance infiltration and thus minimize erosion and reduce runoff; and
- minimize or reduce soil-solution concentrations of agricultural chemicals, heavy metals, toxics, and plant nutrients to reduce the potential for contamination of water sources during heavy precipitation events (8).

USDA and EPA only recently have begun to develop BMPs specifically to reduce nonpoint-source contamination of groundwater. BMPs for groundwater protection need to account for infiltration, volubility and soil affinity of the potential contaminant, relative agrichemical loading, timing, and the ability of the practice to alter any or all of these conditions. Research could identify which combinations of BMPs are best suited to a State's soil, hydrogeological, and agricultural conditions in a systematic fashion.

Groundwater contaminants may be sorted into two broad categories: 1) those that maybe managed by practices affecting the physical system (e.g., sediment, pathogens, and heavy metals) such as maintaining vegetative cover and soil pH and land leveling; and 2) those that may be managed by practices affecting inputs (e.g., pesticides, nitrogen and phosphorus, and easily oxidizable organics) such as rate and timing of applications (8). Development of management plans that effectively incorporate practices designed to manage both types of contamination may be problematic. Practices designed to manage one contaminant or resource concern may conflict with efforts to manage another.

For example, conservation tillage (primarily designed for erosion control) is suggested to exacerbate movement of agrichemicals through the soil profile. Although highly successful in reducing sediment losses, it seems that this practice should be examined for its effect on other resource conservation goals.

The broad number of environmental variables that comprise an agroecosystem make determination of BMPs complex, Specific practices must be developed on a site-by-site basis to account for variations in the geologic, hydrologic, and climatic attributes of a given agroecosystem. A key problem facing researchers is the development of combinations of BMPs that address several environmental pollution problems, rather than just one. To minimize environmental impacts, BMP combinations therefore need to fit into a total farm management system, which considers local environmental and economic conditions. Further, the skills and motivation of the practitioners are an added component that cannot be extracted from the overall equation, Although no single formula is likely to exist for developing and implementing BMPs, the broadly stated goals of BMP development may serve as a guide.

The initial concept of BMPs as a package of agricultural practices designed to meet conservation and quality goals for a specific resource may no longer be appropriate given broadened concerns over partitioning of agricultural chemicals to other media (e.g., agriculturally generated nitrous oxides and methane losses to the atmosphere). An expanded approach that includes identification of practices designed to mediate or mitigate losses across media could address this need.

Farmstead Assessment Programs

Farmstead Assessment programs are under development in several States as a mechanism to: 1) assess potential farmstead sources of groundwater contamination; 2) educate farmers about management practices to prevent groundwater contamination; and 3) clarify the relevant laws, regulations, and sources of assistance in farmstead management for farmers.

Increased documentation that agriculture is a contributor to agrichemical contamination of groundwater has focused on agronomic practices as the major pathways of contamination. Insufficient consideration has been given to potential for farmstead practices and structures to cause groundwater contamination (98).

Farmstead describes the area centered on the farm residence, including: barns, silos, and related buildings; structures and facilities used for storage and handling of agrichemicals and household and livestock waste; and potable water wells for human or livestock use. Management and maintenance of these structures and facilities may have a major influence on groundwater quality in general and most significantly on that used on the far-m itself.

As currently developed, a farmstead assessment includes the following steps:

- evaluation of soil, geologic, and hydrologic conditions to identify the pollution potential of the individual farmsite;
- evaluation of farmstead structures and activities affecting pollution potential (e.g., well design and location; agrichemical handling, storage, and disposal; silage storage facilities and management; petroleum-products storage and disposal; septic system location and management; farm and household hazardous-waste disposal and recycling; and milkhouse-waste handling); and
- integration of the above evaluations to form an assessment of farmstead groundwater-contamination potential, and suggestions for structural and management changes to reduce that potential.

Expertise is being developed in the assessment of groundwater contamination potential from farmstead activities. However, current efforts lack the support system needed to: 1) educate practitioners on the links between activities and contamination potential, 2) demonstrate the long-term management changes needed to protect groundwater, and 3) provide financial and technical support to implement management plans (98).

Integrated Farm Management Systems

Integrated approaches to developing farm management plans are needed. Existing resource management plans may provide a base for development of broader management systems. For example, integration of a farmstead assessment plan with complementary management plans designed to reduce adverse environmental impacts from agronomic activities may provide a base for development of whole-farm management systems.

Resource Management Systems

The Resource Management System (RMS) is a land-management concept proposed and developed by the Soil Conservation Service (SCS). The RMS combines multidisciplinary input to develop a farm management and conservation plan coupling the landowner's goals for resource use and SCS goals of reducing erosion and nonpoint-source contamination. This farm management approach links agricultural production and conservation. SCS provides technical assistance to the farmer in developing such farm plans. The farmer then decides on what part of his/her land the plan will be applied.

SCS's RMS integrates conservation practices and management for the identified primary use of land or water. At a minimum the RMS is supposed to provide protection for the resource base by meeting acceptable soil losses, maintaining water quality, and maintaining acceptable ecological and management levels for the selected resource use in accordance with the Field Office Technical Guide (FOTG). Currently there are six resource concerns incorporated in RMS development:

- erosion control-reduction of sheet and x-ill erosion to the soil loss tolerance level for the most vulnerable soil within the field;
- water disposal-management of surface or subsurface water in drainage systems to protect the quality of linked water sources;
- livestock waste and agrichemical management—for pesticides: adherence to label recommendations, regulations, appropriate timing and application method, and alternative control methods in highly vulnerable areas; for nutrients: application based on plant need, soil tests, accounting for nitrogen credits, appropriate timing, chemical form, and application rate;
- resource management—mitigation of adverse effects on water quality or quantity from plant or animal production and vice versa;
- water management—management of irrigation, drainage, and land to protect water quantity and quality; and
- off-site effects—resource management to avoid potential adverse effects on groundwater or surface water from agricultural production activities (232).

The RMS approach is undergoing revision to broaden its application for conservation of resources. Under the revised protocol, there will be five categories of resource concern: 1) soil, 2) water, 3) air, 4) plants, and 5) animals (233). The inclusion of air as a resource of concern expands the RMS approach to address potential impacts of resource use on the atmosphere.

The RMS approach is adaptive-as new resource concerns arise an evaluation and revision process may be conducted. The procedure for such revision is outlined in the SCS field office guide and involves the following six steps:

- assess and evaluate water-resource information with plant and soils information,
- determine effects of agricultural production on water quality and quantity,
- evaluate current RMS on water resources,
- identfy applicable practices with beneficial effects on water resources,
- evaluate combinations of practices, and
- select combinations of practices.

Once the evaluation is complete, the revised RMS is developed incorporating practices to address the resource concern (232,233) (box 4-L).

Integrated Crop Management

An Integrated Crop Management (ICM) program was recently approved by ASCS as an approach to reduce excess use of nutrients and pesticides while maintaining farm income. The practice is being tested under the Agricultural Conservation Program on a limited basis in 1990 with a goal of reducing agrichemical use by 20 percent. A maximum of 20 producers from 5 counties per State may take part in the demonstration program. These demonstration sites are to represent a cross section of farming types within the State. The overall program goal is to encourage adoption of practices that integrate nutient management practices and integrated pest management into an overall crop management system. ICM practices are intended to reduce water, land, and atmospheric contamination by agrichemicals through use reduction.

The program provides cost-sharing assistance for development and implementation of integrated crop management systems (224). Eligibility requirements for participating in cost sharing include the following: 1) producers must have an ICM system developed in writing that reduces the level of agrichemi-

Box 4-L-Evaluating and Revising RMS—An Example

Below is a sample of how an RMS might be evaluated and revised given water quality concerns. The site of production is the Southern Coastal Plains, characterized by nearly level terrain, and deep, somewhat poorly drained soils on uplands and floodplains. Major environmental concerns were for water disposal, water management, and resources management. Detections of nitrogen and phosphorus in farm drainage ditches raised concern about possible contamination of ground and surface water, leading to the revision of the initial RMS. In absence of pesticide analysis of associated water sources, it was assumed that leachable pesticides were also moving with the water. While the initial RMS was developed based largely on site characteristics, the revised version incorporates management practices designed to address the detections of nutrient contamination of adjacent water sources.

Resource Management Systems	Erosion control	Water disposal	Animal waste & Agrichem management	Resource management	Water management	Off-site effects
Initial RMS						
Conservation cropping sequence	X			x		x
Crop residue use	X			x		
Surface drainage main or lateral		x			x	
Surface drainage field ditch		x			x	
Land smoothing		x			x	
Revised RMS						
Conservation cropping sequence				X		x
Crop residue use	X			X		
Surface drainage field main or lateral		x			x	
Surface dranage field ditch		x			x	
Land smoothing		x			x	
Pesticide management			x	x		x
Nutrient management			x	x		x
Structure **for water control**			x	x	x	x
Regulating water in drainage systems			x	x	x	x

SOURCE: U.S. Department of Agriculture, Soil Conservation Service, Conservation Planning Division, ***National Planning Manual,*** Parti 501 (Washington, DC: 1984).

cal input historically used on the land, and 2) producers must have sufficient documentation to verify the rates and methods of agrichemical application before and after system development. Approval of the system is also dependent on the availability of appropriate technical resources. Technical assistance may be provided by CES, SCS, or certified private consultants. The ICM system may incorporate such tactics as soil and tissue testing, pest scouting, biocontrol, crop rotation, soil enhancement and conservation measures, and use of green manures or host crops (224).

SUMMARY AND POLICY IMPLICATIONS

The U.S. agricultural sector will be facing new issues and opportunities in the 1990s. The agricultural research system is being called on to respond to newly articulated environmental concerns associated with agricultural production practices; concerns for food safety and the environment seem likely to increase in importance. Meeting these challenges will require an agricultural research system with an effective national strategy. It will also require advances in science and technology of a scale and scope the system has not previously experienced (216).

Increased understanding of cross-media effects of technology implementation will enhance the potential for developing agricultural practices that address the broad spectrum of environmental concerns (e.g., soil erosion, surface water and groundwater pollution, atmospheric releases). Whether the agriculture research and technology development base is sufficiently broad, or the current structure is adequate to address the plethora of environmental concerns related to agriculture, however, is under question (216).

Integration of agriculture and environmental protection will mean that agricultural technologies and practices cannot be designed in isolation from their interactions within agroecosystems. Research and development efforts will need to examine the array of impacts arising from implementation. Integrated approaches to the development of agricultural practices and technologies have been taken, and further efforts are being made in this direction. For example, USDA's Low Input Sustainable Agriculture Program is designed to provide information on the productivity of low-input systems and the interaction of agricultural inputs within the agroecosystem (box4-M).

Enhancing Knowledge of the Agroecosystem

Agricultural researchers without a solid understanding of the sciences fundamental to agroecology (e.g., agronomy, hydrogeology, ecology), or not operating within a multidisciplinary or interdisciplinary framework, may develop products or practices without consideration of the broad array of potential impacts that might be generated from their implementation. A systems approach is needed in developing agricultural technologies designed to minimize agrichemical contamination of groundwater. Such an approach is likely to depend on increased understanding of agroecosystem components; the general principles of cycling, transport, and fate of agrichemicals within those systems; how certain technologies may affect their function; and how these interactions may affect groundwater vulnerability.

Congress could establish an Agroecosystem Research Initiative that directs and coordinates federally funded basic research on improved understanding of agroecosystem components and processes. The knowledge gained from such basic research could then support technology research and development efforts to design agricultural products and practices that could contribute to reducing groundwater contamination. An initial step in implementing an Agroecosystem Research Initiative could be to establish a coordinating body responsible for outlining an overall approach to the initiative. Topic-specific working groups could then be established that would evaluate the extent of knowledge on certain agroecosystem components and their interactions and report these findings to the coordinating body. The coordinating body could consequently identify research priorities and protocols for gathering the necessary information. Finally, research results could be synthesized and distributed throughout the agricultural research system.

Such an initiative could be implemented by USDA, or through a joint effort of several Federal agencies (e.g., USDA, EPA, USGS, NSF, and NOAA) to ensure that the research conducted and information gathered would support efforts to address the wide array of environmental concerns arising from agricultural production. For example, examination of nitrogen transformations in various agroecosystems might be approached differently by the various involved agencies. While one agency might identify the importance of quantifying nitrous oxide emissions to the atmosphere, others would likely approach the same research from a surface or groundwater contamination aspect, and still others might focus on changes in crop yields or quality. Such cross-agency discussion likely would broaden the research question. Further, tapping expertise housed within each cooperating agency might lead to quicker attainment of the research goal than if the required expertise had to be developed within any single agency.

Working groups could be established to prepare reports on the state of research knowledge in specific topic areas. Each working group could: 1) analyze the existing information base from which research currently operates, 2) identify areas of most urgent research need and the tasks required to fill this need, and 3) develop common research protocols so that experiments could be replicated across agroecosystems and thus develop a meaningful information base. These working groups should be interdisciplinary to incorporate a systems approach in agricultural research and thereby be able to identify key research questions related to numerous objectives.

Working groups might best be established across Federal agencies and might follow a model such as the Technical Integration Group, or perhaps be based on other extant informal groups. For example, the ARS Nitrogen Research Workshop, held in 1989 to identify the extent of current knowledge of nitrogen in the agroecosystem, could be expanded to into one such working group. Mechanisms would be needed to provide for regular work group meetings, evaluation of results, and reporting of work group findings to relevant administrative offices for consideration in setting or revising research priorities.

Common protocols used in initial agroecosystem research efforts could provide an information base through which variations in ecosystem response to agricultural technologies could be determined. This

Box 4-M—USDA Low-Input Sustainable Agriculture Program

The Low Input Sustainable Agriculture (LISA) Program was created by USDA in response to the Agricultural Productivity Research Subtitle in the 1985 Food Security Act (Public Law 99-198). The Agriculture Productivity Act provides authority to conduct research and education programs on low-input farming systems to promote profitable farming, conservation of natural resources, and environmental protection (225). LISA was designed to respond to growing farmer interest for more cost-effective and environmentally oriented agricultural production practices. The Program received initial funding for the fiscal year 1988 and USDA policy on low-input farming systems was issued in January of 1988.

The Department encourages research and education programs and activities that provide farmers with a wide choice of cost effective farming systems including systems that minimize or optimize the use of purchased inputs and that minimize environmental hazards. The Department also encourages efforts to expand the use of such systems.

Grants are provided under LISA authority for research and education projects designed to assist agricultural producers in reducing purchased external inputs. Such projects emphasize substituting management, information, and on-farm resources for external inputs and may include techniques such as crop rotation, farm diversification, resource conservation practices, and mechanical and biological pest control approaches. Proposal response to the program has been significant (e.g., finding to support acceptable LISA proposals fell short by roughly fivefold in each of the first 2 years of the program).

LISA is administered through four regional host institutions (Northeast, North Central, Southern, Western) and is organized and directed by the Cooperative State Research Service (CSRS) with the cooperation and participation of several USDA agencies. Project proposals are reviewed in each region by committees of research scientists, practitioners, and educators. A key feature of LISA projects is the involvement of practitioners, interdisciplinary research teams, and private research and education programs.

Most projects are long-term studies requiring several years development and replication to generate meaningful results. *Some* have added to ongoing work allowing expansion/collection of additional data. Short-term projects designed to present known findings through a variety of mechanisms (e.g., video tapes, computer software development) are also funded under LISA.

Funding levels for the LISA program have increased roughly 14 percent in the last 2 years ($3.9 million in 1988 and $4.45 million in 1989). However, this has been insufficient to fund all of the acceptable proposals. For example, roughly $20 million would have been needed to fund acceptable proposals in 1989 (182).

LISA projects are providing the scientific basis for understanding the productivity of low-input systems and providing comparisons between these and conventional systems that emphasize high yields generally through the use of fertilizers, pesticides, and other purchased inputs. While the conventional approach tends to view resource conservation and environmental quality as potential constraints to maximizing profits, the LISA approach strives to integrate these aspects of agricultural production. LISA projects are demonstrating that certain low-input production methods can be profitable when implemented properly (1 18),

Controversy exists over the ability of low-input agriculture approaches to produce sufficient food to meet domestic and international needs; suggesting that LISA would require a significant part of the U.S. population to return to or enter farming. Further, it is argued that ‘‘conventional agriculture’ approaches are sustainable and environmentally sound (241 ,169). In fact, even the term LISA is subject to a variety of definitions. LISA advocates define low-input to mean low purchased inputs, but increased management and information inputs and thus not necessarily low total inputs (182,1 18). Critics tend to focus on the reduction of purchased inputs and suggest that agricultural profitability and thus sustainability depend on availability and use of purchased inputs (241,169). However, this apparent bifurcation in agricultural production approaches is not so widely divided as it may seem on the surface. Agreement exists as to the need for a sustainable system to be profitable and that any input must be properly managed to avoid adverse environmental and economic impacts.

Ten guiding principles of LISA

1. If a farming method is not profitable it cannot be sustainable.
2. Farmers need accurate, readily usable information on the impacts of LISA methods on farm profits, resource productivity, and the environment.

Continued on next page

3. Some farmers can now profitably use low-input methods.
4. Properly designed and executed research and education efforts can enhance profitability of low-input methods.
5. Net results of adoption of low-input methods must be evaluated in terms of the whole farm system (e.g., labor and capital requirements, agroecological interactions, environmental impacts).
6. Success will depend on multiorganizational approach (e.g., interdisciplinary efforts, practitioner involvement, public and private organizations).
7. CSRS and soil conservation agencies (SCS, CES) must be full partners in design and implementation of the program.
8. Administration should be at the regional level to promote decisionmaking by persons with an understanding of the site-specific conditions associated with region.
9. Sustainable systems are highly site-specific and their success depends on practitioner skills and attitudes.
10. Establishment of sustainable systems on the farm should be carefully planned and implemented gradually (118).

effort could provide a base from which to correlate specific ecosystem features with response differences and thus be used to identify adaptive research needs for specific technologies across agroecosystems.

Undertaking a comprehensive Agroecosystem Research Initiative, however, may involve some structural and strategic changes in the participating organizations. For example, it would likely require increased emphasis on biological, ecological, and systems sciences and thus might involve shifting research funds and staffing to place higher priority on these sciences. Research funding also probably would have to be increased and allocation formulae or programs modified to address priorities established by the Initiative.

Environmental research in agriculture also maybe more costly and time consuming than production research, requiring different research designs and measurement techniques. In addition, jointly conducted agroecosystem research may have to incorporate a large administrative component to achieve the level of coordination necessary for effective planning and evaluation of results.

Federal funding levels for agricultural research have remained relatively stable for the past three decades due to Administration and congressional arguments against funding increases because of agricultural surpluses, the budget deficit, and other competing priorities. Some new Federal funding has been allocated under the Water Quality Initiative, but this has not been directly aimed at increasing understanding of agroecosystems. Redirection of these funds could slow efforts to develop and extend practices already identified as having beneficial effects on reducing potential contamination of groundwater. Still, allocation of funds to directed research efforts under an Agroecosystem Research Initiative would accord with expressed priorities for addressing environmental problems in agriculture and so may attract new appropriations.

Long-term research activities commonly are accomplished through base funding to the 57 State Agricultural Experiment Stations (SAESs) and, less commonly, through grants for special initiatives. Although base funding provides for dispersed research addressing a large number of commodities and agroecosystems, no formal mechanism exists to direct how base funds should be spent by the States. Thus, implementation of an Agroecosystem Research Initiative through individual SAES efforts without additional appropriations may be problematic and lead to fragmentary efforts.

Congress could direct the General Accounting Office (GAO) to analyze the relative merits and costs of implementing an Agroecosystem Research Initiative through: 1) the 57 SAESs, 2) Lead Agroecosystem SAESs, or 3) Regional Agroecosystem Experiment Stations. Funding allocated under the Initiative could be apportioned among the existing SAESs for conduct of specific research tasks related to characterization of agroecosystems. However, such an extensive division of funding could result in each station receiving too little to conduct useful or timely research. Alternatively, appropriating substantial funding to each station would likely have too large a price tag in this time of budgetary austerity.

Specific SAESs could be identified to fulfill the role of Lead Agroecosystem Experiment Station (LAES). Stations identified as LAESs would coordinate research and funding to research units in cooperating SAESs, and would disseminate information. However, the substantial autonomy of SAESs could create difficulties in coordinating efforts across State boundaries as well as in evaluation of research efforts. Further, the LAES would likely require a substantial administrative component to organize and accomplish these new tasks with attendant increases in staffing to allow completion of normal duties as well as the newly assumed coordination responsibilities.

Alternatively, Regional Agroecosystem Experiment Stations could be established to centralize research activities and reduce constraints likely to be associated with coordinating separate stations. These RAESs might be drawn from existing SAESs or be newly identified sites. USDA could conduct an assessment of the site characteristics (e.g., climate, soils, hydrogeology) of existing agricultural research stations and categorize each station by agroecosystem to form the base for identification of potential RAESs or LAESs. Based on the analysis provided by GAO, the most cost-effective approach to providing infrastructure and staffing necessary to implement an Agroecosystem Research Initiative could be determined.

Priority Setting for Groundwater Protection Programs

U.S. agriculture is highly diverse and unevenly distributed across the country. Cropland acreage, predominant commodity (crop or livestock), and type and intensity of agrichemical use vary by region (203). Some areas may be more vulnerable than other areas to agrichemical contamination of groundwater by virtue of the larger agrichemical volumes applied and greater land areas involved in certain cropping systems. Similarly, centers of concentrated livestock agriculture, with attendant high volumes of waste production, may present areas of special concern. Regional factors, such as climate, hydrogeology, and types of agrichemicals used, will also affect the relationship between crop production activities and potential for groundwater contamination.

Research priorities can be established for the development of production practices that reduce groundwater contamination and other adverse impacts on the environment according to: 1) geographic area, depending on agricultural production intensity and hydrogeologic vulnerability; 2) need for data, information, or other types of knowledge, which depends on the number and urgency of the purposes they would serve; and 3) need for certain technologies and practices, which depends on the numbers and locations of farmers who could use them. Research priority setting would involve evaluation of the use and suitability of existing practices and ongoing research initiatives as they operate in the agricultural production system.

Identification of major information gaps and areas where greatest actual or potential environmental hazards exist offers a mechanism for developing research priorities to reduce the adverse environmental impacts associated with agricultural production. For example, baseline information on patterns and locations of agrichemical use could be a tool for identifying regions with the highest potential vulnerability to groundwater contamination. Basic and applied research efforts to reduce groundwater contamination potential then could focus on these regions. Once collection of natural resource and agrichemical use-data and assessment of the extent of current knowledge are complete, conditions will be improved for prioritizing needed basic research.

Some data and research gaps are known currently and could provide a focus for certain agricultural research activities. For example, past research on fertilizer and pesticide efficacy and movement largely has been conducted under conventional tillage regimes. However, use of reduced tillage methods is increasing. Thus, a need exists to examine the effects of alternate tillage systems on agrichemical movement and fate. Research conducted under USDA's Low Input Sustainable Agriculture (LISA) program addresses this need in part. Increased funding for LISA might shift the balance to favor greater attention on reduced input systems and thus promote development of products and practices more responsive to the diversity of U.S. farms.

Similarly, lack of understanding of mineralization rates of soil organic matter constrains improved nitrogen application practices. Some research within ARS could be refocused or redirected to ensure investigation of the fate of applied nitrogen (fertilizers, manures, and legumes) at a network of geographical sites that may be vulnerable to groundwater contamination. The focus would be on obtaining complete nitrogen balances at all sites in the network to support development of annualized nitrate-loss rates from cropping systems to groundwater. This information would be critical in determining a benchmark of acceptable' nitrate loss—a certain amount of nitrate is normally lost from unfertilized fields and thus a loss rate set below this level may be impossible to achieve.

Congress could direct USDA to expand information gathered under an Agroecosystem Research Initiative to develop agroecoregion maps that would delineate agricultural regions displaying similar ecological attributes. These maps could provide a tool for prioritizing and coordinating research efforts. Enhanced applications of an Agroecosystem Research Initiative might include development of 'agroecoregion maps' that display areas exhibiting similar site and farming system characteristics. Information and research results should be broadly applicable within regions. Further, agroecoregion maps might provide a broader base from which adaptive research could be performed and information shared.

Preliminary identification of agroecoregions could be done today and revised as additional resource attribute and land use data become available, and knowledge of important agroecosystem parameters and processes improves. For example, data from USDA's planned National Pesticide Use Survey and the National Agriculture Census could be correlated with USGS and EPA water quality data to identify agroecoregions highly vulnerable to groundwater contamination from agricultural sources. Based on this analysis, priority agroecoregions might be identified. Activities such as data collection, agroecosystem modeling, and GIS development efforts then might be directed preferentially to these regions.

Developing priorities on an agroecoregion basis may provide a mechanism for enhancing information sharing and avoiding duplication of certain research efforts. Thus, establishment of applied research priorities for the development of agricultural technologies to reduce groundwater contamination might be underpinned by characterization of agroecoregions.

Adaptive Research

Adaptation of technologies and practices to specific environments or cropping systems is an important aspect of reducing the potential for agrichemical contamination of the environment generally and groundwater specifically. Given the diversity of agricultural regions, production practices, and practitioners, the adaptation of practices suited to these factors becomes critical. Within the Federal agricultural research system, such adaptive research is carried out by the SAES; however, the extent of these efforts varies widely by State.

Site-specific problems also are addressed within farmer organizations that test and share information on innovative practices (commonly referred to as farmer-to-farmer referral networks). Groups such as Practical Farmers of Iowa, for example, conduct on-farm research with the assistance of land-grant university researchers. This type of organization can help fill information gaps and provide support to farmers who want to minimize environmental pollution problems.

Several aspects of federally funded research at SAESs may interfere with timely development of farm practices that have positive impacts on protecting groundwater quality. Agricultural researchers at land-grant universities and SAESs have greater incentives to conduct basic, disciplinary research than applied, interdisciplinary research. Because of the substantial autonomy of each SAES and the individual researchers, no formal mechanisms exist to coordinate research, determine where data gaps exist, or ensure that such gaps are addressed in applied-research efforts (21 1). Further, a lack of systematic evaluation of SAES research at the national level hinders monitoring of the amount of federally funded research being conducted on management practices to reduce agrichemical contamination of groundwater.

Individuals responsible for the conduct of adaptive research are rarely involved in development of the initial program or practice. This factor is seen as a major constraint to implementation of existing IPM research and program efforts. Research programs within USDA could be enhanced **through an** increased stress on the importance of transitional and applied research, particularly with regard to the specific constraints to adoption embodied by various agricultural sectors. Increased staffing likely would be required to extend current and developing IPM technologies adequately and thus promote adoption by growers. The extant agrichemical industry infrastructure for extending advice and products currently may overshadow developing low chemical-input approaches to pest control. For example, in Fresno County, 5,500 farms are serviced by over 500 licensed pest control advisors, a majority of which are pesticide retailers. Only three Fresno County CES staff have pest-control management responsibilities, only one direct IPM responsibilities (1 1).

Nitrogen management decisions also are dependent on information derived from site-specific, adaptive research. Policies that encourage conversion from contemporary nitrogen-use practices to ones posing reduced risk to groundwater should be crafted with consideration of individual enterprises and site conditions. Direct subsidies, tax credits, low-interest loans, rezoning, direct buyout, coupling, cross-compliance, or combinations thereof are potential policy tools. However, whatever policy is adopted, procedures for compliance will have to emerge on a farm-by-farm basis given the site specificity of nitrogen-use decisions.

If agricultural research efforts are to address resource protection to a greater extent, the traditional focus of agricultural research and education on commodity production will need to be expanded to include farming systems that reduce adverse environmental impacts and promote resource protection in agricultural production. Traditional incentives for researchers in land-grant universities will probably need to be changed to foster interdisciplinary work and a systems approach to research. Potential for Federal intervention in adaptive research is limited to 'carrots' of finding because States have primacy over their educational institutions, and professional organizations are primary actors in setting incentives for researchers (21 1).

Congress could authorize and fund a new USDA research and demonstration program to ensure that adaptive research on agricultural technologies is designed specifically to be suitable to agroecological site conditions and socioeconomic adopter conditions. To accomplish this, National Agricultural Test Sites could be established within identified agroecoregions for site-specific, adaptive research. Alternatively, such a role could be fulfilled by Regional Agroecosystem Experiment Stations identified under an Agroecosystem Research Initiative. These stations might also serve as demonstration sites where agricultural technologies shown to have a beneficial effect on protecting groundwater quality could be shown to farmers.

Technology development and adaptation research and grant proposals related to these test sites could be required to include statements of who the potential adopters would be, and identify mechanisms through which technology or practice adoption could be encouraged. Research finding could be made contingent on: 1) identification of likely adopters; 2) specification of the farming system improvement expected (e.g., reduced agrichemical waste); and 3) estimation of costs and benefits accruing to the profiled adopters in terms of funds, time, and effort. Adaptive research and extension results could be compared to this information to assist with development of future adaptive research and to draw general lessons for successful adaptation and extension activities.

Proposal specifications probably would require increased interaction between adaptive researchers and extension specialists. Such increased interactions could provide benefits in technology development and extension; however, they would also increase demands on already strained work schedules. Increased research and extension staffing might be required to ensure adequate planning, evaluation, and extension of research results within agroecoregions.

Research Coordination

Improved coordination among and between public and private efforts could have beneficial effects on development of technologies designed to reduce agrichemical contamination of groundwater (e.g., pesticides and application equipment). Research coordination at the public level will be particularly important in developing systems-oriented agricultural management practices designed to reduce adverse impacts on soil, surface water, and groundwater resources. Best Management Practices (BMPs) have been developed and used by SCS, EPA, and CES. However, the approach commonly has been designed to address a single resource concern and thus potential adverse impacts on other resources may have not been examined. Integrated approaches are being developed that consider a site's soil, hydrogeological, and agricultural conditions to address this need. Coordinated development of such approaches by agencies having relevant expertise or experience would speed their development, reduce duplicative efforts, and contribute to successful efforts.

Coordination of federally funded agricultural research could be improved within and among States through mechanisms by which State and Federal agency personnel, local governments, and producers work together to identify public research questions. Each State's SCS Resource Conservationist and technical staff could work more closely with CES, other State agencies, and producer groups to develop appropriate management practices for conservation planning. SCS Resource Conservationists and their staff currently conduct studies of conservation practices in cooperation with the State's land-grant university and State agricultural experiment station,

Congress **could direct USDA, EPA, and USGS to coordinate technology research and development efforts with State land-grant universities to ensure conformation of farm practice recommendations.** Funding could be earmarked for coordination and communication efforts needed among land-grant and SAES researchers and the relevant State and Federal agencies in each agroecoregion. Coordinating groups might be drawn from topic-specific working groups established under an Agroecosystem Research Initiative, or be subgroups that would interact with these larger working groups. Such a structure might yield beneficial impacts for overall research coordination and exchange of information.

One possible mechanism for research coordination is through the inter-regional groups of land-grant universities. However, researchers within regions may not formally meet to identify key research questions and agree upon methodology, and if they do, it may be on an ad hoc basis (83). Even if researchers meet within or between regions, no formal mechanism exists to evaluate their efforts and to communicate results to other regions. Earmarked funding could specify the coordination and communication efforts required among land-grant and SAES researchers and among the relevant State and Federal agencies in each region.

For example, researchers on a regional nitrogen project could agree on research questions and methodologies that would be replicated in selected areas to provide the most useful information. State agencies, SCS, and EPA regional staff could assist researchers in selecting target areas for intensified research efforts. Funding could be provided for initial planning and follow-up meetings to ensure consistency and final evaluation and communication.

However, coordination of public and private research activities would not necessarily be improved through such a mechanism. Further, public and private coordination may become increasingly important in research areas receiving little public or private funding (e.g., pesticide application technology) in order to avoid duplicative efforts and promote complementarily of efforts.

Coordination between public and private efforts may be critical to technology development with potential impact on agrichemical contamination of groundwater. For example, Federal effort in development of pesticides or agrichemical application equipment is small. For example, ARS efforts in herbicide equipment development fell from 8.7 to 1.7 scientist-years between 1972 and 1982; similar trends can be noted for insect and disease control equipment (60). Additionally, major developers of pesticide application equipment currently comprise just a few small companies that specialize their products for specialized markets (60,73).

Currently, farm equipment manufacturers are not in a position to spend large amounts on the development of this technology without passing these expenditures along to the user by increasing equipment cost. Neither do these companies have research capability for chemical application technology and few have the resources to develop equip ment from other technology. Thus, input from the public sector can be critical in advancing the state of the art in this arena.

Coordination of advances in application equip ment with development of associated agrichemical products could facilitate adoption of improved agrichemical application practices. For example, while enhanced use of chemigation techniques may offer some potential to reduce frequency and volume of chemical applications and promote more uniform distribution, lack of agrichemical formulations designed specifically for chemigation systems hinders achieving these benefits. Research shows that formula alteration of certain pesticides and subsequent chemigation has allowed significant reduction in amount of active ingredient applied while achieving needed pest control (208).

Congress could direct USDA to establish a public-private research and development coordination body that would be responsible for reviewing Federal research proposals for complementarity of activities in both sectors. The role of the current Users Advisory Board-to identify and report research and technology transfer problems to Congress and USDA-could be expanded to fulfill such a role. The mission of this group would be to promote coordinated research and development among the various agricultural research and development entities. It might also serve as a mechanism to track research and development directions and, thus, provide some input as Federal agencies set their agricultural research priorities. For example, continuous review of ongoing agricultural research in the public and private sectors could facilitate identification of areas where little effort is being directed and these could be reviewed for a potential increased Federal research role.

Clearly, appropriate technologies and management practices will be critical to reducing the potential for adverse environmental impacts associated with current agricultural production practices. However, of equal importance is development of technology-transfer mechanisms that will promote the adoption of such practices. Current avenues of technology transfer may need to be improved and expanded in order to address this aspect of integrating agricultural productivity and environmental quality.

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Chapter 5

Farmer Decisionmaking and Technical Assistance

CHAPTER HIGHLIGHTS

- People who make decisions about nutrient and pest management in agriculture include farmers, commercial applicators, and the individuals who advise them. A comprehensive approach to reducing agrichemical contamination of groundwater will consider the roles, opportunities, and constraints of all types of agrichemical applicators and advisors.
- Agricultural applicators handle fertilizers, general-use pesticides, and restricted-use pesticides (RUPs). EPA's applicator certification requirements solely apply to RUP applicators, and RUPs constitute only 20 percent of total agricultural pesticide volume used. EPA does not require States to train applicators, and certification requirements vary widely. Expanded Federal directives for applicator training may be needed to improve agrichemical management nationwide.
- Two of the four approaches to reducing agrichemical contamination of groundwater, *improved point-source controls* and *improved agrichemical efficacy and application draw* from a huger information base, employ well-established information sources, and are perceived to be less risky and easier to implement than *use-reduction* and *nonchemical* approaches.
- Farmers interested in use-reduction and nonchemical practices have noted that State Cooperative Extension Services (CESs) have provided inadequate information on these approaches. Such farmers seek information from other experienced fanners; these "farmer-to-farmer networks are playing important roles in disseminating information on more complex farming system changes.
- Farmers, or private applicators, are responsible for applying at least half of all agrichemicals in agriculture. Keeping records of the types, amounts, and locations of agrichemicals used would provide the means for farmers to quantify nutrient and pest management costs and evaluate new practices. Agrichemical recordkeeping may be the most important prerequisite to optimizing agrichemical rates used.
- Farmers' decisions are based on their fundamental objectives for farming. Although other social and environmental factors influence objective-setting, economic factors define what is financially possible for farmers, often forcing them to focus on the short term Institutional factors (e.g., commodity programs) influence farmers' willingness and ability to implement resource-protecting practices.
- Since most farmers hold off-farm jobs and may not have needed time or expertise, farmers could purchase advisory services that reduce their operations' adverse environmental impacts. Increasing services and improving commercial employees' environmental expertise would result in improved nutrient and pest management decisions.
- Decisionmaking for groundwater protection represents only one aspect of societal efforts to protect natural resources in agriculture. Programs that help farmers protect groundwater could fit into a broader research and extension strategy that aids farmer decisionmaking to protect natural resources overall.
- The range of assistance available to all types of agrichemical applicators will depend *on the local "mix"* of Federal, State, and local programs. Technical assistance opportunities also will be influenced by the degree of coordination among public-sector personnel and their commitment to natural resource protection in agriculture.

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Chapter 5

Farmer Decisionmaking and Technical Assistance To Reduce Agrichemical Contamination of Groundwater

INTRODUCTION

Farmers use agrichemicals to save time and labor, increase productivity, and reduce the uncertainty and risk involved in obtaining consistent, desired yields. Groundwater contamination by agrichemicals, however, may occur when: 1) agrichemicals are mismanaged, regardless of the area's intrinsic hydrogeologic vulnerability; or 2) hydrogeologic vulnerability is so great that even proper management practices may not prevent groundwater entry by certain types of agrichemicals. Although a wide range of management practices, technologies, and cropping systems is available to reduce agrichemical contamination of groundwater, their adoption and use ultimately depend on decisions made by individual farmers. Thus, farmer decisionmaking is particularly important to consider when assessing the costs, feasibility, and effectiveness of management practices to reduce groundwater contamination.

Management changes to protect groundwater can be grouped into four approaches:

- agrichemical management to reduce point-source contamination (mixing, loading, storage and disposal practices);
- improved agrichemical application management (agrichemical selection, application rate, timing, method, and equipment);
- agrichemical use reduction; and
- use of nonchemical practices (biological and cultural).

Each of these approaches is associated with different constraints that will influence adoption by farmers. Regardless of the approach, however, farmers' selection and maintenance of groundwater-protecting practices will be a critical link in reducing agrichemical contamination of groundwater, whether this is done through voluntary, cross-compliance, or regulatory programs.

AGRICHEMICAL APPLICATORS IN THE AGRICULTURAL SECTOR

Today's agricultural production methods rely on agrichemical use, and a large but unknown number of individuals within the agricultural work force mix, apply, and dispose of agrichemical products. Farmers apply agrichemicals themselves or pay for custom application services. Thus, strategies to reduce groundwater contamination should consider the numbers, types, and roles of private and commercial agrichemica1 applicators, their relative contributions to agrichemical management overall, and their specific constraints and opportunities.

Agrichemical applicators area highly heterogeneous group and include part- and full-time farm operators, hired farmworkers, unpaid farmworkers, hired farm managers. and custom applicators (table 5-1). Agrichemical applicators differ in terms of occupational setting, business objectives, available resources, and management skills. Policies and program which address the different objectives, needs, and skills of all agrichemical applicator groups are more likely to result in improved agrichemical management and reduced groundwater contamination than policies that are generalized and uniformly applied.

General Categories

Classifying agrichemical applicators by group is useful in identifying specific constraints and opportunities to improve agrichemical management. Agricultural applicators handle three general categories of agrichemicals: 1) fertilizers; 2) general-use pesticides; and 3) restricted-use pesticides. Persons using

Table 5-1—Agrichemical Applicator Groups in the Agricultural Sector

Private agricultural sector	Commercial agricultural sector
Farm operators (full-time; part-time)	Independent custom applicators
Farmworkers (hired; unpaid)	Custom applicators employed by: Farmer cooperatives Franchised dealerships Independent dealerships Fertilizer plants with sales outlet Farm management service firms
Farm managers employed by banks, real estate firms, etc.	
Independent farm managers	
	Independent farm management consultants

SOURCE: Office of Technology Assessment, 1990.

fertilizers are typically not subject to applicator certification requirements. Persons using general-use pesticides are also not subject to certification requirements, except for commercial applicators in some States (table 5-2). All persons handling restricted-use pesticides (RUPs), however, must either be certified or under the direct supervision of a certified applicator (see box 5-A). Thus, RUP applicators are of three general types: 1) private certified; 2) commercial certified; and 3) noncertified applicators under the direct supervision of a certified applicator.

Table 5-2—Agrichemical Categories and Applicator Certification Requirements

Type of applicator	Certification needed to apply: Fertilizers	General-use Pesticides	Restricted-use Pesticides
Private	No[a]	No	Yes
Commercial	No	Yes, in some States only	Yes

[a]An exception is Nebraska, where farmers in some Natural Resources Districts with documented groundwater contamination by nitrates are required to undergo training on fertilizer application procedures.

SOURCE: Office of Technology Assessment, 1990.

Private v. Commercial Applicators

Private agricultural applicators use or supervise the use of agrichemicals on property they own or rent, and they may apply agrichemicals on another grower's property without financial compensation as a way of trading personal services. Commercial applicators use or supervise the use of agrichemicals as a business service and are licensed or registered to conduct business in their States. Depending on their business volumes, commercial applicators are often responsible for applying agrichemicals over larger land areas than private applicators and are subject to more certification and reporting requirements. However, private applicators working on large farm operations may also apply agrichemicals over thousands of acres.

Overall, private applicators are responsible for applying at least half of all agrichemicals in agriculture, with commercial firms and contractors applying the remainder. Custom-applied fertilizer accounts for about 47 percent of the tonnage sold by bulk blend and fluid fertilizer plants, and 32 percent of the tonnage sold by retail outlets (56). About 40 percent of total farm expenditures for either commercial fertilizers or pesticides in 1986 were for custom applications, which included materials and application costs (158).

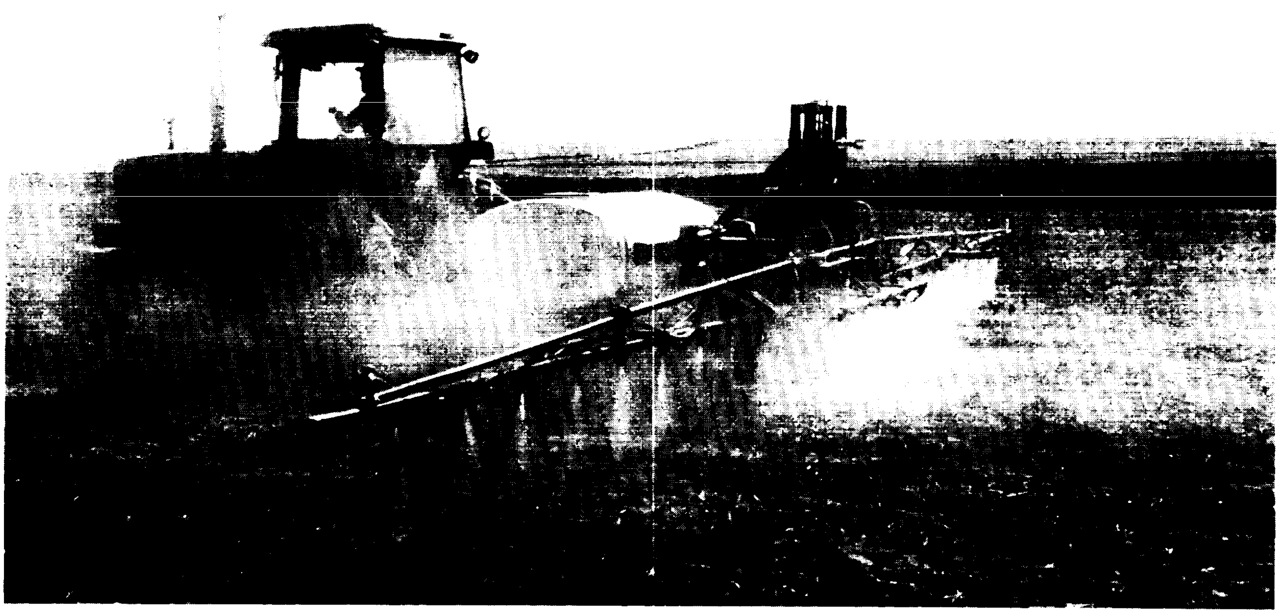


Photo credit: U.S. Department of Agriculture, Agricultural Research Service

EPA estimates that 2.3 million persons applied restricted-use pesticides in U.S. agriculture in 1988. This estimate does not include applicators of general-use pesticides or fertilizers.

Box 5-A—Pesticide Classification and Applicator Certification

The 1972 FIFRA amendments authorized EPA to set conditions for pesticide use through a two-tiered pesticide classification system. EPA classifies pesticides for general-use if it determines that the pesticide will not cause unreasonable adverse effects on human health or the environment if applied according to label directions or commonly recognized practice. EPA classifies pesticides for restricted-use if they may cause unreasonable adverse effects under such conditions.

FIFRA requires restricted-use pesticides (RUPs) to be applied only by persons who are: 1) certified as competent in handling pesticides, or 2) under direct supervision of a certified applicator (39). Persons using general-use pesticides need not be certified but they are legally required to follow pesticide label directions. For certain pesticides, some uses (but not all) may be classified as restricted, depending on the pesticide's acute toxicity and the site and purpose of use. States also have the authority to classify additional pesticides used within their borders as "restricted-use' or "limited-use."

The number of EPA-designated RUPs varies, depending on new products, new restrictions, and product cancellations. As of July 1988, EPA restricted 102 federally registered pesticides:

Type of pesticide	Number restricted as of July 1988	Percent total volume of RUPs used in 1987
Insecticide	54	10.6
Herbicide	11	7.4
Fumigant	11	[a]
Vertebrate control	11	[a]
Wood preservative	8	71.3
Fungicide	6	Use data not available
Other	1	[a]

"Collectively, 11 fumigants, 11 vertebrate controls (3 avicides and 8 rodenticides) and 1 molluscicide accounted for 10.6 percent of restricted-material volume.

SOURCE: U. S. Environmental Protection Agency, Office of Pesticide Programs, Certification and Training Branch, "Certification and Training Program, Update," 1989.

General-use pesticides constituted 80 percent of the estimated 2.5 billion pounds of active pesticide ingredients used in all sectors of the United States in 1987 (167). This total included 1.5 billion pounds of wood preservatives, sulfur, and disinfectants, and about 1 billion pounds of ''conventional" pesticides, U.S. agriculture used about 75 percent of all conventional pesticides that year, and RUPs constituted only about 19 percent of the volume of agricultural pesticides used. Because each State varies in the number of additional pesticides which are State-restricted, ' this percentage estimate may be low for some States.

Type of pesticide	Estimates of pounds used in 1987
Total "conventional" pesticides	1,085 million
Agricultural pesticides	815 million[a]
Maximum estimate for agricultural pesticides classified by EPA as RUPs	151 million[b]
Volume of agricultural pesticides not covered by EPA certification requirements	934 million

aSOURCE: U.S. Environmental Protection Agency, Office of Pesticide Programs, Economic Analysis Branch, Pesticide *Industry Sales and Usage: 1988 Market Estimates,* February 1990.

bEPA estimated that 526 million pounds of restricted-use materials were used in 1987, of which 71 percent were wood preservatives (167). Assuming that the remainder, or 29 percent, of restricted-use materials were pesticides ued in agriculture would yield 151 million pounds. Note that this is a maximum estimate, because RUPs used outside of agriculture would be included.

Thus, the major share of agricultural pesticides are not covered by Federal applicator certification requirements. Lack of coverage means that most pesticides can be applied by people who are not required to demonstrate their knowledge of pesticide hazards to a government agency. Although in practice many general-use pesticide applicators are certified, the low number of Federal restrictions requiring applicator certification reflects a low level of national commitment to supporting proper pesticide use. Although it is still possible for a certified applicator to mismanage pesticides, certified applicators are at least exposed to a State examination procedure that conveys the importance of proper management to the applicator. Stricter Federal applicator requirements applied to a greater number of pesticides would provide more incentives for proper management of pesticides in agriculture.

EPA is authorized to classify pesticides for restricted-use if they cause groundwater contamination, but some pesticides that have been found in groundwater have not been classified as restricted-use at the Federal level. In the absence of stricter Federal restrictions, States may act to protect groundwater resources by classifying for restricted use all pesticides found in groundwater. States could also require applicators to receive training on pesticide impacts and management methods to minimize groundwater contamination.

Certified v. Noncertified Applicators

The terms "certified" and "noncertified" refer only to RUP applicators. Certified applicators hold EPA-approved State certifications to apply RUPs by having demonstrated a standard level of competence in pesticide handling. Certified applicators also are allowed to supervise RUP use by noncertified applicators, who are typically employees. Private applicators fall under one certification category—agricultural pest control (12 1). Commercial applicators, on the other hand, can receive certification in at least 10 different categories:

- agricultural pest control (plant and animal);
- forest pest control;
- ornamental and turf pest control;
- seed treatment;
- aquatic pest control;
- right-of-way pest control;
- industrial, institutional, structural, and health-related pest control;
- public health pest control;
- regulatory pest control; and
- demonstration and research pest control.

Approximately 1.27 million applicators held valid certifications in 1988; 1 million of these were private certifications (all agricultural) and 254,000 were commercial, of which 72,000 were for agricultural pest control (table 5-3). The EPA estimates that each certified private applicator supervises one noncertified applicator; each certified commercial agricultural applicator supervises three to four noncertified applicators (61). Thus, an estimated 50 to 55 percent of all agricultural RUP applicators were noncertified in 1988 (121).

No estimates exist for the number of persons applying general-use pesticides. Many farmers apply both general-use and restricted-use pesticides, although some farmers avoid using RUPs, which eliminates the need to be certified. Differences among agrichemical applicator groups with respect to certification, supervision, and private v. commercial work setting imply that some applicators are more experienced or better prepared to manage agrichemicals than others. Poorly trained, inexperienced, or hurried applicators are more likely to mismanage agrichemicals. Agrichemical mismanagement is the intentional or unintentional mishandling of agrichemicals, including improper mixing, inappropriate timing of application, use of excess application rates, mixing or disposal in areas at high risk of contaminating water sources, application under inappropriate weather conditions, and improper disposal. Applicator certification and training programs can help applicators manage agrichemicals safely and properly, but current programs primarily assist RUP users rather than applicators of general-use pesticides or fertilizers.

Table 5-3-Number of Restricted-use Pesticide Applicator Certifications and Estimated Number of Potential Noncertified Applicators, 1988

Applicator category	Number of certifications
Commercial	250,268
Agricultural	72,350
Plant pest control	63,832
Animal pest control	8,968
Non-agricultural	177,918
Private (essentially all agricultural)[a]	1,019,978
Total certifications[b]	1,270,246
Potential noncertified applicators (includes commercial and private):	
Agricultural	1,300,000
Non-agricultural	1,000,000

[a]National figures compiled from reported numbers Of State certifications, personal communication with Charles Reese, Chief, Certification and Training Branch, Office of Pesticide Programs, U.S. Environmental Protection Agency, Oct. 24, 1989.
[b]EPA estimates that about one-third of all certified individuals hold both private and commercial certifications (personal communication, Yvette Hopkins, Economic Analysis Branch, Office of Pesticide Programs, U.S. Environmental Protection Agency, Nov. 29, 1989).
[c]From "Certification and Training Program," unpublished briefing outline prepared for Linda Fisher, Office of Pesticide Programs, by Certification and Training Branch, Office of Pesticide Programs, U.S. Environmental Protection Agency, June 22, 1989.

SOURCE: Office of Technology Assessment, 1990.

Private Applicator Groups

Private agricultural applicators comprise farm operators, who manage their own farm businesses, and farmworkers, who work for farm operators and may be assigned to apply fertilizers or pesticides as part of their job responsibilities. Of the 7.7 million people employed on farms either full-time, part-time, or seasonally in 1987 (table 5-4), EPA estimated that approximately one-fourth of the total used restricted-use pesticides that year (61).[1] However, the proportion of private agricultural workers using all types of agrichemicals, including fertilizers and general-use pesticides, is probably higher.

[1]In 1988, EPA began compiling national figures from State reports on the numbers of certified restricted-use pesticide applicators. Based on certifications, the number of individuals using restricted-use pesticides in agriculture that year was estimated at 2.3 million (121).

Table 5-4-Numbers of Farm Operators, Hired Farmworkers, and Unpaid Farmworkers, 1987a

Group	Number
Farm operators	2,753,000[b]
Hired farmworkers	2,463,000[c]
Unpaid farmworkers	3,559,000[d]
Total	7,687,000[e]

[a]These numbers do not include estimates of foreign nationals or illegal aliens who worked on farms in the United States in 1987. No reliable estimates of the numbers of illegal aliens exist, although one USDA estimate of Illegal aliens in the early 1980s was 10 to 15 percent of all hired farmworkers (from 'Trends in Farm Labor," *Agricultural Outlook*, U.S. Department of Agriculture, Economic Research Service, September 1984).

[b]The number of farm operators is slightly higher than the National Agricultural Statistics Service (NASS) estimate for the number of farms (2,1 73,000), because the NASS definition of a farm permits only one operator to be counted per farm, About 24 percent of farm operator households have more than one operator. The number of farm operator households (2,1 78,000) in 1987 is similar to the number of farms (from table 532, *Agricultural Statistics*, U.S. Department of Agriculture, 1988).

[c]Of all hired farmworkers, 1.6 million had 25 or more days of hired farmwork.

[d]Of all unpaid farmworkers, 1.2 million had 25 or more days of farmwork.

[e]Total number of Individuals in the agricultural work force is less than the sum of farm operators, hired farmworkers, and unpaid farmworkers, because some individuals are included in more than one group.

SOURCE: Compiled from Victor J. Oliveira and E. Jane Cox, *The Agricultural Work Force of 1987: A Statistic/ Profile,* U.S. Department of Agriculture, Economic Research Service, May 1989.

Table 5-5—Primary Employment Status of Farm Operators, 1987

Primary employment status	Farm operators: Thousands	Farm operators: Percent
In labor force	2,298	83.5%
Operating a farm	1,183	43.0
Non-farmworker	1,107	36.9
Hired farmworker	57	2.1
Unpaid farmworker	30	1.1
Unemployed	12	0.4
Not in labor force	455	16.50/0
Keeping house	208	7.6
Attending school	60	2.2
Other	187	6.8
Total farm operators	2,753	100.0

SOURCE: Victor J. Oliveira and E. Jane Cox, *The Agricultural Work Force of* 1987: *A Statistical Profile*, table 14, U.S. Department of Agriculture Economic Research Service, May 1989.

Farm Operators

Farm operators are individuals directly responsible for a farm's routine purchasing, marketing, and management decisions, and they can be owners, tenants, or corporate managers. The total number of farm operators in the United States in 1987 was estimated at 2.7 million (153). That year, only 43 percent of all farm operators reported their primary employment status as operating a farm, with 37 percent reporting primary employment in off-farm jobs (table 5-5) (105). Operators of farms in small and part-time ''sales classes' are more numerous than moderate- and large-size farm operators, although they account for only about one-fifth of all farm products sold (table 5-6), Small and part-time farm operators are more likely to hold off-farm jobs than large-farm operators, since farms in smaller sales classes often provide lower net incomes. Numbers of farm operators are decreasing due to the overall decline in farm numbers, a trend reviewed in a previous OTA report (144).

The number of farm operators who use agrichemicals can be estimated from USDAs Farm Costs and Returns Survey,[2] which gives the number of farms reporting expenditures on fertilizers and pesticides (assuming at least one farm operator per farm). An estimated 57 percent of all farms in 1986 had pesticide expenditures, and 75 percent had fertilizer expenditures (158). However, since farm operators of commercial-sized crop farms are more likely to use agrichemicals than operators of livestock operations, organic farms, and small hobby farms (all of which were included in the survey), these percentages would be higher if they were based on commercial-sized crop farms only. Percentages of commercial-sized crop farms using certain types of agrichemicals (e.g., herbicides) are likely to be higher--+. g., at least 95 percent of all corn, cotton, and soybean acres in the United States had been treated with herbicide in 1987 (107).

Regardless of the type of farm, farm operators and managers are more likely than farmworkers to select and purchase agrichemicals applied, because they make the financial decisions for their farms. In the case of larger farms owned by more than one operator, several individuals may be involved in making decisions about agrichemical use and associated changes in farm practices. Farm size and ownership arrangements thus could affect farm operators' abilities to respond to environmental concerns. A sole proprietor of a farm business, for example, would probably have more autonomy in making farm management changes to reduce groundwater contamination than individual partners in a

[2]USDA and the States' Departments of Agriculture coordinate the Farm Costs and Returns Survey, conducted in February-March of each year on a sample of 24,000 to 26,000 farmers, who respond on a voluntary basis. Responses from the sample are statistically expanded to represent national totals. The survey collects information on costs of production, earnings, debts and assets, and some production practices.

Table 5-&Distribution of Farms[a] by Sales Class[b] and Percent of Total Cash Receipts by Sales Class, 1987[c]

Sales class	Value of farm products sold	Number of farms	Percent of all farms	Percent of total cash receipts
Small, part-time	<$20,000	1,380,000	63.4%	5.2%0
Part-time	$20,000-99,999	495,000	22.8	17.3
Moderate	$100,000-249,999	201,000	9.2	22.0
Large	$250,000-499,999	71,000	3.2	17.9
Very large	2$500,000	29,000	1.3	37.5
Total	—	2,176,000	100.0	100.0

[a] A farm is defined as an establishment that sold or would normally have sold $1,000 Or more Of agricultural products during the year.
[b] Categorization of farms into sales classes is based on the gross market value of all agricultual products of farms that are sold, placed under government loan programs, or otherwise removed from the farm. It excludes the value of direct government payments, farm-related income, and nonmoney income.
[c] Sales class distributions for 1987 are based on the 1982 Census of Agriculture (U.S. Department Of commerce, Bureau of the Census, *Statistical Abstract of the United States,* December 1988).

SOURCE: Compiled from U.S. Department of Agriculture, Economic Research Service, *Economic Indicators of the Farm Sector, National Financial Summary, 1987,* tables 28 and 31, 1988.

farm partnership. Trends in the changing structure of agriculture and their farm impacts will also influence farm operators' decisions on agrichemical use and management (see box 5-B).

Farmworkers

Farmworkers may be either hired or unpaid, and as a group they vary greatly in demographic features, employment status, and earnings. Hired farmworkers are persons 14 years or older who earn money by doing farm work at any time during the year, even for one day. The number of hired farmworkers in 1987 was estimated at 2.5 million (table 5-4). Only about 18 percent of all hired farmworkers worked for 250 days or more, and about 35 percent worked fewer than 25 days during the year (105). Hired farmworkers constitute a greater percentage of total farm employment than they did 10 years ago, because unpaid family labor has declined as a proportion of the total agricultural labor force. In the last 10 years, numbers of hired farmworkers has remained steady, with an increasing proportion of hired farmworkers working more days per year.

Unpaid farmworkers do not receive cash payments for farm work but may receive a token allowance, room and board, or payment-in-kind. USDA estimated that the number of unpaid farmworkers in 1987 was 3.6 million and that 65 percent of these worked fewer than 25 days during the year, with their labor concentrated during peak harvesting or planting seasons (105).

EPA estimated that 18 percent of all hired farmworkers applied RUPs in 1987 (61), but no other estimates are available for the number of farmworkers using other categories of agrichemicals. Farmworkers are probably involved more in agrichemical mixing, application, and equipment maintenance than in selecting the agrichemicals used. Training in proper handling procedures and supervision are key issues in the use of agrichemicals by farmworkers. Short terms of employment, lack of familiarity with equipment, and inadequate communication between the farmworker and farm operator are factors that can increase the chances of agrichemical mismanagement.

Commercial Applicator Groups

Many farmers hire outside contractors or custom applicators to apply agrichemicals to their fields and orchards. Farmers purchase custom application services because they may not own needed application equipment or they want to save time or labor. Approximately 30 percent of the farms having fertilizer expenditures and 22 percent of the farms having pesticide expenditures in 1986 paid for some custom application services (153). The percentage of farms using custom agrichemical application services has remained constant since 1980.

Farmers purchase agrichemicals and custom application services from a variety of outlets: 1) agrichemical dealerships owned by large, chain-type companies; 2) agrichemical dealerships that are individual, independent firms; 3) farmer cooperatives that sell agrichemicals and other farm supplies; 4) grain and feed manufacturing elevators; and 5) other agricultural service firms (e.g., cropdusting). Employees of these commercial firms play three distinct roles in agrichemical use and management.

Box S-B—Agricultural Sector Characteristics Influencing Decisionmaking

Constraints and opportunities in the agricultural sector will affect farmers' capacity to respond to concerns about agrichemical contamination of groundwater. Following are characteristics of the agricultural sector likely to influence agrichemical use and thus the potential for agrichemical contamination of groundwater:

Bimodal Structure of Agriculture—The structure of agriculture is represented by an uneven distribution of farms among small, moderate, large, and very large sizes based on annual farm product sales. The current agricultural sector can be described as "bimodal," with many small and part-time farms, increasing numbers of large farms, and declining numbers of moderate-size farms; the result of a long-term trend toward fewer and larger farms. If present trends continue, the total number of farms will decline at a rate of about 100,000 farms per year to 1.2 million in 2000. The number of large and very large farms is expected to increase substantially, although small and part-time farms are still expected to make up about 80 percent of total farms by 2000:

Sales class	Value of farm products sold[a]	Number of farms 1969	1978	1982	2000 (Projected)	Percent of farms 1969	1978	1982	2000 (Projected)
Small and part-time	<$99,999	2,588,031	2,191,361	1,936,920	1,000,000	94.9%	89.4%	86.5%	80.O%
Moderate	$100,000-199,999	85,589	160,289	180,689	75,000	3.1	6.5	8.1	6.0
Large and very large	>$200,000	54,491	97,391	121,691	175,000	2.0	4.0	5.4	14.0
All farms		2,728,111	2,449,041	2,239,300	1,250,200	100.0%	100.0%	100.0?(0	100.0%

[a]1982 dollars, price indices in *Agricultural Statistics*, 1988.

SOURCE: Office of Technology Assessment, *Technology, Public Policy, and the Changing Structure of American Agriculture*. Compiled from data in *Economic Indicators of the Farm Sector: Income and Balance Sheet Statistics*, USDA Economic Research Service, 1988 and preceding years. Data adjustment for inflation based on redistribution of farm numbers in the *Census of* Agriculture, 1969, 1978, 1982, and 1987, Bureau of the Census, U.S. Department of Commerce,

The trend toward increasing concentration in agriculture, however, may be significantly affected by environmental programs influencing agriculture in the 1990s. The 1985 Food Security Act signaled a period in which conservation and environmental groups began to participate to a greater extent in the drafting of farm legislation than ever before, and this trend is likely to continue given the public concern over food safety and groundwater contamination. It is not clear how increased legislative attention to agriculture's environmental impacts will influence the trend toward larger and fewer farms. Environmental regulations could accelerate the trend by increasing the cost of farming and requiring more recordkeeping and monitoring. On the other hand, environmental requirements could make it more difficult for large farms to achieve economies of scale (165).

Despite the uncertainty surrounding impacts of environmental policies on the structure of agriculture, concentration in agriculture is expected to continue. Economic policies, institutions, and economies of scale that have contributed to the trend toward concentration of agricultural resources are likely to continue unless strong public support for alternative policies is generated (144). The degree of concentration, however, will vary by region and commodity, and thus no predictions can be made about its effects on agrichemical contamination of groundwater.

Farm Income Trends—The agricultural sector's capacity to respond to voluntary programs for reducing groundwater contamination will be affected by financial constraints such as low commodity prices or increasing production costs. However, income for the smallest classes declined to a greater extent between 1969 and 1982 than did that of large and very large farms. Overall, half of all farm households depended primarily on off-farm income for family living expenses (14). The need for off-farm income imposes time and labor constraints on many farm households, with concomitant implications for the types of farming practices that farmers will be willing or able to adopt.

Farmland Ownership and Tenancy-Relative proportions and locations of rented and owned farmland in the United States have implications for groundwater protection programs. Nonfarmers owned about 36 percent of all farmland and 89 percent of rented farmland in 1982 (147). Farm operators may be less motivated to invest in groundwater protection activities on rented land than on their own land, especially when land is rented for short periods. Tenants also have less autonomy than landowners when making management decisions (143). Tenants and part-owners are operating an increasing proportion of the number of farms, managing increasing numbers of

Continued *on next page*

Box 5-B—Agricultural Sector Characteristics Influencing Decisionmaking-Continued

farmland acres, and accounting for increasing values of products sold (147). Landowners in hydrogeologically vulnerable areas will need to pay increased attention to agrichemical use decisions by their tenants. Tenants typically rent farmland under one of two main types of rental agreements-share leases and cash leases-which may impart different abilities or tendencies to adopt groundwater protection farming practices.

Contract Farming-Contract farming, including a range of contracting agreements through which farmers agree to produce and deliver farm commodities under conditions specified by a contractor, also is becoming more common (147). Types of production becoming increasingly associated with contract farming are poultry products, and fruits and vegetables Cattle feeding, hog production, and feed and forage production also have seen recent increases in contract farming. For example, commercial feedlots frequently contract with neighboring farmers to raise feed grains or forage. Contract farming has advantages for the contractor, who is able to secure a certain quantity of product of specified quality at an agreed-upon time. Producer advantages include financing, technical advice, and assurance of a market.

Contract farming has implications for agrichemical use, because contractors may require producers to use only specified types and amounts of inputs. Contract farming could result in greater agrichemical use, especially when producers are required to apply prophylactic pesticide treatments to meet contractor standards or to ensure a given yield at a certain time (10). On the other hand, contracting firms responding to public concern about agrichemical residues in foods may encourage producers to reduce agrichemical use when growing their products (e.g., Ocean Spray, Gerber Foods),

Vertical Integration-Vertical integration—securing two or more sequential production stages under the ownership of one corporate entity—increased in agriculture and food processing from about 5 to 7 percent between 1970 and 1980 (147). Vertical integration provides food processors a more stable and uniform supply of commodities, making it easier to meet consumer demand for high-quality and attractive produce. Some vegetable and fruit processing companies, for example, own land to produce some of their own crops. Little evidence is available on how increased vertical integration affects agrichemical use overall. Vertical integration in fruit and vegetable processing, for example, could intensify agrichemical use if prophylactic treatments were employed to protect capital investments and minimize production risks. Corporate responsibilities to stockholders can create cost-cutting pressures that would hamper adoption of practices requiring more time, management, or labor, thus requiring farm managers to seek support from stockholders to justify costs of changing farming practices to protect vulnerable groundwater resources. On the other hand, vertically integrated corporations tend to employ professionally trained managers who may be sensitive to public concerns about adverse environmental impacts from farming practices as well as food safety.

First, commercial firm employees advise farmers on the types and amounts of agrichemicals to be applied on farmers' fields. Employees who are: aware of potential environmental impacts and motivated to communicate environmental information are more likely to help farmers make better decisions, on which agrichemicals to use, when, where, and. how.

Second, commercial firm employees apply agrichemicals as custom services. Since roughly one-third to one-half of all agrichemicals in the agricultural sector are applied commercially (158,56), training and supervision of all commercial applicators are important considerations in strategies to reduce nonpoint agrichemical contamination of groundwater. Also, since EPA estimates that the average commercial certified RUP applicator supervises three to four noncertified applicators, as many as 80 percent of all commercial RUP applicators are potentially noncertified (121). Noncertified applicators have less forma! exposure to information on RUP application procedures, and some may not be well-trained on agrichemical application equipment. Training and supervision of part-time or seasonal applicators, particularly during peak planting periods, may pose special problems for permanent employees who are also pressed for time.

Third, commercial firm employees operate and maintain agrichemical storage, handling, and disposal sites, which represent significant potential sources of groundwater contamination, Adequate training and supervision of employees and their preparedness in handling accidental spills are critical factors in reducing point-source contamination of groundwater from agrichemical sales outlets.

The importance of commercial applicators in agrichemical application and management warrants attention to commercial firm numbers, locations, and methods of operation. Since certification requirements and work situations differ for commercial and individual agrichemical applicators, policy approaches to improve agrichemical management by these two groups are also likely to differ.

Agrichemical Dealerships

An agrichemical dealership is a retail outlet that purchases agrichemicals from a distributor and sells them to farmers. Dealerships may be independent firms with single outlets, franchises of large, chain-type companies (e.g., Terra, Inc.), or farm cooperative sales outlets. Roughly 80 percent of all dealerships sell both fertilizers and pesticides (129,27).

Distribution and size of dealerships reflect regional variation in the structure of agriculture: dealerships, like farms, are smaller and more numerous in the Midwestern and southern regions. Average annual pesticide sales per dealership, for example, are $300,000 to $400,000 in the Midwest and South, $500,000 to $600,000 in the Northwest, and almost $2 million in California (170). The Midwest and South have eight and five dealerships per thousand square miles, respectively, while one or two dealerships per thousand square miles are found in California and the Northwest region. The total number of dealerships is expected to decline by 20 to 25 percent by the year 2000, due to concentration in the industry from mergers and loss of small dealerships (170).

Fertilizer Dealerships—The National Fertilizer and Environmental Research Center of the Tennessee Valley Authority tracks the total number of registered or licensed fertilizer dealers for all States. Fertilizer dealerships in 1987-88 totaled 13,044, including fertilizer manufacturers and bulk blending and fluid fertilizer plants having fertilizer sales outlets (56). Fertilizer manufacturers and blenders generally sell directly to dealers, rather than through distributors, because fertilizers are high-bulk commodities. Fertilizer is typically shipped by rail or barge to a central point (often owned by the manufacturer), where dealers come to pick up the product.

Pesticide Dealerships—Neither EPA, USDA, nor the Department of Commerce collects data on the number of pesticide dealerships nationwide. Some States require licensing of pesticide dealers, but these States do not report numbers of licensed pesticide dealers to any Federal office. National estimates for pesticide dealers vary widely, from an industry estimate of 5,600 (129) to an EPA estimate of 32,400 (61). Other estimates typically used in the pesticide industry range between 12,000 and 16,000 (27).

Thus, no national data exist on the numbers, locations, and facilities of pesticide dealerships, making it difficult to monitor industry trends or to estimate aggregate costs of proposed regulations or facility improvements. State and Federal records on dealerships would make it possible to evaluate the progress of industry and government initiatives to improve handling, storage, and disposal at these sites. Also, if large numbers of small dealerships go out of business in the next decade as predicted, records on their numbers and locations would make it possible to monitor abandonment of facilities to ensure environmental compliance.

Farmer *Cooperatives-A* farmer cooperative is a membership organization in which farmers have controlling interest. Farmer cooperatives are incorporated under State laws and classified as marketing, farm supply, or service cooperatives, depending on their primary business. The USDA's Agricultural Cooperative Service (ACS) provides annual statistics on farmer cooperatives. In 1987 an estimated 3,000 of the 5,100 farmer cooperatives in the United States sold agrichemicals (150). Many farmer cooperatives are members of regional or interregional cooperative organizations, with the 16 largest regional cooperatives handling about 40 percent of all fertilizer products sold in the United States. CF Industries, for example, is an interregional fertilizer manufacturer owned by 13 regional cooperatives supplying fertilizers to 1.2 million farmer-members in 46 States (171).

Farmer cooperatives that supply agrichemicals help their members obtain secure, competitively priced supplies of fertilizers and pesticides. Employees of farm-supply cooperatives perform agrichemical management roles similar to those of employees of agrichemical dealerships. In theory, a farm-supply cooperative differs from other types of agrichemical dealerships in that it is owned by members who join the cooperative to enhance their own farming operations rather than to earn income from the cooperative business. Thus, farmer cooperatives would appear to have stronger incentives to employ well-trained custom applicators and to help their members reduce excess agrichemical inputs. However, cooperatives are run by hired managers, whose salaries and job stability depend on demonstrating good business performance through strong product sales. As a result, cooperative managers, like dealership employees, face the possible disincentive of reduced sales if they advise farmers to reduce agrichemical use.

Some farmer cooperatives, on the other hand, exist solely to provide advisory and field scouting services to their members and do not sell agrichemical products. One example is Centrol, Inc., a subsidiary of Cenex-Land O'Lakes headquartered in Minnesota. Such cooperatives presumably would not have an interest in providing recommendations that increase volumes of products sold.

Agricultural Service Firms

Commercial applicators may be employed by agricultural service firms other than agrichemical dealerships and farmer cooperatives. These include agricultural contractors, crop protection firms, agricultural aviation or cropdusting firms, and agricultural management companies. Information on trends, numbers, and types of services available from agricultural service firms is helpful in assessing these fins' roles and significance in agrichemical management.

Many agricultural service firms are classified under the Standard Industrial Classification (SIC) code ''07' as establishments that obtain at least half of their sales income by providing the following agricultural services:[3] soil preparation, crop, veterinary and animal, farm labor and management, and landscape and horticultural services. Employees of many such service firms are likely to handle agrichemicals. The most current estimates of these fins' numbers are available in County Business Patterns (CBP) data from the U.S. Department of Commerce. CBP estimates, however, are probably low, because they represent counts only of larger firms with payrolls reportable to the Internal Revenue Service (163). CBP estimates do not include many self-employed agricultural contractors or small service firms having mostly part-time workers.

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

Wire-mesh cones baited with pheromones contain sensors that count insects flying into the trap. Field scouts may routinely use similar technologies in the future to advise farmers on the need for agrichemical applications.

More accurate estimates of the numbers of these firms had been obtained every 5 yearn through the Agricultural Services Survey of the Census of Agriculture, but this survey was discontinued for lack of funding in 1979. The Agricultural Services survey attempted to reach as many small firms as possible and required a mandatory survey response (178). As a result, its national estimates of the numbers of firms classified under ''07' SIC codes were roughly twice as high as CBP estimates (e.g., 93,100 compared to CBP's 40,900 in 1978) (163).

CBP data can be used to assess trends among larger agricultural service fins, recognizing that these data tend to underestimate total numbers of

[3] This definition does not include wholesale farm supply firms or farmer cooperatives.

Figure 5-1 —Increase in U.S. Establishments Primarily Engaged in Selling Landscape and Horticultural Services,[a] Estimated Numbers of Establishments and Employment, 1974-86

[a]Estimates for establishments classified under SIC Code 078, which includes lawn and garden services, ornamental shrub and tree services, and tree services, and landscape counseling and planning.

SOURCE: U.S. Department of Commerce, Bureau of the Census, County Business Patterns, table 1 b. Washington, DC, 1986 and previous years.

fins. During the 1970s, all types of agricultural service firms increased in number. From 1974 to 1984, for example, the number of landscape (including lawn care) and horticulture service firms doubled (figure 5-l), which implies that concomitant increases in agrichemical applications occurred during this time in residential and commercial areas. The rapid growth of landscape and horticulture service firms thus has implications for urban contributions to groundwater contamination by agrichemicals and for the need to adequately train and supervise service firm employees to reduce contamination.

An increase in service firms was also seen in the agricultural industry during the 1970s, due to record growth in both domestic and export agricultural markets. The number of farm management fins, which operate farms for absentee owners or investors, more than doubled during this decade (figure 5-2). Expansion of agricultural services paralleled increases in planted acreage, crop production, land values, price supports, available cash to producers, and input prices in the 1970s (31). In the 1980s, however, reductions in planted acreage and farm financial stress led to loss or merging of some agricultural service firms, indicated by lower CBP estimates (figure 5-3). Despite lower input prices, farmers were using fewer inputs and demanding fewer services in the 1980s. The fertilizer industry also reported a decline in the sale of in-house advisory services by dealers and blending plants during this period (174). Agricultural service firms

Figure 5-2-increase in U.S. Establishments Primarily Engaged in Selling Farm Management Services,[a] Estimated Numbers of Establishments and Employment, 1974-86

[a]Estimates for establishments classified under SIC Code 0762, primarily engaged in providing farm management services, including management or complete maintenance of citrus groves, orchards, and vineyards. Such activities may include cultivating, harvesting, *or* other specialized activities.

SOURCE: U.S. Department of Commerce, Bureau of the Census. *County Business Patterns*, table 1 b. Washington, DC, 1986 and previous years.

Figure 5-3-Changes in U.S. Establishments Primarily Engaged in Wholesale Distribution of Farm Supplies,[a] Estimated Numbers of Establishments and Employment, 1974-86

[a]Estimates for establishment classified under SIC Code 5191, which includes those primarily engaged in the wholesale distribution of farm supplies includes selling of merchandise to farm users.

SOURCE: U.S. Department of Commerce, Bureau of the Census. *County Business Patterns,* table lb. Washington, DC, 1986 and previous years.

thus were affected by the economic contraction in agriculture in the 1980s, although agriculture is likely to recover some financial strength in the 1990s.

Agricultural service industry trends will influence the responsiveness of these firms to environmental concerns by affecting their ability to invest in new company start-ups, additional employee training, and service innovations. Better Federal data on the numbers and types of agricultural service firms would facilitate tracking and assessment of the roles of service firms in improving agrichemical management and providing agrichemical alternatives. Environmental services development and employee training programs for agricultural service firms would enhance the technical support farmers receive from the private sector. Lack of comprehensive data. however, makes it difficult to assess the progress. needs, and opportunities of service firms[4] (165).

Applicator Certification and Training: Needs and Opportunities

Applicator certification requirements, as noted earlier, pertain to restricted-use pesticides (RUPs) in all cases, general-use pesticides in some cases, and fertilizers in no cases. Thus, mandatory programs for applicator certification and training primarily address regulatory needs of RUP applicators, but RUPs constitute only a small proportion of the total volume of agricultural pesticides used (less than 20 percent in 1987, box 5-A). Even though pesticide applicator training and educational materials are available, persons who are not required to be certified or trained (e.g., private agrichemical users in urban areas and farmers who use only fertilizers and general-use pesticides) may never take advantage of these opportunities. Thus, the main means of encouraging proper use of most agrichemicals is through provision of product labeling information and applicators' voluntary compliance with label directions.

States have primary responsibility for pesticide applicator programs but they must follow EPA competency standards (see box 5-C) and planning guidelines in implementing applicator certification programs (38). Each State has a designated pesticide "lead agency" responsible for certifying RUP applicators as competent to handle pesticides in several technical categories, including agricultural use (154). EPA requires States to give commercial applicators a written test for initial certification, but States are not required to test private applicators or to train commercial or private applicators. Although States are required to recertify applicators, the recertification interval is not specified.[5] Some States have implemented certification and training procedures that are more stringent than EPA requirements, and as a result, applicator certification and training procedures and opportunities vary from State to State.

Box 5-C-Competency Standards for Pesticide Applicator Certification

Standards for certification of commercial applicators require that competence be determined by written examinations and, where appropriate, by performance testing (38). Commercial applicators must meet general standards as well as standards specific for each category. General standards for commercial applicators are: 1) comprehension of labeling information, 2) knowledge of safety factors, 3) environmental consequences, 4) pests, 5) pesticides, 6) equipment, 7) application techniques, and 8) relevant laws and regulations.

Category-specific standards for agricultural plant pest control applicators include practical knowledge of: 1) crops, 2) pest targets, 3) soil and water problems, 4) time intervals needed between pesticide application and crop harvest, 5) time intervals needed between pesticide application and worker entry into treated fields, 6) plant toxicity problems, and 7) potential for environmental contamination, nontarget injury, and community problems resulting from pesticide use (169). Category-specific standards for ornamental and turf pest control applicators include knowledge of: 1) pesticide problems in production and maintenance of trees, shrubs, plantings, and turf; 2) potential plant toxicity; 3) problems of drift and persistence; and 4) application methods which minimize or prevent hazards to humans and domestic animals.

EPA has no other requirements for written examinations for commercial applicators. Thus, the examinations may be either open-or closed-book or take-home. Neither does EPA specify a passing grade for the examination. In practice, however, most States require a passing grade of 70 percent correct answers and require commercial applicators to go through performance tests with application equipment. EPA requires States to renew all applicator certifications, but the time internal for recertification is not specified.

[4] Lack of Federal data has also been noted for environmental service firms (165).

[5] EPA is proposing a revision to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) regulations that would require States to establish a minimum recertification interval of 5 years.

Although it is not known whether groundwater contamination has resulted more from agrichemical mismanagement than from ''proper' application of leachable chemicals, it is clear that programs to reduce potential contamination must include training and education to improve agrichemical management. The Federal Government provides only a minor share (20 percent) of funding spent on RUP applicator training and States provide the remainder (156). In the absence of additional funding from State sources, the Federal Government will likely need to increase financial support so that applicator education programs can: 1) implement new regulatory requirements for current applicators, expand topics covered in current programs, and extend the length and frequency of training; and 2) train audiences not currently covered by Federal or State regulations. Federal leadership and support for training and education in agrichemical management would expedite programs that reduce mismanagement overall, as well as address the needs of people currently using agrichemicals in hydrogeologically sensitive areas.

Applicator Testing for Certification

States must administer an EPA-approved written test to commercial agricultural applicators prior to certification, but States can employ a variety of methods in certifying private applicators as ' 'competent, ' as long as the method is approved by EPA. At a minimum, private applicators must demonstrate practical knowledge of pest problems; pest control practices; proper pesticide storage, handling, application, and disposal procedures; and related legal responsibilities. Private applicators must show that they are able to apply pesticides in accordance with label instructions and warnings and recognize local environmental situations that should be considered during application. Private applicator certifications may be granted through examinations (e.g., oral, written, closed-book, open-book, take-home, graded, pass/fail, or ungraded) or other "equivalent" systems, such as training, self-study, and self-evaluation. Private applicator testing procedures thus vary widely and may be less rigorous than those for commercial applicators (166).

Since both private and commercial applicators are responsible for controlling point-source and nonpoint-source contamination of groundwater by pesticides, ideally all applicators should be able to demonstrate equivalent levels of knowledge about contamination risks and proper control methods, particularly if they are certified to apply pesticides in hydrogeologically vulnerable areas. However, EPA's most recent national survey of State applicator certification and training programs, conducted in 1986, indicated that commercial applicators' exams have been more extensive than private applicator exams (166). For example, fewer private applicator exams contained questions on groundwater vulnerability and pesticide leaching, and only one commercial applicator exam (and no private applicator exams) covered local groundwater conditions (table 5-7). Since the year in which EPA conducted the survey, however, some progress has been made in updating certification and training programs to address groundwater quality concerns. In 1988, for example, USDA disseminated to all State Cooperative Extension Services (CESs) a slide-tape program on groundwater protection for pesticide users (117). Closer coordination between State CESs and pesticide lead agencies in developing applicator examinations and training would improve applicators' ability to address emerging environmental concerns.

Table 5-7—Number of States in 1986 Specifically Addressing Groundwater Concerns in Pesticide Applicator Certification Training and Testing Programs

	Initial certification		Recertification	
Applicator program for certification	Private	Commercial	Private	Commercial
Training:				
General groundwater vulnerability	29	28	24	29
Pesticide movement through soils	32	36	28	34
Local groundwater conditions	7	8	13	14
Testing:				
General groundwater vulnerability	10	15	7	6
Pesticide movement through soils	18	26	12	19
Local groundwater conditions	0	0	0	1

SOURCE: U.S. Environmental Protection Agency, Office of Pesticide Programs, Certification and Training Branch, draft report, "Review of State Plan Questionnaires on Certification and Training, Preliminary Summary of Results," Apr. 8, 1987, pp. 38-43.

Applicator Training and Education

EPA does not require States to train private or commercial applicators, but it does fired development of pesticide education and applicator training materials (see box 5-D). Each State develops its own pesticide applicator training (PAT) materials, typically through the CES PAT coordinators in conjunction with the State's pesticide lead agency (155). The CES is responsible in most States for applicator training, but the State's pesticide lead agency can also approve other applicator training programs (e.g., by private industry). In 1989, State CESs trained about 500,000 people nationwide, although the number of people trained each year varies, due to changes in State laws and fluctuations in applicator recertification cycles. State CESs have given applicator training to as many as 1 million people in 1 year (1 16).

At the Federal level, EPA's Certification and Training Branch in the Office of Pesticide Programs and the USDA Extension Service (ES) share responsibilities for pesticide applicator training. USDA provides the salary for a National Program Leader for Pesticide Education to help guide and coordinate State CES activities, while EPA provides pesticide training funds that are allocated by formula to State CESs through USDA. From 1982 to 1990, EPA gave USDA about $1.6 million annually for pesticide training. Thus, the Federal Government spends less than $1 for pesticide training per agricultural applicator per year.[6]

Each State CES annually receives at least $15,000 in Federal base funding for pesticide certification training. Some of the larger agricultural States receive the highest amounts of EPA funding at about $60,000 per year (116). Applicator certification training funds are in addition to other EPA funds given to State pesticide lead agencies for pesticide regulation and enforcement. EPA has also provided some discretionary funding for special projects to support development of pesticide education bibliographies and computer software (44) by USDA's National Agricultural Library (157).

The amount of State funding for pesticide training varies from State to State, which results in varied staffing levels for PAT programs. In many States, one PAT coordinator is responsible for all pesticide training and education programs. Many PAT coordinators have additional job responsibilities and may only be appointed to work one-quarter or one-half time on pesticide training. States also vary in the lengths of their applicator training programs, which range from 2 to 6 hours (166), and in the methods used to verify that trainees understand the information presented during training. In some States, for example, applicators must fill out a worksheet when training has been completed, while in other States mere attendance at a training session is sufficient to receive a training certificate. Thus, applicator training methods and requirements, like testing procedures, vary widely from State to State.

Currently, CES pesticide education programs are facing extensive additional program demands as a result of new or proposed EPA regulatory provisions on farmworker safety, endangered species protection, groundwater protection, and applicator supervision requirements (156). Furthermore, inadequate resources for PAT programs has made it difficult for States to hire staff, regularly update PAT materials, and incorporate new information in training programs. Many PAT programs are using outdated educational materials that may not reflect the most recent techniques for controlling pests, or address environmental concerns that have recently emerged. Inadequate staffing and outdated educational materials in pesticide training programs will hamper State responsiveness to public concerns about agrichemical contamination of groundwater.

Supervision of Noncertified Applicators

All noncertified RUP applicators must be under the direct supervision of a certified applicator. ''Direct' supervision is defined as "the act or process whereby application of a pesticide is made by a competent person acting under the instructions and control of a certified applicator who is responsible for the actions of that person and who is available if and when needed, even though such certified applicator is not physically present at the time and place the pesticide is applied" (38,169). This definition is open to interpretation. FIFRA regulations specify only that the certified applicators' availability to the noncertified person be directly related to the hazard of the situation, but ''hazard' is not clearly defined. Thus, it is difficult to monitor and enforce application procedures by noncertified applicators.

[6] In 1989, EPA estimated there were 2.3 million agricultural RUP applicators, including certified and noncertified applicators (refer to table 5-4).

Box 5-D—EPA's Pesticide Applicator Certification and Training Program

The goal of the EPA Office of Pesticide Program's Certification and Training (C&T) program is to prevent potential pesticide problems by providing funding, guidance, and coordination for pesticide applicator certification and training. The C&T program is located in OPP's Field Operations Division to create and maintain cooperative relationships and communications among EPA regional offices, other Federal agencies, and the States (167). The C&T program performs the following roles:

- **Provides funds to** USDA to support materials **development and CES training of pesticide applicators:**
  - **-Gives training** funds to USDA through a USDA/EPA interagency agreement, authorized by Section 23(c) of FIFRA. USDA then allocates funds to State CES pesticide applicator training programs.
  - --Gives discretionary funds to USDA for special initiatives, such as the National Agricultural Library clearinghouse for applicator training materials.
- Guides and funds State certification programs:
  - —Reviews State certification program plans, mainly to ensure that Part 17140 CFR requirements are met. Once a State program is approved, EPA has little influence on State programs, outside of informal discussions.
  - -Oversees cooperative agreements on certification programs, which are negotiated between EPA regional offices and State lead agencies.
  - —Provides formula funding to States for their certification programs through EPA regional offices. EPA funds are matched by the States and are based on numbers of applicators certified, numbers of farms, and whether or not the States have recertification provisions.
- **Develops, funds, and evaluates pesticide training materials:**
  - —Identifies areas in need of training materials (e.g., farmworker safety, chronic health effects, endangered species).
  - —Solicits proposals for developing training materials from USDA, the States, private-sector contractors, universities, and the private sector.
  - -Grants discretionary funds for development of training modules and training initiatives, such as State special projects.
  - —Funds the Public/Private Pesticide Initiative for Pesticide Training and Education (P/PSI), a cooperative effort between EPA, the National Association of State Universities and Land Grant Colleges, and industry to support development and dissemination of training materials by the private sector,
  - —Helps coordinate private organizations' efforts in applicator training through the P/PSI Commission, which consists of industry, environmental, user, and farmworker group representatives.
  - —Supports seminars and workshops (e.g., to train Native American tribal officials on certification program administration).
  - —Reports periodically on certification and training materials in "The Certification and Training Update. "
  - —Conducts joint reviews with USDA of the State's private applicator training programs. Data from these reviews are used to identify weaknesses and strengths and to improve training programs. Half of the 27 State programs reviewed in FY 1988 had not yet included groundwater quality concerns in their programs.
- Develops State grant guidance to coordinate pesticide-related activities:
  - —Works with other EPA offices to establish guidelines for States to develop consolidated cooperative agreements with EPA. Such an agreement allows a State to obtain funding from EPA on all pesticide activities for which financial aid is available.
- Develops regulations for pesticide applicator training:
  - —Proposes revisions to Part 171 CFR 40 regulations pertaining to pesticide applicator training.

EPA is proposing regulations and labeling changes that classify RUPs into three hazard categories with different supervisory requirements: 1) "Hazard Level One" pesticides may be applied only by certified applicators; 2) ''Hazard Level Two' pesticides may be applied by a noncertified applicator if a certified applicator is on-site and available within 5 minutes; and 3) ''Hazard Level Three" pesticides may be applied by a noncertified applicator when a certified applicator is not on-site but is available within a''reasonable' amount of time (167). If these proposed changes are implemented, supervisory requirements will be defined more narrowly, although the word "reasonable" for Hazard Level Three pesticides is still ambiguous. Unclear supervisory requirements may cause more people to become certified for fear that they might misinterpret or fail to comply with new regulations. Increased demand for applicator certifications would increase PAT program participation and CES training workloads.

States are not required to report names or numbers of noncertified RUP applicators to EPA. Since EPA can only estimate the numbers of noncertified RUP applicators in the field, it is difficult to assess costs of regulatory changes affecting noncertified applicators. Furthermore, information is unavailable on how States verify and monitor supervisory competence of certified applicators, even though FIFRA regulations state that certified applicators ''whose activities indicate a supervisory role' must demonstrate their knowledge of any supervisory requirements for RUP use (38). Thus, the quality of training and supervision received by noncertified applicators may also be highly variable from State to State.

Obtaining an Overview

EPA does not maintain an annually updated national overview of State pesticide applicator certification and training programs (12 1). Each State lead agency for pesticide programs must be contacted for current information in order to track applicator certification and training activities within the State (123). The lack of comprehensive national information makes it difficult to obtain an overall picture of applicator certification and training programs. EPA apparently does not maintain a high level of activity in monitoring applicator programs because States have primacy in this area, and because EPA's mandate is primarily regulatory rather than educational. However, the lack of regular Federal oversight on State applicator programs nationwide could hamper national responsiveness to environmental concerns related to pesticide use.

The 1986 EPA survey of State pesticide applicator certification and training programs indicated which States exceeded FIFRA requirements for applicator certification (e.g., written exams required for private applicators; training required for private and commercial RUP applicators) (166). Of the 53 States and Territories surveyed, only 16 required training for initial private applicator certification and only 9 required training for commercial applicators (table 5-8). Survey data for 10 States ranked as the highest-volume users of agricultural pesticides are given in table 5-9 (45). Of these States, only seven required either testing (Illinois, Minnesota, Indiana, and Ohio) or training (Nebraska, Texas, and Arkansas) for private applicators. Only Texas required training for commercial applicators. It should be emphasized that some of these States (e.g., Iowa)

Table 5-8—Number of States and Territories[a] That Required Training for Restricted-use Pesticide Applicators in 1986b

Requirement	Number of States	States or Territories
Private applicators-initial certification:		
Training required	16	AL. AR, HI, KY, LA, MO, ND, NE, OK, PR, SC, SD, TN, TX, VI, WI
Training not required	36	AR, AZ, CA, CO, CT DC, DE, FL, GA, 1A, ID, IL, IN, KS, MA, MD, ME, MI, MN, MS, MT NC, NM, NH, NJ, NV, NY OH, OR, PA, RI, UT, VA, VT, WA, WY
No response	1	WV
Private applicators-certification renewal:		
Training required	13	AL, ID, KY MD, ND, OK, PA, PR, RI, SD, TN, Vi, WI
Training not required	38	AK, CA, CO, CT, DC, DE, FL, GA, HI, 1A, IL, IN, KS, IA, MA, ME, MI, MN, MO, MS, MT, NC, NE, NH, NJ, NM, NV, NY, OH, OR, SC, TX, UT, VA, VT, WA, WV, WY
No response	2	AR, AZ
Commercial applicators-initial certification:[c]		
Training required	9	MD, ND, NJ, NM, NY, PR, TX, WA, WI
Training not required	44	AK, AL, AR, AZ, CA, CO, CT DC, DE, FL, GA, Hi, 1A, ID, IL, IN, KS, KY, LA, MA, ME, MI, MN, MO, MT, MS, NE, NC, NH, NV, OH, OR, OK, PA, RI, SC, SD, TN, UT, VA, VI, VT WV, WY
Commercial applicators-certification renewal		State information not available.

[a]Territories included Puerto Rico and the Virgin Islands.
[b]This table presents States' certification and training status in 1988 and does not indicate changes which may have occurred since that year.
[c]All commercial applicators are required to take a Written exam to be certified.

SOURCE: U.S. Environmental Protection Agency, Office of Pesticide Programs, Certification and Training Branch, draft report, "Review of State Plan Questionnaires on Certification and Training, Preliminary Summary of Results," Apr. 8, 1987.

Table 5-9-Applicator Certification and Training Provisions in Ten States[a] With Highest-Volume Agrichemical Use, 1986 Status[b]

Provision	States in descending order of pesticide volume used									
	1A	IL	MN	IN	OH	CA	NE	TX	AR	MS
Private applicators:										
Initial certification:										
Mandatory testing	-	+	+	+	+	+	-	-	-	-
Voluntary testing	+	-	-	-	-		+	-		+
Mandatory training	-	-	-	-			+	+	+	-
Voluntary training	+	+	+	+	+	-	+	-	-	+
Certification renewal:										
Mandatory testing	-	+	+	+						
Voluntary testing	+				+		+	-		+
Mandatory training	-	-	-	-	-	-	-	-	-	-
Voluntary training	+	+	+	+	+	-	+	-	-	+
Commercial applicators:										
Initial certification:[c]										
Mandatory training	-	-	-	-	-	-	-	+	-	-
Voluntary training[d]	-	-	-	+	+	+	-	-	-	+
All applicators:										
1PM materials available	+			+	-	+	+	+	+	+
Training offered for noncertified applicators	-	+	-	+	-	-	-	-[e]	-	-

[a]Ten States ranked as highest volume users of agricultural pesticides in Resources for the Future national pesticide usage database (45).
[b]Blank spaces indicate "no response reported."
[c]Written examinations for certification of commercial applicators is required by law.
[d]Voluntary training provided through State cooperation with industry.
[e]Training materials available to noncertified applicators on request.

SOURCE: U.S. Environmental Protection Agency, Office of Pesticide Programs, Certification and Training Branch, draft report, "'Review of State Plan Questionnaires on Certification and Training, Preliminary Summary of Results," Apr. 8, 1987.

have implemented new pesticide laws or regulations that are not reflected in the 1986 survey data.[7]

Opportunities for Applicator Certification and Training

Applicator certification and training programs are important intervention points in State pesticide programs, because they can help Federal and State governments ensure a certain level of competence among pesticide applicators. One way for States to respond to groundwater contamination problems would be to evaluate how applicator certification and training programs could be expanded or enhanced to improve agrichemical selection based on soil and hydrogeologic conditions, reduce mismanagement, or incorporate information on alternatives to pesticide use.

States can evaluate possible program changes by assessing information shared among pesticide lead agencies (e.g., through the American Association of Pest Control Officials) and CES pesticide education coordinators (e.g., through regional and national PAT workshops). Another vehicle for program assessment is the State-Federal Issues Research and Evaluation Group (SFIREG), composed of representatives from State agencies responsible for pesticide enforcement, certification, and training. SFIREG Working Committees (e.g., Enforcement and Certification, Groundwater Protection, and Pesticide Waste Disposal) review, evaluate, and make recommendations on regulatory changes proposed by EPA. Recommendations for certification and training activities that go beyond EPA requirements have been presented by EPA/SFIREG Certification and Training Task Force (167).

Although some States have responded to groundwater contamination concerns by requiring training for all RUP applicators or by incorporating groundwater information in training programs, States' use of certification and training programs as a strategy to reduce agrichemical contamination of groundwater has three serious limitations. First, certification programs are limited to RUP applicators unless States enact legislation authorizing broader coverage. The lack of applicator certification requirements for fertilizers and general-use pesticides has

[7]In Iowa, applicator training remains optional for initial certification of private and commercial applicators, but continuing education is required for recertification. Also, Iowa now requires certification for 'pesticide handlers, ' who do not apply pesticides but who mix, handle, and dispose of pesticides at commercial sites. FIFRA only requires certification for RUP applicators.

groundwater quality implications, because the two most prevalent groundwater contaminants are nitrate and atrazine, an herbicide which had been registered as a general-use pesticide until February 1990 (29,51). The high frequency of groundwater contamination by these two categories of agrichemicals reflects their greater capacity to leach through soils but may also reflect overuse or mismanagement that could be addressed through expanded certification and training requirements. Thus, one way for States to help reduce nitrate and herbicide contamination of groundwater would be to require certification and training for applicators of fertilizers and general-use pesticides.[8] Increased certification and training requirements could be implemented either statewide or only in hydrogeologically vulnerable areas with documented groundwater contamination.

A second drawback to using applicator certification and training programs as a way of addressing groundwater concerns is these programs' history of being inadequately funded. Although FIFRA authorizes EPA to provide up to 50 percent of the funding for States to implement pesticide programs, EPA's share of total pesticide program funding is currently much lower. A funding survey of the 50 State pesticide lead agencies, State CESs, and four Territories in 1989 indicated that States provide about 70 percent of all pesticide program funding while EPA provides only 30 percent (2). The Federal share is even lower for applicator certification and training programs (156). Furthermore, States are being required by EPA to implement new pesticide initiatives starting in 1990 without receiving concomitant increases in EPA funding for these efforts. Lack of funding will hinder efforts to enhance or expand applicator education programs.

The third drawback is that applicator certification and training programs have been established to support agrichemical use, but not reduced-input or nonchemical farming practices. The latter may be the only techniques that will significantly reduce groundwater contamination in some hydrogeologically vulnerable areas. Expansion of training programs to include greater emphasis on integrated pest management or alternative farming practices, however, would require significant funding and involve a risk of spreading training resources too thinly. One alternative would be to create additional basic training or continuing education programs with earmarked funding, although such programs are unlikely to have strong impacts on target audiences unless all applicators are given incentives or required to undergo additional training.

As currently implemented, FIFRA requirements for RUP applicators are weak. Moreover, strengthening RUP applicator requirements could improve pesticide management by certified applicators, but these changes would not affect most users of general-use pesticides or fertilizers under current statutes. Agrichemical applicators thus have inconsistent and unequal access to preparatory and in-service training, certification and recertification procedures, supervision, and performance evaluation. This inconsistency is at least partly due to the Federal policy of granting States primacy and flexibility in their pesticide programs, but it also stems from a lack of clear congressional directives on applicator requirements and low levels of Federal funding for applicator training.

Inconsistency and lack of training in applicator programs thus leads to highly variable levels of management skills among agrichemical applicators and appears to represent a high potential for agrichemical mismanagement. Clearly defined and expanded Federal directives for applicator preparation and training may be needed to improve agrichemical management, because large numbers of individuals use agrichemicals under widely varying situations; monitoring and enforcement of agrichemical management are extremely difficult; and penalties for mismanagement may not serve as effective deterrents (proving mismanagement after the fact is also difficult). Wide discrepancies in certification, training, and supervision opportunities for agrichemical applicators represents a serious deficiency in the Federal effort to assure that agrichemicals are applied properly across the Nation. Clear Federal directives for applicator certification and training could reduce the incidence of agrichemical mismanagement and waste.

[8] EPA's Special Review and Registration Division is developing a proposed "ground water restricted-use' rule currently under review by OMB and USDA. Under the proposed rule as initially drawn up, as many as 25 chemicals could become classified as restricted-use pesticides if they are: 1) detected in three separate geographical regions; and 2) meet one of several technical criteria on chemical persistence and mobility (51).

FACTORS INFLUENCING AGRICULTURAL DECISIONMAKING

Factors influencing farmer decisionmaking, in general, and input choice and agrichemical use, in particular, will affect farmer decisionmaking related to groundwater protection. Technical assistance strategies, tools, and programs will be more effective in facilitating farmer decisions to reduce groundwater contamination if they take these factors into account.

Social science researchers have studied farmer decisionmaking over the past 50 years, at first examining decisionmaking involved in the "diffusion," or spread of agricultural innovations among farmers. More recently, researchers have studied farmers' adoption of conservation practices as well as decisions made within the context of "farming systems. Although little research has been conducted specifically on adoption of technologies to reduce groundwater contamination, decisionmaking research in general provides some relevant insights. For brevity, this discussion on decisionmaking refers to all private applicators as ''farmers, although some applicators will probably have more latitude than others in deciding which agrichemicals to apply, when, and how (e.g., Ml-time farm owner-operators v. hired employees).

Research on diffusion of innovations provides a basic understanding of the decisionmaking process and identifies the characteristics of innovations that are most likely to be adopted. Diffusion research, however, has limited applicability because it has focused largely on adoption of productivity-increasing technologies (1 13,127). Research on farmer adoption of soil conservation practices is more relevant to decisionmaking to reduce groundwater contamination because it identifies obstacles to adopting resource-protecting practices (98). However, institutional obstacles (e.g., farm programs, tax and credit policy), which many researchers consider more influential than the characteristics of individual farmers or technologies, have only begun to be investigated (90). Although farming systems research considers institutional influences on decisionmaking, much of this research has been conducted in other countries and is not immediately applicable to decisions made within the U.S. policy framework (cf: 77,12,9). Thus, each type of research has shortcomings, but lessons from research findings can be synthesized to help identify possible implementation problems in groundwater protection programs. Relevant findings are highlighted below.

Farmers are a heterogeneous group with unequal abilities and unequal access to information and resources for decisionmaking. Farmers vary in their objectives, level of awareness, use of information, and willingness to take risks; factors strongly influencing some farmers may have very little effect on others. Flexible groundwater protection programs and policies could be designed to accommodate this variation (13,100).

Farmers' decisions are based on their fundamental reasons for farming; their objectives may not be clearly defined or articulated. Farmers' objectives include: making a satisfactory living (either as an owner-operator, tenant, or employee); keeping a farm in operation for family inheritance or other personal reasons, perhaps while working at an off-farm job; obtaining a satisfactory return on investments in land, labor, and equipment; obtaining tax benefits from the farm; obtaining recreation or esthetic enjoyment from the farm; or a combination of these. Farmers' decisions to reduce agrichemical contamination will be made within the context of these basic objectives. Farmers are more likely to view favorably, and use, those technologies that allow them to meet their objectives (128).

Economic factors exert important, but not sole, influences on farmer decisionmaking. Fixed-cost expenditures and the farm family's total budget (on-farm and off-farm) place limits on actions farmers can take. Economic factors are key in defining what is financially possible for farmers, but a variety of personal, cultural, and environmental factors also shape farmers' decisionmaking. These include time and information availability, parental and sibling partnership arrangements, and influence of informal social networks (104,15,136,103). Economics will not be the only factor dictating adoption of groundwater-protecting farm practices.

Farmers typically make production decisions within short timeframes, which discourages investments in resource protection measures. Farmers currently operate in an economy that places higher priority on short-term returns and income guarantees than on longer-term resource conservation (135). Economic factors are typically the most pressing in farmer decisionmaking; market prices, support levels, credit availability, and debt load are critical considerations at the individual farm level. Farmers often are forced to make decisions within a short-term, year-to-year planning horizon that can prevent them from taking risks or making the most economically efficient decisions over a longer term (13). Farmers asked to respond voluntarily to public concerns about groundwater contamination tend to evaluate proposed technologies for their relative advantage within the existing set of economic conditions (128,41).

Farmers make changes slowly. Farm management changes, even relatively minor ones, are not decisions made overnight. Farmer adoption of relatively simple, highly profitable technologies such as hybrid corn has taken as long as 9 years on average (128). The decision to change farming practices requires a considerable degree of deliberation, and maintaining new changes frequently necessitates on-farm experimentation and adaptation beyond that conducted during initial technology development.

A farmer's innovation decision process consists of several sequential stages. These proceed through: 1) knowledge, when the farmer learns about an innovation; 2) persuasion, when the farmer forms a favorable or unfavorable attitude toward the innovation; 3) decision, when the farmer chooses to adopt or reject the innovation; 4) implementation, when the innovation is put to use and possibly modified; and 5) confirmation, when the farmer seeks reinforcement of the decision already made, possibly reversing it if confronted with conflicting messages (128). Farmers need different kinds of information and use different communication channels at each stage (103).

Farmers adopt "preventive innovations'' more slowly than "incremental innovations.'? Agricultural innovations studied in most diffusion research have been ''incremental innovations, ' or ideas adopted in the present (e.g., hybrid corn, commercial fertilizers) to gain possible increases in value in the future. Many agricultural innovations to reduce agrichemical contamination of groundwater, however, will be ''preventive innovations. ' These are new ideas adopted in the present to avoid possible loss in the future (127). Adoption rates of preventive innovations usually are slower than those for incremental innovations. Also, the motivation to adopt a preventive innovation is often a cue-to-action, or an event that prompts translation of an attitude into overt behavior (128). Personal and family health concerns about drinking water impacts are potential cues for farmers to adopt practices to protect groundwater.

Individual and farm characteristics appear to explain only a small portion of conservation adoption behavior; institutional factors (e.g., farm programs, credit availability) probably are highly influential. Research on individual farm characteristics (e.g., size, specialization, land tenure) and farmer traits (e.g., age, education) and their relation to conservation adoption has yielded mixed results. Most researchers consider institutional factors to be much more influential, but few studies have been conducted on these to date (90).

Studies on adoption of farm practices have rarely examined the physical settings of adoption decisions or the extent of resource degradation as it relates to adoption of remedial farm practices. Although many adoption studies have tested individual and farm characteristics as potential variables influencing adoption of farm practice changes, few studies have included data on the farm's physical environment, including topography, extent of soil erosion, proximity to water bodies, and regional hydrogeology (100). As a result, sociological studies typically categorized farmers who did not adopt soil conservation practices as "non-adopters,' whether or not these farmers needed to reduce soil erosion in the first place. Thus, while agricultural specialists in the physical and natural sciences have tended to ignore social influences in technology adoption, social scientists have also tended to ignore nonsocial variables in their studies.

Farmers tend to underestimate the severity of soil and water quality problems on their own farms. Farmers tend to perceive that soil erosion and water quality problems are more severe at the national level than they are in their own counties. They also tend to perceive these problems as least severe on their own farms (111). This "proximity effect' indicates that farmers are aware of the need to protect soil and water in general but often underestimate the need on their own farms (103).

Farmers are most likely to adopt technologies with certain characteristics. Favored technologies are those that: 1) have relative advantage over other technologies (e.g., lower costs, higher yields); 2) are compatible with current management objectives and practices; 3) are easy to implement; 4) are capable of being observed or demonstrated; and 5) are capable of being adopted on an incremental or partial basis. Diffusion research indicates that farmers are probably more likely to test technologies or practices that they think have these characteristics (128,113). Cropping systems approaches and Best Management Practice (BMP) combinations to reduce groundwater contamination are much more complex than individual BMPs or technological products. Complexity of systems-oriented changes will slow their adoption.

Decentralized information exchange among farmers promotes a wider range of innovations than do more centralized diffusion channels. Diffusion research indicates that local social networks are more important in the dissemination of preventive innovations than they are in incremental innovations (127). Due to the complexity of groundwater contamination problems, decentralized information exchange is likely to be very important in implementation of appropriate farming practices to protect groundwater. Groundwater quality improvements will require broad understanding of complex factors, knowledge of site-specific conditions, and trial-and-error in developing appropriate combinations of farming practices. These prerequisites cannot be readily achieved through centralized information mechanisms alone (77,75). Farming changes to protect groundwater will likely be facilitated by decentralized farmer-to-farmer information exchange (103).

In summary, decisionmaking research indicates that farmers are a heterogeneous group, whose decisions on agrichemical use and groundwater protection will be made based on their fundamental objectives for farming. Economic factors typically define what is financially possible for farmers, particularly in the short-term, but other personal, social, and environmental factors also influence decisionmaking. Institutional factors may be particularly important in farmers' decisions to implement resource-protecting practices, which are adopted more slowly than other types of innovations. Voluntary adoption of resource-protecting practices may be slowed due to farmers' tendency to underestimate the severity of resource degradation problems on their own farms.

FACTORS INFLUENCING AGRICHEMICAL USE AND GROUNDWATER PROTECTION

Farmers' decisions are shaped by their objectives, constraints, and opportunities. Different constraints and opportunities are associated with each of the four approaches to reducing agrichemical contamination of groundwater: agrichemical management to reduce point-source contamination, improving agrichemical application management, agrichemical use reduction, and use of nonchemical practices.

Risk

Farming is risky, subject to uncontrollable influences such as weather, pest infestations, and changing market conditions. Farmers who use agrichemicals know which crop yields and levels of pest control have been obtained in past seasons with tried-and-true application rates. Even though equivalent crop yields could be achieved by reducing agrichemical use, many farmers perceive that crop yields would be lowered if they did so (111). Alternatively, farmers may be aware that they are applying agrichemicals at higher-than-needed rates but are willing to pay for this yield "insurance" (118).

Before adopting a new practice, farmers need site-specific and pertinent information to compare costs and benefits of current v. other available technologies. In considering any change, farmers not only risk losing ''insurance' benefits of previous practices but they also incur the risk of trying a new practice, which may involve "learning costs" that are poorly quantified. This ''double risk' associated with adopting a new practice makes farmers reluctant to change practices without sufficient information and poses severe obstacles to reducing agrichemical use through use of alternative practices.

Farmers vary in their willingness to accept risks and benefits of agrichemical use, influencing the kinds of farming practices they are willing to try. Farmers willing to try alternative practices are more likely to be economic risk-takers than those less willing to experiment (46). Conversely, such farmers may actually be more averse than average to health and environmental risks.

Complexity

Farmers face greater risks and transition costs in decisions to use technologies or management practices that are more complex or greatly different from their usual practices (172). Agrichemical technologies, once incorporated into a farming system, have become relatively easy technologies to use, and they confer important benefits to farmers by reducing the time or labor needed to control pests or provide plant nutrients, compared to some nonchemical practices (tables 5-10 and 5-11). Thus, technologies that maintain these benefits at acceptable levels, that modify existing farming systems only incrementally, or that require little more than a new understanding are more likely to be voluntarily adopted than technologies requiring increased management, different skills, or major modifications to farming systems (e.g., different equipment).

Addressing point sources of agrichemical contamination is perhaps the least disruptive groundwater protection approach, because it implies that the farmer will continue to use agrichemicals but modify storage, handling, and disposal practices to minimize contamination, Convincing farmers who currently rely on conventional agrichemical techniques to invest in other management approaches that are more information- or skill-intensive is likely to require substantial information, documentation, and incentives. Farmers will need time, additional knowledge, and possibly technical assistance to plan, learn about, and gain experience with new practices to reduce groundwater contamination.

Lack of Information

Information serves to reduce uncertainty and helps close the gap between actual and farmer-perceived risks associated with resource-protecting technologies. Two types of information are needed in assisting farmers to reduce agrichemical contamination of groundwater and both types of information may be of limited availability to farmers.

First, the problem of agrichemical contamination of groundwater must be defined and specified to farmers, because farmers are not likely to consider farming practice changes until they first recognize that a problem is arising from current practices (103). Furthermore, farmers tend to perceive resource problems that are farther away from the farm operation as being more severe than resource problems closer to the farm operation (1 12,90). This implies that a critical component of groundwater-related information programs is the ability to provide site-specific problem definition. Although a site-specific agrichemical contamination problem can be identified by testing groundwater for contaminants, groundwater monitoring data are often unavailable in many areas, too costly to obtain, or too difficult for the farmer to interpret in terms of associated health risks or the economic losses from wasted agrichemicals.

Table 5-10-Production Inputs for Nitrogen Management

Type of Input:
. Additional inputs needed for use

Soil nitrogen:
- **Soil tests**
- **Information and planning to determine nitrogen credits**

Commercial nitrogen fertilizers:
- **information and planning to determine timing and rates**
- **Labor and time involved in application or payment for custom application services**
- **Application equipment investment or rental**
- **Fuel required for application**

Legumes:
- **Additional land for crop rotation**
- **information and planning to determine cropping sequence, crop mix, seeding rates, and cutting or plow-down times**
- **Legume seed**
- **Soil preparation and planting equipment**
- **Labor and time involved in planting, cutting, and plow-down**
- **Cutting, mowing, and plow-down equipment**
- **Fuel required for soil preparation, planting, cutting or mowing, and plow-down**

Manures:
- **information and planning to determine application sites and rates**
- **Manure source**
- **Manure hauling costs**
- **Manure storage site or facility**
- **Equipment for comporting or turning manure**
- **Labor and time involved in comporting or conditioning manure before application**
- **Nutrient analyses**
- **Manure spreading equipment**
- **Labor and time involved in manure spreading**
- **Fuel required for manure spreading**

SOURCE: Office of Technology Assessment, 1990.

Second, farmers need site-specific economic and agronomic information on practices that reduce agrichemical contamination of groundwater. Farmers are not likely to adopt alternative practices based on stewardship themes or vaguely defined health risks. Although these messages may motivate farmers to seek alternatives, there is low probability of adoption unless they can obtain adequate economic and agronomic information about suggested corrective practices. However, economic or agronomic

Table 5-11-Constraints To Reducing Herbicide Use

Constraint	Possible solutions
Lack of equipment to replace herbicides with mechanical cultivation (rotary hoe, disk hillers, etc.)	Low-interest loans for equipment purchase
Unpredictability of spring weather, which can make soil *too* wet for mechanical cultivation	Use of mechanical cultivation when weather permits; use post-emergent herbicides when weather too wet for cultivation
Lack of time to cultivate fields	Contractor services
Lack of skills in using nonchemical weed control methods	Extension programs; contractor services
Increased use of herbicides for conservation tillage	Extension information and demonstration on herbicide use for conservation tillage; Extension surveys to monitor herbicide use
Field equipment that spreads weed seeds	Technical assistance to design and retrofit equipment (e.g., combines) to capture weed seeds
Lack of information on weed seed populations	Weed seed measurements; computer software to calculate herbicide use on basis of weed seeds; contractor services

SOURCE: Office of Technology Assessment, 1990.

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

State agricultural scientists and Cooperative Extension Services offer assistance to farmers on improving nutrient and pest management. Here, Iowa State researchers examine a soil sample which will be tested for nitrates and organic matter.

facts may not be presented in accessible or usable formats for the farmer. The right type of information in the appropriate format needs to be made available to the farmer at the stage of the decision process when that information is relevant (103).

Of the four approaches to reducing groundwater contamination, more information is available on reducing point-source contamination and improving agrichemical application management than on use reduction or nonchemical practices. For many farmers, point-source controls and improved agrichemical application techniques are easier to implement than extensive farming practice changes, because these approaches allow farmers to continue to rely on their own experience and knowledge with agrichemical-based techniques. Information on more complex farming practice changes is not as extensive or readily available. Many farmers interested in reducing agrichemical use through low-input, sustainable, or organic cropping systems have stated that the Cooperative Extension Service (CES) is an inadequate information source on these approaches (103, 140). Instead, these farmers have sought information from other farmers experienced in these approaches, and informal groups of farmers have emerged to find viable methods of reducing agrichemical inputs (103). Such farmer-to-farmer information and assistance networks confirm the observation that individual farmers are important both as sources and evaluators of information (78). Thus, farmer-to-farmer transfer can play important roles in disseminating information on more complex farming system changes to reduce groundwater contamination by agrichemicals.

Lack of Documented Research

Farmers are more likely to adopt technologies that have proven, documented results. The performance of farming practices to protect groundwater will have to be evaluated in two areas: 1) farm profitability in the short and long term; and 2) improved groundwater quality. Documentation in both areas will require baseline data collection and recordkeeping. Demonstrations and financial analyses showing yield maintenance or improvements, cost reductions, or higher net returns from farm practice changes are more likely to convince farmers to try them.

Although anecdotal evidence exists of the profitability of alternative practices at the individual farm level, it is difficult to determine whether the profitability results from reductions in purchased inputs or from better management (10). More research is becoming available on the profitability of crop rotations, such as in east-central Nebraska, where rotation systems were observed to have higher average net returns than continuously cropped systems (59). Nevertheless, useful economic analyses of the cost-effectiveness of alternative practices cannot be obtained unless farmers keep accurate records of all nutrient and pest control inputs, including time, labor, and management requirements. Demonstration projects will be more effective if they provide assistance in farm recordkeeping.

Difficulty in Demonstration

Groundwater quality improvements will be more difficult and expensive to demonstrate than farm profitability, because groundwater quality changes can only be evaluated through long-term monitoring. Of the four approaches to protecting groundwater, farmers are most likely to implement agrichemical storage and handling improvements, recognizing that these practices address obvious point sources. Point-source controls also lend themselves more readily to regulatory oversight through construction specifications, permits, and maintenance and calibration checks.

On the other hand, farmers are less likely to assume that changing farm practices in the field will reduce nonpoint-source contamination. Given the lag time before groundwater quality improvements can be demonstrated through monitoring, farm records showing fertilizer and pesticide reductions may provide the only information on which to evaluate possible groundwater impacts. Farmers in hydrogeologically vulnerable areas who receive assistance to change their practices would need to keep good records of the types, amounts, and locations of pesticide and fertilizer use.

DECISIONMAKING TO PROTECT GROUNDWATER

Farmers have available a range of practices under four general approaches to reduce groundwater contamination by agrichemicals. However, practices under the first two approaches, ***reducing point-source contamination*** and ***improving agrichemical application,*** draw from a larger information base, employ well-established information sources such as agrichemical dealers and the CES, and are perceived to be less risky and easier to implement. Practices falling under the latter two approaches, ***we-reduction*** and ***nonchemical alternatives,*** on the other hand, are perceived as more risky, although some established information sources are providing more documentation on these practices' impacts on yields and net returns. Nonchemical practices may be the most complicated and riskiest types of practices to implement, because they have a less-developed research base, and information on them tends to be disseminated through less well-established sources such as farmer networks.

Which technologies, if any, ***should*** farmers adopt in response to groundwater contamination concerns? Which technologies ***can they*** adopt, given current economic and institutional constraints? Which technologies ***will they*** adopt? Four conditions are prerequisites for planned change to occur within a target population, and these can be applied to the problem of groundwater protection in agriculture:

- knowledge of the problem and of potential solutions;
- perception of a need to solve the problem;
- ability to commit resources to solve the problem; and
- access to sufficient resources, skills, and time to implement solutions (179).

Groundwater protection strategies that achieve these four prerequisites are more likely to reduce agrichemical contamination of groundwater by facilitating farmers' decisions to take groundwater-related actions.

Knowledge of Agrichemical Contamination of Groundwater

The people who will be most directly affected by groundwater protection policies for agriculture are people who work and live on farms (68). Landowners, farm managers, and farm workers will be responsible for implementing changes in farming practices and will most directly bear the economic costs of any changes. Farm residents also will derive the most immediate benefits from any resulting improvements in drinking water quality. Farm residents are more likely to be exposed to any hazards of contamination, because farmstead drinking water wells are closest to sites of groundwater pollution and agrichemical concentration in groundwater is greatest near the source of pollution.

Farmers are highly aware of agrichemical contamination of groundwater (see box 5-E). However, they may not be sufficiently convinced of the severity of the problem or of the efficacy of ''corrective' farm practice changes to take action. Before farmers undertake farm practice changes, they are likely to consider a multitude of questions, for example:

- Is the groundwater beneath *my* farmland contaminated by agrichemicals?
- How does contamination affect the safety of my family's and other people's drinking water supplies?
- Have my farming practices or agrichemical management methods caused this contamination?
- What will it cost to reduce contamination, in time, labor, money, and crop yields?
- If I change practices, how will I know if these changes really do reduce contamination and any attendant hazards?
- Will I be liable for any hazards associated with my farming practices?

Many farmers believe that a groundwater contamination problem exists overall, but they are likely to want specific evidence that a problem exists on their own farms. Information on regional hydrogeologic vulnerability is a starting point, but this must be supplemented by local well testing, groundwater monitoring results, and evidence linking farm practices to groundwater contamination in their areas.

Need To Reduce Agrichemical Contamination

Farmers will consider groundwater protection a priority only if they perceive a real need for it. Possible motivations for farmers include:

- confirmed high hydrogeologic vulnerability of farm site (e.g., sandy soils, high water table, karst area);
- high nitrate levels or pesticide detections in drinking water well;
- evidence linking on-farm point sources to groundwater contamination;
- evidence linking farm practices to groundwater contamination (e.g., application rates in excess of crop needs);
- evidence of lost dollars due to wasted agrichemicals or costs of excess agrichemical applications;
- high level of personal or family health concerns;
- high level of concern about adverse impacts on the farming system or environment;
- liability concerns due to community or neighbor complaints;
- existence of regulations and penalties; and
- impending pesticide bans or restrictions.

Farmers' main motivations to reduce groundwater contamination will be personal health concerns, liability, and need to reduce costs from wasted agrichemicals. These motivations, however, must outweigh constraints imposed by risk aversion; fear of yield reductions; lack of time, skills, or appropriate equipment; and perceived high costs of farm practice changes.

Ability To Commit Resources To Reduce Groundwater Contamination

Farmers' ability to respond to groundwater contamination problems or comply with increased environmental restrictions will greatly depend on their farms' financial conditions, which vary within and between farm types (e.g., field crops, specialty crops, livestock) and sales classes (see box 5-F). Farmers with high debt-to-asset ratios and negative cash flows in all sales classes will be less able to commit resources for environmental controls (165). Although financial impacts will depend on the type of farm pollution controls needed, smaller farms may experience the greatest financial constraints, because these farms typically have fewer financial resources overall. Point-source controls requiring large initial capital outlays would be most likely to impose financial constraints on farms in smaller sales classes. However, farm practices to reduce nonpoint-source contamination may be easier to implement for smaller farms and larger farms with low cropland use intensity.

Box 5-E—Farmer Awareness and Concerns About Groundwater Quality

An understanding of farmers' attitudes toward groundwater contamination by agrichemicals is important in anticipating reactions to policy alternatives. In the fall of 1988 OTA commissioned a review of emerging literature on farmers' general attitudes toward agrichemicals and groundwater quality, and preferences for policy responses to the issue (1 11). AU major studies identified in the review had been conducted within the last 5 years, with the most relevant ones reported within the last 2 years. Substantive data from 14 States[1] were obtained, but studies varied considerably among States in the areas covered by the surveys. Most of the studies were descriptive in nature and were not used to draw statistical conclusions. Because of variation in survey methodology, only some of the data could be aggregated to make comparisons.

More surveys had been completed in cash grain-producing regions of the Midwest, particularly in Iowa and Wisconsin, where groundwater quality has become an issue of public concern and debate. At the time of the analysis, no studies had been identified from the western region and only a few from the southern region. These geographic information gaps preclude any generalizations about farmers' attitudes on a national basis. Despite data limitations, these studies provide insights into attitudes of surveyed farmers, particularly where the issue has been given greater attention by the media.

Importance of Drinking Water Quality-Surveys of farmers in Iowa, Minnesota, and Virginia clearly indicate that these farmers attach a great deal of importance to drinking water quality (63,76,108,110,33,54). When farmers were asked to rank drinking water quality among a series of issues, the general pattern was for farmers to rate water quality as slightly less important than profitability or economic well-being. Data also suggest that agrichemical and groundwater quality receive greater importance when posed as health issues rather than environmental ones. Greater health concerns have been expressed for pesticides than for nitrate. Findings from the above studies consistently indicated that surveyed farmers consider agrichemicals to be a major contributor to groundwater pollution.

Attitudes About Seriousness and Proximity of Groundwater Contamination Problem—Although surveyed farmers considered groundwater contamination by agrichemicals as 'serious, " they tended to view the problem as more serious for people in other areas and less serious on their own farms. The policy implications of this tendency are that educational programs alone are not likely to provide sufficient motivation for farmers to change their practices. Farming practice changes may not occur unless farmers can be shown specific evidence of the extent and degree of groundwater contamination on their own farms.

Attitudes Toward Benefits-Costs of Agrichemicals-Statewide surveys of over 300 randomly selected New York farmers and nearly 600 Iowa fanners indicated that the majority-as high as 80 percent in Iowa—would like viable alternatives to agrichemicals (17,112). Even though these studies indicate that farmers want alternatives, chemical use remains widespread. Studies among row crop grain farmers have found that the majority believe pesticides are their best current alternative to control weeds, pests, and plant diseases. Studies in Wisconsin, Iowa, California, Florida, and Pennsylvania indicate that the majority of farmers believe that they have already reduced agrichemical use as much as they profitably can. These majority percentages ranged from 65 and 66 percent in Iowa and Wisconsin to a high of 80 percent in Florida (177,112,35).

In the Wisconsin statewide survey, 71 percent of the farmers felt their yields would drop if chemical inputs were reduced The Iowa statewide survey showed half the respondents stating that increased costs for tillage, labor, and machinery would cancel any savings from herbicide reductions. When asked their opinions about health and environment concerns associated with agrichemical use, farmers in Iowa, Minnesota Virginia, Oklahoma, and New York were split fairly evenly between those agreeing and disagreeing with the idea that significant health and environmental threats exist (109,1 10,33,54,89,17). Thus, despite divided opinion about health and environmental impacts, farmers justify their use of chemicals from an economic decisionmaking framework.

Relationships Between Attitudes and Intensity of Agrichemical Use—In a survey of about 570 farmers in North Carolina, full-time farmers with more agrichemical-intensive operations expressed significantly less concern about whether the products might be harmful to wildlife than farmers with less chemically intensive

[1] California, Florida, Georgia, Indiana, Iowa, Massachusetts, Minnesota, Mississippi, New York, North Carolina, Oklahoma, Pennsylvania, Virginia, and Wisconsin.

operations (7). Similarly, studies in Iowa and Virginia revealed that farmers who applied high levels of nitrogen fertilizer consistently saw agrichemicals as significantly less of an environmental problem than farmers who applied lower levels (54,108). The policy implications of these findings are that intensive users of agrichemicals may be less motivated to reduce agrichemical use than less intensive users, even though their practices have greater potential to contaminate groundwater.

In summary, survey findings indicate there is general awareness among farmers of the groundwater contamination issue in areas where groundwater quality has received public attention. However, farmers are suspicious, but uncertain, about the true health risks associated with agrichemicals. There *seems* to be a lack of motivation for personal action, in part because farmers do not acknowledge a serious problem on their own farms. This may be either genuine nonrecognition or a lack of concern about a potential problem. Whichever the case, in the absence of specific knowledge about one's own drinking water or documented associated health problems, voluntary change is not likely to occur on a widespread basis.

If the problem is genuine nonrecognition, education and assistance could have an important impact, and farmers have reported that such evidence would be motivation for them to change. Since many private wells are not regularly tested, particularly for pesticides, monitoring programs in hydrogeologically sensitive areas would provide important information and bases for motivation. Another impediment to voluntary change may be beliefs or knowledge about alternatives. Survey findings indicate that farmers are willing to consider alternatives to agrichemicals. At present, however, most farmers believe that pesticides are their best tools against insects, weeds, and plant disease and that they have already reduced their chemical inputs as much as they economically can. Thus, by fostering attitude change it may be possible to encourage farming practice changes. Farmers appear to be open-minded but not fully convinced of the true seriousness of the problem or of the viability of current alternatives.

Farmers' ability to respond to environmental concerns also will depend on trends in the agricultural sector, such as increasing concentration of farmland among larger farms, ownership arrangements, and contract obligations (see box 5-B). For example, tenants and partial owners, who managed about two-thirds of all farmland in 1982 (table 5- 12), may be less willing or able to invest in groundwater protection practices on rented land than farmers who fully own their land. Thus, a farm operator's ability to achieve changes in groundwater quality will depend on the extent of change needed, incentives and freedom to make changes, and the farm's financial and management capacity to accommodate farm practice changes.

Access To Resources and Technical Assistance To Achieve Solutions

Farm size and financial condition will affect farmers' ability to commit resources, but their ability to achieve real improvements in groundwater quality probably will require technical, administrative, and financial assistance. A variety of groups can participate in assisting farmers to reduce agrichemical contamination of groundwater, including State, local, and Federal agencies providing assistance at the farm-level. Increasing farmers' access to resources and assistance will depend on available Federal, State, and local funding used to identify groundwater problems and solutions and on a clear definition of agency roles in providing technical assistance.

TECHNICAL ASSISTANCE TO REDUCE AGRICHEMICAL CONTAMINATION OF GROUNDWATER

Agricultural producers receive information and technical assistance from a variety of sources when making decisions about crop selection, nutrient and pest control inputs, and soil and water management (table 5-13). Private-sector information sources include agrichemical manufacturers, dealerships, farm cooperatives, crop consultants, agricultural magazines, and radio and television advertising. Public-sector sources include Federal, State, and local agencies and organizations. The most frequently used sources of agrichemical information are agrichemical dealers, although many producers perceive CES to be the most reliable source (1 12). Pesticide labeling and agricultural publications also are important information sources for the farmer. Although formal information sources play important

Box 5-F—Implications of Farm Size for Technical Assistance

Farm size is typically measured by the annual gross market value of agricultural commodities produced per farm (153). Farm size reflects the magnitude of a farm's financial resources and is likely to influence farmers' risks and abilities to change production practices. Farm size and financial status thus are relevant in designing appropriate technical assistance strategies that encourage changes in nutrient and pest management. The following table shows one classification of U.S. farms based on annual gross sales and indicates the percentages of total farmland area covered by farms in different sales classes in 1987.

Sales class	Value of farm products sold per farm	Average farm size (acres)	Farmland area in sales class (1,000 acres)	Percent of total farmland area
Small, part-time	>$20,000	148	220,573	20,7%
Part-time	$20,000-99,999	689	340,885	34.0
Moderate	$100,000-249,999	1,278	250,650	25.8
Large and very large	2$250,000	2,304	190,650	19.5
Total			1,002,603	100.0

SOURCE: U.S. Department of Agriculture, "Table 533: Percent of Farms, Land in Farms, and Average Aize, by Economic Class, United States, 1987," *Agricultural Statistics* 1988.

Although these data aggregate all types of farms (crop and livestock) and fail to distinguish regional variations, they are still useful in showing the extent of land area managed as farms in different sales classes overall. For example, a significant proportion of the Nation's farmland (roughly 55 percent) was managed as small or part-time farms in 1987. Overall potential for different-sized farms to contribute to nonpoint-source groundwater contamination (therefore determining their need for assistance) will depend on farm locations relative to hydrogeologically vulnerable areas, extent of farmland involved, commodities produced, and intensity of agrichemical use.

Farm size also affects the financial status of the farm and the need for off-farm income. The following table gives aggregate national data on farm income by sales class in 1987.

Sales class	Value of farm products sold	Average net farm income	Average off - farm income	Average total income
Small, part-time	>$20,000	$ -323	$24,000	$23,677
Part-time	$20,000-99,999	13,000	17,0i)o	31,074
Moderate	$100,000-249,999	51,749	14,383	66,132
Large	$250,000-499,999	128,678	16,090	144,768
Very large	2$500,000	738,132	29,363	767,495

SOURCE: U.S. Department of Agriculture, Economic Research Service, "Table 37: Average Net Farm Income Before Inventory Adjustment Per Agricultural Operation, by Value of Sales Class," and "Table 40: Average Off-farm Income Per Agricultural Operation, by Value of Sales Class," *Economic Indicators of the Farm Sector, National Financial Summary, 1987,* October 1988.

Again it should be noted that these aggregated data do not characterize regional or local trends, because the distribution of farms among different sales classes varies by region and commodity. Also, per-farm statistics by sales class should not be interpreted as per-farmer statistics, since more than one operator may share in production risk per farm, particularly in the larger sales classes (153). Nevertheless, these data provide a useful context for understanding general income trends and potential decisionmaking constraints to groundwater protection:

Small Farms—Farms with gross sales of less than **$20,000** per year generally do not provide a significant source of income to their operators. Most farm operators in this class obtain their primary net income from off-farm sources. Average net farm income for this sales class in 1987 was negative, with off-farm income averaging $24,000. The small farm subsector, however, is not homogeneous—it contains a large number of subsistence farms whose operators live at or below the poverty level as well as a large number of affluent families to whom the farm is more a form of recreation than a source of income. One in five farm operators in this sales class in 1982 was a full-time operator (138). Fifty-eight percent of this group were part-time farmers working 100 days or more per year off the farm. The remaining farmers were full- or part-time farmers over the age of 65, Part-time operators, who include individuals using the farm as either a tax shelter or for recreation, had the highest total incomes in this sales class because of their off-farm employment.

Although small farms constitute 21 percent of total farmland, the percentage of agrichemical-treated farmland covered by small and part-time farm operations may actually be lower. Small farms involving livestock or recreation are likely to be less agrichemical-intensive than farms producing commodity or specialty crops. Since small-farm operators historically have taken less advantage of technical assistance programs than have large-farm operators, small farms located in hydrogeologically vulnerable areas may require more intensive outreach efforts. Also, technical assistance to small farms would need to be tailored to their financial and time constraints (180). Small farms are also more likely to need low-cost technologies or financial assistance to reduce groundwater contamination. Any increases in net income resulting from more efficient agrichemical use would benefit small-farm operators to a proportionally greater extent than large-farm operators.

Part-time Farms—Farms with annual gross sales between $20,000 to $100,000 may produce significant net income but are typically operated by people who depend on off-farm employment for their primary source of income. Because net farm income is low and off-farm income tends to be lower than average, farms in this sales class are likely to experience financial difficulties. Moreover, part-time farmers who work 40 hours a week at an off-farm job have only about 43 percent of their time available for farming (99).

If recent trends continue, part-time farms could increase in number, but this will require the families living on these farms to earn the bulk of their income from off-farm sources. Part-time farmers may rely heavily on agrichemical use to save time and labor, which would make it difficult for them to adopt farming practices requiring more time and management. Part-time farmers thus are likely to experience greater time constraints to reducing agrichemical use. On the other hand, part-time farmers may be more willing to make changes in their farm practices simply because their principal income is derived off the farm, allowing them to undertake some potentially risky activities in their farming ventures.

Moderate-sized Farms—Farms that generate more than $100,000 in annual gross income are generally capable of supporting full-time operators, and commonly require labor and management from at least one full-time manager. Average off-farm income in this sales class is lowest of all classes, but the net income of moderate-sized farms is decreasing in absolute terms and in terms of their share of total farm income (144).

In upcoming years, moderate-sized farms are expected to decline in number if they are not able to increase farm income or obtain more off-farm income. Moderate-sized farms are most prevalent among cash grain, hog, and dairy operations in the North-Central and Northeast regions. Many moderate-sized farm operators have been under severe pressure in the 1980s to increase yields to offset reductions in farm prices. One strategy has been to produce more commodities by expanding or renting more land; another is to intensify use of agrichemicals. Many of these operations use high levels of agrichemicals to maintain productivity. Under voluntary programs to reduce groundwater contamination, operators of these farms are likely to implement only those farm practice changes that maintain or increase net returns.

Large and Very Large Farms—Farms with annual gross sales greater than $250,000 are maintaining or increasing their shares of farm income. As a group, the households that own and operate these farms have moderate off-farm incomes and moderate-to-very large net farm incomes. Most farms in this class require one or more full-time operators, and many depend on hired labor on a full-time basis to manage their larger land areas. Five percent of these farms in 1982 were owned by nonfamily corporations, thus involving more than one owner in decisionmaking. This will mean that some agreement has to be reached among owners and managers in deciding whether to implement farm operation changes related to groundwater protection.

The amount of farmland managed by large and very large farm operations is expected to increase beyond the present 20 percent of all farmland with the continued trend toward concentration in the agricultural sector. Farms in these sales classes are projected to account for about 15 percent of all farms by 2000, or three times their proportion in 1982 (144). Changes implemented on large farms would have relatively high environmental impacts, because management changes per farm would affect a large acreage. Since large and very large farms will probably continue to produce the greatest shares of commodities in the United States, incentives aimed at large farms would affect larger land areas on which the majority of commodities are produced.

Larger farms historically have adopted conservation methods to a greater extent than smaller farms, because large farms have more financial resources and contacts with local extension and conservation agencies (149). Large farms with greater financial resources are probably more capable of making financial adjustments to accommodate farm practice changes without government assistance. However, the need to capture returns from previous capital investments in production systems could discourage large farms' adoption of practices to reduce groundwater contamination.

Policy Implications—Farm sizes and sales classes have implications for the amounts and types of technical assistance local farmers are likely to need to improve the quality of local natural resources. Small and part-timefarmers are more likely to experience financial and time constraints in making farming practice changes to reduce agrichemical contamination of groundwater, while large farmers are more likely to want to continue using practices in which they have invested large amounts of capital. State and local programs to reduce agrichemical contamination of groundwater have better chances of being effective if they are built on a good understanding of the local structure of agriculture and likely constraints which could interfere with local resource protection efforts. Thus, State and local governments could consider local and regional distributions of farms among small, moderate-sized, and large sales classes when developing and implementing groundwater protection programs.

Table 5-1 2—Land Ownership and Tenancy: Number of Farms and Land in Farms, 1982

Land tenure classification	Number of farms	Percent of farms	Farmland acres (thousands)	Percent of farmland
Fully owned	1,321,000	59	345,379	35
Fully rented	269,000	12	108,547	11
Part-owned/rented	649,000	29	532,870	54
Total	2,239,000	100	986,796	100

SOURCE: Compiled from U.S. Department of Agriculture, tables 535 and 536, *Agricultural Statistics* 1988, based on data from U.S. Department of Commerce, Bureau of the Census, the 1982 Census of Agriculture.

Table 5-13--Sources of Information and Technical Assistance to Farmers on Agrichemical Management

	Role
Public sector:	
State Cooperative Extension Service (C ES) specialists and agents	Information on production techniques and farm management; pesticide applicator training; soil testing services
USDA Soil Conservation Service (SCS)	Technical assistance on soil and water conservation and resource management planning
USDA Agricultural Stabilization and Conservation service (ASCS)	Financial assistance for soil and water conservation, integrated crop management, farm program participation
State Department of Agriculture	Pesticide applicator certification
State Departments of Health; Natural Resources; or Environmental Quality	Well water monitoring and testing; well construction standards
Private sector:	
Farmer cooperatives; agrichemical dealers and suppliers	Sales and service of production inputs; product selection and application rate recommendations
Agrichemical manufacturers	Pesticide labeling information; training programs and educational materials
Advisory and technical service firms	Soil testing; pest scouting; computer services
Agricultural media	Production information and product advertising
Farm commodity purchasing firms	Production requirements or quality standards
Other farmers (neighbors; commodity groups; farmer-to-farmer referral groups)	Advice, observation, and experience on production techniques
Agricultural management firms and consultants	High-management production services

SOURCE: Office of Technology Assessment, 1990.

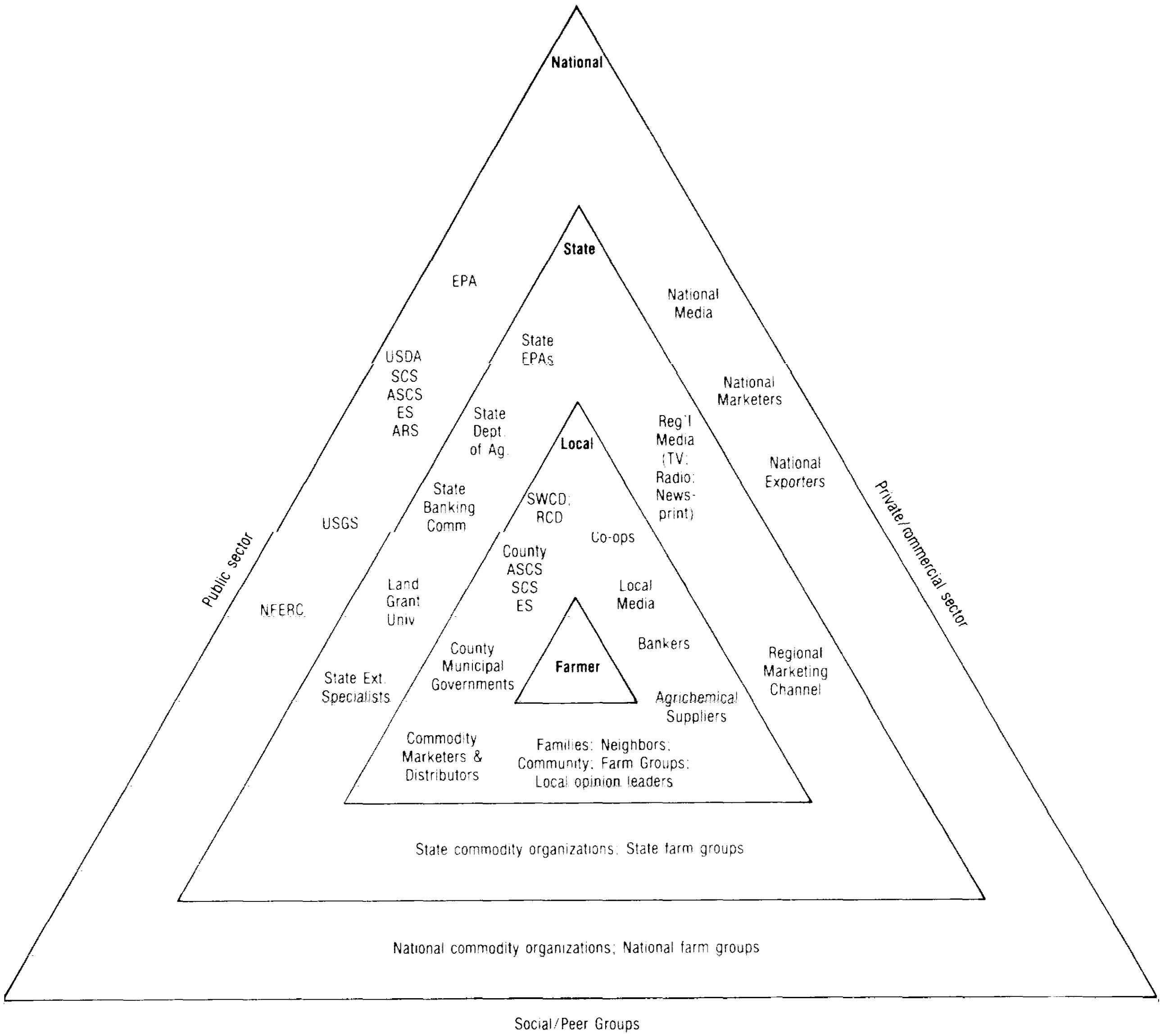
roles in influencing farmers' decisions, farmers also obtain guidance from numerous informal contacts with other farmers, family members, landlords, lenders, other business people, and local residents. The opinions and choices of these other individuals and organizations also inform and motivate farmers (figure 5-4).

Most farmers face ''a situation of information overload rather than information deprivation' (102). Information flow to and among farmers is a competitive process, and farmers must pick and choose among diverse sources of information and assistance. If farmers hear consistent messages from public, private, and informal information sources regarding the importance of proper agrichemical use and resource protection in agriculture, they will be much more likely to implement practices that protect groundwater.

Public-Sector Assistance—Federal Agencies

Two Federal agencies are structured to provide routine assistance to farmers at the local level—USDA's Soil Conservation Service (SCS) and Agricultural Stabilization and Conservation Service (ASCs). Several other agencies and offices within the USDA, EPA, and the Department of the Interior contribute to research, monitoring, and technical assistance related to agriculture and groundwater, but these agencies do not assist individual farmers through local offices (figure 5-5). Administrative and technical guidance offered by field offices can predispose farmers toward certain farming practices, and Federal assistance at the local level can facilitate

Figure 5-4--Socioeconomic Support Systems for Farmers Influencing Their Decision making



Sources of information for, and thus of influence on, farmer decisionmaking are numerous and some may be providing conflicting advice. Examples of influential groups affecting farmer decisionmaking include public agencies, private-sector groups, and social or peer groups at local, State, and national levels.

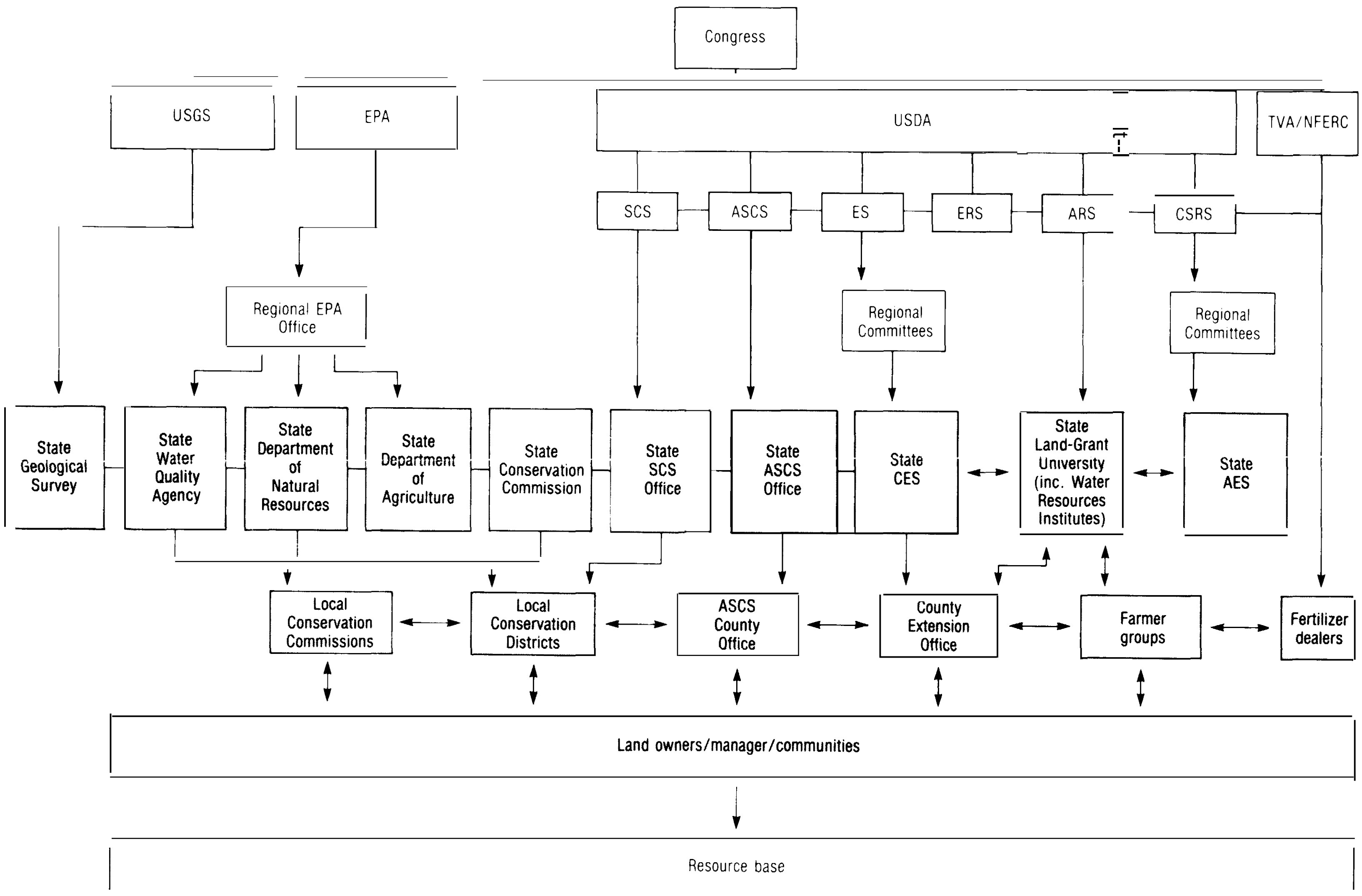
SOURCE: Office of Technology Assessment, 1990.

farm practice changes to reduce groundwater contamination.

USDA Soil Conservation Service

The SCS was created in 1935 to 'provide national leadership in the conservation and wise use of soil, water, and related resources' (160). SCS offers technical assistance to individuals, groups, and governments through SCS offices in local conservation districts. SCS State Conservationists, who answer directly to the national SCS Chief, head State-level SCS offices and are the primary SCS contacts for State interagency efforts. SCS offices at the State- and district-levels are coordinated as Federal agency components, in contrast to CES and State Agricultural Experiment Stations (SAESs), which are administered as State organizations. State-level SCS offices typically receive input on funding priorities and preferred management practices from conservation district representatives.

Figure 5-5—Federal, State, and Local Organizations With Roles in Protecting Surface and Groundwater From Agricultural Impacts



SOURCE: Adapted from the "Proposed Strategy for Protecting Surface and Ground Water from Adverse Impacts Resulting from Agricultural Activities," National Association of Conservation Districts, June 1989.

SCS District Conservationists assigned to field offices receive general guidance on conservation planning policies and procedures from SCS's National Conservation Planning Manual. Specific technical guidance, on the other hand, is provided through Field Office Technical Guides (FOTGs) developed at the State level. FOTGs provide guidelines on conservation and resource management practices that correspond to local land use needs and agricultural production conditions. The SCS planning process is designed to help landowners ''define natural resource problems, determine alternative solutions, choose among cost-effective solutions that are consistent with their objectives, and implement solutions as rapidly as is feasible and practical" (160).

SCS conservationists help land users develop soil conservation plans based on soil surveys, topographical maps, and FOTG guidelines, They also encourage land users to implement conservation practices and structures (e.g., terraces) by helping them obtain cost-share financing through the Agricultural Conservation Program (ACP). ACP payments for approved conservation practices are made through local ASCS offices. Although SCS technical assistance has traditionally emphasized soil erosion control, its scope has expanded to address additional resource concerns, such as protecting water quality and quantity, managing grazing lands and forests, and preserving wildlife habitat. SCS initiated a water pollution control effort in 1981 and has begun to address agrichemical contamination of groundwater as a component of this effort.

''Progressive conservation planning' is a concept developed by SCS to encourage land users to go beyond adopting single conservation practices to implementing a full set of practices and land uses for resource protection (122). SCS conservationists can help land users plan Resource Management Systems (RMSs), which are coordinated sets of conservation practices and management techniques designed to address the entire range of resources (e.g., soil, water, air, plant, and animal) specific to a farm or land use. SCS technical staff at the State level develop RMSs for field offices. Some groundwater-related materials have been developed for use in conservation and RMS planning. These include:

- local soil and site information, ratings on likelihood of nitrate leaching, pesticide characteristics and soil-pesticide interactions;
- water resource data and effects of land use, management, and conservation practices on water resources;
- standards and specifications for practices to protect water quality, including nutrient and pesticide management standards;
- water quality policies and regulations at national, State, and local levels;
- planning guidelines and criteria to develop RMSs that incorporate water quality concerns (160); and
- economic, environmental, and social trade-offs which the farmer can use to evaluate conservation options and water quality impacts (161).

SCS water quality and RMS materials, however, may not be consistently or fully utilized throughout all SCS field offices. Since State Conservationists are responsible for the "development, quality, coordination, use, and maintenance' of FOTGs used throughout their States (162), deployment and full application of these materials may depend on strong administrative support from State Conservationists. In addition, fuller implementation of comprehensive conservation planning assistance will depend on the motivation and training of individual conservationists and their ability to devote the time needed in advising and motivating landowners to pursue RMS development. Thus, SCS's role in assisting farmers to reduce groundwater contamination could be enhanced through clear Federal and State directives on groundwater protection as a component of conservation planning; full implementation of RMS and water quality materials in all field offices; and employee training on the use of these materials.

In 1985, Congress made SCS responsible for implementing the conservation cross-compliance provisions of the Food Security Act (FSA). The FSA directs SCS to develop "conservation compliance" plans by 1990 for all farmers having highly erodible lands who want to retain eligibility for Federal farm program payments. FSA conservation compliance requirements have nearly doubled the number of farmers using SCS assistance, currently estimated at about 1.5 million (122). SCS will continue to assist farmers on cross-compliance implementation in upcoming years, since conservation compliance plans must be fully implemented by 1995. Conservation compliance plans, however, constitute neither full conservation plans nor RMSs, and they have often incorporated weakened regulations on ''Alternative Conservation Practices, which permit higher levels of erosion than those called for in the original FSA legislation. Although FSA statutory requirements have increased the number of farmers seeking assistance from SCS, they have not necessarily fostered comprehensive conservation planning, because conservation compliance plans solely address erosion control on highly erodible lands.

Congress is considering further cross-compliance provisions involving agrichemical management planning to protect groundwater. If such legislation is passed, SCS will also likely be responsible for assisting farmers in developing agrichemical management plans. Policymakers will need to take into account key implementation issues in developing such provisions. SCS's current staffing and technical capabilities will need to be increased and expanded tithe agency is to implement agrichernical-related planning, because the agency's traditional expertise is in soil and water management. Clear goals and directives will also be needed, because local interpretation and flexibility in implementing management practices may make it difficult for SCS management plans to lead to significant reductions in groundwater contamination.

Agricultural Stabilization and Conservation Service

ASCS administers and distributes all Federal farm program payments to farmers who apply for programs at county ASCS offices. ASCS thus provides administrative and financial assistance to farmers, including ACP cost-share payments for implementing conservation practices. Local committees are responsible for approving the types of conservation structures and practices that are eligible at the local level for conservation cost-share payments.

ASCS's specific role in improving agrichemical management is through its current pilot cost-share project, Integrated Crop Management (ICM), which has been approved as an ACP practice. Impartially pays for consultant and scout services used by farmers to improve nutrient and pesticide management, up to $7/acre for field crops and $14/acre for specialty crops (151). The ASCS program will be tested in up to five counties in each State in 1990 and aims to achieve a 20 percent reduction in agrichemical use among participating farmers. If successful, the ICM program is likely to spur development and increase availability of field advisory services.

Public-Sector Assistance-State and Local Agencies

Information and assistance from State and local agencies complement Federal Government assistance and may be highly influential in farmers' decisionmaking. Although State and local governments vary widely in their organizational structures, decisionmaking committees, and roles of departments providing assistance to farmers and other landowners, some commonalities exist. Each State has a land-grant university with an associated CES and SAES to conduct research, education, and extension for the State's farmers. The land-grant university system thus is the primary public-sector source of information on agricultural production, agrichemical use, and agricultural resource management, including water quality. Each State also has a network of SCS district offices providing assistance to landowners on soil and water conservation. Although district offices advise farmers on conservation-related crop rotations and nutrient management to improve water quality, they have not been as heavily involved as CESs in agrichemical management assistance. In some States, other departments and agencies may play important roles in facilitating farmers' access to technical assistance.

Cooperative Extension Service

State CESs play the most important role in public-sector delivery of information and assistance to farmers, whose primary CES contacts are county or area extension agents in local offices and specialists at the land-grant university or experiment stations. CESs nationwide currently receive about 50 percent of their funding from State governments, 30 percent from the USDA Extension Service (ES), 17 percent from county governments, and 3 percent from private sources (48). As a result, CES program priorities are influenced most heavily by State needs and concerns, which may be identified by extension users and advisory groups, land-grant university administrators, and State legislatures. Priorities set at the national level (e.g., by the national Extension Committee on Organization and Policy are non-binding and may be less influential than State needs in affecting CES activities) (142). Regional committees formed by CESs in the four extension regions (Northeast, South, North Central, and West) may also set priorities for extension programs which address regional needs more specifically.

Reduced funding in recent years has forced many State CESs to cut staffing levels, particularly at the county level. Extension agents no longer have the time or resources to visit farms personally, and many agents make most of their contacts with farmers by telephone or through meetings where as many as several hundred farmers can receive information at a time (47). In the area of agrichemical management, CESs provide recommendations on fertilizer and pesticide selection, application rates, and handling practices. Common CES information dissemination formats include newsletters, technical bulletins, computer databases, and field days. However, CES contacts with farmers on agrichemical management have often been superseded by farmers' more frequent contacts with agrichemical dealers, whom farmers typically see immediately prior to making agrichemical purchases (175,70). Some CESs (e.g., Illinois) have established training programs for dealers, through whom CESs can indirectly reach more farmers on agrichemical management. Other CES activities related to agrichemicals and groundwater quality include soil testing services, water quality education programs, and pesticide applicator certification training funded through FIFRA.

Farmers interested in low-input or nonchemical practices have noted that CESs lack information and expertise on management practices based on crop rotations and reduced agrichemical use (140). Some CESs, however, are developing their capacities to provide assistance on low-input and nonchemical farming practices, particularly as components of Low-Input/Sustainable Agriculture (LISA) research and education projects (81). LISA projects are playing key roles in expanding research and information bases on use-reduction and nonchemical approaches to reducing groundwater contamination. Another information source for farmers, when assistance is not forthcoming from local extension sources, is the ATTRA hotline, which draws on CES resources nationwide and acts as a national clearinghouse for alternative agriculture information (see box 5-G).

State Departments of Agriculture

State Departments of Agriculture (DOAs) play important 'gate-keeping' roles in managing agrichemical use within their borders. State DOAs with EPA-approved pesticide programs can expand or restrict the State's range of pesticide uses by granting experimental or conditional permits for nonregistered pesticides and instituting restrictions that are more stringent than Federal regulations.

The State Department of Agriculture is the lead agency for administering pesticide applicator certification programs in all but 16 of the 57 States and U.S. territories (167). In order for a State to administer its own certification program, the State's program plan must meet minimum Federal requirements and be approved by Federal and regional EPA offices (38). EPA administers the certification program if the State's plan is not approved. EPA currently administers programs in only two States: Colorado and Nebraska.

Some departments may also administer programs that help farmers try new agricultural practices. The Minnesota Department of Agriculture, for example, offers a "Sustainable Agriculture Loan Program" for farmers to borrow up to $15,000 at 6-percent interest for purchases or installations providing environmental benefits. Minnesota's DOA also has established a "Sustainable Agriculture Demonstration Grants Program,' which provided $284,000 in funding in 1989 (up to $25,000 per recipient) to encourage farmers to demonstrate alternative practices (87).

State Conservation Agencies

State conservation agencies are distinct from State-level SCS offices. They may be organized as State government departments, departmental divisions, committees, boards, or commissions. State conservation agencies administer State conservation laws, regulations, and programs; oversee Federal soil and water conservation activities; and provide technical assistance and training related to conservation. Cooperative relationships include State water quality agencies, State Departments of Agriculture, EPA regional offices, and State-level SCS offices.

State Water Agencies

Many States have designated a water resources agency or board to coordinate groundwater protection activities. In some States these agencies are active in providing assistance to local communities to protect groundwater resources. The Massachusetts Water Resources Authority, for example, initiated a project in 1989 to assist 14 communities to collect data on water supplies and possible contamination sources, identify recharge and watershed areas, prioritize water supplies at greater risk, and develop resource protection plans for each

Box 5-G—ATTRA: National Information Source on Agrichemical Use Reduction and Alternative Practices

ATTRA (Appropriate Technology Transfer for Rural Areas) is a national information hotline service that collects and disseminates information on agricultural technologies and cropping systems that reduce agrichemical use while maintaining crop yields. ATTRA specialists gather information nationwide from a variety of sources: electronic databases, university researchers, extension specialists, the USDA National Agricultural Library, and networks of technical experts and practitioners. Any person can request free information from ATTRA in writing or by calling its toll-free hotline, although ATTRA asks that requesters first try to obtain needed information from their local extension services. ATTRA specialists respond to requests by sending informational materials; providing referrals to experts and practitioners; and discussing alternative technologies, practices, or crops that might be considered by the requester.

ATTRA provides two main categories of information: 1) farm practices that reduce off-site environmental impacts of agrichemical from leaching, drift, and runoff; and 2) production systems characterized by greater crop diversity, which can reduce the need for agrichemicals, particularly insecticides. Information requests from ATTRA are increasing by 50 to 60 percent each year. ATTRA responded to 2,600 and 4,100 requests in 1988 and 1989 respectively, and 3,300 in the first half of FY 1990 (79). Increased requests appear to reflect rising interest among farmers in technologies that reduce agrichemical and production costs. Thus, ATTRA appears to provide an easy, accessible centralized information source for farmers and consultants on reduced-input and alternative (biological and cultural) agricultural practices.

The ATTRA hotline was established in Memphis, Tennessee, in 1987 but was moved in 1989 to the University of Arkansas campus in Fayetteville, Arkansas. Congress appropriated $500,000 and $750,000, respectively, for ATTRA for FY 1987 and 1988 through USDA-Extension Service funding, but appropriated $900,000 in funding for FY 1989 through the U.S. Department of the Interior's Fish and Wildlife Service, Office of Information (79). Prospects for continued funding, however, are uncertain. The high level of public concern about agrichemical contamination of surface and groundwaters, which is not likely to subside in upcoming years, may provide Congress with a strong rationale for appropriating sufficient funding for ATTRA to meet increased demands for information.

ATTRA's address is P.O. Box 3657, Fayetteville, AR 72702. The hotline number is 1-800-346-9140.

community. The project employs a computer-based geographic information system to combine databases and identify critical areas (49).

A variety of other State departments and agencies (e.g., State Department of Health, State Geological Survey) administer or cooperate in research, monitoring, and other programs to provide information and assistance to farmers on groundwater. Georgia's Department of Agriculture, for example, received EPA funding to evaluate pesticide impacts on groundwater and is working with the State's Department of Natural Resources to conduct well sampling and testing (50). The Washington State Department of Ecology samples well water for agrichemicals to obtain information on which conditions lead to groundwater contamination (49).

Soil Conservation Districts

Conservation districts are special-purpose units of government, organized under State law, that plan and coordinate local soil and water conservation efforts (159,94). Local citizens establish conservation districts by electing boards or commissions that sign Memoranda of Understanding with the Secretary of Agriculture and SCS. SCS then assigns conservationists to the districts, which may hire support staff to help provide services to farmers and other landowners. Conservation districts are governed by their elected boards, and they are commonly organized as State government subdivisions that follow county boundaries. In some States (e.g., Nebraska, Georgia, and California), conservation districts follow watershed boundaries.[9] The approximately 3,000 conservation districts in the United States cover about 98 percent of non-Federal land. Conservation districts form private, nonprofit associations at the State level to coordinate activities, exchange information, and participate as members in the National Association of Conservation Districts.

[9]Exceptions are Wisconsin, where conservation districts are units of county government; and New Hampshire and Alaska, where the entire State is a SOS conservation district divided into subdistricts.

Conservation districts are important interfaces between Federal policy directives and local implementation efforts in agricultural conservation programs. Although SCS conservationists assigned to the districts must respond to Federal agricultural legislation and regulations, the extent and kinds of assistance that conservation districts offer to farmers will also depend on staffing levels, available funding, and local resource management priorities. Conservation districts ''review and approve, or concur with plans developed by SCS," and their governing bodies "establish general priorities for addressing identified resource concerns' jointly with SCS (160). Thus, the agricultural conservation programs and practices supported through conservation districts are heavily influenced by State and local priorities and landowner needs.

Since 1985, for example, conservation districts have had to devote a major share of their workload to helping farmers meet FSA requirements (e.g., Conservation Reserve Program; conservation compliance for highly erodible lands). A national survey of conservation districts conducted in 1990 indicates that FSA assistance currently supersedes all other program priorities (table 5-14) and that conservation districts have inadequate levels of personnel to meet needs in all program areas, particularly in water quality (93). Insufficient staffing and finding will make it difficult for conservation districts to help implement additional cross-compliance provisions related to groundwater quality (e.g., agrichemical management plans).

County Governments and Local Committees

County governments (or other local governmental entities) also play a role in providing technical assistance to farmers through county extension funding. The proportion of county extension funding, however, varies greatly from State to State and within States (48). In some States, counties provide no funding at all, while in other States, counties may provide as much as 60 percent of the funding needed to support a local extension agent.

A variety of local boards, committees, or commissions also help set priorities for extension and agricultural conservation programs. Local boards may have a high degree of influence on the assistance programs available to farmers and on the kinds of conservation practices that are supported technically and financially. Wide variation in the types of local groups and their relative influence on

Table 5-14-Types of Programs Conducted by Conservation Districts and Their Priority Rankings in 1990a

Program category	Mean priority ranking[b]
Food Security Act (conservation compliance, sod/swampbuster, conservation reserve)	4.09
Cropland erosion control	4.04
Water quality (nonpoint-source control)	3.91
Administrative support	3.69
Conservation education	3.64
Water quantity (irrigation, flood control, drainage)	3.35
Grazing land management	3.13
Urban erosion and sediment control	3.02
Municipal assistance (landfills, recycling, sludge disposal, etc.)	2.82
Forest management	2.66
Stormwater management	2.60
Mined land reclamation	2.40

[a]Survey conducted in December 1989. Survey results are based on responses from 1,982 conservation districts, or 67 percent of the total number of conservation districts nationality.

[b]Mean priority ranting scale: 1 = low priority to 5- high priority.

SOURCE: National Association of Conservation Districts, *America's Conservation Districts Workload Analysis Survey* (Washington, DC: March 1990), p. 1.

priority setting explains a large portion of the difficulty in implementing national priorities in resource conservation.

Private-Sector Assistance: Commercial Agricultural Services

Reducing groundwater contamination by agrichemicals will require more information for and management by farmers. Since many farmers may not have time or expertise to devote to additional information-gathering or management, one strategy is for farmers to purchase advisory or management services that minimize environmental contamination or help reduce agrichemical use. Commercial services to improve nutrient and pest management could be provided by: 1) service departments of agrichemical dealerships and agrichemical-supply cooperatives; 2) advisory service firms and cooperatives which do not sell agrichemicals; and 3) independent consultants and field scouts.

Dealerships and Cooperatives

Agrichemical dealerships and supply cooperatives have helped disseminate innovations that can reduce groundwater contamination potential. These include rope-wick application of herbicides onto weeds; agrichemical banding rather than broadcast application; and use of returnable pesticide containers or recyclable container systems. Many regional farm-supply cooperatives have developed advisory service packages that generate agrichemical recommendations based on individually tailored management plans or computer programs that adjust for soil tests and field characteristics (73). For example, Cenex-Land O'Lakes offers a crop management assistance program called AgriSource, which provides information on fertilizer application rates and pesticide compliance needs (21). Agway, Inc., a cooperative with over 100,000 members in the Northeast, offers an integrated crop management program incorporating Integrated Pest Management (IPM) strategies (171).

However, many cooperative advisory services, some of which are free-of-charge, serve as marketing techniques to encourage product sales. These services thus may conflict with goals to reduce agrichemical use as a way of protecting groundwater. Furthermore, the capacity of dealerships and farm-supply cooperatives to provide services that support alternative practices is not as well developed. Several features of agrichemical sales firms inhibit provision of information, advice, or innovations designed to reduce potential for groundwater contamination.

First, it is not in the interest of an agrichemical supplier to provide advisory services that ***reduce*** agrichemical use. Employees may not readily supply information to farmers about ways to reduce agrichemical use, because they are understandably reluctant to decrease sales (181,139). Recognizing this, some farmers obtain agrichemical recommendations only from firms that do not sell agrichemicals, since these firms do not have an interest in the amounts of agrichemicals sold (83). Care in selecting a reliable source of agrichemical recommendations is warranted; studies conducted by the University of Nebraska (106) and other land-grant universities indicate that fertilizer recommendations from some commercial testing labs were as much as two to three times higher than recommendations from university labs for identical soil samples (43). Since commercial labs in many cases are retained by dealers who have an economic stake in higher recommendations, farmers wanting to reduce environmental contamination by agrichemicals are likely to evaluate information sources carefully for potential conflicts of interest.

Second, employees of dealerships and cooperatives may simply not have the skills or expertise to offer advisory services that can help farmers reduce agrichemical use. Agrichemical supply f-need to develop and test services that replace product sales, because they face the risk of losing customers if they advise farmers incorrectly. Thus, agrichemical service firms are likely to require evidence that new services will keep their customers coming back and that service provision will be profitable. Some State CESs and professional trade associations offer training programs specifically designed for agrichemical dealers and their employees (70). Nebraska's Fertilizer & Agchem Association, for example, has established a Certified Crop Production Advisor Program to train and certify crop advisors (114).

Third, provision of advisory services by commercial agrichemical suppliers is constrained by current industry trends (175,56). These include a decline in the number of dealerships, liability concerns, and increased regulatory requirements which add to the cost of doing business (e.g., sales reporting, recordkeeping, construction standards, accident plans, spill reporting, secondary containment, and disposal). These factors are causing some dealers to go out of business and are making it difficult for agrichemical suppliers to offer new services, hire new employees with environmental expertise, or improve current employees' technical and communications skills.

In light of the above constraints, programs to enhance agrichemical dealers' and cooperatives' capacity to provide advisory services are likely to require economic, fiscal, or professional incentives. These include government-sponsored training programs, subsidies for employee training, and 'dealership accreditation" for firms that participate in training programs or offer specified services. Licensing requirements for agrichemical sales outlets could also specify training and services provision. The incentive to provide cost-saving advisory services may be greater for cooperatives than dealerships, however, because cooperatives are owned by their customers who ultimately benefit. Although advisory services would seem to be an attractive option for cooperatives, this strategy would require coordination and communication among cooperative members, directors, and managers. Regardless of the type of agrichemical sales firm, however, farmers are the ones who will ultimately pay for services and their development costs.

Independent Advisory Firms and Consultants

Advisory firms and independent crop consultants who do not sell agrichemicals can offer services without conflicts of interest associated with sales volumes. These firms and consultants are playing an increasingly important role in providing technical assistance to farmers, and groundwater protection concerns are likely to generate further demand for these services. Increasing the demand and availability of crop advisory services is one of the goals of the ASCS pilot program offering cost-share for "Integrated Crop Management" services in the 1990 to 1992 crop years. The ASCS program confers cost-share payment eligibility only on consultants not associated with agrichemical sales firms (151).

Development of advisory services will require adequate availability of persons who are trained and skilled in delivering needed services. Currently, professional organizations and trade associations are the best sources of information on agricultural firms and consultants offering environmental advisory services. In 1988, the number of agricultural consultants who were independent or employed by other firms was estimated at about 13,200 (table 5-15). The American Registry of Certified Professional Agricultural Consultants (ARCPACs), a certification program co-sponsored by the American Society of Agronomy, the Soil Science Society of America, and the Weed Science Society of America, also provides regional estimates of the numbers of trained agricultural professionals (4,125). Some States (e.g., Indiana) have established certification programs for agricultural consultants based on ARCPACs criteria. State licensing or certification programs for consultants can facilitate farmers' access to reliable services by trained advisors.

The public sector could assist the private sector in design, development, and delivery of advisory services in the following ways: 1) providing agronomic and economic information on feasibility of modified or reduced agrichemical applications; 2) training programs for employees; 3) education and licensing programs for advisors (e.g., IPM consultants, field scouts, crop advisors); and 4) education programs on innovative service delivery to replace products with services. Programs to enhance commercial fins' capacity to provide information and services on reduced-chemical use or nonchemical practices will expand farmers' management options overall.

Table 5-15-Numbers of Agricultural Consultants, National Estimates, 1989

Type of consultant	Estimated numbers
Independent	8,584
Employed by other firms (dealerships, cooperatives, agrichemical manufacturers)	4,664
Farm managers employed by banks, real estate firms, etc.	4,863
Farm managers employed by government agencies	5,463
Farm managers employed by large-sale farms or food processing firms	693
Others in allied fields (business or academia)	572
Total	24,839

SOURCE: *Ag. Consultant* (Willoughby, OH: Meister Publishing, June 1989).

Farmer Initiatives

Producer organizations and other farm membership groups have undertaken initiatives to test well-water, facilitate farmstead assessments, and educate members about groundwater vulnerability. The American Farm Bureau Federation, for example, has developed a "Self-Help Checklist for Farmsteads and Farm Fields" to help producers assess their farming operation's potential to affect groundwater supplies (3). Technical assistance programs can draw on producer initiatives as startup points for encouraging producers and other landowners to protect groundwater from contamination.

Information exchange among farmers is an important mechanism for disseminating information on farm practices. Farmer-to-farmer exchange complements information from formal sources in the public and private sectors and addresses constraints sometimes associated with these sources (e.g., conflicting information from different organizations, scarcity of information on alternative practices). Farmer-to-farmer information exchange may take on new and even greater importance in facilitating adoption of groundwater protection practices as a source of information relevant to local conditions and producers' experiences. Mechanisms for farmer-to-farmer information exchange include farmer-to-farmer referral networks (103), crop management associations (19), and soil and water conservation groups. These can provide farmers with peer and community support and help them determine which groundwater protection practices are feasible and profitable.

Farmer-to-Farmer Networks

Many farmers experimenting with reduced-chemical-input, biological pest control, or other nonchemical. farming practices have perceived that the agricultural research and extension community has been uninterested in or uninformed about such practices (140). Furthermore, alternative farming practices tend to require a greater understanding of farming systems interactions and longer adoption periods during which producers can test and adapt them gradually. As a result, farmers interested in alternative approaches have largely sought information and advice from each other, forming what are referred to as ''farmer-to-farmer networks" (103).

Some of these networks are highly informal, while some have incorporated as nonprofit membership organizations to provide information and assistance to other farmers. In some cases, nonprofit organizations have facilitated the development of farmer networks. Private nonprofit organizations associated with farmer-to-farmer networks vary widely in composition and structure, and many employ full-time help to provide technical support. Some organizations are composed entirely of farmer-members, such as Practical Farmers of Iowa, while other organizations, such as the Land Stewardship Project in Minnesota, have broader memberships that include nonfarmers interested in supporting land stewardship efforts.

Farmer-to-farmer networks have up to three functions: 1) on-farm experimentation, 2) information-gathering through contacts with external sources of assistance, and 3) information dissemination through educational programs or field demonstrations. All organizations provide some type of information and technical assistance on alternative practices, and these may range from improved agrichemical management techniques to reduced-chemical-input methods to organic cropping systems. OTA estimates that at least 100 such organizations existed in the United States in 1988. In October 1988, OTA sent survey questionnaires to 40 of these organizations representing a wide geographic range and received 29 responses (table 5-16) (140).

Most of the organizations that responded to the survey are involved in investigating and sharing information on alternatives to agrichemical inputs (box 5-H). Surveyed organizations reported conducting education, demonstration, and information-sharing, either through interested volunteers or paid

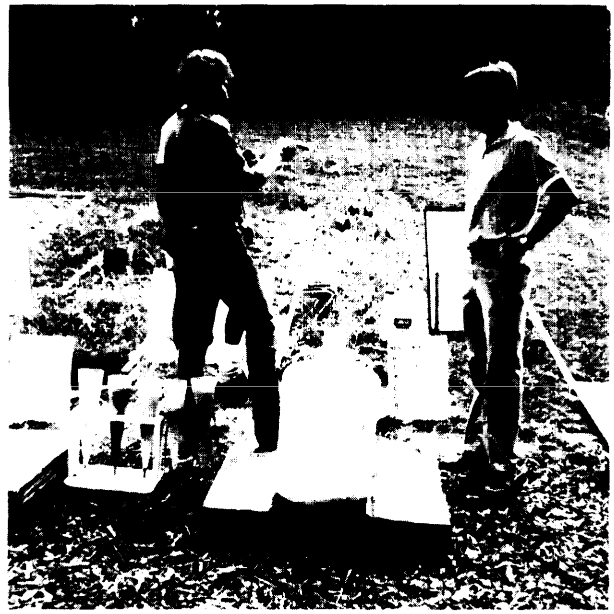


Photo credit: Office of Technology Assessment

Field days sponsored by educational organizations and farmer-to-farmer networks serve to disseminate information on improved agrichemical management and reduced-chemical and alternative farming practices. Here, test plots are viewed at the Chesapeake Bay Foundation's Claggett Farm.

staff. Organizational activities are funded either by member donations, foundation grants, or contributions from other sources such as churches or endowments. Most organizations are small, with five or fewer full-time staff and median budgets in the $100,000 to $150,000 range. Half of the organizations operate at the State or sub-State level. The median number of farmers providing information per organization is 50 to 100, with 300 to 400 farmers receiving information. Twenty-five of the twenty-nine respondents worked with State land-grant university researchers in 1987-88, and 20 had cooperative projects with CESs that year. The organizations' most frequently cited information dissemination methods were farmer meetings, workshops, and field demonstrations.

Farmer-to-farmer networks and their associated support organizations are emerging as important local sources of information on reduced-agrichemical practices and nonchemical practices and production systems (103). Two-thirds of the groups responding to the survey had been established after 1976, with the three newest ones starting in 1987. Recent increases in numbers of these groups appear to indicate a growing interest among farmers in

Table 5-16-OTA Survey Respondents: Private[a] Nonprofit Organizations Associated With Farmer-to-Farmer Networks

Name	Location
Alternative Energy Resources Organization (AERO)	Helena, MT
California Certified Organic Farmers	Santa Cruz, CA
California Clean Growers Association	Dinuba, CA
California Institute for Rural Studies	Bakersfield, CA
Center for Holistic Resource Management, Inc.	Albuquerque, NM
Claggett Farm, Chesapeake Bay Foundation	Upper Marlboro, MD
Committee for Sustainable Agriculture	Colfax, CA
High Desert Research Farm	Abiquiu, NM
Iowa Natural Heritage Foundation	Des Moines, IA
Kansas Rural Center	Whiting, KS
The Kerr Center for Sustainable Agriculture, Inc.	Poteau, OK
Land Stewardship Project	Marine, MN
Maine Organic Farmers	Augusta ,ME
Meadowcreek Project	Fox, AR
Michael Fields Agricultural Institute	East Troy, WI
Nebraska Sustainable Agriculture Society	Hartington, NE
New Alchemy Institute	East Falmouth, MA
Northern Plains Sustainable Agriculture Society	Windsor, ND
Ohio Ecological Food and Farm Association	Plymouth, OH
Oregon Tilth, Inc.	Tualatin, OR
Practical Farmers of Iowa.	Boone, 1A
Rodale Institute-Wisconsin	Lodi, WI
Rodale Insitute-Arkansas	Fox, AR
Sunny Valley Foundation	New Milford, CT
Virginia Association of Biological Farmers	Flint Hill, VA
Winrock International, Inc.[b]	Morrilton, AR
Wisconsin Rural Development Center	Black Earth, WI

[a]Survey questionnaires also were sent to two Resource Conservation and Development Districts (RC&Ds) for information on exam pies of RC&D activities. RC&Ds are publicly funded organizations associated with local soil and water conservation districts, and they promote a wide variety of projects, including include resource planning and technical assistance for farmers and ranchers to reduce soil erosion and protect water resources. West Stanislaus RC&D in Patterson, CA, conducts irrigation seminars but notes a lack of locally applicable practices to address acute groundwater problems in its area. Seneca Trail RC&D in Franklinville, NY, is not directly involved in practices for reducing groundwater contamination but provides assistance on rotational grazing and no-till seeding which reduce erosion and runoff. RC&Ds provide potential structures for assisting farmers in implementing practices to improve groundwater quality.

[b]Winrock International institute for Agricultural Development, Inc. does not directly work with farmer-to-farmer networks but is lead organization for a farmer extension/research project and farming systems database involving 18 organizations.

SOURCE: Office of Technology Assessment, 1990.

alternative practices. Because farmers in local networks have had more experience in developing farming systems that aim to reduce agrichemical use, they offer important sources of assistance on use-reduction and nonchemical approaches to groundwater protection. Farmer-to-farmer networks also offer research and extension opportunities for documenting production practices to reduce groundwater contamination that are specific for local climatic, topographic, and hydrogeologic conditions. Closer examination of these farmers' production records and methods will be required in order to evaluate the profitability, production potential, and water-quality impacts of these systems.

Some land-grant universities have established formal working relationships with farmer-to-farmer networks (55). These universities are seeking technical observations and information from farmers on biological and cultural practices, a process that might be considered ''reverse technology transfer. A key advantage to working with farmer-to-farmer networks is their ability to provide locally relevant, area-specific information on management practices that can serve to offset agrichemical use. A possible drawback, however, is that farmers associated with many networks are not viewed as "typical,' because their primary strategy for maintaining economic viability is to reduce costs rather than expand their operations (140). Nevertheless, land-grant university collaboration with farmer networks is one way for universities to respond to criticisms that the traditional agricultural research and extension system has overly emphasized research that favors large-farm, capital-intensive agriculture.

Box 5-H—Alternative Farming Practices: Examples Cited by Farmer-to-Farmer Networks in OTA Survey (categories in order of decreasing frequency)

Animal Manure Management—Uses of animal manure as substitute for commercial nitrogen fertilizers; collection and storage of animal wastes; control of run-off from storage sites or fields; comporting; application timing and method.

Cropping Practices-Optimal sequences for crop rotations; identification of crop rotations and component crops best suited to region; cover cropping; uses of legumes or green manures as substitutes for commercial nitrogen fertilizers; intercropping of legumes and grains to test crop complementarily; use of legumes for improved nutrition for livestock hay and pasture.

Tillage Practices—Experimentation with various types of tillage equipment, e.g., harrows, rod weeds, undercutter; rotary hoes; effectiveness of tillage methods; combinations of tillage and reduced herbicide applications as weed control system.

Comporting and Mulching Methods—Use of mulches to prevent water loss; use of mulches to add nutrients to soil and discourage weed growth; comporting as a method of reducing waste runoff and leaching to groundwater comporting as a method for building soil organic matter.

Soil ***Testing-soil*** testing for nitrogen to reduce the amount of purchased nitrogen fertilizer; identification of most effective times and methods for applying animal wastes; effectiveness of cover crops and crop rotations in building soil nitrogen.

Economic Comparisons—Economic comparisons of herbicide-based weed control systems v. tillage-based weed control; general economic comparisons between experimental and current practices.

Pasture Utilization and Management-Grazing management methods, including rotational grazing; increased pasture diversity and legume use; multiple species grazing.

Biological Insect and Nematode Controls-Use of diatomaceous earth for internal and external livestock parasites; use of pheromones to control oriental fruit moth; effect of increased soil organic matter on nematode control.

Biological Weed Controls-Use of rye (which has allelopathic properties) as a cover crop to control weeds; use of walnut leaves to control weeds; rotational sheep grazing as weed control method.

SOURCE: Responses to OTA "Survey of Private, Nonprofit Organizations' Activities in Research, Education, and Public Policy on Farming Practices That Can Reduce Groundwater Contamination," November 1988, summarized in OTA contractor report by Turck and Kroese, 1989.

Therefore, land-grant university support of peer-based information exchange within farmer-to-farmer networks can complement CES's more centralized mode of information and assistance delivery. In the next decade, universities collaborating with farmer networks are likely to be the institutions most readily able to supply farmers with information and recommendations that fall under the use-reduction and nonchemical approaches to reducing groundwater contamination.

Crop Management Associations

Crop Management Associations (CMAs) are local, farmer-run, nonprofit organizations in Pennsylvania, in which farmer-members pool resources to hire their own full-time technical help (19). Many farmers in Pennsylvania are dairy farmers, with average farm size of 150 to 200 acres, and they often apply "insurance' treatments of agrichemicals because they lack the time to monitor field conditions closely (119). The first CMA began in 1979 when farmers requested organizational help from their county extension agent. The Pennsylvania State CES currently coordinates a statewide CMA program, in which members pay annual membership dues plus per-acre fees to employ their own field scouts or "consultants. '

The current CMA program has 13 CMAs, employing 15 full-time consultants with undergraduate interns providing summer help. CMA consultants, who typically hold bachelor's degrees in agronomy or related areas, gather and record crop production data, scout insect populations, monitor crop diseases and nutrient deficiencies, and help keep production cost records. CMA members have documented up to 75 percent savings in production costs for chemicals, labor, and equipment resulting from weekly field insect scouting (75).

Since the beginning of the CMA program, some CMAs have stopped functioning while others have been highly successful. The main problem with the CMA program is difficulty in recruiting and retaining good consultants, because the key to CMA success is a competent consultant who has the trust and confidence of its members. Members who are not satisfied with their consultant's performance tend to drop out of CMAs. Since CMA consultant jobs provide excellent learning experiences, many consultants leave after 1 or 2 years after being offered better-paying jobs with agrichemical companies or independent consultant fins.

The Pennsylvania CES is trying to find solutions to the problem of employee retainment by advising CMAs on how to provide better salaries that will keep talented people working for them. CMA members are currently paying about $3 to $4/acre for consultant services, which provides annual salaries of only $14,000/year. Pennsylvania's CES estimates that the minimum payment needed to retain a consultant at an annual salary of $20,000 would be $7/acre. Since the average CMA involves 25 farms and 4,000 acres, $7/acre fees and annual membership dues of $100/farm would generate $30,000 to cover a consultant's salary and operating expenses.

Only an estimated 1 to 2 percent of Pennsylvania's farmers participate in CMAs, presumably due to the difficulty in convincing farmers that consultant services are worth their cost (1 19). Consequently, the Pennsylvania CES is developing a farm recordkeeping system for personal computers, which could make recordkeeping faster and easier; next year CES plans to assist 100 farmers in their recordkeeping in order to document agrichemical and other expenditures and the costs and savings from consultant services. Thus, if staffing problems can be resolved and adequate documentation of cost-savings provided, CMAs could be an effective mechanism for CES to extend its resources and provide technical assistance to larger numbers of farmers.

Financial Assistance for Water Quality Protection

Cost-share and other financial incentive programs can encourage farmers and ranchers to implement groundwater protection practices. Possible vehicles for such financial assistance include Federal, State, and local government programs. However, States have primary responsibility for most environmental programs, and policymakers must recognize that State financial assistance to landowners for groundwater protection will have to compete with a growing number of other environmental program being implemented by the States. The ***1989*** National Governor's Association (NGA) report emphasizes that States' environmental program costs are quickly outstripping government revenues (95). By the year 2000, annual Federal, State, and local costs for all environmental programs are projected to reach $60 billion, up from $31 billion in 1977 (134).

State environmental protection programs can receive funding from three principal sources: 1) Federal grants designated for environmental operating budgets, construction, or capital improvements (including Federal cost-share programs); 2) State general revenues, which come from income, sales, and property taxes; and 3) State sources other than general revenues, sometimes called "Alternative Financing Mechanisms" (AFMs), which include user fees, permit fees, pollution discharge fees, environmental taxes, bonds, revolving loan funds, and compliance penalties. AFMs have become common sources of capital and revenue for specific environmental activities.

State funding allocated to county or watershed programs may also be supplemented with revenues from county or municipal governments or special units of government, such as Soil and Water Conservation Districts. Potential sources of State funding (general revenue funds and AFMs) have been administered in three ways:

- State cost-share funds administered through State agricultural or conservation agencies and local Conservation Districts,
- low-interest loan programs, and
- property tax breaks.

Appendix 5-1 demonstrates the variety of cost-share and financial incentive programs by which States have already attempted to address a range of resource management problems in agriculture. Some mechanisms allocate general revenue funds for high-priority resource areas, while others establish new income sources (AFMs).

Federal contributions to States' environmental programs have declined in the last 10 years. Overall, EPA grants to States for environmental operations budgets dropped 42 percent (from ***$499*** million to $288 million, based on 1988 dollars), between 1979 and 1988. Water quality funding fell by 50 percent during the same period from $217 million to $108 million (134). Thus, even as States increased their environmental programs, they received less from the Federal Government.

Funding new environmental programs also has been difficult because many States' general revenues have remained at previous levels or declined. The NGA reported that 44 States have implemented a total of 431 different AFM programs, which generate $3.2 billion for States' environmental budgets. The NGA report noted that AFMs currently support 11 to 20 percent of State environmental budgets but that this proportion is not likely to become larger (95). New monies received from AFMs, however, have often replaced general revenues that were shifted to nonenvironmental programs, resulting in little net gain in environmental program support. Many State officials believe that future environmental protection demands will have to be met through increases in general revenues. Thus, if Federal funding trends continue, and State and local governments shoulder primary financial responsibility, the public must recognize that increases in sales, property, or income taxes are likely to be needed for implementation of new environmental programs.

Public-Sector Coordination To Enhance Technical Assistance

States can improve mechanisms to expedite research, coordinate agency actions, and disseminate information on agricultural management to protect groundwater resources. Problem areas can be identified, and agricultural practices appropriate for local soil, water, and other resource conditions in the State can be developed and promoted.

Various multi-State, State, and sub-State management programs have been established to address single or multiple resource concerns. However, most current programs, which focus on one or a few resources, have arisen from separate legislative origins and are administered by different agencies or divisions. Producers or landowners who seek assistance on comprehensive resource management face difficulties in bridging the separate "turfs" created by different agencies and their programs. Some landowners may not pursue efforts to improve resource management because they hear conflicting messages from public agencies. Thus, many current programs are not designed or managed to provide landowners with information on dealing with the whole range of resource concerns. One exception is Iowa's Integrated Farm Management Demonstration program, which provides "packages" of information and assistance to farmers on soil, water, and other crop management practices (see box 5-I).

Agricultural decisionmakers today may be concerned not only about groundwater contamination, but also about groundwater depletion, surface water pollution, soil erosion, sediment deposition, wetlands protection, and loss of wildlife habitat. With Shrinking revenues and growing environmental costs, creation of a separate groundwater protection program may be less cost-effective and more duplicative than a program which builds on existing resource programs. Just as producers need to consider all relevant resource concerns in making farm or ranch management decisions, State and local governments need to develop mechanisms to review, prioritize, and coordinate their efforts in delivering resource management assistance.

In addition, individual or scattered efforts by self-motivated producers to seek information and implement improved management practices may not be sufficient to achieve desired reductions in groundwater contamination over broad regions. If States and local communities are to achieve groundwater protection across broad areas overlying critical aquifers, strong public support for protection efforts needs to be communicated to all landowners involved. Landowners will be much more motivated to consider off-site impacts and groundwater quality if they are made aware of the surrounding community's interest in improved resource management (75). Thus, landowners' voluntary actions may depend on hearing coordinated messages from the public as well as from government agencies.

Some mechanisms already exist to effect broad-based coordination and public participation that can influence individual decisionmaking on resource management. These include decisionmaking through Soil and Water Conservation Districts, Resource Conservation and Development Districts, and State Water Quality Management Boards. Other procedures such as Coordinated Resource Management Planning could be assessed for their potential

Box 5-I—Iowa's Integrated Farm Management Demonstration Projects

As the Nation's highest ranking State in agrichemical use, Iowa has taken a leadership role in implementing demonstration projects to encourage voluntary improvements in agnchemical management. Projects are designed to improve nutrient, pesticide, crop, soil, and water management on Iowa farms and promote the integration of agrichemical management techniques with tillage and cropping practices. Demonstration projects thus aim to address several resource degradation problems at once, including groundwater and surface water contamination from agrichemicals, soil erosion, and Iowa's high consumption of nonrenewable fuels (used in the manufacture of fertilizers and pesticides).

All projects demonstrate combined "Best Management Practices" (BMPs) or integrated management techniques, such as evaluating nitrogen placement or herbicide banding with ridge tillage (65). However, different projects may emphasize certain practices depending on local resource concerns, production systems, and participant organizations. Many demonstrations involve water chemistry monitoring; testing of soils, manures, and plant tissues; pest scouting and crop monitoring; measurements of energy consumption; and pesticide sprayer calibration. In some cases, farmers also are assisted with crop enterprise recordkeeping, crop, livestock and land management inventories, and cost-share for consultant services (64).

Demonstration projects have been funded with oil overcharge monies from the Iowa's Agricultural Energy Management Fund, agrichemical taxes and fees authorized by the Iowa Groundwater Protection Act of 1987, and State general revenues. Project implementation has involved broad-based cooperation and coordination among: 1) State agencies, including the Iowa Department of Agriculture and Land Stewardship (DALS) and Iowa Department of Natural Resources (DNR); 2) Iowa's three public universities, including Iowa State University's Cooperative Extension Service (CES) and State Agricultural Experiment Station (SAES); 3) nonprofit farm and conservation groups, such as the Iowa Natural Heritage Foundation and Practical Farmers of Iowa; and 4) USDA's Agricultural Research Service and Soil Conservation Service. Iowa's farm management education and demonstration efforts include five major projects.

Integrated Farm Management Demonstration Project—The Integrated Farm Management (EM) Demonstration Project is a statewide, 5-year project begun in 1987. Iowa's CES and SAES have set up demonstration sites at more than 300 locations, some in each of Iowa's 99 counties. Although some demonstration sites are located at university research centers, the majority of demonstration sites are in farmers' fields. Extension staff design, set up, and provide most of the labor and management required by the experimental plots, with farmers providing land, supplies, and some labor. However, some projects are wholly operated by farmers. Each demonstration shows replicated plots of several different management treatments for comparison, including a treatment using farmers' current practices (64). The project, authorized to continue through the 1991 crop year, also has survey and evaluation components to monitor local farmers' receptivity to educational programs and effectiveness of project efforts in changing farm practices to protect groundwater (110,30).

Butler County Integrated Crop Management Cost-Share Project—The Butler County Integrated Crop Management (ICM) project is a 3-year pilot program which provides cost-share assistance to 50 farmer-cooperators for implementing agrichemical-related BMPs. The purpose of the project is to assess how crop advisory services can improve farmers' profitability and management practices. Because the costs of advisory services to farmers are being phased in gradually, the project also provides a test to see how services provision can be transferred to the private sector over the 3-year period. In the first year, farmers are provided with services free-charge by six field scouts trained by CES. The farmer-cooperators are expected to pay $1.50 and $3.00 per acre for scout services in the second and third years, respectively, and then take over full payment for scout services when the project is over. In 1989, the total cost of services was estimated at $4.50 per acre, with farmers saving about $20 per acre in agrichemical costs. That year the 50 cooperators reduced nitrogen applications by about 260,000 pounds and improved their net income overall by a total of $500,000. One farmer-cooperator reported avoiding a loss of $42,000 due to timely treatment of cutworms, while another saved $15,000 in additional fertilizer costs when soil tests showed that he did not have to add phosphorus and potassium (66).

Watershed-Based Projects—Farm demonstration projects in three Iowa watersheds have also been established to evaluate current farm practices, provide information on BMPs, and monitor BMP implementation. The frost and best known project, located in the Big Spring Basin of northeast Iowa, has provided a unique outdoor 'laboratory' to observe groundwater impacts of farming activities in karst areas, because Big Spring is a completely agricultural

Continued on next page

Box 5-I—Iowa's Integrated Farm Management Demonstration Projects-Continued

108-square-mile watershed draining into a single outflow (52). Virtually all 300 farmers in the Big Spring Basin, an intensive livestock and grain area, received information on groundwater impacts and recommended manure and fertilizer practices (69). About 40 percent of Big Spring Basin farmers had reduced their nitrogen applications after 2 years (108). In addition, Iowa CES established two other watershed projects, each with about ten cooperators, in Audubon and Clayton Counties to demonstrate BMPs. Cooperating farmers have documented nitrogen reductions of up to 20 percent of nitrogen and lower herbicide expenditures (67).

Model Farms Demonstration Project—Based on favorable results of previous farm demonstration projects, the Iowa Legislature in 1989 appropriated $600,000 per year over 3 years for five additional "model farm demonstration projects." The model farm demonstration projects will be designed to enhance farm profitability and reduce environmental impacts of row crop production. The model farm projects, patterned after the Big Spring and Butler County projects, will provide information and demonstrations of integrated farm management packages involving 15 to 50 farm demonstrators per project, with information "marketed" to residents in each multi-country area, reaching an estimated total of 2,050,000 people statewide over the course of the project (53). All projects will enlist the participation of local government, farm, and conservation groups. Three of the projects will involve a 3-year phase-in of crop advisory services described above, including expanded training of crop consultants, agrichemical dealers, and staff of farm supply cooperatives.

Additional Public Education Inititives-In addition to its integrated approach to resource protection on farms, Iowa is funding resource protection and education efforts to reach significant numbers of urban and rural nonfarm populations as well. The Resource Enhancement and Protection Act (REAP) of 1989 authorizes expenditures totaling $300 million over the next 10 years for environmental programs, using revenues from State corporate income taxes, the State lottery, and a State-sponsored credit card (57). REAP provides funding to county conservation boards and creates county and regional "Resources Enhancement Committees," composed of government, farm, conservation, and other local representatives, to develop 5-year plans for proposing and implementing resource enhancement projects. REAP also authorizes funds for purchase of public lands for permanent land retirement and resource protection and for permanent conservation plantings, all of which could have major groundwater quality impacts. Finally, REAP provides funds for water quality protection projects which integrate traditional soil conservation cost-share payments with agrichemical management initiatives.

Public education efforts like those provided for in REAP could help urban and rural residents recognize that they share responsibilities with farmers in protecting the State's natural resources. Such programs have potential to encourage adoption of improved farm management practices in three ways: 1) encouraging urban and rural residents to "clean up their own acts, " since farm residents are likely to resent being ''singled out' on resource protection efforts; 2) influencing nonfarm populations to financially support programs that help farmers implement resource-protecting practices; and 3) stimulating broad-based local participation in resource protection efforts and encouraging communication between nonfarm residents and farmers on local priorities and goals for resource protection.

to help producers integrate resource management concerns (5). Program coordination at the State level could be greatly improved and public input could be broadened to build and communicate support for integrated resource management in agriculture.

Several agencies have developed agrichemical management and water quality programs and educational materials that could be incorporated into more comprehensive farm resource management planning. These include CES fertilizer and pesticide recommendations, soil testing and field scouting programs, educational materials on water quality, and SCS information on water quality and Best Management Practices. Effective use of these materials and programs in agricultural resource management, however, depends on: 1) the validity and usefulness of available information; 2) the degree to which extension agents and conservationists understand and integrate the information into daily procedures; 3) extension agents' and conservationists' skills in conveying new information and techniques to landowners; and 4) their degree of commitment in using the materials and convincing landowners of the importance and trade-offs of incorporating water quality and other resource concerns into decisionmaking. CES and SCS efforts could be coordinated better with each other and with those of conservation districts and State government agencies to ensure improved and consistent use and updating of water quality materials.

A 1989 National Governors' Association (NGA) report on State initiatives addressing agricultural impacts on water quality recognized regulatory approaches as often being ''impractical and ineffective' and emphasized the use of voluntary approaches in encouraging farmers to reduce adverse environmental impacts from their farm operations (95). In supporting voluntary approaches, the report cited five main strategies for States to consider in setting program priorities:

1. emphasizing education and technical assistance for farmers;
2. investing in research designed to address the biggest information gaps and to assist areas in greatest need;
3. initially placing highest priority on program efforts with lowest costs and greatest potential impacts;
4. building a comprehensive approach to resource protection, including surface water, groundwater, and soil erosion; and
5. including public education in State efforts.

These strategies will require coordination and commitment of a wide variety of State and local agencies, as well as input from State and regional offices of Federal agencies, in order to facilitate communication, promote implementation, and allow for adequate program monitoring and evaluation.

A public-sector framework of State and local agencies and local conservation districts already is in place to provide technical and financial assistance to farmers on reducing agrichemical contamination of groundwater. However, some problems and obstacles will need to be addressed to make the system more effective in delivering needed information and assistance, and specific changes relative to agrichemical management will need to be implemented. Whenever possible, public-sector assistance should support development of private-sector capacity to provide information and assistance.

RESEARCH, EXTENSION, AND EDUCATION TO ENHANCE DECISIOMAKING

In response to perceived public needs, the agricultural research and extension community has in the past given highest priority to increased production efficiency, providing a cheap, stable, and abundant food supply and increasing food for export. U.S. agriculture today, however, faces broader, long-term public demands to reduce environmental pollution and protect natural resources in agriculture. These latter objectives, however, often are of low priority for individual farmers confronted with short-term economic pressures. Farmers and the public will need to share responsibility for natural resource protection if U.S. agriculture is to move away from its emphasis on individual, production-oriented decisionmaking toward a greater integration of individual and societal objectives that also emphasize environmental quality.

Satisfying the broader demands placed on U.S. agriculture will require a wider range of research, extension, and implementation efforts that place higher priority on natural resource protection and environmental quality. Decisionmaking for groundwater protection represents only one aspect of the societal need to protect natural resources in agriculture. Thus, a comprehensive approach to natural resource protection in agriculture will not focus solely on groundwater protection-it will also address the need to maintain surface water quality, air quality, water quantity, land and energy supplies, soil productivity, plant and animal diversity, and the pool of human knowledge and skills needed to manage these resources. Programs to assist farmers in making management decisions to protect groundwater could fit into a broader research and extension strategy to enhance farmer decisionmaking to protect natural resources overall.

Enhanced Decisionmaking for Natural Resource Protection in Agriculture

Enhanced farmer decisionmaking for natural resource protection is characterized by:

1. an understanding of the farm's natural resource protection needs and appropriate priorities, which will depend on the type of farm and the farm's physical setting;
2. an understanding of the farm as a system of interrelated components and its relation to the surrounding environment; and
3. an ability to integrate resource protection and production objectives in short- and long-term planning and decisionmaking.

If a farm is located in a hydrogeologically vulnerable setting, or if agrichemical management practices are associated with a high degree of contamination risk, the farmer's need to reduce groundwater contamination will be a higher priority than some other resource concerns. In different settings or production systems, other natural resource concerns may need to be of higher priority in management plans. Thus, programs to enhance farmer decisionmaking will not only have to be broad but also flexible and adaptable to the site-specific natural resource protection needs of each farm.

Enhanced farmer decisionmaking to protect natural resources on a comprehensive basis will require improved decisionmaking by researchers, policymakers, and technical assistance agencies. Broader, multi-objective responses from the research and extension community will be more complex and interdisciplinary than previous efforts emphasizing production (120). This broader approach will require greater attention to decisionmaking and increased coordination and linkages among research, extension, farmers, policymakers, and the public. Thus, multi-objective research and extension efforts will require increased use of the social sciences and greater support for interdisciplinary research and extension. The United States' capacity to support groundwater protection decisionmaking through its research, extension, and education systems will be framed by these systems' capacities to support natural resource protection decisionmaking in general.

Research and Extension Needs To Enhance Decisionmaking

The U.S. public agricultural research system is linked to an extensive information and assistance delivery system made up of State and Federal extension, conservation, and financial agencies (146,142,40,16,97). To date, agricultural research priorities- shaped by individual scientists' interests, Federal competitive grants programs, State legislative priorities, agricultural experiment station policies, scientific societies, and trade associations—have primarily emphasized technological research for obtaining "low cost, safe food, and efficient production" (82). As a result, technology-based priorities have also been emphasized in the agricultural information and assistance delivery system. Less attention has been paid to farmer constraints to adopting technologies (101) and to socioeconomic and environmental impacts that can result from technology adoption (1 15).

Need for Broader Research Input and Two-Way Information Exchange

Although the U.S. agricultural research and extension system was originally created to meet farmer needs, the main focus of the research and extension system has shifted since World War II toward development of science-based production technologies (115). Less emphasis has been placed on farmer needs and constraints, particularly as they relate to natural resource protection in agriculture. To a great extent, the prevailing agricultural technology transfer process can now be characterized as a "top-down" and centralized flow of information from researchers to extension specialists to progressive farmers having the management skills and capital resources to invest in new technologies (128,16). The prevailing model of agricultural technology transfer also embodies a widely accepted view that innovations will spread from progressive farmers to less innovative farmers (see box 5-J). The prevailing perspective on technology transfer has been useful in explaining farmer adoption of commercially successful technologies that increase productivity or net returns, but it has not been as applicable to understanding adoption of less profitable, "environmental" technologies that protect natural resources (113).

Similarly, the technology-based, top-down approach to agricultural research and extension has worked extremely well in promoting productivity increases, but it may not work as well in facilitating natural resource protection (103). In fact, the current agricultural research and extension system's record in promoting natural resource protection in U.S. agriculture is relatively poor—American farmers continue to lose 3 billion tons of topsoil every year, and many areas of the country have failed to achieve extensive implementation of farming practices that reduce soil erosion and water quality degradation (34,103). Since natural resource protection practices for agriculture (e.g., BMPs) typically have been developed and presented to farmers through "top-down" research and extension programs, inappropriate technology transfer approaches may be one reason why farmers have not extensively adopted natural resource protection practices throughout the United States (113).

Prevailing views on the agricultural technology transfer process appear to have shaped research and extension relationships with farmers over the last

Box 5-J—Agricultural Innovations and the Legacy of Diffusion Research

"Diffusion" in agriculture is the process by which innovations, or different ideas, are communicated and adopted among farmers over time (128). The most influential early article on diffusion of innovations was on adoption of hybrid corn in Iowa (130). Diffusion research on farmer adoption of hybrid corn and other commercially successful innovations has led to widely held perceptions among agricultural researchers about the ways innovations spread among farmers.

Hybrid corn was developed by researchers at Iowa State University and other hind-grant universities and released in Iowa in 1928, Farmers prior to that time grew their own open-pollinated corn and saved seed for planting the following year. Hybrid corn increased yields per acre by 20 percent but lost its yield-producing vigor if planted the next year. Farmers switching to hybrid corn thus had to purchase seed every year, which meant significant changes in management behavior. Agricultural extension agents and seed salespersons heavily promoted the innovation (128).

Ryan and Gross traced the adoption of hybrid corn among 259 Iowa farmers between 1928 and 1941. They found that the adoption rate formed an "S-shaped curve" over time. Only 10 percent of the farmers had adopted hybrid corn in the first 5 years, after which the number of adopters increased rapidly. About 40 percent of the farmers adopted hybrid corn by 1936, with the adoption curve soon leveling off as fewer and fewer non-adopters remained. Early adopters were described in positive terms as ''innovators' and were observed to have larger farms, higher incomes, and more education. Non-adopters were described in negative terms (e.g., 'laggards '), and were observed to be less educated or less well-traveled (20,130).

Diffusion studies of hybrid corn and other highly profitable agricultural technologies, such as commercial. fertilizer, in the 1940s and 1950s established the precedent for a ''classical diffusion model" in adoption research (42). By the 1970s, however, social scientists were beginning to find flaws in the classical model: 1) a ''pro-innovation bias, ' which caused researchers to view all innovations as improvements over existing practices; 2) an "individual-blame bias," when individuals did not adopt an innovation, rather than finding some fault with the "system" or change agent; and 3) overemphasis on centralized ''top-down' communication from researcher to successful farmer to rank-and-file farmer, with inattention to farmer-to-farmer information exchange as a means of disseminating information (128,77).

Although rural sociologists recognize shortcomings of the classical diffusion model, agricultural scientists in other disciplines may not be sufficiently informed about the limitations of the diffusion model. Many scientists' perceptions about farmer adoption of innovations are still shaped by the classical model, which may cause them to approach research and extension with the model's biases (24). A pro-innovation research perspective, however, could lead to unrealistic expectations about simple solutions, or ''technological fixes' for groundwater contamination and other environmental problems in agriculture. Too much emphasis may be placed on developing bio-engineered products, for example, at the expense of research on improving management practices and information delivery methods.

The pro-innovation perspective in agriculture also may help explain some researchers' and farmers' views that certain technologies, such as crop rotations, represent the "horse-and-buggy days" and are steps ''backward' for the farmer. Research and extension perspectives on the nature and desirability of innovations will influence the research base and educational approaches taken to encourage farmers to change behavior or practices (128,25,75).

five decades. Farmers who have interacted most with researchers in the past have frequently been members of specialized commodity groups, many of which sponsor ''commodity check-off programs' (16). Such programs generate research funds by allocating a small amount of money per commodity unit sold for commodity-oriented research. In addition, large farm operators with greater capital resources are recognized as being more capable of investing in new productivity-increasing technologies and are often considered to have better management skills than operators of smaller farms. As a result, agricultural researchers have had much more input from specialized producers with larger farming operations than from farmers with more diversified operations who may not view expansion as a high priority. In fact, researchers have had disincentives to seek advice of diversified farmers interested in reduced-input or nonchemical production methods, because these farmers are in the minority (141) and they are not viewed as traditional community opinion leaders. Furthermore, many diversified farmers have been discouraged from approaching researchers about their information needs, because they perceive research and extension to be uninterested in and uninformed about alternative production methods (140). As a result, farmers who want to experiment with biological and cultural production methods largely have sought information and advice from each other.

Although early adoption and diffusion research in the 1950s identified peer groups as playing major roles in the technology adoption process, little research has been done on them since. Thus, information is lacking on their roles and effectiveness in disseminating farming practices (103). Recent social research findings provide insights on the types and sources of information farmers use when making farm practice changes, and these findings appear to be relevant to adoption of natural resource protection practices. Farmers appear to use three general learning techniques in considering farm practice changes:

1. informational learning through exposure to and gathering of information;
2. observational learning through examination of on-site farm practices; and
3. experiential learning through implementation, correcting mistakes, and additional practice (172).

Informational learning can be done through more formal, established sources of information, but observational and experiential learning tend to be achieved by observing different practices on one's own farm or other farms, comparing relative successes of various practices achieved by other farmers, and informal discussions with other farmers. In other words, the relevant source of information during technology adoption appears to shift when the farmer moves from an initial knowledge-gathering phase to a later phase when different practices are compared, selected, and implemented (103). Farmer-to-farmer networks could thus play important roles in helping farmers reduce the risk of adopting resource-protecting practices by providing social support, discussions with experienced peers, opportunities to observe field trials, and a site-specific structure in which to compare and test new practices.

The prevailing agricultural research and extension system has not facilitated broad farmer input into the research and extension process or mechanisms that promote and support peer-based learning among farmers. Technical assistance programs that promote on-farm trials and information transfer may be necessary to effect widespread farm practice changes to protect natural resources. Thus, if farmers are to achieve locally desired goals for resource protection in their areas, two kinds of research and information delivery may be needed to provide two very different types of support: 1) the prevailing research and extension system to develop new technologies and systems and disseminate technical information, modified to accommodate farmer-based experiential learning and facilitate communication from farmers to researchers; and 2) a farmer-based system that encourages on-farm recordkeeping, experimentation, and information-sharing and is actively supported by the research and extension system.

Need for a "Farming Systems Perspective" in Research and Extension

Additional criticisms have been raised about the U.S. agricultural research and extension system relating particularly to the lack of attention to farmer needs and constraints in technology adoption and natural resource protection. Critics have argued that:

- research topics and technological developments are derived from within scientific disciplines and are advanced because of professional rather than societal needs;
- little interdisciplinary interaction occurs among scientists, with resultant gaps in knowledge critical to the development of socioeconomic and technological bases for environmental protection in agriculture;
- researchers' tend to view all farmers as a homogeneous group, e.g., assuming that attention to the needs of a single commodity group is beneficial to all farmers;
- emphasis on capital-intensive technologies tends to skew research benefits toward larger farms (16);
- communication is lacking between farmers and researchers and little connection exists between the direction of researchers' efforts and farmers' needs (84);
- attention is lacking to dissemination and institutional processes that facilitate technology adoption (103); and

- **it is** assumed that traditional information dissemination methods are effective and solely in need of more sophisticated technologies, e.g., computers, teleconferencing (103).

These criticisms of the prevailing U.S. agricultural research and technology transfer process have been strongly articulated by researchers working in less-developed countries. In many of these countries, technical assistance methodologies like those implemented in the United States have been unsuccessful in increasing productivity because of farmers' socioeconomic and natural resource constraints (145,24). These observations have led to the development of other, more comprehensive research and extension approaches that focus on farmers, their constraints to technology adoption, and the socioeconomic and institutional contexts of farmer decisionmaking. These approaches are characterized by a ' 'farming systems perspective' that is intended to complement rather than replace the more top-down, technology-oriented research and extension approach (115).

Farming systems approaches include "farming systems research' (115,1 31) and the 'farmer-first-and-last' method in agricultural research and extension (24). Farming systems research is concerned with the ' 'optimization of the farming system as a whole' rather than optimization of production of a particular commodity (16), while the farmer-first-and-last approach strives to gain understanding of farmers' priorities and choices, then develop and refine strategies in collaboration with farmers (25). Farming systems approaches begin by considering farm practice changes in the context of farmers' social, economic, institutional, and environmental constraints. Although farming systems approaches originally were developed for use in other countries where resource constraints are more severe, many land-grant universities have recognized the relevance and usefulness of the farming systems perspective in the United States and have implemented farming systems research methods in local agricultural projects (115). A farming systems approach appears to be a highly appropriate method to facilitate adoption of natural resource protection practices, because this approach is based on an understanding of actual constraints to technology adoption.

Need for Increased Interdisciplinary Research Which Includes Social and Environmental Sciences

Research for enhanced decisionmaking is farmer-focused and interdisciplinary in nature, requires communication with farmers or other community members, and usually involves participation by social scientists. However, several constraints exist to increasing this type of research. First, definitions, methodologies, and protocols for interdisciplinary research in the agricultural and social sciences are not well developed. Increasing the amount of interdisciplinary research conducted in the agricultural research system, for example, will require clear definitions and criteria for the terms ' 'interdisciplinary' and ''multidisciplinary, ' which are different but often used interchangeably. Interdisciplinary research implies that scientists within several disciplines (and in some cases, nonscientist-members of advisory groups) interact in an organized fashion to assure that the overall research direction attempts to mitigate social conflicts and to address societal concerns relating to research implementation. Multidisciplinary research, on the other hand, implies that scientists from several disciplines contribute to the research but it does not imply that they work together or with other members of the nonscientific community to identify and resolve cross-sectoral or social conflicts in the research design (145).

Federal agency support for agricultural research expressly recognizes the importance of 'multidisciplinary" research, because applied problems are widely recognized to require collaboration among scientists from several scientific disciplines (96). However, the types and numbers of disciplines that should be involved in multidisciplinary research are not specified. As a result, the objectives, activities, and methods of multidisciplinary approaches like farming systems research have not been well-defined. The term "farming systems" thus has become a "catch-all" to include "any research that does not fall within the conventional, institutional categories of commodity or disciplinary research' (131).

Second, agricultural scientists may be reluctant to collaborate with social scientists or farmers on farmer-based approaches to protect natural resources, because traditional, disciplinary efforts toward developing productivity-increasing technologies are associated with the greatest academic and professional rewards. For example, site-specific research based on suggestions from farmer advisory groups is less likely to be published in more prestigious professional journals than it is in State agricultural experiment station bulletins and reports. Moreover, professional scientific societies typically have developed around individual disciplines and thus have less interest in mechanisms to support interdisciplinary research.

Third, less financial support has been available for research to enhance decisionmaking than for other production-oriented research areas. Federal competitive grants for agricultural research, for example, do not support work in the social sciences (103). As a result, funding sources for farmer-based approaches are most likely to come from State funding or from Federal formula funds, which are not necessarily allocated on the basis of social science needs. Support for research to enhance farmers' decisionmaking depends on the degree of State governments commitment to this type of effort, and some States have taken more steps in this direction than others. State support of farming practice demonstrations and on-farm experimentation to improve agrichemica1 management is particularly strong in Iowa, for example, which has made a policy commitment to agricultural resource stewardship.

Need for Increased Interdisciplinary Training and Education

State land-grant university and vocational agricultural education programs provide the research and education base for agricultural activities within each State. The State's agricultural schools train many of the people who become local agricultural professionals: farmers, agrichemical dealers, agricultural consultants, and public-sector workers in agricultural agencies. Thus, the agricultural education system can play a long-term role in enhancing the technical expertise available to farmers in responding to environmental concerns (box 5-K).

A key issue in enhancing the ability of researchers, extension workers, and educators to respond to multi-dimensional problems in agriculture is the need for interdisciplinary training that encourages professionals to think more comprehensively and inclusively. Researchers and technical assistance professionals with a broadened outlook will be more likely to cultivate interagency contacts and obtain information from a wider range of sources. This could increase interagency coordination, help avoid duplication, and expedite the flow of technical assistance to the areas that need it most. Enhanced decisionmaking by researchers and technical assistance personnel could be facilitated through: 1) interdisciplinary components in postsecondary education and professional programs, 2) pre-service or in-service training stressing interdisciplinary coordination and discussion, and 3) strong administration agency commitment to interdisciplinary communication and interaction.

Enhanced Decisionmaking for Groundwater Protection

Two-pronged technical assistance efforts, which use conventional and farming systems approaches, may be especially appropriate in providing farmers with information and support on appropriate farming practices in hydrogeologically sensitive areas. In areas where a groundwater contamination problem has been clearly identified, integrating the conventional technology transfer process with a farming systems approach could provide an improved understanding of the most relevant farmer constraints to adopting remedial practices. Involuntary groundwater protection programs, a farming systems approach thus could improve the effectiveness of educational efforts. In the case of regulatory programs, a farming systems perspective could help researchers and policymakers identify regulations that could be implemented more easily. Traditional extension and technical assistance approaches through CES and SCS will probably continue to be the best vehicles for providing farmers with technical information on patterns and severity of groundwater contamination, likely mode of contamination (point v. nonpoint source), and how management of the pertinent physical aspects of the farm could be changed to reduce contamination.

An initial prerequisite for an effective voluntary approach to reducing groundwater contamination is a clear definition of the contamination problem. However, the quality of information provided by technical assistance personnel will depend on the extent of State and local groundwater testing efforts and State commitment to understanding the problem. Additional prerequisites for effective voluntary programs are an in-depth understanding of current farming practices and farmer constraints, and support for farmers' observational and experiential validation of proposed farm practice changes. These latter requirements are best met through farming

Box 5-K—Integrating Postsecondary Agricultural and Environmental Education

Postsecondary undergraduate institutions in agriculture and natural resources (ANR) provide the bulk of agricultural training in the United States. Undergraduate ANR institutions are of three types:

- 74 land-grant colleges, established by two Acts of Congress in 1862 and 1890, and which belong to the Division of Agriculture of the National Association of State Universities and Land-Grant Colleges (NASULGC);
- 65 non-land-grant colleges, which belong to the American Association of State Colleges of Agriculture and Renewable Resources (AASCARR); and
- 45 forestry schools, with curricula accredited by the Society of American Foresters. Nineteen of these programs are offered by land-grant and AASCARR institutions (86).

In 1987, a total of approximately 78,000 baccalaureate students were enrolled in agriculture and natural resources programs in all ANR colleges. About one-tenth of these students were natural resources majors. About 57,000 of all ANR students were enrolled in land-grant colleges (36,37). This compares to a total 1988 undergraduate enrollment in all United States colleges of 7.8 million students, with an expected 2.7 million students expected to graduate from all high schools that year (26). Roughly one-tenth of one percent of all undergraduate students in the United States are enrolled in agricultural and natural resources programs.

Enhancing environmental technical assistance in agriculture requires consideration of the following questions:

- Who currently provides technical assistance to farmers and how have these persons been trained? Are these persons adequately trained in the agricultural and environmental sciences to help farmers achieve significant reductions in adverse environmental impacts?
- How can the current supply of agricultural assistance professionals improve their knowledge and skills in environmental and agricultural sciences?
- How can future agricultural science graduates be better trained in the environmental sciences and vice versa?
- Will the supply of future graduates meet the demand for increased environmental technical assistance in agriculture?

The following programs could enhance the environmental knowledge and skills obtained by students in ANR colleges:

- general environmental awareness courses;
- environmental studies minor programs, such as those offered by the University of Wisconsin and Rutgers University;
- professional programs in environmental sciences/studies;
- continuing professional education programs in environmental awareness/sciences; and
- agricultural teacher education programs with strong environmental components (86).

Some attempts have been made to include a "systems approach" to curriculum development and problem-solving in the agricultural sciences (1 1,1 76). The National Agricultural and Natural Resources *Curriculum* Project's Food and Agricultural Systems Task Group developed an education source book for faculty members wishing to encourage students to consider the broad range of socioeconomic and environmental impacts in coursework involving problem-solving (91). Efforts of the task force represent initial steps toward making ANR educational programs more comprehensive and likely to address social and environmental concerns.

systems approaches, including individual case studies, farmer surveys, support of farmer-to-farmer information networks, development of recordkeeping and planning tools for farmers, advisory services, and on-farm experimentation and demonstration plots. Iowa's Integrated Farm Management Program is an example of a well-developed farmer-based program with documented effectiveness in reducing farmers agrichemical expenditures and application rates (see box 5-I).

Planning and Objective-Setting

Traditional agricultural research and extension efforts in the area of farmer decisionmaking have concentrated largely on farmers' short-term or tactical decisions made throughout the crop production cycle (103). When research and extension have focused on more long-term farm management decisions, such efforts have emphasized development of production-related ''enterprise budgets' or assistance in making strategic decisions related to capital investments and enterprise expansion. As a result, substantial gaps exist in knowledge and methods needed to make strategic resource protection decisions and to integrate production and resource protection objectives in farm management. Research and extension could provide increased support for strategic, long-term planning for agricultural resource protection and devote greater effort to estimating benefits and costs of resource protection efforts in both the short- and long-terms.

One promising approach to addressing these gaps is through the USDA Soil Conservation Service's concept known as ''progressive conservation planning, '' which encourages land users to go beyond implementation of single conservation structures to address all relevant resource management concerns on the farm (122). Since most land users come to SCS at first to obtain help with a single conservation practice (e.g., installing a grassed waterway to alleviate particularly severe gully erosion), a progressive planning process could help them consider more long-term resource protection objectives. However, SCS methods for progressive conservation planning do not appear to be well defined and other responsibilities typically are more pressing for SCS conservationists. Decisionmaking guidelines and a list of environmental and economic ''trade-offs' to consider in conservation planning could help landowners identify and begin to integrate production and resource objectives (161).

Some private organizations also have tried to address gaps in strategic resource planning assistance for farmers by developing planning methods and materials. For example, the Center for Rural Affairs in northeast Nebraska, has developed a ''Resource Audit and Planning Guide for Integrated Farm Management" (22,23). Another planning approach to long-term resource protection for range management, called Holistic Resource Management (132), also has applications for crop producers (88). Farmers' integration of long-term resource planning with crop production objectives will be facilitated by development and widespread use of educational and planning materials and methods.

Recordkeeping and Information Management

Demands for more and better information in agriculture have grown with concerns about controlling adverse environmental impacts, and resource protection goals will require farmers to take even more factors into account when making manage-

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

Field scouts can monitor crop conditions and pest populations, providing farmers with more accurate information on pests to avoid unnecessary pesticide applications. Here, researchers check pheromone-baited traps in a peach orchard.

ment decisions (72). Improved recordkeeping and information management tools would help farmers and other land users integrate their production and resource protection objectives. At the individual farm level, keeping records of the types, amounts, and locations of agrichemical use would enable farmers to track costs and benefits of nutrient and pest management inputs. At the aggregate level, agrichemical use records would help researchers evaluate agrichemical use patterns and their relationships to hydrogeologically vulnerable areas. Agrichemical use records thus could be used to identify areas where more intensive educational efforts or stricter regulations could be implemented to achieve the greatest improvements in groundwater quality.

The collection and evaluation of records on aggregate agrichemical use will involve some type of reporting to a government agency. California currently is the only State in which private and commercial agricultural applicators are required to keep records and report agrichemical use to the State. Many States require commercial applicators to keep records of agrichemicals applied for periods of 1 to 3 years, but few States require annual reporting. Outside of California, no State has a recordkeeping system to track the extent and locations of agrichemical use, nor does the Federal Government currently maintain a national agrichemical-use database. Better information on agrichemical use, which would help farmers and policymakers evaluate potential impacts of farming practice changes, could be obtained through voluntary or obligatory reporting programs.

Many members of the agricultural community, however, are deeply concerned about potential liability associated with government agencies' use of records in assessing agrichemical use patterns. Fear of liability thus could reduce farmers' participation in voluntary recordkeeping programs to the extent that any data collected would not provide a sufficient or accurate basis for improved policymaking. Farmers will be more likely to keep records and report agrichemical use voluntarily if they are exempted from liability or if they receive assurance that label-directed use will not make them liable for environmental contamination by agrichemicals. In the case of obligatory agrichemical use reporting, farmers might choose to reduce their liability concerns by having commercial applicators apply agrichemicals for them.

Computer and Information Technologies

State and local governments and agricultural extension need to use relevant and effective formats in presenting information to farmers on protecting groundwater and other natural resources. If information is presented in a format that is not used by farmers in resource-affected areas, it will not induce land users to make desired farm practice changes. In Iowa's Big Spring Basin project, for example, even traditional information formats such as extension pamphlets, field demonstrations, and trade fairs were used by a minority of farmers in learning about agrichemical contamination of groundwater (103). This needs to be considered when evaluating the potential effectiveness of newer formats such as computer models. If some traditional formats, which have been available for 50 years, are used by less than 20 percent of all farmers, it may not be realistic to expect widespread audience receptivity to newer formats (126).

Computer software programs can be important tools in improving agrichemical decisionmaking. The effectiveness of computer tools for use on the farm in improving agrichemical management, however, could be limited by the low percentage of farmers who own and use computers for farm management purposes. Roughly 12 to 14 percent of all farmers use personal computers, mainly for financial recordkeeping and tax purposes (72). Large farm operators presently account for most sales of agricultural software and this trend seems likely to continue in the future.

The private sector has been active in developing, selling, and supporting microcomputer software for such purposes as improving nutrient, pesticide, crop, and water management (e.g., Deane's Information Services) (32). Because the agricultural software market is small, however, it does not generate a high volume of demand. Thus, the trend is for the private sector to increase agricultural software costs per customer (85), which restricts agricultural software accessibility to producers who can afford it.

Some computer software and support services also are available to producers at little or no cost at CES and SCS offices. These include information systems such as SS1S (soil survey information systems) or software programs for improved agrichemical selection and management (box 5-L). Pesticide and nutrient management programs available from CES in some regions to improve agrichemical decisionmaking include:

- herbicide use decision-support packages, such as SOYHERB (124,80,71);
- Integrated Pest Management packages, such as the Field Crops Insect Management program (74); and
- plant disease decision-support packages, such as a computer-based advisory system for soybean plant diseases (137).

Expert systems for integrating whole-farm management are under development at the Univerity of Missouri (62), The Pennsylvania State University (8), and Michigan State University (58). A national research and development effort is also underway to implement a national Computer-Aided Decision-Support System (CADSS) that will attempt to integrate existing and evolving modules into a

Box 5-L-Soil Survey Information System

County soil survey reports, which contain information on the locations of different types of soils, are large, technical documents which are difficult and time-consuming to interpret manually. The Soil Survey Information System, or SSIS, is a computer software package developed for the State of Minnesota to quickly access the soil survey, relate it to a specific tract of land, and present the information in a graphic display or printout (6).

SSIS accesses soils information for one section of land at a time. (One section equals 1 square mile, or 640 acres.) Depending on information available, a county's SSIS program can incorporate physical and chemical properties of soils (soil texture, pH, organic matter), soil productivity, and groundwater pollution susceptibility by nitrates and some pesticides.

SSIS was developed at the University of Minnesota for use on standard microcomputers by extension and county government staff, State policy makers, students, and individual landowners. SSIS has been used principally to appraise individual land parcels, make recommendations on soils and crop management, and establish field eligibility for State and Federal conservation programs (i.e., Conservation Reserve Program), On farms, SSIS can be used to select sites for soil samples, improve fertilizer and herbicide management, and develop conservation and cropping plans. SSIS, currently only developed for the State of Minnesota, has been incorporated into another software program, SOILSAMP, which allows farmers to keep track of soil samples taken within fields.

SSIS maps can also be overlaid with other digitized maps such as land use, land ownership, vegetation, and drainage patterns, Map overlays are useful to county and State program officers to identify target areas, allocate resources or incentives programs, or concentrate educational efforts.

database system cross-linking information from several sources (60). CADSS will utilize national, regional, and local services of ARS, CES, and CSRS and include an environmental component.

Integrated research efforts on production systems also employ computer programs coordinated through artificial intelligence to produce information for farmers addressing multiple production and resource concerns (173). Although such systems may in the future provide more comprehensive information to farmers, their current use appears to be more applicable to developing basic computer systems technologies and identifying interactions in basic and applied research rather than meeting existing needs of individual farmers.

POLICY OPTIONS TO SUPPORT IMPROVED DECISIONMAKING ON AGRICHEMICAL USE

People who make decisions about nutrient and pest management in agriculture constitute a diverse group and include private applicators, commercial applicators, and the individuals who advise them. The commercial sector is probably just as important to consider as private applicators, because roughly half of all agricultural agrichemicals are applied by commercial applicators, and agrichemical dealers are responsible for advising large numbers of private applicators. A comprehensive approach to improving nutrient and pest management decisions to reduce agrichemical contamination of groundwater will consider activities by all types of agrichemical applicators and advisors. Comprehensive approaches to enhancing nutrient and pest management will include improved point-source controls, more efficient agrichemical application, and agrichemical use reduction through greater efficiency and nonchemical practices.

A variety of congressional options exist to provide assistance to private and commercial applicators, agrichemical dealers, and environmental advisory firms to reduce agrichemical contamination of groundwater. These options commonly require broadening of agricultural research, education, and technical assistance objectives, expanded information gathering, and increased agency coordination.

Options To Assist Agrichemical Applicators

Assistance can be provided to agrichemical applicators in several ways to improve nutrient and pest management decisions. The range of assistance available to applicators, however, will depend on the local ‘‘mix” of State, local, and Federal education, demonstration, groundwater monitoring, and financial support programs. Assistance opportunities will be influenced by the degree of coordination and commitment among public-sector assistance personnel; expertise and services available in the private sector; and presence of farmer-to-farmer information and referral networks. The more opportunities that are available, the more likely applicators will be able to make nutient and pest management decisions that reduce agrichemical contamination of groundwater.

Publicly funded assistance programs can be designed to address needs of al! or only some of the applicators in an affected area. Intervention programs to assist farmers in changing practices to reduce groundwater contamination can begin by first obtaining profiles of the ''target' population of farmers in the area, their resources, constraints, and typical management practices. Such profiles can identify groups needing different assistance strategies, common mismanagement problems, and individuals who are likely to need more assistance based on their practices, available resources, and location relative to critical groundwater supplies.

Agrichemical Use Information

Many agricultural producers do not keep routine field records of the types, amounts, and locations of agrichemicals used. More accurate and complete agrichemical use information at the farm level would have two main benefits. First, agrichemical use information would help producers and technical assistance personnel evaluate whether excess or inappropriate agrichemicals are being applied and any costs involved. Second, aggregated information on agrichemical use would help policymakers evaluate impacts of proposed pesticide regulations or other agrichemical restrictions that could affect agricultural production. Voluntary or regulatory programs to track agrichemical use will call for agrichemical recordkeeping and some type of reporting system for evaluation.

Congress could direct USDA to develop and support on-farm agrichemical record keeping and reporting systems to facilitate agrichemical tracking. Agrichemical recordkeeping provides the means for farmers to quantify and evaluate nutrient and pest management costs. Recordkeeping may be the most important prerequisite to reducing the gap between actual agrichemical rates used and rates that are economically and environmentally optimal. Farmer-based assistance programs in Pennsylvania and Iowa indicate that recordkeeping efforts can reduce unnecessary expenditures for agrichemicals. Quantification of excess agrichemical costs could provide significant motivation for farmers to optimize or reduce agrichemical use.

Congress could direct USDA to conduct economic analyses of agrichemical use based on national and regional agrichemical use databases. Agricultural economists and other social scientists have insufficient information with which to assess economic impacts of proposed changes in agrichemical use, largely because so few data are available on actual types and amounts used at the individual farm level. Economics of nutrient and pesticide practices thus have not been studied sufficiently at the individual farm, regional, or national levels in order to make sound predictions about the feasibility of management changes. Since severe groundwater contamination problems may result in proposals to restrict, reduce, or replace agrichemicals in some areas, economic analyses based on actual agrichemical use could be used to determine courses of action most economically feasible for producers.

Information on Alternative Agricultural Practices

Producers and policymakers are asking for information on costs and benefits of alternative practices that could at least partially replace agrichemicals and on the distribution of these costs and benefits among farmers and agribusinesses. Currently available research includes: 1) economic returns derived from research plot data, 2) direct comparisons of economic returns from conventional farms with returns from farms using fewer agrichemical inputs, and 3) comparisons based on modeling (18). However, research on alternative practices and farming systems is limited and fraught with conflicting results, which may reflect the sensitivity of such research to assumptions about the economic potential of alternative practices (10).

Farmers who have implemented alternative practices can be found in nearly every region of the United States, although these farmers constitute a small minority. Case studies examining these farmers' experiences can identify promising alternative practices (96), but it is unlikely that the majority of farmers will adopt alternative practices rapidly, especially without better documentation of costs and benefits (141). Because additional time, labor, financial, and other management inputs usually are needed to achieve agrichemical substitution, the transferability of alternative farmers' successes or failures is difficult to predict without more comprehensive data from case studies.

Congress could direct USDA to assess and address research needs for conducting comparative economic analyses of agrichemical-based and alternative farming practices. Adequate economic documentation will be a key prerequisite for wider adoption of unfamiliar alternative practices and systems. Information from an assessment of comparative benefits and costs of agrichemical-based technologies and alternative practices would facilitate decisionmaking on farm practice changes. Research questions for such an assessment include: What types of alternative practices are being used as viable replacements for agrichemicals? What adjustments in management, crop choices, and production practices have farmers made to accommodate alternative practices? What were the costs involved and benefits gained? Valid economic comparisons are likely to require better accounting and valuation of nonpurchased inputs, environmental impacts, and beneficial and adverse interactions occurring in alternative production systems. Since alternative farmers typically produce a variety of commodities through diversified enterprises, economic analysis of alternative farming systems is less clear-cut than analysis of specialized commodity production. Thus, economic comparisons of alternative and conventional farming systems must be carefully designed, since USDA data on production costs are tracked on the basis of individual commodities and use of these data may be inappropriate in comparing conventional and alternative production systems.

Options for Applicator Certification and Training

The primary current means of encouraging proper management of commercial fertilizers and general-use pesticides is an ‘‘honor system’ based on customers’ voluntary compliance with labeling instructions. Proper management of restricted-use pesticides (RUPs), on the other hand, is encouraged through labeling information and EPA and State requirements that all RUP applicators be certified or under the direct supervision of a certified applicator. Agrichemical management procedures and applicator training and certification programs are important areas for Federal and State Governments to assess in efforts to reduce agrichemical contamination of groundwater.

Obtaining an Overview of State Programs

EPA does not maintain a regularly updated national overview of State pesticide applicator certification and training programs. No national guidelines for the Pesticide Applicator Training program exist, and the quality of the training varies greatly by State. The lack of guidelines and a national overview makes it difficult to obtain an overall picture for assessing the status of applicator certification and training programs and their adequacy in addressing environmental concerns that are relevant to each State. Furthermore, EPA and most States can only roughly estimate the numbers of persons applying general-use pesticides in agriculture and of noncertified RUP applicators under the direct supervision of certified applicators. Better information on agrichemical applicators would enable policymakers to more accurately assess benefits and costs of providing enhanced certification and training programs. Better documentation and reporting on applicators also would provide incentives for improving agrichemical management.

Congress could authorize EPA to maintain a regularly updated national overview of State pesticide programs, including applicator certification and training requirements. The lack of regular Federal oversight on State applicator programs nationwide could hamper national responsiveness to environmental concerns related to pesticide use. Currently, a major obstacle to obtaining State information on a regular basis is the Federal paperwork-reduction regulation requiring Federal agencies to obtain permission from the Office of Management and Budget to send survey questionnaires to more than nine States at a time. EPA authorization to maintain national pesticide program overviews could provide a specific exemption from paperwork-reduction regulations for the purposes of assessing the status and adequacy of State pesticide programs, Alternatively, State reporting requirements to EPA could be expanded to include State program updates on a regular basis.

Congress could direct EPA and States to create and maintain a national database on pesticide applicators. States could require that the number of noncertified applicators supervised by each certified applicator be registered annually. States could annually report numbers and types of applicator certifications and numbers of noncertified applicators. Information on numbers of applicators would improve benefit-cost analyses of proposed voluntary programs or regulatory changes to improve management skills and systematic oversight of pesticide applicators.

Congress could direct EPA and States to create and maintain a national database on agrichemical dealerships. States could report numbers and locations of licensed facilities. Accurate information on numbers of agrichemical dealerships would improve benefit-cost analyses of proposed regulatory changes regarding dealership facilities or employee training requirements.

Aiming To Reduce Agrichemical Mismanagement and Waste

Agrichemical mismanagement includes use of inappropriate agrichemicals or formulations, use of excess application rates, mixing or disposal in areas at high risk of contaminating water sources, application at inappropriate times or under wrong weather conditions, and improper disposal, all of which contribute to the release of unnecessarily high amounts of agrichemicals to the surrounding environment. The risk of agrichemical mismanagement appears to be high, and has potentially serious consequences in hydrogeologically sensitive areas. Information on the extent and types of agrichemical mismanagement, the situations and settings where it is most likely to occur, and the most cost-effective interventions for its reduction could aid development of technologies or programs to reduce agrichemical mismanagement and waste.

Congress could direct the USDA to conduct a national assessment of agrichemical management practices to identify certification and training needs for agricultural, commercial, and residential users. Information is scant on the extent and types of agrichemical mismanagement, its point-source or nonpoint-source nature, and its likely impacts on groundwater quality. A national assessment of agrichemical management practices could be similar to the national IPM assessment conducted in 1982-86. Information from this assessment could help identify high-risk areas and educational needs to prevent mismanagement. However, achieving good agrichemical management by all land users may not reduce groundwater contamination to the extent that health-based contaminant standards are not exceeded. This strategy does not address contamination due to climatic and technological-failure causes nor extreme cases of hydrogeological vulnerability of soils (133). Nevertheless, reducing agrichemical mismanagement appears to be a highly cost-effective strategy for addressing groundwater contamination in general.

An agrichemical management practices assessment could help determine the relative significance of point-source v. nonpoint-source contributions to groundwater contamination and the types of contamination sources that are most prevalent. Research to address these questions could include assessments of farmstead point-sources, livestock operations, and agrichemical dealerships and case studies to characterize point-source control practices and typical conditions of nutrient and pesticide storage and handling facilities. Nonpoint-source contributions could be assessed by determiningnutrient and pesticide application rates used by private and commercial applicators and the sources of information used for calculating application rates. Research to address these questions could include farmer surveys, interviews, and observational farm case studies. One problem likely to be encountered with farmer or applicator surveys and interviews is that responses are based on self-evaluation, which may not accurately describe the actual quality of agrichemical management. Nor are farmers and applicators likely to admit they are mismanaging agrichemicals. Findings from such research efforts may have to be interpreted in light of possible shortcomings and limitations of the research methodologies.

Assessing Federal v. State Financial Support of Applicator Programs

States currently provide 70 to 80 percent of applicator certification and training finding, and they are facing additional costs associated with new Federal pesticide program requirements. Since State and local funding sources are stretched increasingly to meet EPA requirements, States will have difficulty expanding applicator certification and training programs unless Federal funding is increased. The high level of public concern about agrichemical contamination of groundwater, however, may justify increases in Federal support for pesticide programs.

Congress could direct USDA and EPA to assess costs of expanded applicator certification and training programs based on a national assessment of certification and training needs. Stricter Federal requirements for agrichemical applicators would provide more incentives for proper management of pesticides nationwide, particularly if they apply to agrichemical users who have previously not been required to be certified or trained. Clearly, use of applicator certification and training programs to reduce the potential for agrichemical mismanagement and groundwater contamination will require increased finding for applicator education. Benefit-cost estimates of expanded applicator certification and training programs could be used to inform policymakers and the public on the costs and trade-offs involved. Since program expansion cannot be achieved without concomitant financial support, such support may first have to be generated through informed public discussion and decision-making.

Another option would be for Congress to direct EPA and USDA to assess costs and provide funding for expanded applicator certification and training programs in hydrogeologically vulnerable areas only. Rather than supporting nationwide changes in applicator certification and training programs, Congress could call for expanded applicator programs solely in hydrogeologically vulnerable areas. More rigorous applicator programs could improve agrichemical management practices in these areas, especially if they were expanded to include applicators of fertilizers and general-use pesticides as well as noncertified applicators.

Alternatively, Congress could immediately increase Federal subsidies to States for applicator certification and training programs. Because accountability for pesticide applicator programs is shared by EPA, USDA, and the States; specifically earmarked funding and clear Federal directives may be needed to prevent weak, nonrigorous certification and training programs. If Congress wants EPA, USDA, and the States to strengthen applicator certification programs, regularly update applicator education programs, and implement additional training programs in IPM, reduced-input, and nonchemical approaches; it can expedite these changes by appropriating earmarked funding for these purposes. An alternative is to require EPA to fund the authorized 50-percent Federal share for States' pesticide programs, but this option will likely take EPA funding away from other areas. Congress also could authorize education programs for other types of applicators (e.g., private residential applicators). However, if USDA's and EPA's Pesticide Applicator Training program is to be strengthened and expanded, some resolution of the respective authorities of the two agencies must occur. Congress could put the authority and appropriations for PAT programs solely into USDA-ES or clearly define the respective responsibilities of the two agencies.

Options To Encourage Development of Private-Sector Services

Some producers may not have the skills, training, or time to identify or customize integrated practices on their farms to reduce agrichemicals' adverse environmental impacts. One mechanism for assisting farmers to reduce adverse environmental impacts is through private-sector advisory services (e.g., soil testing, pest scouting, IPM consulting). However, the supply of pest, soil, or crop advisors may be limited in some areas due to lack of education and training programs that could prepare trained personnel. Development of private-sector environmental services may also be hampered by lack of State licensing programs and potential liability concerns. State and Federal governments could play a role in facilitating the development of such services as one strategy to reduce adverse environmental impacts in agriculture. Development of private-sector environmental advisory services in agriculture could be fostered in several ways.

Congress could direct the USDA-Extension Service to provide extension training for agrichemical dealers. The Cooperative Extension Service could magnify its environmental education efforts by training agrichemical dealers, each of whom may advise hundreds of farmer-customers who purchase agrichemicals from them. The Federal Government, for example, might provide funding for at least one extension specialist per State to conduct agrichemical dealer training. Agrichemical dealer training could be designated as a temporary program to address specific groundwater concerns or it could be established as an ongoing education program to support dealer licensing, certification, or accreditation. In ongoing programs, CES could train employees in proper agrichemical storage, handling, and waste disposal procedures and equipment maintenance. A less costly alternative would be for Congress to authorize a single appropriation for USDA to develop dealer education materials which could be utilized by States CESs on a voluntary basis.

Congress could direct EPA and USDA to develop agrichemical dealership licensing guidelines for States. Dealership-based environmental advisory services could be developed through State licensing, accreditation, or liability insurance programs. For example, licensing programs could require dealerships to provide IPM information or use IPM principles in all commercial services. States could also require agrichemical dealers to train employees in groundwater protection principles, IPM techniques, and other environmentally related topics as a condition for licensing or accreditation. Dealership licensing and accreditation guidelines could also include construction and maintenance specifications for commercial agrichemical storage, handling, and disposal sites. Implementation of the latter guidelines would likely require a State inspection system to verify dealership compliance.

Congress could direct USDA to conduct a national assessment to identify the need for and supply of private-sector agricultural services to reduce adverse environmental impacts by agriculture. Current capacity of commercial environmental advisory firms to offer farmers soil-testing, pest-scouting, and agrichemical-recommendation services may be inadequate to meet potential demand. USDA, in collaboration with the U.S. Department of Commerce, could obtain estimates of the numbers and types of agricultural service firms currently available and evaluate whether current training and development programs are adequate to provide sufficient service delivery. One mechanism to obtain such estimates would be through an Agricultural Services Survey similar to the one that was discontinued in the Census of Agriculture in 1979. Based on its estimates and assessment, USDA could identify training or support programs that would expand private-sector advisory services available to farmers. Support programs could include State accreditation or licensing for consultants and internship programs for agricultural and environmental science students.

Congress could direct the Small Business Administration to provide startup financing and training for small agricultural advisory firms. The Small Business Administration and Job Training Partnership Act programs could be vehicles for training and startup of environmental advisory firms that could expand the range of services to agricultural producers. New firm startups would help increase the supply of advisory professionals in the private sector and provide employment and training opportunities in rural areas. Training programs could be implemented at State or community colleges, and these could include pest scouting, soil testing, and crop and field monitoring services.

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

Beneficial insects are mass-reared in laboratory cups to produce sufficient numbers for release in fields. Private firms and services supporting alternative methods of pest control are likely to increase with demand.

Congress could direct USDA's Extension Service and Agricultural Cooperative Service to conduct joint organizational training and support for farmer cooperatives formed to provide advisory services. The Agricultural Cooperative Service (ACS) is the USDA agency which provides organizational assistance to farmer cooperatives. The USDA could encourage the establishment of cooperatives, similar to Pennsylvania's Crop Management Associations, which help producers pool financial resources to hire their own field consultants. ES and the Economic Research Service could" complement ACS startup activities by providing cooperatives with assistance on agronomic, economic, and other technical aspects of cooperative advisory services.

Congress could expand USDA's Agricultural Stabilization and Conservation Service (ASCS) cost-share programs for integrated crop management. An ASCS integrated crop management program being tested in 1990 currently funds up to 100 farmers per State for cost-share assistance for advisory services to reduce agrichemical use and improve agrichemical management. One goal of this program is to encourage the development of private-sector advisory services. To this end, Congress could direct USDA to expand this ASCS program and increase cost-share funding available for advisory firms.

Options To Improve Extension Support for Enhanced Decisionmaking

State CESs have suffered financial and personnel cutbacks in recent years, which will make it more difficult to meet the needs of individual farmers in addressing emerging environmental concerns. CESs could increase their technical assistance impacts by increasing coordination and cross-agency training between CES and other State and local agencies involved in agricultural and resource conservation.

Congress could direct USDA and encourage States to conduct cross-training of technical assistance staff in different agencies to foster coordination and consistency in information and assistance delivery. A variety of agencies provide information and technical assistance to producers on agricultural management and natural resource protection. However, technical assistance staff in one agency may not be aware of or use the educational materials and guidelines developed by other agencies. Effective use and implementation of educational and planning materials will depend on:

1. the validity and usefulness of water-quality information;
2. the degree to which all technical assistance staff understand and integrate the information into daily procedures;
3. staff skills in conveying new information and techniques to landowners; and
4. their degree of commitment in using the materials and convincing landowners of the importance and trade-offs of incorporating water quality into decisionmaking.

Thus, cross-training programs could include CES educational materials on water quality and agrichemical management, SCS guidelines for conservation cross-compliance plans and comprehensive resource planning, and ASCS materials on integrated crop management services. As a result, SCS conservationists would be more likely to use water quality materials at the field office level, and CES staff could play a greater role in supporting implementation of SCS's Resource Management Systems (RMSs). SCS and CES also could be encouraged to coordinate their efforts better with conservation districts and State government agencies to ensure consistent use of new water quality materials and resource planning guidelines. Furthermore, issue-oriented continuing education and training workshops could be used to develop staff capabilities in managing water quality programs. Such issue-oriented training could be an operating part of each agency's management programs. Career advancement or salary increases could be based on the successful completion of courses and training. Those who already have the training could test out of specific programs, to avoid wasting time on unnecessary review and to avoid being penalized for not participating.

Congress could direct USDA to develop and promote long-term natural resource planning assistance to help agricultural producers integrate environmental protection objectives into production decisions. Producers' integration of resource-protection and crop-production objectives could be facilitated by development of educational materials and planning methods for integrating natural resource protection measures. One promising approach to addressing these gaps is through SCS's "progressive conservation planning" concept, which encourages land users to go beyond installation of single conservation structures and to implement RMSs addressing all relevant resource management concerns. However, SCS methods for progressive conservation planning and RMS implementation do not seem to be well-defined and other agency priorities are typically more pressing for SCS conservationists. As a result, progressive conservation planning may not receive sufficient support or emphasis at the field office level. One possible strategy to increase RMS implementation is to educate local conservation committees about RMSs and the planning guidelines for achieving more comprehensive consideration of resource impacts during development of conservation plans. Education of conservation groups at the grass-roots levels could provide the "demand-pull" for more comprehensive resource management assistance from SCS.

Congress could direct USDA to assess the effectiveness of current methods used nationwide to disseminate information and technical assistance to producers on agrichemical contamination of groundwater and remedial farm practices. Alternatively, Congress could direct USDA to focus assessment of information and assistance delivery-systems in hydrogeologically sensitive areas. Site-specific information on groundwater quality and vulnerability is an important prerequisite in identifying where, when, and how groundwater protection actions should be undertaken. Significant efforts are underway to define the extent of agrichemical contamination of groundwater and to generate knowledge of remedial practices, but little attention is being given to the effectiveness of different dissemination methods to encourage adoption of remedial practices where needed. Methods to disseminate information and encourage adoption of remedial farm practices must recognize the complexity of the technology transfer process and include efforts to understand the needs and capabilities of multiple target audiences. Further, eligibility for competitive grants for agricultural research could be expanded to allow assessments of different target audiences in designing effective programs to facilitate dissemination of remedial farm practices.

Overall, little is known on a national level regarding the capability of local assistance networks to define and specify the groundwater contamination problem. Thus, research on the adequacy of existing information and assistance-delivery systems could include assessments of:

1. the extent to which potential and actual groundwater contamination by agrichemicals is clearly defined and specified to farmers;
2. extent of research and extension's knowledge of viable farming practice changes to reduce contamination;
3. extent to which land users are currently being supplied with needed information and assistance; and
4. extent to which current research and extension methods recognize that different farmers need different types and sources of information.

Additional emphasis needs to be placed on ways to mobilize or modify existing information and education programs to address existing problems with existing technologies and management strategies.

In areas where agrichemical contamination of groundwater has been confined, the information and assistance delivery systems could be assessed and modified to increase the effectiveness of voluntary programs to change farming practices. Since such programs are likely to be more effective if they are based on an in-depth understanding of current farming practices and farmer constraints, a two-pronged approach (i.e., traditional "top-down" and farmer-based) to providing farmers with information and technical support may be especially appropriate for assistance programs in these areas. These approaches could include farmer surveys, case studies, support of farmer-to-farmer information networks, development of recordkeeping and planning tools for farmers, advisory services, and on-farm experimentation and demonstration plots. Integrating the traditional technology transfer process with a farmer-based approach could increase dissemination and implementation of remedial practices in these areas.

Options To Improve Research Support for Enhanced Decisionmaking

Redirected and coordinated research efforts would contribute to a better understanding of how farmers can be encouraged to protect natural resources in general and reduce agrichemical contamination of groundwater in particular. Effective voluntary approaches will be based on a good understanding of farmers' constraints and will require farmers' access to pertinent and usable information and adequate assistance.

Directing Research To Support Technology Adoption

Social, economic, and environmental factors will affect the adoption of practices that reduce agrichemical contamination of groundwater. However, agricultural research and development efforts often underemphasize these factors during development of technologies and management practices. Since agricultural practices that reduce agrichemical contamination will do little to improve groundwater quality if they are not widely adopted, research efforts could involve increased participation by social and environmental scientists in developing technologies and practices that can be successfully integrated into farming systems. Critical questions that should be answered for agricultural technologies as they are developed include:

1. are there likely to be social, economic, and environmental obstacles to adoption?
2. if such obstacles exist, what are they and how could they be addressed in implementation programs?
3. who are the proposed adopters and will the technology or practice be within their means? and
4. are the necessary institutional supports available to ensure continued use or operation of technologies if they are adopted?

Lack of attention to the ultimate target of research and development efforts is likely to result in peer adoption rates. Lack of institutional support, for example, has been identified as a key constraint to more widespread adoption of IPM techniques.

Congress could direct USDA to develop farmer "profiles" that would identify categories of farmers based on production practices, access to information, and constraints to adopting new technologies. Relevant characteristics to distinguish categories could include farm size, operating capital, and tenure as well as predominant crop and cropping system. Some of this information could be obtained from the National Agriculture Census and future Census' could be expanded to include key questions to provide the necessary information. Further, USDA's National Pesticide Use Survey could be expanded to include a ''Pesticide-Use Decisionmaking" component that could provide more specific information relative to agrichemical-use decisions. Farmer profiles could be developed frost at a national level to identify general categories and then refined further at the local level.

Broadening Farmer Input

Congress could direct USDA and the land-grant universities to assess roles of farmer-to-farmer networks and work with them in implementing use-reduction and nonchemical practices for groundwater protection. Informal groups of farmers have formed in several areas of the country in response to the issue of finding viable methods of reducing agrichemical inputs. One research option could be assessment of these local assistance networks and identification of ways to support their functions. Plans are being developed in many States to accelerate information and assistance through traditional university, extension, and conservation agency networks, but few are considering formal support for the development and maintenance of farmer-to-farmer information and assistance networks. One possibility would be to pay farmers for conducting field demonstrations or experiments related to reduced agrichemical use or nonchemical management practices in return for participation in a local network where experimental results were reported. Funds could be used to support dissemination of results in multiple formats both within and beyond the network. The role of government agencies and private-sector organizations in this process thus would be one of support rather than leadership.

Congress could direct USDA to assess current mechanisms for obtaining farmer input into development of BMPs and other farming practices and production systems. Despite criticisms that the traditional research and extension system is too "top down, " USDA is still considered a grass-roots agency and does incorporate some mechanisms for farmers to provide input to researchers and extension agents through local extension advisory committees, soil and water conservation commissions, and local commodity groups. However, the effectiveness of these traditional communication charnels in transmitting farmers' concerns and ideas to researchers and extension staff has not been adequately assessed. What are the roles of these groups? Who participates? How representative are these groups of whole populations of local farmers? Research on these traditional farm-based input groups could identify mechanisms by which these organizations could be made more effective or representative in providing research advice. Farmer-to-farmer networks are one mechanism to gain understanding of the concerns and constraints of different producer groups. Research administrators could facilitate researcher-farmer meetings and encourage involvement of a broader range of farmers in developing funding priorities for research and design of research extension activities.

Congress could direct USDA to develop protocols and criteria for on-farm field experiments. Several States have implemented demonstration programs involving on-farm experiments, technical assistance, and support of farmer-to-farmer networks. Current examples include the Sustainable Agriculture program of the Wisconsin Department of Agriculture, Trade and Consumer Protection; the Minnesota Department of Agriculture's Energy and Sustainable Agriculture On-Farm Demonstration Program; Iowa State University Leopold Center's cooperative relationship with the Practical Farmers of Iowa; and the California Energy Commission's Farm Energy Assistance Program. However, these programs do not provide sufficient incentives for large numbers of farmers to offset risks involved with field experimentation and most programs require farmers to go through a formal grant application and review process, thus limiting participation. As a result, these programs will have impacts only on relatively small numbers of farmers at first, which will make it important for States to provide funding and personnel support for adequate dissemination of results. Federal or State funding for such programs could be increased on a short-term basis, with the intent that as soon as implementation of remedial technologies reaches pre-determined levels in target areas, funding could be phased out. Additionally, such programs could be established in areas of the country where groundwater contamination potential is high.

Facilitating Interdisciplinary Research Processes

Multidisciplinary and interdisciplinary research will become increasingly important in developing agricultural production systems that integrate social, economic, and environmental objectives. Multidisciplinary research involves specialists from several disciplines who contribute to the research but who do not necessarily work together to identify and resolve cross-sectoral conflicts between their separate research efforts. Interdisciplinary research, on the other hand, involves specialists from several disciplines who interact within the framework of a systematic, tested method to assure that the overall research effort is internally consistent and that foreseeable conflicts are identified and resolved.

Most land-grant university researchers have more incentives to conduct basic, disciplinary research than multidisciplinary or interdisciplinary research. Dearth of incentives to participate in collaborative research will likely impede development of farm practices which are suited to local environmental conditions. However, incentives for institutions which receive Federal funding for agricultural research may be changing. For example, funding for agricultural research by agencies other than USDA tends to be directed toward institutions exhibiting a capacity for interdisciplinary and multidisciplinary research. Although some incentives are changing, researchers will probably need further encouragement to engage in multidisciplinary and interdisciplinary collaboration.

Congress could establish an agricultural research task force with a mission to identify the obstacles to systems-oriented, interdisciplinary research within the agricultural research system. The task force could conduct an assessment of USDA and federally funded land-grant university research, and identify disincentives to interdisciplinary research arising from institutional structures, policies, or practices (e.g., proposal review requirements). The task force might expand its analysis to examine disincentives posed by professional advancement requirements (e.g., publication in peer-reviewed disciplinary journals). Based on this analysis, the task force could provide recommendations for encouraging adoption of interdisciplinary research approaches within the agricultural research system.

Congress could direct Federal agencies to develop research protocols and methodologies for conducting interdisciplinary agricultural research that integrate social sciences. Federally funded research programs recommend that persons experienced in managing and working on multidisciplinary teams evaluate multidisciplinary grant proposals and that at least one research team member be experienced in multidisciplinary research. Research programs could also include sociologists linked to delivery issues on project teams and peer review panels for proposals. Protocols and research methods could be designed by national scientific research organizations in collaboration with professional societies.

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Appendix 5-I-Selected State Agricultural and Water Quality Cost-Share Programs, 1988

State	Type of program	Administered by	Source of funds	Details
Alabama	Soil Erosion, Agricultural Water Quality, Forestry	Agricultural and Conservation Development Commission through the State Soil and Water Conservation Committee	State General Fund	Cost-sharing for soil and water conservation, agricultural water quality and reforestation. Established base allocation of 1°/0 of appropriated funds to each of the 67 districts. Remaining 330/. allocated on basis of problem identification.
Arizona	Range Improvement Cost Share	Apache Natural Resource Conservation District	General Fund	A State grazing lands cost-share program for specific range improvements on the Coyote Creek watershed. Cost-share percentages range from 10 to 95°/0 per improvement with a $10,000 maximum per lessee.
Arkansas	Water Resource Conservation Development Incentives	Soil and Water Conservation Commission	State Income Tax Credit	Up to $3,000 per year tax credit (l O-year limit) toward the construction or restoration of ponds, lakes (20 ac/ft. minimum), or other water control structures used for irrigation, water supply, sediment control, agriculture, or water management. A 3 year, 10°/0 tax credit of the costs incurred in switching from groundwater use to surface water.
California	Soil Survey	California Department of Conservation Soil Resource Protection Project	Special Fund	$240,000 per year for 5 years. Provides pass through funds to SCS to augment soil surveys in key agricultural counties of State.
Connecticut	Animal Waste Pollution Abatement	Connecticut Department of Agriculture through the USDA Agricultural Conservation and Stabilization Service (ASCS)	Annual Appropriation by General Assembly	Cost-share is limited to animal waste systems. The funds are used in conjunction with ASCS Agricultural Conservation Program funds. The total combined Federal and State cost-share amount cannot exceed 75% of the total costs of the system. Landowners apply for State cost-share funds at the local ASCS office. If the county ASCS committee approves the application, it is forwarded to the State ASCS committee. ASCS certifies completion and forwards the bills to the Connecticut Department of Agriculture for payment.
Delaware	General Conservation Practices	Department of Natural Resources and Environmental Control	Bond Act of the State of Delaware, 1985	Cost-sharing for erosion and sediment control, water quality, organic waste systems, water management, forestry, wildlife habitat development, and others. The program addresses both urban and agricultural concerns.
Florida	Agricultural Water Quality	Department of Agriculture and consumer Services, Bureau of Soil and Water Conservation	State General Fund	Cost-sharing for dairy operations in the lower Kissimmee River Basin to install Best Management Practices for animal waste management to reduce the phosphorus loading into Lake Okeechobee. Provides up to 75% State cost-share of actual project cost. Average $141,800 per project.
	Soil and Water Action Projects	Department of Agriculture and Consumer services, Bureau of Soil and Water Conservation	Florida Department of Agriculture and Consumer Services annual budget	Six projects funded for 1988-89: 1) Water Quality Study; 2) canal erosion and sediment control; 3) water conservation project; 4) plugging free flowing wells; 5) Environmental Learning Center; 6) National Weather Service Antenna.
Georgia	State Committee Technician Program	State Soil and Water Conservation Commission	Appropriations from State General Revenue funds	Conservation commission contracts with county governments to pay salary of conservation technicians. Technician is hired by county but trained and supervised by SCS. Local provides direction through its annual plan of operations. SCS provides office space, vehicle, and working tools. County pays all fringes and absorbs costs of any increase in salary above initial base salary determined by conservation commission.

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Appendix 5-l-Selected State Agricultural and Water Quality Cost-Share Programs, 1988-Continued

State	Type of program	Administered by	Source of funds	Details
Idaho	Agricultural Water Quality	Department of Health and Welfare and Idaho Soil Conservation Commission. Program is administered locally by soil conservation districts.	Water Pollution Control Fund financed by State taxes on cigarettes, alcohol, inheritance and sales tax	Up to $50,000 maximum cost-share per participant for Best Management Practices identified by soil conservation districts in the State Agricultural Water Quality Management Plan. Participants must be within the boundaries of an approved project area as identified in the State Agricultural Water Quality Plan.
	Resource Conservation and Rangeland Development Loan Program.	Idaho Soil Conservation commission in cooperation with local soil conservation districts.	A portion of inheritance tax collections.	Long-term (up to 15 years), low-interest loans (up to $50,000 at 69% or less) to farmers and ranchers for conservation improvements through local soil conservation districts. The conservation improvements eligible for the program are determined and adopted by the local soil conservation district. These measures may address resource needs for management of rangeland, riparian areas, irrigated and non-irrigated agricultural land on private and public land within the State of Idaho.
Indiana	Structural Measures	Division of Soil Conservation	Dedicated Fund-tax on tobacco products	—
Illinois	County Conservation Practices Program (CPP) Watershed Land Treatment Program (WLTP)	Department of Agriculture Division of Natural Resources	State General Fund, Bond Monies	CPP will be used to cost-share with farmers on instruction of enduring practices. WLTP will be targeted to high-priority watersheds for crest-sharing on enduring practices. Both programs are designed to assist in meeting the State goal of T by 2000.
	Erosion and Sediment Control	Department of Agriculture Division of Natural Resources	State General Fund	Cost-sharing only for landowners who have had a complaint lodged against them under the Illinois Erosion Control Law.
Iowa	Soil Conservation	Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation	State General Fund	Soil Conservation-State funds made available to pay up to 50%. of cost of approved permanent soil and water conservation practices. Mandatory practices installed to comply with the Iowa Erosion Control Law are cost-shared at 75%. A one-time payment of up to $1 O/acre will be made for a l-year contract to establish no-till, ridge till, and strip till. The district will make a one-time payment of $6/acre for contouring and $15/acre for contour stripcropping. The program also contains three special incentives features: 1. Special Watershed Projects: Permits cost-sharing up to 60% of the cost of a project where the owners jointly agree to a watershed conservation plan in injunction with their respective farm-unit conservation plans; 2. Summer Construction Incentives; 3. Management Practices: Allows the commissioners of a soil and water conservation district the option to allocate not more than 30% of a district's original and supplemental allocation for the establishment of management practices to control soil erosion on land that Is now rowcropped.
Iowa	Wind Erosion Control Incentive Program	Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation in cooperation with Department of Transportation	State Road Use Tax Revenue	One payment of $1 ,000/acre for fields with windbreaks (must be maintained 20 years); one payment of $500/acre for grass windbreaks (must be maintained 20 years); and one payment of $30/acre for Iowa till (must be maintained for 5 years).

	Conservation Practices Revolving Loan Fund	Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation	State General Fund	Under terms of the no-interest loan program eligible landowners may receive a maximum of $10,000 for installation of permanent soil conservation practices on their lands. A conservation plan must be developed by the soil conservation district and the project must be approved by the district. Revolving loan funds and public cost-sharing funds shall not be used in combination for funding a particular soil and water conservation practice.
	Water Quality Protection Projects	Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation	Lottery Funds	These projects will protect the State's groundwater and surface water from point and nonpoint sources of contamination, including but not limited to agricultural drainage wells, sinkholes, sedimentation, and chemical pollutants. Water protection fund resources will provide administrative, operational, and personnel support for the projects, and funds for management and structural measures to address identified water quality problems.
Kansas	Water Resources Cost-Share Program	State Conservation Commission	State General Fund	Provides up to 800/0 cost-share with landowners for enduring water conservation practices to improve water quality and quantity by the reduction of soil, water, and nutrient loss from the land.
	Water Resources-High Priority Cost-Share Program	State Conservation Commission	State General Fund	This cost-share program provides assistance to landowners for land treatment in identified areas of high-priority needs to develop and improve the quality and quantity of Kansas water resources with respect to rural flood management, agricultural water conservation, and nonpoint-source pollution.
	Water Resources-Watershed Planning Assistance Program	State Conservation Commission	State General Fund	Cost-share assistance for planning the development of a targeted watershed area to solve a high-priority long-term problem resulting from channelization processes over the last 20 years.
Maryland	Agricultural Water Pollution Control	Department of Agriculture; Department of the Environment	Chesapeake Bay Water Quality Loan Act of 1988	Water Pollution Control: Up to 87.5% (up to $10,000/project, $20,000/pooled project, $25,000/farm) cost-share for approved BMP for agricultural pollution control.
Minnesota	Erosion Control and Water Quality Management	Minnesota Board of Water and Soil Resources	State General Fund	Beginning 7/1/85 a variable cost-share rate is in effect. Up to 75%. for high-priority erosion, sedimentation or water quality problems; up to 50°/0 for less severe erosion problems. Cost-sharing eligibility is tied to land capability classification, erosion rate or distances from protected waters of the State. Specifically, land capability classes VI-VIII are excluded from cost-sharing eligibility.
	Reinvest in Minnesota (RIM)	Minnesota Board of Water and Soil Resources	General Revenue Bond-easements; State General Fund-program administration	The RIM program authorizes a State conservation reserve which pays landowners to convert marginal farmland to wildlife habitat or restore previously drained wetlands. Farmers may choose between 20-year and perpetual conservation easements in exchange for a single lump-sum payment. The 20-year RIM easement payment is 70% of the present value of average cash rent in the area. The payment for the perpetual easement is calculated as 100% of the present value of average cash rent in the area. Of the funds appropriated for the program, $750,000 is reserved for conservation districts to cover administrative and technical assistance costs.

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Appendix 5-I-Selected State Agricultural and Water Quality Cost-Share Programs, 1988-Continued

State	Type of program	Administered by	Source of funds	Details
Mississippi	Soil and Water Conservation	State Soil and Water Conservation Commission	General Fund	Rules and regulations have been developed and adopted by the Mississippi Soil and Water Conservation Commission. Five Soil and Water Conservation Districts will be chosen as pilot projects.
Missouri	Soil Erosion Control	Missouri Soil and Water Districts Commission	State FY-1982; Environmental Protection Agency, Continuing 208 funds. State W-83; State General Revenues; 1982 Constitutional Amendment No. 1 establishing the Third State Building Fund; and 1984 Constitutional Amendment establishing 0.1% sales tax for soil and water conservation	Up to 75% cost-share for eligible practices in conservation plan. Cost-share for lands eroding above tolerable soil loss limits, plus other special areas to encourage long-term, less intensive land uses.
	Soil and Water Conservation (Loan Interest-Share)	Missouri Soil and Water Districts Commission	1984 Constitutional Amendment No. 2	Interest drawn on State fund investments refunded to landowner for State's share or private loan for eligible practices. $2,500 to $25,000, loans qualify for interest-sharing, 10-year maximum. Predominant utilization of the program is for no-till equipment (maximum term, 5 years).
	Soil and Water Conservation (SALT: Special Area Land Treatment)	Soil and Water Distrists Land mission	1984 Constitutional Amendment No. 2	Program combines benefits of State cost-share program and loan interest program for landowners within locally identified higher priority watershed areas of 1,000 to 4,000 acres needing treatment. Loan interest-share assistance for landowner portion of cost-share practices to carry complete farm Resource Management Systems (RMSS) plus loan interest-sharing for practices in RMSS not qualifying for cost-sharing. Program also provides an annual grant to districts for demonstration/Information/Technical needs to support the project. SALT projects are funded for 5 years.
	Wildlife Habitat Improvement	Missouri Soil and Water Districts Commission	Conservation Sales Tax Amendment (1977)	Additional incentives to farmers who complete wildlife habitat and warm season grass practices on Conservation Reserve Program (CRP) acreages. The incentive is 25% of average county costs of eligible practices.
	Native Prairies Restoration Incentive	Missouri Soil and Water Districts Commission	Conservation Sales Tax Amendment (1977)	Additional incentive available in four test counties to promote soil conservation and wildlife improvement through restoration of native prairie areas. The incentive is available for 2 years at $20/acre year with a 5-year maintenance period.
Montana	Range Improvement Loan	Department of Natural Resources and Conservation, Conservation District Division	Renewable Resource Development Fund-Coal Severance Tax Revenues	Rangeland Improvement bins-Up to $20,000 low-interest loan exclusively for improving rangeland conditions. Administered locally by conservation districts. (Loans currently at 4%).
	Conservation District Grants	Department of Natural Resources and Conservation, Conservation District Division	Coal Severance Tax Revenues	Grants to conservation districts (CDs) for projects and/or equipment to promote on-the-ground conservation, Maximum grant $30,000.
	Conservation District Grants	Department of Natural Resources and Conservation, Conservation District Division	Resource Indemnity Trust Funds	Grants to CDs for district administration. Provided to CDs whose county mill levy is not sufficient to finance all administrative expenses.

	Conservation District Riparian Management Grant	Department of Natural Resources and Conservation, Conservation District Division	Renewable Resource Development Fund-Coal Severance Tax Revenues	Grants to CDs for demonstration type projects showing proper riparian management practices. Program will emphasize nonstructural type practices.
	Renewable Resource Development Grants	Department of Natural Resources and Conservation, Water Resources Division	Coal Severance Tax Revenues	Grants to public entities (e.g., CDs) for development of renewable natural resources.
	Conservation District Agricultural Energy Conservation Grants	Department of Natural Resources and Conservation, Conservation District Division	Oil Overcharge Funds from U.S. Department of Energy-State Energy Conservation Program	Grants to CDs for projects that conserve energy and promote sound soil and water conservation practices.
Nevada	Energy Demonstration	Conservation Commission	Exxon Oil Overcharge Funds	The conservation commission awards grant funds to CDs for energy demonstration projects. The projects have been associated with photovoltaic and infrared technology and their uses in agriculture. To date about $73,000 have been awarded.
Nebraska	Soil and Water Conservation	Nebraska Natural Resources Commission	State General Fund	Water Resources: Up to 75% cost-share for water impoundment structures, terraces, outlets, irrigation reuse pits, grass seeding, tree planting, diversions, grade stabilization structures, sediment control basins, and planned grazing systems.
New Jersey	Farmland Preservation, Soil and Water Conservation	New Jersey State Agriculture Development Committee and New Jersey State Soil Conservation Committee (through local conservation districts)	Bonds of the State of New Jersey :Totalof $50,000,000 authorized-88% for purchase of development easements; 120/. for cost-sharing with farmland owners.	Bonds sold to initiate Farmland Preservation Fund for providing up to 80°/0 State share, 20°/0 county share of cost of acquiring development easements on farmlands and or 500/0 costs of approved soil and water conservation projects. Land must be enrolled in a Voluntary Agriculture District as designated by the Agriculture Retention and Development Act to be eligible for soil and waler conservation cost-sharing. Conservation projects must be approved by the State Soil Conservation Committee, cost-share practices must be part of conservation plan approved by the local soil conservation district.
North Carolina	Agricultural Cost-Share Program	Department of Natural Resources and Community Development, Division of Soil and Water	State General Fund	Begun as a pilot program in FY 1984-85. Has now been expanded statewide and is currently available in 56 of 100 counties. Cost-share of 75%, up to $1 5,000/year/applicant, for specified practices including conservation tillage, diversions, field borders, critical area plantings, sediment control structures, sod-based rotations, grassed waterways, stripcropping, terraces, cropland conversion to grass or trees, grade control structures, water control structures, and animal waste management systems that reduce the input of agricultural nonpoint source pollutants into the waters of the state. Annual and long-term (3 year) agreements available.$825.000 goes to local conservation districts on a 50/50 cost-share basis to hire additional technical assistance.
	Tax Credit for Purchase of Conservation Tillage Equipment for Agriculture and Forestry	Tax Commission	N/A	Provides for a State income tax credit of 25%, or up to $2,500/year (the lesser) for the purchase of conservation tillage equipment for use in agriculture and or forestry. The amount of the tax credit may not exceed the individuals tax liability for the year. Excessive credits may be carried forward to the next 5 tax years.

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Appendix 5-I—Selected State Agricultural and Water Quality Cost-Share Programs, 1988-Continued

State	Type of program	Administered by	Source of funds	Details
North Dakota	Wildlife Cost-Share Program	Game and Fish Department	Interest money earned on Game and Fish Reserve Funds	Wildlife-Provides 75 to 100% of funds for practices which improve water quality and enhance wildlife habitat.
Ohio	Agricultural Pollution Abatement	Department of Natural Resources, Division of Soil and Water Conservation	Capital Improvements Fund	Cost-share for installing enduring practices for reducing agricultural sediment pollution at not less than 75%. of cost, but not more than $5,000 for animal waste management and erosion control.
	Natural Resource Protection	Ohio Department of Natural Resources, Division of Soil and Water Conservation	Capital Improvements Fund	Provides up to 50% State funding of works of improvement to promote natural resource management including erosion control, drainage and flood control, water quality and water supply, wildlife enhancement, streambank stabilization.
Oklahoma	Soil Erosion and NPS Pollution Prevention	Oklahoma Conservation Corn mission		Effectively broadens the duties of the Oklahoma Conservation Commission (OCC) and the Conservation Districts. Authorizes OCC to act as management agency having jurisdiction over, and responsibility for, directing nonpoint source pollution abatement programs outside the jurisdiction of cities and towns. It also empowers OCC to administer a cost-share program which would provide State funds to CDs for carrying out conservation or management practices on the land to benefit the public through prevention of soil erosion or nonpoint-source pollution. The program is administered locally by CDs.
Oregon	Discretionary Grants, Senate Bill 617 planning Funds, District Operation Funds	Oregon Departmentof Agriculture, Soil and Water Conservation Division	State General Fund	Funds for discretionary grants; planning grants; district operations; confined animal feeding; and Interagency Clean Water Program.
Pennsylvania	Chesapeake Bay Agriculture Program Financial Assistance Funding Program	State Conservation Commission Bureau of Soil and Water Conservation	State-General Fund Federal-EPA Chesapeake Bay Program	Purpose of the Financial Assistance Funding Program is to assist landowners with the cost of installing practices to manage the disposal and application of nutrients on land areas that are responsible for nonpoint-source pollution. First priority is given to those high- and medium-priority watersheds identified in the “agriculture and earthmoving plan” developed under the 208 program, and other areas the Commission determines are high priority based on additional surveys and studies. The cost-share program is administered by the State Conservation Commission cooperatively with conservation districts and the USDA Agricultural Stabilization and Conservation Service.
South Carolina	Forest Renewal	Forestry Commission	Forest Renewal Fund (funded with State appropriations and assessment on forest products; 4:1 ratio-forest products: State appropriations)	Reforestation: Funds to provide site preparation, natural and artificial reforestation or stand improvement on up to 100 acres per landowner.
South Carolina	Tax Credit-Conservation Tillage and Drip/Trickle irrigation Equipment	Tax Commission	N/A	Conservation Tillage and Drip/Trickle Irrigation Equipment: Claim a 25% tax credit on expenditures (up to $2,500/year) for purchase of conservation tillage equipment, drip/trickle irrigation systems and dual-purpose truck and crane equipment; a one-time credit.
South Dakota	Shelterbelt Incentive Program	South Dakota Department of Agriculture Division of Conservation	State General Fund matched by State Game, Fish and Parks (GF&P) Funds	Program pays $5/acre for new tree plantings or renovations for a contract period of 10 years during which tree plantings must be maintained.

	Conservation Project Grants	South Dakota Department of Agriculture Division of Conservation	State General Fund	Funds used to cost-share conservation projects on a matching 50/50 basis.
Utah	Revolvingbxm-Agricultural Resources Development Loan	Utah soil Conservation corn mission	State General Fund; interest on loans	Provides low-interest loans for agricultural and energy conservation, range improvement, and watershed development. One-time 4%. administrative fee; 3%. per annum interest rate.
Vermont	On-Site Sewage Program	Vermont Association of Conservation Districts, Natural Resource Conservation Districts	State Appropriation and User Fees	Service program to help towns administer ordinances regulating single-family home on-site sewage systems. Assistance in adopting, administering and enforcing local ordinances. Septic system evaluation, planning, design and inspection services provided. Program supported by user fees and appropriations from the State legislature.
Virginia	Reforestation of Timberlands	Division of Forestry	1/2 Reforestation of Timberlands State Funds; 1/2 Forest Products Tax	Reforestation-Up to 50% ($60/acre) for site preparation and planting seedlings for commercial species of pines.
	Chesapeake Bay Agricultural BMP Program	Department of Conservation and Historic Resources, Division of Soil and Water Conservation	Commonwealth of Virginia EPA Chesapeake Bay Program	Variable percentage or flat rates. State cost-share assistance alone or combined with ACP cost-share rate not to exceed the maximum rate established by the State ASCS Committee. Eligible practices include animal waste control facilities, diversions, grass filter strips, conservation tillage, vegetative cover on critical areas, sediment retention, erosion or water control structures, sod water, stream protection, stripcropping, terraces, conversion of marginal cropland to pasture or forest. flat rate rest-share practices funded only by State.
	Statewide Agricultural BMP Program	Department of Conservation and Historic Resources, Division of Soil and Water Conservation	Commonwealth of Virginia	Variable rate and flat rate cost-share incentives for selected BMPs in Virginia's Agricultural BMP cost-share manual. Soil and water conservation districts administer this water-quality program locally to control sediment and nutrient loss and animal wastes.
	Tax Credit for the Purchase of Conservation Tillage Equipment		N/A	Provides for a 250/~ State income tax credit, up to $2,500, for individuals and corporations for the purchase of conservation tillage equipment, defined as a no-till planter or drill. If the tax credit exceeds the tax liability for that year, the excess may be carried over for credit in the next five succeeding taxable years until the amount of the tax credit has been taken,
Washington	Nonpoint Water Quality Matching Grants for Conservation Districts	Washington State Conservation Commission	Centennial Clean Water Act Biennial Appropriation	Makes available to the Washington State Conservation Commission 2.50/. of the Centennial Clean Water Act's biennial appropriation to provide matching grants to conservation districts. The grants will be used to implement locally identified projects that address nonpoint water pollution problems identified in the districts' annual plans of work. All grants require a 25%. local match. Although the Commission does not require a county match, it will add bonus points during project evaluation for district proposals containing evidence of at least a 5% cash or in-kind match from county government.

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Appendix 5-I-Selected State Agricultural and Water Quality Cost-Share Programs, 1988-Continued

State	Type of program	Administered by	Source of funds	Details
Wisconsin	Soil and Water Resource Management Program	Overall administration by the Department of Agriculture, Trade and Consumer Protection with planning and project implementation activities administered through county Land Conservation Committees (LCCS).	State General Purpose Revenues	Program goal is T by 2000. A soil erosion control plan is prepared by targeted, high erosion counties, with program funds providing up to 50% of the cost to prepare the plans. After the Department approves a plan, a county may apply for implementation funds for cost-sharing, technical assistance, information and education, and other soil and water resource management activities.
	Farmland Preservation Income Tax Credit Program	Local--County Government State-Department of Agriculture, Trade and Consumer Protection; Department of Revenue	Wisconsin General Fund	The program provides a mechanism for farmers subject to farmland preservation agreements or exclusive agricultural zoning (with soil conservation requirements) to receive an income tax credit based on a formula which takes into account farm income, property taxes, and income taxes paid.
Wisconsin	NPS Pollution Abatement	Department of Natural Resources	Wisconsin General Fund	NPS Water Pollution Abatement-Up to 75% of cost of BMPs identified in 208 Water Quality Management Plans for both urban and agricultural NPS problems. Funds must be spent in priority watersheds established in 208 planning effort.

SOURCE: National Association of Conservation Districts, Washington, DC.

Chapter 6

Public Influences on Agrichemical Contamination of Groundwater: Findings, Issues, and Options for Congress

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Chapter 6

Public Influences on Agrichemical Contamination of Groundwater: Findings, Issues, and Options for Congress

INTRODUCTION

Since the founding of the United States, agriculture has been a mainstay of the economy, and an important component of our cultural heritage. Although the number of farmers has declined over the last 50 years, the food and fiber sector currently accounts for about 18 percent of the gross national product (GNP). Farm production accounts for about 2 percent of total GNP, and farm input industries contribute only another 2 percent. The number of farmers has declined to just over 2 million, or roughly 3 percent of total employment (172).

Between 1970 and the early 1980s, agriculture maintained a favorable annual trade balance while almost all other sectors of the economy faced growing deficits (178); that surplus declined with the rise in the dollar's value and other world economic changes during the early 1980s. Since the dollar's devaluation, which began in 1985, the agricultural surplus recovered substantially, from a low of $5.4 billion in 1986 to $16.4 billion in 1988 (178). In addition, American agriculture has continued to produce a relatively low-priced domestic food supply; on average, Americans spend only 15 percent of per capita income on food whereas other developed countries may spend as much as 23 percent (e.g., Japan—21 percent, West Germany—23 percent, United Kingdom-19 percent, Canada—16 percent) (128).

Maintenance of an abundant and affordable food supply has occurred despite the decline in number of farmers due to the scientific and technological advances occurring largely since World War II. Since that time, farms have become more specialized-moving from a diversity of crop and livestock products toward concentration on one commodity—and more dependent on off-farm inputs. Further, widespread adoption of high-yielding hybrid seeds, commercial fertilizers, and pesticides increased specialization in certain crops, even continuous cropping of a single commodity crop. For certain crops, such as corn, the costs of fertilizer and pesticide inputs exceed all other operating costs (1 12).

Commercial fertilizers and pesticides have been widely accepted given their time and labor savings and relatively low cost, particularly at times when oil and natural gas prices were low. Product cosmetic quality standards and increasing pest resistance also have spurred agrichemical use. Wide recognition of the benefits of agrichemicals may have led to their application in larger amounts than needed, or to more frequent, ''prophylactic' applications to reduce risk and assure consistent crop yields. Few farmers, agricultural researchers, or policymakers were considering the possibility of unnecessary costs associated with wasted agrichemicals; some may have assumed that applying 'a little extra' was still cost-effective in terms of reduced time, labor, and worry. Farmers are likely to welcome assistance and technologies that reduce their operating costs or provide the same benefits of lowered time and labor inputs. However, many will understandably question the need to reduce agrichemical use if this means reduced income or increased management demands or risk.

The United States also has seen an "environmental revolution' occur during this century, emerging into a force of widespread national significance since the late 1960s. Legislation restricting the ''rights' of those degrading environmental quality have been increasingly enacted, following a progression from the more visible to less visible (e.g., end-of-pipe effluent controls to more general protection of surface-water quality); the more attributable to less attributable (point-source pollution to nonpoint-source pollution controls); the more easily blamed ''corporate villains' to less easily blamed "common man" (e.g., industry to farmers and households); and from specific human health hazards to general environmental degradation threats.

The environmental concerns specifically attributed to agriculture have similarly followed a progression: from "on-site," to "off-site" and, today, to ''out-of-sight. Concern over soil erosion's capacity for reducing soil fertility and thus farms' productive capacity has run high since the Dust Bowl era (1930s), prompting substantial Federal involvement in farm and natural resource management. Added concerns for surface-water quality, such as sedimentation of navigable waters and lake eutrophication, drove the development of conservation programs leading to those instituted in the 1985 Food Security Act. And today, concerns are arising about agriculture's contribution of invisible chemical gases to acid rain and climate change. Similarly, concerns about agrichemicals, especially pesticides, have moved from restrictions on use of those directly hazardous to their handlers or other farmworkers, to restrictions based on long-term hazards to the consuming population, to wildlife, or to the environment generally.

The current concern about agrichemical contamination of groundwater can be seen, thus, as a natural part of the progression of these trends. As governmental policy and programs address the "easier" environmental concerns, the public enters debate over the harder ones. Each 'era' involves balancing public desire for zero-risk or zero-degradation of the environment, on the one hand, and economic need for chemical use or waste disposal on the other. Because in agriculture at least, achieving zero degradation is impossible, and because agriculture is so important to the continuation of U.S. society and economy, the trade-offs may seem more difficult. Further, because agriculture has been largely exempt from the environmental restrictions placed on industries, it is perhaps facing a more abrupt demand to change. Transition to more environmentally responsible practices may require precipitous changes in traditions and practices. However, this transition is not substantially different from those that have gone before in other sectors: the public wants the benefits of a productive agricultural sector with a minimum of environmental costs.

While it may be impractical to deal with all cross-cutting environmental and agricultural issues at once, going to the other extreme and dealing just with groundwater out of the context of the surrounding environment may lead to inappropriate actions. More specifically, laws that address only a fragment of the hydrologic cycle will fail to address problems completely, and may inadvertently create new problems (1 18), that will give rise to further public demand for change. Because nonpoint-source groundwater contamination is largely beyond reach of remedial actions, prevention of groundwater contamination is the only means currently available of safeguarding a major environmental resource.

Similarly, it is impractical to expect that U.S. agriculture solve its associated environmental problems instantly. A comprehensive approach to the cross-cutting issues of agriculture and the environment will take time to develop, to implement, to evaluate, and to adapt to ever-changing conditions. Thus, development of policies today to deal with agrichemical contamination need to be made with consideration of how these policies, and the changes in U.S. agriculture that they foster, will fit into the larger picture of environmental and economic change taking place in this country. This requires a long-term view, and an analysis of the institutional capacity for foresight and for change.

Summary of Obstacles to "Solving the Problem"

Prevention or minimization of groundwater contamination from agricultural sources is fraught with barriers, some of historical precedent and others inherent to complex systems. Obstacles to preventing agrichemical contamination of groundwater have been shown to include the following:

- *Inherent obstacles (see* chs. 2 and 3), such as the nonpoint-source character of contamination, complexity and variability in site characteristics, close linkages of groundwater with other resources and resource issues, and uncontrollability of important factors such as weather.
- *Intrinsic obstacles (see* ch. 4), deriving from the functioning of agriculture within natural cycles that cannot be halted; and the systems nature of U.S. agriculture, such that pest control and nutrient management cannot be separated from other elements of farming, or from management of off-site resources.
- ***Extrinsic obstacles (see*** ch. 5), deriving from the diverse characteristics of farms and farmers, the nature of the current structure of U.S. agriculture, and the nature of agricultural and economic policies.

In each of these are significant areas where insufficient knowledge inhibits development of clear-cut policies. Thus, legislation that endeavors to be a cost-effective approach to reducing agrichemical waste or contamination of groundwater must be designed for high levels of uncertainty. Further, three cumulative lag times may make changes in groundwater quality unnoticeable for decades: 1) lag time of chemicals already applied and moving through the soil profile to appear in groundwater; 2) lag time in research to develop and make available practices, especially if highly site-specific; and 3) lag time in adoption of practices and transition of farm management.

Several conclusions derived from this assessment have clear policy implications. First, agriculture is a national, strategic resource (13); the agriculture sector of the economy is and will continue to be a mainstay of the U.S. economy and society. Moreover, it can be considered a strategic industry in that loss of the capacity to supply basic commodities to the domestic population could be considered a threat to national security. Options that severely reduce the U.S. capacity (in terms of amount of productive farmland, of farmland productivity, or of number of skilled farmers) to produce food to feed the domestic population are clearly adverse to the interests of society.

Agriculture also is characterized by significant natural and farm diversity: no technological "black box" exists that can be universally adopted to solve agrichemical contamination of groundwater. Moreover, agrichemical will not, in the foreseeable future, be entirely replaced by other technologies or management practices. Although we are entering a new, and potentially revolutionary era in U.S. agriculture, with a concomitant change in focus from mechanical and chemical technologies to biological/ biotechnological, and informational technologies (162), its ability to resolve the problems created by current practices is not yet defined. Environmental problems could be addressed by changes in bioengineering and information technology such that agrichemicals, as they currently exist, may eventually be rendered a minor part of U.S. agriculture. Still, strong forces are driving change in agriculture requiring changes in the form and use of agrichemicals today.

Agrichemical contamination might be addressed by simply banning (canceling registration and prohibiting new registration) all pesticides detected in groundwater (or groundwater and surface water) to date, or those fulfilling agreed-upon criteria for "leachers." However, this policy could not include nitrate, the most common agrichemical groundwater contaminant, which derives from multiple (including natural) sources, and is necessary for sustaining agricultural production. In addition, banning all chemicals appearing in groundwater could result in cancellation of ''non-leachers' '—pesticides that arrived in groundwater through point sources. Such a policy of banning pesticides without any consideration of the potential impacts of exposure (human, animal, or ecosystem) to agrichemically-contaminated groundwater, is likely to be a politically untenable solution placing potentially unnecessary and therefore unacceptable burdens on farmers.

Only point sources of agrichemicals are readily amenable to regulatory actions, given difficulties and high costs of monitoring and enforcement for nonpoint-source pollution. Further, the historical dependence on incentives and voluntary adoption of changes in farming practices implies that sweeping regulatory actions will be controversial and not easily instituted. Finally, the combined dearth of necessary knowledge and the need to make assumptions and generalizations in national policy, disallow any simple policy solution. There are no simple answers: reducing agrichemical losses or contamination of groundwater likely will require a combination of new or modified programs involving education, incentives, technical assistance, technology research and development, and regulation.

Call to Action on Agriculture and the Environment

A growing public concern about risk to safety, health, and the environment combined with an apparent growing public distrust of governments abilities to minimize or eliminate these risks is spurring demands that Congress, and Federal and State governments take action on agriculture and the environment. The growing urbanization of the U.S. population, and thus of Congress, will likely result in more vociferous or numerous arguments that agriculture address its associated environmental problems.

Changing Views of Public Risk

Public concern over agrichemical contamination of groundwater illustrates the extent to which perceptions of risk are changing. While the presence of agrichemicals in drinking water have been shown to have some association with disease and mortality, public surveys have shown that contaminated groundwater commonly is believed more risky than other conditions suggested by some scientists to be more hazardous to personal health (e.g., indoor air pollution). Individual and, thus, societal decisions about risk may depend more on the conditions of exposure than on knowledge about the probabilities of adverse outcomes. For example, people tend to accept risks if they are self-imposed or if they are familiar. However, agrichemically contaminated drinking water involves an involuntary risk; one associated with a resource for which there are no substitutes (i.e., water), with unfamiliar multisyllablic chemical names, and with uncertain and far distant consequences (6).

The public's understanding of relative risks often is called ''perceived risk" to distinguish it from a scientifically determined ''real, ' or ''measured risk. " A common response to a disparity between "perceived" and "measured" risk is to call for increased communication with and education of the public (64). Further, claims are often made that the public is ignoring risks much more hazardous than those appearing in the press and on television, and thus their attention should be redirected towards the ''real' risks, presumably allowing the ''perceived' risks to sink low on lists of concerns: to end a ''constant squishing of ants while the elephants run wild" (85).

However, risk assessment, and thus risk management, cannot be value-free (19). The difference between ''measured risk" or "relative risk' and ''perceived risk' may lie in the relative differences between public and scientific estimates of values, or differential knowledge about the extent and strengths of values. For example, economists continue to try to thrust natural resources conservation into economic terms, whereas the public seems to care more that tap water has no additives than about the monetary trade-offs involved in resource protection versus economic development. Thus, the obverse may be true, the scientists and decisionmakers may need to listen more closely to the public's risk assessment.

Because the decisions about the risk of adverse impacts from consuming contaminated groundwater include societal valuations as well as scientific determinations, they involve ''transcientific' questions-questions that cannot be answered by science alone. And, because such questions involve consideration of values, and differing values are held by different groups in society (e.g., consumers, producers, urban environmentalists), risk management and communication decisions must be negotiated between those concerned and those who govern the process that decides and acts on the risk. Clearly, the public is unwilling to wait until scientific inquiry provides all the facts necessary to determine an uncontroversial, measurable level of risk. Instead, it is calling on Congress to meet a challenge 'posed by policy-related science issues, characterized by uncertain facts, disputed values, high stakes, and a need for urgent decisions" (19).

When organizations are perceived to be ignoring the values voiced in the debate, the public has a tendency to lose faith in the ability or willingness of the organization charged with minimizing risk, and may undertake risk management on its own. For example, information about potential risks from consuming apples treated with a growth regulator (Alar) prompted people to seriously reduce their consumption of apples, causing apple growers to lose nearly $25 million over a 2-month period in 1989 (173). Such unanticipated changes in consumption can have far more adverse impacts than a gradual shift in production practices in response to public concerns.

The oft-repeated statement that the U.S. food supply is the most safe, most varied, and cheapest in the world is now being countered by public pronouncements that belie a trust in the safety, and a willingness to ''sacrifice' variety and low prices to regain perceived safety (cf: 61). A recent news report cited a demonstration against aerial spraying of malathion to combat the Mediterranean fruit fly (the "Medfly") resolving into a chant to "Just say no to oranges! (99). California orange growers may lose substantial amounts of money by ignoring the Medfly, but they may lose as much by ignoring the public.

Growing Distrust in Bureaucracies

Consumers may increasingly take risk management into their own hands as trust in the government's capability to protect them from unacceptable risk declines. For example, discovery that EPA's estimate of the percentage of apples treated with Alar was incorrect, and its later cancellation of the use of Alar due to disclosure of additional health risk information, only fueled a g-rowing public concern that government organizations may be unable or unwilling to provide the level of safety demanded by the public. Similarly, EPA's database on the impacts of pesticides depends on studies conducted and data generated by the chemical companies who stand to gain by registration of the chemicals. This has long been a suspected source of conflict of interest (cf:

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

The Mediterranean fruit fly (Medfly) damages numerous types of fruit crops. Malathion spray programs used for Medfly control in California have caused considerable controversy.

48), and another reason for public distrust of government assurances of safety.

> As water resources problems in this country grow increasingly complex and interrelated, so too have the institutions and the programmatic and regulatory cures devised by government. Fragmentation, excessive ''red tape, ' and lack of incentives for innovation have called into question the problem-solving capacity of our institutions. . .. The problem centers on the inability of governments to collectively translate beliefs into tangible results. If left unattended, this problem will continue to seriously weaken both the credibility and performance of government services at all levels (86).

Increasing Urbanization of the American Public and of Congress

U.S. agriculture has changed significantly since the onset of the ''chemical revolution. During the Depression, farm families still made up one-third of the U.S. population, and Federal government involvement in agriculture, already well-entrenched, expanded to include even more wide-ranging programs. In the 1980s, however, the budget crisis and ballooning payments to farmers, consumer concerns about food and drinking water safety, and increasing concern about environmental quality led urban interests and their representatives to reexamine the Federal role in agriculture (135).

The number of congressional districts considered "farm-oriented" totaled only 46 (out of 435) in 1986 (72). This number is expected to drop further with congressional district reapportionment after the 1990 census. Urban interests have historically tended to be more strongly ''consumerism' and ''environmentalist" than agricultural interests (cf: 135).

While Congress and governments may prefer to defer decisionmaking on agrichemical contamination of the environment until more information is available, or until a path of incremental changes in institutions, policies, and programs can be clearly determined, it seems unlikely that the current public clamor for action will subside. Actions to gain needed knowledge, to develop technologies with potential to reduce agrichemical contamination of groundwater, and to increase adoption of such technologies already are underway, promulgated by Congress, by Federal agencies, and by State and local government agencies. However, institutional structures and interrelationships among these institutions, which were designed for or have evolved to address other purposes, seem likely to hinder development of an integrated, comprehensive approach to reducing agrichemical contamination of groundwater or to reducing the adverse impacts of agriculture on the environment.

Overarching Barriers to Preventing Agrichemical Contamination of Groundwater

Protection of the Nation's groundwater resources has become an issue of pressing concern to the public, to Congress, and to many Federal, State, and local agencies. Agencies and organizations at all levels are undertaking programs designed to affect a farmer's choice of technology, and thus the potential for introduction of agrichemicals into groundwater. Consequently, to the earlier list of obstacles to preventing agrichemical contamination of groundwater must be added the overarching barriers-the *meta-obstacles-posed* by organizational histories, structures, and interrelationships that determine policies and programs affecting farmers' decisions. These overarching barriers include:

- rapidly *changing perceptions **of** agriculture and environment* and lack of expressly defined goals in either area;
- *multiplicity **of** organizations* involved and difficulty defining relative roles or coordinating efforts;
- complex and *entrenched missions and operating procedures* of agencies and programs, especially those with long histories, that commonly hinder incorporation of or directly conflict with new missions or goals; and
- *declining human and financial resources* available to all levels of government, with concomitant concerns over dilution and duplication of effort, and over ***inadequate information*** availability, reliability, and accessibility for decision-makers at all levels of the public sector.

Each of these has myriad policy implications that Congress could address.

CHANGING PERCEPTIONS OF AGRICULTURE AND THE ENVIRONMENT

Introduction

Water circulates continuously through the hydrologic cycle (ocean, atmosphere, and land); movement of water from surficial sources to groundwater or oceans and vice versa is a common attribute of the cycle. Agrichemical contamination of water can originate at various phases of the cycle. The route of contamination commonly is difficult to determine, highlighting the need for an integrated approach to development of groundwater protection schemes.

The 1980s witnessed an expansion of the traditional view of agriculture to include concerns over a broad spectrum of adverse environmental impacts attributed to conventional agricultural production practices. Agriculture's environmental externalities—"those costs borne by society and not reflected in market prices for commodities' '-exist, although they remain largely unexamined and unquantified (34).

> The environmental problems facing society and agriculture particularly may be largely attributed to the absence of a market for environmental quality. Society and farmers may in fact place a greater value on alternative uses for agricultural land than can be generated through commodity markets (104).

The Conservation Title (XII) of the 1985 Food Security Act (FSA) represented the initiation of this expanded approach to the development of agricultural policy (34,50). This Title contained a significant environmental component and clear identification of agriculture's responsibility for maintaining the resource base. Further, the creation of the Low-Input Sustainable Agriculture research program, and changes to other titles of the omnibus farm bill, indicate the tone is set for increasing legislative mandates related to agricultural impacts on the environment.

Adverse off-site impacts from agricultural production (e.g., soil erosion, groundwater contamination) may have large price tags, particularly when viewed in the light of recurrent commodity surpluses. Monitoring costs of potentially contaminated rural water-wells alone may range from almost $1 billion to $2 billion or more (174,1 17,34). Similarly, a 1985 study estimated that soil eroded from agricultural lands into surface waters costs $3 billion to $13 billion annually ($6 billion midpoint; 1980 dollars) (34). Although farmers may be bearing the costs of loss of farmland productivity due to erosion, and some may face the costs of contaminated water supplies, for the most part the environmental costs of agricultural activities are not borne by farmers, but by society.

Land-use and production practices of U.S. agriculturalists are now under scrutiny by the public-at-large; detections of agrichemicals in groundwater have served to catalyze public and political action. As a result, new socially-determined values have been identified to which the agricultural sector (producers, institutions, etc.) will need to respond (1 1). Despite ambiguous identification of the extent of agrichemical contamination of groundwater or of the realm of potential adverse impacts that may be generated by this occurrence, agricultural production practices are seen as a serious source of contamination (11),

Agricultural technologies and policies that have encouraged heavy chemical use and resource consumption are now perceived as having promoted agriculture's current economic and environmental problems. It has been suggested that broad changes in policies and production approaches will be needed to address these problems (34). The current legislative debate seems to focus on mechanisms to promote the integration of agriculture and environ.

mental concerns, with extremes falling into two major categories: 1) those believing that continued or increased agrichemical use would be environmentally catastrophic, and 2) others arguing that non-chemical production practices would render most of U.S. agriculture economically unviable. Neither situation is likely; reducing agrichemical losses and thus the adverse environmental effects of agricultural production is not necessarily incompatible with economic competitiveness (140,159).

The ability of the current agricultural system to reduce the adverse environmental impacts of agricultural is under question (162). A recent, report by the National Research Council identified a need for significant enhancement in the research and development efforts funded through the U.S. Department of Agriculture (USDA) as well as needs for multidisciplinary approaches to research and problem solving (1 13). The technological base from which researchers may draw potential solutions is increasing, with major emphases on biotechnology and information technologies. Ultimately the benefit of these advances to agriculture will be determined by how well they are integrated into a systems approach to agricultural production; one that incorporates productivity, economic viability, and environmental and public health protection.

Changing Definition of Public Trust Resources and Property Rights

Federal, State, and local governments exert substantial influence on agricultural land-use directly through such actions as property taxation, purchase or transfer of development rights, farmland preservation and right-to-farm laws, or more indirectly through environmental requirements or agrichemical-use restrictions (53,58). Governments also have established public interests in "privately-owned" resources such as surface water, wetlands, and endangered species, and some analysts have suggested that this may eventually extend as far as soil quality (9), or nature itself (147). The definition of a resource, and how it may be used, changes as knowledge and socially recognized values evolve.

The nature of property rights-an owner's accepted rights to control, use, or otherwise dispose of property-to natural resources has changed considerably since the publication of Rachel Carson's *Silent Spring in 1969 (25).* The rapid growth in land-use regulations and resource protection programs illustrates the accelerating social concern for ecological integrity. In relation to wetlands, an important part of the hydrologic cycle, recent court cases have affirmed that:

> Private land owners own a slice of an ecosystem-if not affirmatively obligated to protect the ecological role of their land, owners nonetheless do not have the right to alter the land's natural integrity by using it in a way that is incompatible with that role (84).

Court decisions have applied the public-trust doctrine-that the States hold certain resources in trust for certain public uses—to virtually any public use associated with surface water resources (e.g., navigation, fishing, recreation, aesthetics) (194,65). However, the U.S. Supreme Court recently recognized Federal authority to supercede historical States' primacy over the hydrologic cycle in its decision that Federal water law extends to protection of the lands that affect surface-water quality (84). Should the same principles be extended, for example, to groundwater recharge areas, agriculture and other development activities could be restricted beyond simple evaluation and registration of chemicals.

Inclusion of Agriculture in Environmental Stewardship

Under a new view of agriculture as an industry, liability for adverse environmental consequences generated by the activities undertaken in production has become an issue of broad public concern. Identification of responsible parties and degree of responsibility is a major point of debate. Is agriculture to be defined as a "strategic industry" such that the burden of liability is to be shouldered by all those who share in the benefits derived from its conduct (e.g., the taxpayer)? Or will a strict "polluter pays' approach be used? Likely, some compromise of these two extremes will evolve.

Historically, precedence has led to exemptions of specific agricultural activities from certain environmental protection acts. For example, irrigation return flow water is specifically excluded as a potential point source contamination route in the Clean Water Act.

However, the President's Water Quality Initiative specified that "farmers are ultimately responsible for avoiding contamination of water resulting from management practices they apply to the landscape' (165). Identification of agriculture as an industry with off-site environmental responsibilities is a new concept for many producers, particularly with regard to responsibility or liability for environmental contamination. Further, many practitioners view the water-quality issue largely as an information problem to be addressed through minor changes to extant agricultural policies and programs, major emphases on research, and little regulatory involvement. Most agriculturalists view actions to reallocate property rights as unnecessary (1 1).

For many years, farmer surveys and farm organization representatives have indicated strong opposition to regulatory approaches in agriculture (130). Environmental regulations in agriculture have been viewed as threats to U.S. agriculture's ability to provide an adequate food supply for meeting domestic and export needs (cf: 59). However, farmers and farm organizations do not hold uniform views regarding environmental regulation. More recent surveys indicate that some farmers may have moderated their opposition to regulation, particularly in relation to agrichemical use (95,130). Farmers thus may be distinguishing between regulations with clear personal health and safety implications and those which they perceive to be poorly thought-out reactions to exaggerated or poorly documented environmental problems. Thus, representation of all farmers as being uniformly opposed to regulation fails to accurately portray the diversity of opinion among farmers or the varied reactions to a broad array of possible regulatory approaches.

Trends suggest that agricultural producers no longer will be exempt from environmental responsibility. Whether any assignment of liability will be in response to Federal or State legislative actions or some combination of these however, has yet to be defined. Legislative action at the State level indicates the beginning of an era of environmental law that will affect agricultural practices (140), Landmark State initiatives exist that clearly identify polluter liability based on current "best" scientific knowledge. These have come despite the dearth of knowledge of potential adverse health effects from long-term exposure to contaminants at specific levels.

Connecticut, for example, applied strict liability for groundwater contamination, whereby the polluter was responsible for damages regardless of the level of care exercised. The State is not required to prove fault, negligence, or harm. After a court finding that the owners of five of Connecticut's largest and most profitable farms were liable for frees and provision of potable water to injured parties, the Connecticut Governor's Task Force on Pesticides and Ground Water recommended that strict liability remain in force, and that those potentially liable (including golf course owners, etc.) make mandatory contributions to a self-insurance fund. The latter proposal was not adopted although the law was revised to ***reduce the*** burden if:

- agrichemical applications were made properly;
- the applicator is an active agricultural practitioner and the agrichemical was used for agricultural purposes;
- plans to minimize contamination potential are implemented by the applicator; and
- complete records of agrichemical applications have been maintained (12).

Still, under the revised law, farmers and chemical companies remain liable to some extent for contamination.

Detections of agrichemical contamination of private and public wells in California led to development and passage of Proposition 65 that clearly establishes polluter liability for contaminating water with chemicals known to cause cancer, birth defects, or reproductive problems in humans. Under this initiative, water contamination is defined as chemical content beyond what is considered the scientifically safe level. Proving its safety is the burden of the polluter. The Proposition applies to businesses with at least 10 employees (31,12).

A key advantage of policies emphasizing polluter liability is that much of the enforcement and monitoring responsibility falls under the purview of private parties, while under a no-fault approach, responsibility lies with public agencies. However, disadvantages of placing responsibility in the hands of private parties largely lie in the lack of incentives for: 1) monitoring, 2) research on groundwater issues, and 3) development of educational or preventative approaches to mitigate potential contamination. This construct becomes active once damage has occurred, and relies on the judicial system to mediate and determine liability and required compensation on the part of the polluter. In these cases, the burden of proof falls on the plaintiff (12).

Similarly, the precedent for liability for wrongful or negligent acts leading to water contamination currently exists. Criminal provisions exist within numerous Federal environmental statutes, largely related to: 1) knowing or willful violations, 2) negligence, 3) misrepresentation of information to regulatory agencies, 4) disclosure of proprietary or confidential information, and 5) conflict of interest (1 16). Certain pieces of legislation (e.g., Clean Water Act) contain specific reference to punishment for release of pollutants into clearly identified water bodies or conduits thereof (e.g., ocean, sewer systems, etc.). Certain groundwater ' 'conduits' or ''tributaries' may fall under this Act (196), and thus penalties may apply.

Cross-Media Pollution and Media-Specific Programs

The final form and fate of agrichemicals are determined by their interaction with the agroecosystem in which they are applied. Certain cycles exist that are essentially unalterable within an agroecosystem and these cycles affect how inputs move and behave and where they ultimately will be deposited.

Environmental fate of agrichemicals may be affected by many factors including type and method of input, management approach, and the physical and biological attributes of agroecosystems. For example, nitrogen that is not taken up by an actively growing crop may have a variety of fates including: runoff (potential surface water contaminant), leaching (potential groundwater contaminant), volatilization (potential atmospheric contaminant), and immobilization (temporarily sequestered in organic matter). Reducing the potential for loss via one mechanism to one medium cannot ensure that loss to another medium will not occur. Thus, agricultural practices designed to conserve a specific resource (e.g., groundwater, atmosphere, soil) may in fact adversely affect another, particularly given the cyclic nature of certain contaminants (e.g., nitrogen) or contamination pathways.

Agricultural and environmental policy largely have been predicated on impacts affecting a single medium (e.g., air, surface water, groundwater), single sources (end-of-pipe industries, agriculture point source, etc.), or even single organisms (e.g., endangered species). While increasing recognition of the cross-media nature of contamination argues for development of a more systematic, comprehensive approach to environmental protection, the broad array of potential sources, routes, and impacts of contamination make development of such policies and programs difficult.

Currently, approaches to address agrichemical contamination of groundwater focus on regulatory approaches based on chemical attributes, development of risk assessment methodologies, and research on transport and fate of potential contaminants. While these factors warrant incorporation in environmental management approaches, the resultant Federal programs have not led to an integrated approach but rather, seem to exacerbate the existing fragmentation (132).

Prevention v. Remediation

Prevention has been asserted to be more effective (economically and technically) than remediation in agrichemical contamination of groundwater (cf: 117), and may be the more cost-effective approach to controlling all forms of 'environmental externalities. ' The Science Advisory Board for EPA has called for a more pro-active, preventative approach to environmental pollution (102).

The advantages and disadvantages of remedial treatment of contaminated aquifers has been an issue of much discussion and scientific research. Given current technology it seems that prevention of contamination is more feasible than attempting to reclaim aquifers. In many cases, the technology and science necessary for aquifer clean-up simply may not exist; in others, reclamation of degraded groundwater may be technically feasible but financially prohibitive. Preventative groundwater protection, however, is similar to preventative medicine. While prevention is preferred, it seems it is easier to get attention and allocate funding after problems occur (1 19).

Certain EPA planning documents suggest that aquifers known to be contaminated or unlikely to be used for drinking water should be designated as ''dumping areas,' while pristine aquifers should be maintained as drinking water sources, This strategy, however, presumes sufficient understanding of underground water flow to ascertain that contamination will not move from one region to another (144). It also presumes that the degraded aquifers will not be needed in the future.

New Technological Revolution in Agriculture

New technological tools are becoming increasingly available for application in agricultural production. Advances in biotechnology show promise for affecting current production practices significantly. For example, development of pest-resistant

Table 6-l—Percentage of Scientists by Field at 4-Year Colleges and Universities Receiving Federal Science Agency Support, 1987

Field of science and selected disciplines within fields	Number at colleges/ universities	Percent receiving			
		USDA funding	USDA comp. grants	NSF grants	NIH grants
Agricultural scientists	8,654	63.3	3.2	4.8	1.6
Economics related	1,838	68.1	NA	1.0	0
Plant biology-related	2,511	63.6	NA	6.0	1.5
Biological scientists	40,416	9.5	0.1	15.8	45.6
Agricultural-related biological	6,778	28.2	‹0.2	17.6	19.2
Plant-related	1,098	48.0	NA	29.0	5.5
Environmental scientists	7,375	4.6	‹0.1	35.5	1.5
Hydrology and water resources	293	23.2	NA	27.3	0
Ail scientists	185,746	6.8	0.2	12.1	18.5

SOURCE: National Research Council, *Investing in Research:A Proposal to Strengthen the Agricultural, Food, and Environment System* (Washington, DC: National Academy Press, 1989).

crop cultivars could have a dramatic effect on pesticide use. Similarly, information collection and dissemination techniques show promise for enhancing adoption and use of new technologies and improving application of extant practices (e.g., "how-to" videos). While some of these advances are still in their infancy, others are either on-line (e.g., biocontrol agents) or will be available soon (e.g., drought-tolerant tomatoes). Agricultural production methods certainly will be affected by such changes in available technology.

Although USDA is the major actor in developing and extending agricultural practices to producers, other agencies also invest significant effort in research and technology development related to agriculture (table 6-1) (113). At least one-third of the funding for agricultural research is granted by agencies other than USDA (162). As agriculture's technological base broadens, the possibilities of solutions to problems expands as well. However, it is unclear whether this base is sufficiently broad or whether the current research structure is adequate to address the plethora of environmental concerns related to agriculture (162).

It seems clear that the current public and congressional concern over the adverse environmental effects associated with agricultural production practices is likely to result in policy changes affecting agriculture. This situation offers a unique opportunity to develop policies and programs that integrate agriculture and the environment. New agricultural policy will have to address the changing conditions posed by an expanding agri-technological base and public concern over agricultural impacts on the environment.

An ultimate goal of policy development maybe to create policy that is sufficiently flexible to adapt as these conditions continue to evolve (104). Clearly, multidisciplinary research, development, and extension of agricultural production systems will be increasingly needed. However, the current structure of the agricultural research and education system may not be adequate to fulfill this need.

Setting Goals

The agricultural community has long been criticized for not providing or developing a national plan for agriculture (cf: 161,162,144). Policies and programs commonly are created to address individual, and sometimes temporary problems, with little consideration to the overall impact on U.S. agriculture. As programs are added or changed, the impact of this evolving patchwork is modified, and interactions among the multiple components of agricultural and other policies modify the patchwork in unanticipated and sometimes adverse ways. Even the USDA has recognized the problems with "ad hoc, crisis-oriented policymaking" (161). For effective, long-term agricultural development and maintenance of environmental quality, clear-cut food and agricultural goals are necessary.

A goal is defined as ***the end toward which effort is directed. The*** end point must be definable and, at least in theory, achievable. The oft-stated mission of U.S. agriculture is assumed to be: to provide an ample supply of nutritious food for the consumer at reasonable cost with a fair return to the farmer within an agricultural system that is sustainable in perpetuity. However, this "goal" is open-ended and, therefore, not achievable. Further, it contains many unquantifiable facets. For example, what is meant by an ''ample supply?' Does it mean production to meet: a) U.S. demands? b) U.S. demands plus economic demands of the world market? or c) U.S. and world market demand plus confessional food to poor countries? How would we know when an ''ample supply' is achieved? What is ''nutritious' food? How is it defined? Is a "reasonable cost' to consumers 15, 20, or 30 percent of disposable income or some other figure? Is a' 'fair return to the farmer" 10, 15, or 20 percent of investment? And would this "fair return" be achieved by: 1995? 2000? or 2500? Is a sustainable system one that tolerates 5, 10, or 15 tons of erosion per acre annually? Does it provide any allowance for or hold any prohibitions on agrichemical contamination of groundwater? (161).

These and other questions must be answered for a goal to have meaning and to be useful for agricultural policymaking, determining trade-offs in resource allocation, or planning a research agenda. With such questions remaining unanswered, these activities become largely a futile task. Directives that do exist often are so vague that Congress may conclude that directives are being ignored at the same time agencies conclude that they are being addressed (1 19).

Congress has set well-defined, achievable goals in other arenas in the past. Congress set a goal of putting a man on the Moon by the end of the 1960s; the goal was met. Congress has set goals for the level of gasoline consumption for different sizes of cars by certain dates. It should be possible for Congress to set well-defined, achievable, goals for U.S. agriculture as well (161).

In the absence of explicit goals, confusion may exist within the agencies regarding the appropriate direction to take in program development. Agency administrators tend to prefer legislative directives that are brief in length and broad in authority, thus providing a mandate but leaving flexibility to adjust programs as circumstances change. Congress and special interest groups, however, may prefer very specific directives to ensure that the issue of concern will in fact be addressed. Some sort of compromise may be appropriate: a statement of specific goals that includes a certain degree of flexibility and sufficient time prior to evaluation to allow adaptation to changing conditions. In this way a program may be adjusted as necessary, while retaining assurance that there will be real criteria by which to measure agency response (1 19).

The goals of USDA remain undefined and as such complicate identification of priorities; leading to a reactive rather than proactive institution. A recent GAO report noted that significant constraints to coordinated and consistent program implementation exist within USDA (158).

> . . .we believe that the Secretary needs to develop and clearly articulate a management agenda for the Department focused on important cross-cutting issues and improved human resource, information, and financial management systems. GAO management reviews of other agencies indicate that Cabinet secretaries have been able to implement reforms by personally articulating policy and management priorities and by ensuring that the Department responds effectively. The agenda should include a statement of goals, required actions, and management systems to monitor and evaluate achievement of said goals. We believe that such an agenda would be an important first step to ensure that USDA has the appropriate organization, systems, and flexibility to meet its challenges. Further, the next levels of departmental political and career managers must be held accountable for implementing this agenda (158).

Under the existing Federal framework for environmental protection, addressing nonpoint-source water contamination largely depends on increasing the priority of water quality goals contained in programs that are not specifically designed for protection of water quality (8). However, the effectiveness of implementing these program subsections may well depend on agency abilities to set goals, develop an implementation process, and monitor activities to determine success (i.e., the same factors that GAO suggests are lacking in USDA). Additional conditions necessary for success include flexibility to allow adaptation to changing conditions, commitment by implementing officials, and political support (79).

The "T by 2000" program in Indiana is illustrative of the potential effects of environmental goal-setting at the State level. The program seeks to reduce soil loss per acre in Indiana to the soil loss tolerance-limit ('‘T' or below, and, thus associated sedimentation problems from agricultural and non-agricultural sources by the year 2000. The effort began in 1983 with the establishment of the Soil Resources Study Commission. The Commission was given the task of assessing State soil erosion problems and relevant policies, laws, and practices. Recommendations developed in this assessment described operational structure, education and research, technical assistance, financial assistance, and regulatory measures needed to achieve this goal. Based on this analysis, legislation was enacted in 1986 to implement the operational structure. With the addition of a lake-enhancement component (controlling sedimentation and nutrient loss to surface water bodies), broad public support was gained leading to approval of funding and allowing partial implementation of educational and technical assistance aspects of the program. The initial two years of the program have been deemed successful (35).

POLICY ISSUE: Lack of Clear, Measurable, Federal Goals for Agriculture and the Environment

Option: Congress could establish clear and specific national goals to protect the physical and biological integrity of the environment generally, and groundwater resources specifically.

No clearly identified Federal goals related to agriculture and the environment exist. This hinders congressional identification of current activities relevant to issues of public concern such as agrichemical contamination of groundwater, and oversight of resource allocation among competing priorities. The precedent for identification of such goals at the State level also indicates a potential for further development of fragmentary environmental protection efforts.

Program leaders within each of the agencies should be able to define the working objectives, goals, and implementation schedules under which they are operating. Each of these agencies and their respective offices should have clear and specific measurable goals that are relevant, integrated, and coordinated towards attainment of explicitly stated national objectives. Each agency should have a published working plan that states how they will reach their goals and their timetable of implementation, Some agencies are already developing goals and implementation plans, but Congress may wish to ensure that all of the agencies take this action, that the efforts are coordinated, and that they adequately reflect the concerns of Congress and the public.

To reach such a set of goals, objectives and timetables, Congress may wish to pursue a more interactive planning process than is normally used. Rather than a mandate, Congress might instruct the respective agencies to submit working goals to which Congress and the public could respond prior to legislative action.

POLICY ISSUE: Need To Ensure Commitment of Administrators to Goals

*Option: Congress could clearly express its commitment to **goals and priorities during confirmation hearings for administration nominees.***

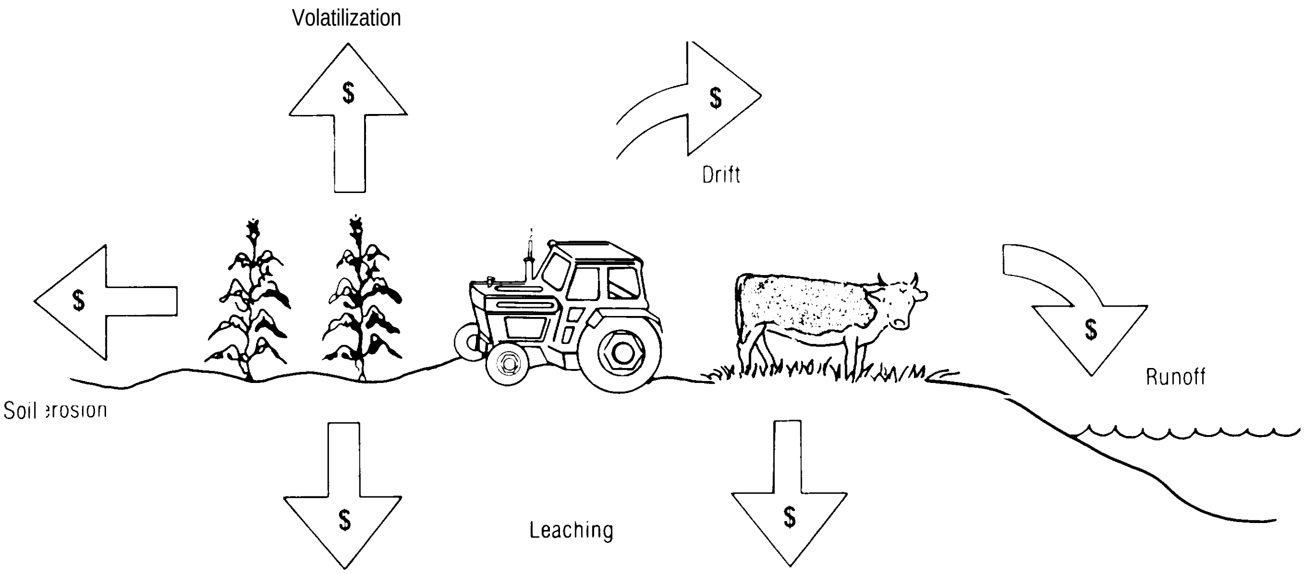
Authorizing legislation may mean little if not followed with appropriations, however, equally important is the coremitment of the administrators to the program (125,1 19). Guidance afforded an agency by top management can be crucial in developing appropriate responses to environmental and technical issues. Thus, the appointment of high-level management possessing the experience and technical background appropriate to the agency mission is likely to be of great importance, particularly with respect to formulation of agency initiatives in response to sensitive agricultural and environmental issues.

The offices of Secretary and Undersecretaries of Agriculture, Administrator of EPA, Director of the U.S. Geological Survey (USGS), etc., are presidentially appointed. Thus, congressional confirmation hearings offer an early opportunity to assess the capabilities and views of these potential candidates. These hearings also provide a forum for raising issues and discerning the depth of a nominee's knowledge of and concern for responding to critical environmental issues. Potential exists during this appointment process to reinforce congressional and public concerns with the appointee.

Focusing on Reduction of "Waste" in Agricultural Systems

Policy approaches that focus on waste reduction seem to offer significant potential for reducing groundwater contamination potential associated with current agricultural production practices. Losses of applied agrichemicals, excess energy use, etc. may all contribute to increased input costs for practitioners as well as create the opportunity for environmental contamination through a variety of pathways (figure 6-l). These wastes may be biodegraded into

Figure 6-l—Losses of Agrichemicals to the Environment are Financial Losses to the Farmer



Agrichemicals may be lost from an agricultural production system through a variety of mechanisms. These represent lost farmer investments as well as potential costs to society.

SOURCE: Office of Technology Assessment, 1990

other compounds, taken up by non-target organisms, or lost to various pathways where they may become pollutants in the hydrologic cycle. Actions to reduce such waste could have beneficial effects on environmental quality generally and groundwater quality specifically.

Thus, one promising approach to reducing the potential for agrichemical contamination of groundwater (as well as other media) is based on the concept of waste reduction. Waste reduction for agriculture may be defined as ''reducing the generation, emission, or discharge of agricultural pollutants or wastes through modification of agricultural production systems and practices' (34). Most farms could benefit from enhanced resource conservation activities and improved use of the physical and biological aspects of the agroecosystem (34,33,1 12).

Waste reduction approaches to agriculture also may have beneficial impacts on other issues of public concern, such as energy-use efficiency in agriculture. New approaches to cultivation (e.g., conservation tillage) have been linked to increased energy efficiency in terms of direct energy inputs. Energy efficiency in U.S. agriculture increased 55 percent between 1974 and 1985, largely through reduced tillage practices, increased control and timeliness of agrichemical and irrigation water applications, and other energy-conservation measures (148). However, use of energy-intensive agrichemicals increased 15 percent between 1974-85. Energy components in fertilizer and pesticide production are nearly 60 and 13 percent respectively (148). Clearly, improving agrichemical application efficiency with a goal of waste reduction also could have beneficial effects on overall energy conservation.

Waste reduction as a policy initiative to address groundwater contamination would require identification of the types of waste to be addressed (e.g., pesticides, nutrients) and the magnitude of reduction. Potential targets for waste reduction in agriculture might include: agrichemicals and livestock wastes, soil erosion, and greenhouse gas emissions (33). While such a policy tool is not specific to particular farming systems, it maybe biased towards heavy-input production systems. Organic production systems (cf: 163) could be viewed by some as the ultimate pesticide waste-reduction approach, however, such systems may rival conventional systems in other types of waste production (e.g., nitrate from livestock wastes). Potential for practices designed to reduce certain inputs could result in greater difficulties with conservation of other resources (e.g., herbicide reduction requiring additional cultivation may lead to increased soil erosion problems).

Federal activities in development of agricultural technologies are significant. Inclusion of waste reduction as a goal of ongoing agricultural research and extension programs, thus, could have a broad effect. A possible approach could include: setting priorities (e.g., identify "most wasteful" systems), assessment of a feasible level of waste reduction, identification of data gaps and the research needed to fill gaps, identification of appropriate extension and support programs, and development of a timetable and system for monitoring success of program,

Human resources and technical expertise was available to help practitioners implement soil conservation measures as outlined in the 1985 Food Security Act. However, dearth of such expertise related to ''agrichemical conservation measures' inhibits adoption of production practices using reduced chemical inputs (33). The scientific understanding of the effects of agrichemicals in food and drinking water is limited in comparison to the understanding of soil erosion processes and potential solutions. Thus, enhancement of organizational structure and technical expertise necessary for implementing new conservation policies related to groundwater protection is unlikely to occur rapidly (33). Analysis of the current capacity, then, is crucial to the development of rational timetables for achievement of water-quality conservation goals.

Design and extension of waste-reduction practices appropriate to cropping patterns or regions highly vulnerable to groundwater contamination could have significant impact on reducing the potential for agrichemical contamination of groundwater. However, development of strategies designed for waste reduction will depend on availability of information on agrichemical use patterns correlated with cropping region and cropping pattern.

POLICY ISSUE: Establishing an Organizing Principle for Goal-Setting

Option: Congress could establish an Agricultural Waste Reduction Initiative to serve as an organizing principle for identifying goals for U.S. agriculture and the environment.

Congress could direct agencies with agriculturally related responsibilities (USDA, EPA, etc.) to develop strategies aimed at achieving reduction of waste over the long term. Initial steps might include identification of the technical and informational needs to make decisions related to goal development and timetables for emission reduction and prioritization of these needs.

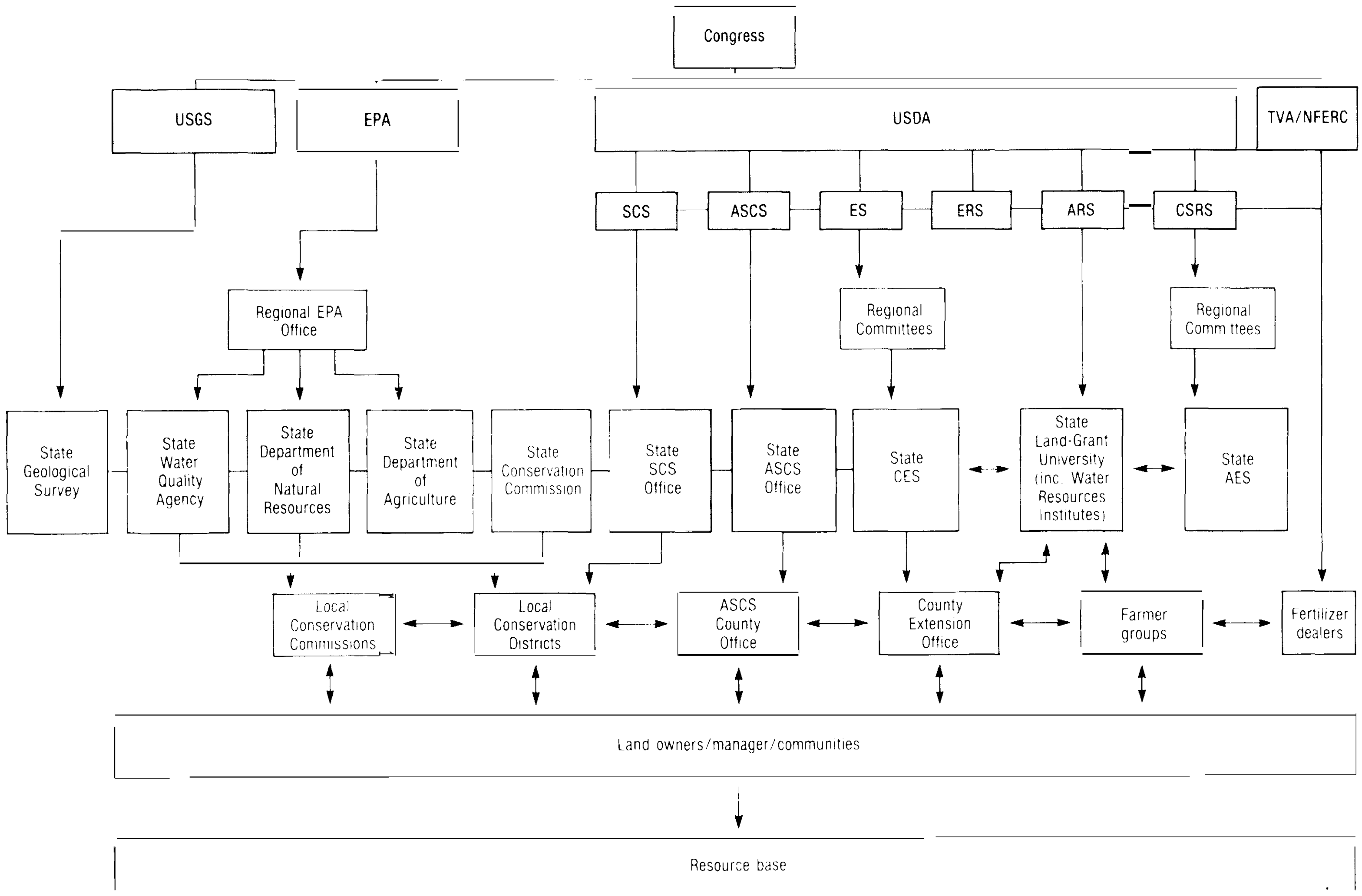
Waste reduction policy development will depend on: 1) accurate, current information on agrichemical use and identification of waste-generating production systems, 2) technically sound information on environmental fate of wastes in different settings, 3) development of technically and economically feasible alternatives for high "waste-generating" production systems, and 4) research and technical-assistance systems adequate to support such changes (33). This type of information could be used in combination with identification of regions highly vulnerable to groundwater contamination, and with information on relative risks of exposure to humans and the environment, to develop a strategy to protect groundwater.

Critical questions that must be answered are: how can conditions be created that would foster grower adoption of waste reduction production practices? and what forms of incentives and technical assistance structure and expertise are needed to support such a change? Analysis is needed of the organizational structures and technical knowledge necessary to support practitioners in implementation of new program titles that may become part of Federal legislative actions.

CHARACTERIZING THE CONFUSION: THE PATCHWORK OF AGENCY INVOLVEMENT IN PREVENTION OF AGRICHEMICAL CONTAMINATION OF GROUNDWATER

Setting goals, redirecting programs, or coordinating Federal efforts to reduce agrichemical contamination of groundwater is complicated by the number and variety of organizations involved in agriculture and water quality (figure 6-2). The Association of State and Interstate Water Pollution Control Administrators in 1985 identified "354 State and local programs, and 32 programs in 17 Federal agencies, which manage nonpoint-source activities and affect water quality' (8). These numbers have undoubtedly risen since then.

Figure 6-2—Primary Organizations Involved in Policymaking and Program Implementation Related to Agrichemical Contamination of Groundwater



Myriad organizations develop and implement policy related to agrichemicals and groundwater—to agriculture and the environment. The subsequent multiplicity of actors, actions, viewpoints, and approaches make it difficult to generalize on current or potential roles, evaluating extent of success, or defining lines of coordination and cooperation.

SOURCE: Adapted from the National Association of Conservation Districts, "Proposed Strategy for Protecting Surface and Groundwater from Agricultural Activities," June 1989.

Organizations Involved in Agrichemical Contamination of Groundwater

Identification of potential policy implementers, or even development of a catalog of current groundwater protection activities, is hindered by the breadth and diversity of public organizations operant in agriculture and groundwater contamination, nonpoint-source pollution, water quality, or other related environmental issues. In addition, some basic organizational characteristics hinder an integrated approach to protection of groundwater from agrichemical contamination.

- Organizations at all levels of government—Congress, Federal, State, local, and in some cases regional or international-are or have potential to become involved in protection of groundwater from agrichemical contamination. Within each of these levels, the types of organizations with potential roles to play include the more traditional agriculture, environment, and public health organizations, as well as newer interagency task forces, councils, and boards that have been developed specifically to address the issues.
- Organizations differ in the types of activities they use to effect change, including education and voluntary programs, incentives designed to lure decisionmakers into modifying farm-management systems, and regulations prohibiting certain types of activities. Organizations typically have been designed (or have evolved) to favor one type of influencing activity over another.
- Organizations also have tended to focus along lines more restrictive than what is needed to encompass the entirety of issues involved. For example, agricultural programs may focus on individual commodities; agricultural conservation and environmental protection programs have tended to single out individual pollution media; and health impact investigations may single out cancer or reproductive hazards from other potential health impacts.

This multiplicity of actors, actions, viewpoints, and approaches makes it difficult to generalize on current or potential roles, evaluate extent of success, or define lines of coordination and cooperation.[1]

The Role of Congress

Nearly 50 bills addressing groundwater topics, many including agricultural issues, were introduced in the 100th Congress (197), and roughly 20 were introduced during the first half of the 101st Congress. In addition to the diversity of approaches suggested in these bills, and an apparent lack of consensus on the most appropriate response, the sheer number of bills reflects a fundamental change in Congress. Bills introduced into the 100th Congress were promulgated by or referred to at least 14 full committees (197) and involved almost twice as many subcommittees (20).

Clearly, the agriculture/environment debate has lifted agricultural policymaking beyond the House and Senate Agriculture Committees, where it traditionally was focused (17). Agriculture no longer has the widespread constituency it once had, and now has to entertain concerns expressed by non-agricultural interests (21). However, agricultural interests have maintained a strong traditional congressional lobby: at least 180 organizations representing agricultural interests are registered with the U.S. Senate lobby (18).

At the same time, the number of Committees and Subcommittees with some jurisdiction over environmental issues has grown rapidly. For example, the number of committees and subcommittees using the words ‘‘environment’ or ‘‘resources’ in their titles grew from 0 in 1965 to 25 in 1990. This explains, to some extent, the number of committees requesting referral of agricultural bills containing environmental protection provisions, which includes much recently proposed agricultural legislation. Historically neither the House nor Senate agriculture committees have fully participated in developing water quality legislation, which generally has been developed by the environment and public works committees (36).

With environmental jurisdiction scattered throughout Congress, no legislative constituency exists for integrating agriculture and environmental policy, nor for integrating environmental policy overall. However, because the boundaries of many agricultural and environmental issues do not match political boundaries-just as boundaries of aquifers do not honor county lines-bargaining becomes essential

1 More detailed discussions of Federal agency legislation and roles in protection of groundwater from agrichemical contamination can be found in Nipp (1 19), Zinn and Tieman (197), FCCSET (56), and OMB (190).

Box 6-A —Federal Agencies With a Role in Protection, Remediation, and Mitigation of Groundwater Contamination From Agrichemicals[1]

Executive Offices of the President

CEQ	Council on Environmental Quality
OMB	Office of Management and Budget
OPD	Office of Policy Development
OSTP	Office of Science and Technology Policy

U.S. Department of Agriculture

APHIS	Animal and Plant Health Inspection Service
ARS	Agricultural Research Service
ASCS	Agricultural Stabilization and Conservation Service
CSRS	Cooperative State Research Service
ERS	Economic Research Service
ES	Extension Service
FmHA	Farmers Home Administration
FS	Forest Service
NAL	National Agricultural Library
NASS	National Agricultural Statistics Service
SCS	Soil Conservation Service

U.S. Environmental Protection Agency

ORD	Office of Research and Development
OECM	Office of Enforcement and Compliance Monitoring
OPPE	Office of Policy, Planning, and Evaluation
OPTS	Office of Pesticides and Toxic Substances
OSWER	Office of Solid Waste and Emergency Response
OW	Office of Water (including the Office of Ground Water Protection)

***U.S.** Department of **the** Interior*

BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
FWS	Fish and Wildlife Service
NPS	National Park Service
USGS	U.S. Geological Survey

Tennessee Vane-y Authority

NFERC	National Fertilizer& Environmental Research Center

Department of Defense

ACOE	U.S. Army Corps of Engineers

[1]OTA commissioned a survey of Federal Departments and agencies to identify relevant agencies and programs, their roles in agriculture and water quality issues, and the extent of their involvement over the decade 1980-1990. The agencies listed above do not include other agencies contacted, which may have a more minor or yet undefined role in groundwater protection, such as the Food and Drug Administration. In addition, other agencies, such as the National Oceanic and Atmospheric Administration were contacted and do have programs that relate to agrichemical use and groundwater contamination, but information on resources or perceived roles was not compiled for OTA. Each agency was asked to interpret aspects of ongoing programs, budgets, and personnel that support groundwater protection and remediation. The voluminous information collected is summarized in L.A. Dye, ''The Federal Role in Reducing Agrichemical Contamination of Groundwater, OTA commissioned paper, 1990.

to discovery of an efficient integrated solution (149). The institution responsible for such an integrated approach, Congress, has taken a fragmented approach. Instead of using the Committee room as an arena for debating national environmental policy, it has continued to expand and pass separate air, water, and solid-waste pollution legislation, impeding more integrative approaches (132). Groundwater may become just one more medium to add to this list.

Federal Roles and Activities

At the Federal level, at least 30 Departments or agencies have some influence over agriculture and groundwater issues (box 6-A); discussion of each of these organizations and their efforts is beyond the scope of this assessment. However, the main Federal organizations affecting agricultural contamination of groundwater are the Environmental Protection Agency (EPA), various programs within the U.S. Department of Agriculture (USDA), the U.S. Geological Survey (USGS), and the Tennessee Valley Authority (TVA), which houses the National Fertilizer & Environmental Research Center (NFERC). A brief summary of their activities follows.

The Tennessee Valley Authority has responsibility for electrical power generation and other development efforts for the seven-state Tennessee River Drainage Basin, including Tennessee, Virginia, North Carolina, Georgia, Alabama, Mississippi, and Kentucky. It also has broad *environmental protec*tion and natural resource management responsibilities for this area. The 201 TVA counties established the cooperative "Land and Water 201" program in 1984 to: 1) reduce soil erosion, 2) improve water quality, 3) increase farm income, and 4) serve as a national model and demonstration for multiagency cooperative soil and water conservation programs (151).

The National Fertilizer Development Center was created with the Tennessee Valley Authority Act in 1933, and is considered the lead national organization in fertilizer research and education. As part of a recent TVA restructuring, the Center was renamed the National Fertilizer & Environmental Research Center, and redefined its mission to "be a leading national source of nutrient-related information for public and private use' and to direct its research to high-priority environmental issues (109,1 10).

The U.S. Geological Survey (USGS) conducts groundwater quantity and quality assessment, monitors aquifers at a number of sites across the nation, investigates temporal and spatial trends, and provides this information to Federal, State, and local agencies in support of their groundwater protection programs (box 6-B). It also maintains a large scientific program to study movement and fate of chemicals in the environment. More directly relevant, USGS is examining the impact of agricultural chemical use on groundwater quality in several U.S. regions in the pilot phase of its National Water Quality Assessment Program (78).

Although the Environmental Protection Agency (EPA) conducts a number of activities that affect agriculture (box 6-C), its primary relevant regulatory authority is over agricultural pesticides through the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The EPA regulates use of pesticides and, through its designated State lead agencies, is responsible for ensuring that users of restricted pesticides are trained in proper use. The first regulatory action

Box 6-B—Major USGS Activities Related to Agrichemical Contamination of Groundwater

The U.S. Geological Survey is engaged in a broad array of information collection, information management, and research projects pertinent to groundwater management and protection.

Coordination and Dissemination of Federal Information on Groundwater. The USGS releases a comprehensive report on water resources annually: the National Water Summary. This report includes comprehensive documentation on water resource quantity and quality for each State, and includes case studies of nonpoint-source contamination. It also summarizes studies on managing and coordinating Federal and State water protection efforts. USGS also maintains a computerized National Water Storage and Retrieval System (WATSTORE) and a computer-based National Water Data Exchange (NAWDEX).

National Water Quality Assessment Program. Since 1986 the NAWQA program has conducted assessments of national and regional status of groundwater resources and monitors trends in factors that can affect groundwater quality, Agrichemical nonpoint-source contamination problems are under study in seven pilot projects (197).

Regional Aquifer Systems Analysis Program. The RASA program was established in 1978 to gather data on the quantity of water resources available in the nation's aquifers. RASA's objectives for each aquifer system study are to determine the availability and chemical quality of stored water and discharge-recharge characteristics, and to develop computer simulation models that may assist in understanding the groundwater flow regime and changes brought about by human activities (98). Twenty-eight aquifer systems have been identified for study, fourteen of which have been completed.

Federal-State Cooperative Program. USGS supports local efforts to collect data on ground and surface waters through cost-sharing arrangements with State and local governments. For example, USGS has provided support for mapping State aquifers, for monitoring pesticide contamination problems, and has assisted in developing wellhead protection programs.

State Water Resources Research Institutes. Under this program the USGS provides grants to 54 State and Territory Water Resources Institutes for research, information dissemination, and for training students in water resources fields. Approximately 35 percent of the Institutes' work is related to groundwater protection. Reauthorization of the Institutes has been hindered by their incorporation in broad and controversial groundwater protection bills.

Mid-continent Initiative. The USGS also is working in cooperation with the USDA's Midwest Initiative on a "Mid-Continent Initiative, " a 5- to 10-year research program characterizing the environmental fate of the widely-used agricultural herbicide atrazine. The area understudy, roughly bounded by the Upper Missouri and Ohio River Basins, was chosen largely because of the coincidence of hydrologic boundaries with a region of intensive agrichemical-use cropland (134).

Box 6-C—Major EPA Programs Affecting Agriculture

FIFRA Pesticide Programs

- The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) gives EPA responsibilities for registering new pesticides and for reviewing and re-registering existing pesticides to ensure that, when used according to label directions, they will not present unreasonable risks to human health or the environment.

National Survey of Pesticides in Drinking Water Wells

- The National Survey is underway to determine the presence and concentration of 127 commonly used agricultural chemicals in 1,350 statistically selected wells. EPA expects to issue a draft report on the survey in late 1991.

Safe Drinking Water Act Programs

- The Safe Drinking Water Act (SDWA) requires EPA to publish maximum contaminant levels (MCLs) for any contaminants, including pesticides, which may have adverse health effects in public water systems (those serving over 25 persons or with 15 connections). Standards established by EPA under the SDWA are also being used as guidelines to assess contamination of groundwater in private wells. The EPA also sets nonregulatory health advisory levels on contaminants for which MCLs have not been established.
- The SDWA also established a Wellhead Protection Program (WHP) to protect wells and wellfields that contribute drinking water to public supply systems. Each State must prepare and submit to EPA a Wellhead Protection Program delineating the recharge areas around public water, identifying potential sources of groundwater contamination within these areas, and addressing identified potential sources to protect the public water supply. Although funds have been appropriated for the WHP Program, the EPA Administrator testified to the Senate that only 30 States have submitted proposed programs for review and approval by EPA (10).

1987 Water Quality Act Nonpoint Programs

- Section 319 of the Act requires States and Territories to file assessment reports with EPA identifying navigable waters where water quality standards cannot be attained or maintained without reducing nonpoint-source pollution. States must also file management programs with EPA identifying steps which will be taken to reduce nonpoint pollution in those waters identified in the State assessment reports. The Act authorizes up to $400 million total in Federal funding for implementing the programs. To date, 43 States and Territories have submitted nonpoint-source pollution assessments to EPA, and 36 have submitted final management programs.

1987 Water Quality Act Clean Lakes Program

- Section 314-of the Act requires States to submit assessment reports on the status and trends of lake water quality, including the nature and extent of pollution loading from point and nonpoint-sources. Also, methods to control pollution and to protect/restore the quality of lakes impaired or threatened by pollution must be described.
- Financial assistance is given to States to prepare assessment reports and to implement watershed improvements, as well as to conduct in-lake restoration activities. Several USDA small watershed projects have been coordinated with Clean Lakes projects.

1987 Water Quality Act National Estuary Program

- Section 320 of the Act provides for identification of nationally significant estuaries threatened by pollution, preparation of conservation and management plans, and Federal grants to prepare the plans. Planning is underway for 12 major estuaries.

'Near Coastal Waters Strategy

- Through its Near Coastal Waters Strategy, EPA is integrating its water quality programs to target priority programs and prevent pollution in near coastal waters. This includes the implementation of nonpoint-source management programs in coastal counties and will, in several cases, encompass accelerated implementation of agricultural conservation programs.

Regional Water Quality Programs

- The EPA and other Federal agencies are cooperating on several regional programs to reduce nonpoint source pollution, including the Chesapeake Bay Program, the Colorado River Salinity Control Program, the Great Lakes Program, the Gulf of Mexico Program, and the Land and Water 201 Program in the Tennessee Valley Region.

SOURCES: After USDA/ERS, "Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report," AR-16, September 1989; and R. Barles, personal communication. Office of Ground Water Protection, Environmental Protection Agency, Mar. 9, 1990.

Photo credit: State of Florida Department of Environmental Regulation

Between 12 and 14 million private wells in the United States provide drinking water, most in rural areas. Private wells currently are not required to be tested nor to comply with Safe Drinking Water Act standards.

taken against a pesticide registration due to groundwater contamination in the continental United States was EPA's ban of DBCP (1,2-dibromo-3-chloropropane) in 1979. Since that time, EPA has canceled other pesticides due to groundwater concerns, established an Office of Groundwater Protection in the Office of Water, and added requests for data on leaching for reregistration of a number of pesticides (31).

The EPA has devised a "Groundwater Protection Strategy" (180) in response to its diverse groundwater protection responsibilities, with four main objectives:

- to support State program development and institution building;
- to assess potential problems from unaddressed sources;
- to issue guidelines for consistent agency decisions affecting groundwater; and
- to strengthen EPA's organization for groundwater management and cooperation with other Federal and State programs.

Following from that strategy, in which States retain primary responsibilities and authorities to protect groundwater, EPA developed a comprehensive plan to improve and coordinate Federal, State, and local efforts to protect groundwater from agrichemical contamination (186). The key component of this plan is development of pesticide/groundwater management plans by the States in accordance with section 319 of the Clean Water Act. EPA also is the primary sponsor of an interagency group, entitled Water Quality 2000, that is preparing to address reauthorization of the Clean Water Act in 1992.

The USDA has repeatedly expressed a growing commitment to enhancing its water quality protection and improvement efforts, of which groundwater protection is stated a major component. Numerous reports listing water quality as a top priority (cf: 51) and agency work plans have been released (cf: 175,167,168,166). These culminated in the development of the Water Quality Program Plan to Support the President's Water Quality Initiative" (165) (see box 6-D detailing plan).

Box 6-D—Major Components of the USDA Water Quality Program Plan

USDA completed its Water Quality Program Plan to Support the President Water Quality Initiative in July 1989. Its objectives are to: "1) determine the precise nature of the relationship between agricultural activities and groundwater quality; and 2) develop and induce the adoption of technically and economically effective agrichemical management and agricultural production strategies that protect the beneficial uses. . ." of groundwater.

Education and Technical Assistance—Adoption of agrichemical use, waste management, and production practices that may reduce or prevent contamination will be accelerated where existing of potential contamination of ground or surface water from agricultural nonpoint sources has been identified as a public concern. Adoption will be encouraged through enhanced education, technical and some financial assistance, and demonstration projects. Specific projects include:

- expanding USDA and CES staff capacity to deliver educational and technical assistance to producers for effective agrichemical and waste product management and environmental stewardship,
- demonstrating and delivering technologies and management systems for voluntary farmer, rancher, and forester adoption and implementation,
- meeting State water quality requirements through education and technical assistance, and
- informing the public of program activities and achievements.

Research and Development---Research programs will be aimed at developing knowledge about the fate and transport processes of agrichemicals, and at analysis of socio-economic effects of current and new agricultural management methods to allow measure of the relative cost-effectiveness of alternative practices and systems. Research programs will be designed to:

- develop methods for sampling, measuring, and evaluating groundwater contamination,
- conduct fundamental research to provide the basis for improved management of chemicals used in agriculture,
- improve agrichemical management and agricultural production systems, and
- evaluate economic, social, and technical impacts of new and improved management practices and systems.

Database Development and Evaluation-Data will be collected nationally on agrichemical use, related farm practices, and links with the physical environment. Further, centralized systems for linking data and statistical information on agricultural productivity, land use, agrichemical use, physical attributes of the land and surrounding watersheds, climate, and water quality are envisioned. Specific goals are to:

- build National and State databases on agrichemical use and related farm practices, and
- provide digitized geographic information systems for State and Federal evaluation of alternative policies and program strategies.

Interagency Coordination-The Water Quality Program Plan ''involves the capabilities and activities of more USDA Agencies, working in closer concert with a wider variety of Federal and State Agencies than any previously established Departmental function" (165). USDA water quality programs are coordinated through a new Working Group on Water Quality established in late 1989 as a unit of the Secretary's Policy and Coordination Council, and chaired by the Deputy Assistant Secretary for Science and Education. The Working Group is charged with: 1) coordinating all USDA policies and programs relating to water quality activities; 2) developing and recommending strategies for carrying out these activities; and 3) providing advice and guidance on water quality issues to the policy council (176).

SOURCE: Unless otherwise noted, information is adapted from U.S. Department of Agriculture and Cooperating State Agencies, "Water Quality Program Plan to Support the President's Water Quality Initiative" (Washington DC: U.S. Department of Agriculture, July 1989).

The USDA, through the Soil Conservation Service (SCS), Economic Research Service (ERS), Agriculture Research Service (ARS), Cooperative States Research Service (CSRS), Extension Service (ES), and Forest Service (FS) primarily conducts research, publishes information, and offers advice to farmers on pesticide and fertilizer use, land management, and agronomic or silvicultural practices (box 6-E). No lead agency has been identified; rather a Working Group on Water Quality has been established to coordinate the activities of eight principal USDA agencies and their cooperating State institutions.

The Resources Conservation Act of 1977 requires SCS to develop national plans and programs for soil

Box 6-E—Major USDA Conservation and Water Quality Programs

_1985_ Food Security Act Provisions

- Conservation Reserve Program (CRP) provides annual rental payments to land owners and operators who voluntarily retire highly erodible and other environmentally critical lands from production for 10 years. It also provides technical assistance and cost-sharing payments up to 50 percent of the cost of establishing a soil-conserving cover on retired land. Rental payments to any person may not exceed $50,000 per year. County enrollment is limited to no more than 25 percent of cropland, unless USDA grants a special waiver. To date, approximately 30 million acres of cropland have been enrolled.
- Conservation Compliance requires that farmers who produce agricultural commodities on highly erodible cropland have approved conservation plans by Jan. 1, 1990, and finish implementing them by Jan. 1, 1995, or lose eligibility for USDA program benefits.
- Sodbuster provision requires that farmers who convert highly erodible land to agricultural commodity production do so under an approved conservation system, or forfeit eligibility for USDA program benefits.
- Swampbuster provision bars farmers who convert wetlands to agricultural commodity production from eligibility for USDA program benefits, unless USDA determines that conversion would have only a minimal effect on wetland hydrology and biology.

Continuing Assistance Programs

- Agricultural Conservation Program (ACP) provides financial assistance to farmers for implementing approved soil and water conservation and pollution abatement practices. Cost-sharing payments to a given farmer may not exceed $3,500 per year on l-year agreements, and may not average over $3,500 per year on multi-year agreements. Except for Water Quality Special Projects, conservation priorities are set by States and counties based on local soil and water quality problems. Program initiated in 1936.
- Conservation Technical Assistance (CTA) provides technical assistance by the Soil Conservation Service (SCS) through Conservation Districts to farmers for planning and implementing soil and water conservation and water quality improvement practices. Program initiated in 1936.
- Great Plains Conservation Program (GPCP) provides technical and financial assistance in Great Plains States to farmers and ranchers who implement total conservation treatment of their entire operation. Cost-sharing assistance is limited to $35,000 per farmer contract. program initiated in 1957.
- Small Watershed Program provides Federal technical and financial help to local organizations for flood prevention, watershed protection, and water management, Program initiated in 1954.
- Resource Conservation and Development Program assists multicounty areas in enhancing conservation, water quality, wildlife habitat and recreation, and rural development. Program initiated in 1962.
- Emergency Conservation Program provides financial assistance to farmers in rehabilitating cropland damaged by natural disasters. Program initiated in 1978.
- Rural Clean Water program is an experimental program implemented in 21 selected projects. It provides cost-sharing and technical assistance to farmers voluntarily implementing best management practices to improve water quality. Cost-sharing limited to $50,000 per farm. Program initiated in 1980; ends in 1995.
- Model Implementation Program provides Federal cost-sharing and technical assistance to encourage practitioner adoption of Best Management Practices that may beneficially affect water quality.
- Extension Service provides information and recommendations on soil and water quality practices to land owners and operators, in cooperation with SCS and Conservation Districts.
- Farmers Home Administration provides loans to farmers and associations of farmers for soil and water conservation, pollution abatement, and building or improving water systems that serve several farms. It may acquire 50-year conservation easements to help farmers reduce loan payments.
- Forestry Incentives Program provides cost-sharing up to 65 percent for tree planting and timber stand improvement for private forest lands of 1,000 acres or less,
- Water Bank program provides annual payments for preserving wetlands in important migratory waterfowl nesting, breeding, or feeding areas. Program initiated in 1970.

Research Programs

- Agricultural Research Service conducts research on new and alternative crops and agricultural technology to reduce agriculture's adverse impacts on soil and water.
- Cooperative State Research Service coordinates conservation and water quality research conducted by State Agricultural Experiment Stations and land-grant universities. This agency allocates and administers funds appropriated for special and competitive grants for water quality research,
- Economic Research Service estimates economic impacts of existing and alternative policies, programs, and technology for preserving and improving soil and water quality. With National Agricultural Statistics Service, collects data on farm chemical use, agricultural practices, and costs and returns.
- Forest Service conducts research on environmental and economic impacts of alternative forest management policies, programs, and practices.

SOURCE: U.S. Department of Agriculture, Economic Research Service, ''Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report " AR-16, September 1989.

and water conservation. The resulting report lists the Department's priorities for soil and water resource protection for the next decade. The most recent plan was completed in 1989, and included a significant redirection from the last plan completed in 1982. In the plan for the 1990s, water quality protection moved from sixth to second national priority.

State and Local Level

State and local governments play perhaps the most active role in groundwater protection (box 6-F), A variety of State departments and agencies administer or cooperate in research, monitoring, and technical assistance programs that provide information to producers on environmentally appropriate farming practices. State agencies also may provide financial or technical assistance to producers to assist them in modification of farming practices (see ch. 5, app. 5-l), and may regulate farming practices or agrichemical use beyond those regulations promulgated by EPA.

At the State and local levels, pesticides are regulated by State Lead Agencies (SLAs) that have been granted FIFRA primacy by EPA. States may ban chemicals from use in certain areas, or may

Box 6-F—Selected State Programs Affecting Agriculture and Groundwater Quality

States increasingly are enacting innovative and sometimes stringent environmental laws. These are "having an indirect impact on Federal policy as States put pressure on the Federal Government to take similar action or as industry goes to Congress in search of uniform Federal laws to replace the patchwork of conflicting State requirements' (93).

Ground Water Quality Protection Programs: Twenty-two States have developed comprehensive programs to protect or improve groundwater quality. Most include one or more common program elements: 1) classification, assessment, and mapping of groundwater sources; 2) groundwater quality standards, 3) groundwater quality monitoring; 4) control of farming practices; 5) control of land uses; 6) economic incentives; and 7) education programs (12). Specific examples include:

- Iowa's Ground Water Protection Fund and Ground Water Protection Strategy, which uses pesticide registration fees and fertilizer taxes to finance sustainable agriculture research and demonstration activities;
- Massachusetts Wellhead Protection Program, which established land use control and restricts pesticide use in critical recharge areas around wells; and
- Wisconsin's Risk Assessment Program, which is based on numerical ground water standards.

Best Management Practices: Thirty-six States provide financial or regulatory incentives for installing and maintaining best management practices (BMPs) to promote soil conservation and protect surface water quality (175).

- Financial incentives include: cost-sharing programs (26 States); income or property tax credits or deductions (7 States), no-or low-interest loans (5 States); and purchasing conservation easements or development rights in agricultural lands (3 States).
- Seventeen States require either approved plans or permits for activities that could cause soil erosion or pollution discharges into waterways, or compliance with established permissible soil loss limits. Ten States give farmers cost-sharing assistance specifically to help them meet the requirements.

Innovative State Financing Mechanisms: States will face competing demands for funding of groundwater, drinking water, and surface water programs in the coming decade, potentially requiring many to develop alternative funding mechanisms. Some States already have created innovative financing mechanisms, including: 1) user and impact development fees; 2) dedicated tax revenue; 3) state revolving loan funds; and 4) special water quality districts and utilities (74).

- Iowa's 1987 Groundwater Protection Act established a Groundwater Protection Fund capitalized by user and producer fees on pesticides, fertilizers, and other products contributing to nonpoint-source pollution.
- Minnesota established an environmental trust fund to be capitalized with one-half of the proceeds from the State lottery. The fund is expected to reach $100-$200 million by the end of 1993.
- Washington State uses an $0.08 per pack increase in the sales tax on cigarettes to finance water pollution control programs. Half of the funds are designated for wastewater treatment; 20 percent for ground water protection; and 10 percent each for nonpoint-source pollution, lake management, and discretionary purposes.

modify the label or use restrictions required by EPA. For example, in the early 1980s the insecticide aldicarb was found in a number of wells in Wisconsin and in shallow groundwater under an experimental plot in Florida (82). As a result, these States enacted significant rate, timing, and spatial use restrictions designed to minimize groundwater contamination (see table 6-2).

Most SLAs are State Departments of Agriculture, but other agencies or even universities may serve as SLAs. Programs to protect public drinking-water supplies, regulated under the Safe Drinking Water Act, commonly are implemented by State health departments. The differing State authorities have caused coordination problems in addressing agrichemical contamination incidents. For example, at least three different agencies in each State became involved in recent groundwater contamination events in Florida, California, and Wisconsin. Several States have established State interagency task forces or coordinating committees to ensure communication among agencies with pesticide and drinking water responsibilities (31). These groups also commonly work with sub-State agencies such as county health departments, regional water quality control boards, or regional planning organizations (cf: 23,74).

A number of States have issued laws and regulations regarding agrichemical contamination of groundwater (cf: 12,75). The States have taken diverse approaches, ranging from taxation of agrichemical purchases to fund special monitoring and extension programs in Iowa, to designation of Special Protection Areas based on proven or potential contamination by agrichemicals in Nebraska (5). As noted earlier, Connecticut has established strict liability for contamination (12).

Several States also now require that field studies be conducted in their States, in addition to those required by the EPA for national product registration, in an attempt to account for differing local hydrogeologic vulnerabilities. For example, groundwater studies are required in California and Florida, costing up to $500,000 each (31). Should other States choose to require local field studies, the cost may inhibit development and registration (or re-registration) of even those pesticides unlikely to cause groundwater contamination. However, EPA currently is unable to supply States with the technical guidance necessary to extrapolate field and laboratory results to different areas of the country (31).

Table 6-2-Sample Restrictions on Aldicarb Use in Wisconsin and Florida

	Wisconsin	Florida
Rate	Maximum 2 lbs. active ingredient per acre	Maximum 5 lbs. active ingredient per acre
Timing	Maximum 1 application per 2 years 4 to 6 weeks after planting	Maximum 1 application per year Between January 1 and April 30 for citrus growers (major users)
Spatial	Moratorium areas defined as 1 mile radii around wells with 10 ppb aldicarb or greater	Minimum of 300 meters lateral distance from a drinking-water well
Other	May be applied only by a State-certified pesticide application specialist Label must contain warning of potential for ground water contamination	Warnings must be posted on the property and on wells near area of use Use will be suspended in an area if concentration of more than 10 ppb are found in drinking water

SOURCE: S.2. Cohen, "Pesticides and Nitrates in Ground Water: An Introductory Overview, "contractor report prepared forthe Office of Technology Assessment (Springfield, VA: National Technical Information Service, August 1989).

EPA's proposed strategy for agricultural chemicals in groundwater includes a prevention strategy and a response strategy, and relies heavily on a decentralized, State implementation approach (181). The prevention strategy relies on the development of State regulatory management plans using a number of regulatory options (see table 6-3) intended to balance pesticide-use risks and benefits depending on the site-specific nature of use, value, and vulnerability of the local groundwater resources. If management plans are not developed by States for areas of suspected vulnerability to certain chemicals, use of those chemicals may be canceled in those States by the EPA. This program may burden some States, particularly those with no analogous preexisting program (100, 198).

EPA plans to issue five criteria./guidance documents to implement the strategy, but funding and staffing required to produce these documents is uncertain (31). The documents include:

- minimum criteria for State groundwater monitoring programs;
- minimum criteria for State response plans, addressing water supply, monitoring, and registration issues;
- criteria EPA will use to review State management plans for adequacy;

Table 6-3—Regulatory Options Available to States Under the EPA Strategy

- Moratorium Areas
- Wellhead Protection Areas
- Well Set Backs (Buffer Zones)
- Future Well Requirements: Location, Depth, Construction
- Change in Rate of Application
- Change in Timing of Application
- Change in Method of Application
- Advance Notice of Application
- Integrated Pest Management
- Best Management Practices
- Additional Monitoring
- Additional Training and Certification

SOURCE: U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances, "Agricultural Chemicals in Ground Water: Proposed Pesticides Strategy," December 1987.

- criteria EPA will use to evaluate effectiveness of State management plans; and
- a hydrogeologic document entitled "Techniques for Assessing the Natural Sensitivity of Aquifers to Pesticide Contamination."

The latter document is scheduled for publication in late 1990 (80).

Trends Affecting Organizational Activities

Controversies and confusion remain over apportionment of roles between Federal and State Governments, and type of approach to use for prevention of agrichemical contamination of groundwater. New trends in both these areas are further blurring the issues. Historically, agricultural programs have been largely a Federal role and water-related and environmental programs have been a State role. Similarly, agricultural programs have tended to rely on encouraging voluntary actions by farmers, and environmental programs have used regulatory options.

Changes in Historical Roles

After the American Revolution, the States were accorded sovereign interests in navigable waters and, thus, responsibility for managing and allocating their water supply. This has been modified to some extent through Federal legislation such as the Clean Water Act (CWA) (28) and the Safe Drinking Water Act (SDWA) (141). For example, "navigable waters' are redefined as the "waters of the United States' under the CWA, discarding the classical view of waters that may be used for navigation (196). These statutes provide the Federal government with substantial responsibility for setting standards, and for developing and delegating federally defined water quality protection program management to States (149).

Environmental protection also was primarily a State concern until the 1960s, but became increasingly a Federal concern during the 1970s and 1980s (most notably with the creation of the Environmental Protection Agency and the Council on Environmental Quality). During the latter two decades, a partnership of sorts has evolved among the different levels of government, with each taking on different responsibilities (149). Despite this evolving partnership, the Federal role continues to dominate environmental protection programs. National-level legislation and Federal agency programs set the national agenda, basic regulatory framework, and determine many of the operating mechanisms (132).

Within this framework, States generally are required to develop and, with EPA approval, implement environmental protection programs. However, fiscal responsibility for environmental protection programs has been shifting to the States. EPA grants to State and local governments have declined over the past 10 years in real terms, and area declining or constant percentage of EPA's budget. Thus, States are funding a growing percentage of their program expenditures (149, 11 1).

Despite confusion over who should do what, and who should pay for what, the States have been at the forefront of actions to prevent agrichemical contamination of groundwater. Most States now have a legal framework that includes some means to address agrichemical contamination of groundwater, but few have developed preventative programs; in most cases, a patchwork of laws exists rather than a comprehensive groundwater management program (12).

Two basic categories of regulations (beyond regulations on the chemicals themselves) can be used to prevent agrichemical contamination of groundwater: 1) land-use controls that regulate the location of certain types of development; and 2) land-management regulations that restrict the types of 1and-uses practiced, even though they may place no restriction on the location or type of development (24). Land-use controls, such as zoning, are traditionally the province of the States. Land-management regulations, which are more likely to be adopted to prevent groundwater contamination by agrichemicals, are being explored in States' new groundwater protection strategies, but depend heavily on information provided by Federal agencies. "With the EPA giving the states the primary responsibility for groundwater policy, and requiring the development of State groundwater strategies, States have begun to realize the deficit of information-both institutional and physical-that they are now facing" (12).

Historically, agriculture rested in Federal hands, based on the premise that access to agricultural information and technologies should be freely available to a largely agricultural populace. However, with the rise of environmental concerns about agriculture, decline in the farming population, and declining Federal role in agricultural research and technology development (cf: 162), decisionmaking about U.S. agriculture is becoming increasingly complex.

Diversity of Approaches

The two Federal agencies with authority to control agricultural nonpoint pollution are the USDA and EPA, each with different missions and approaches. The USDA's goal is agricultural production and it has a voluntary, bottom-up approach; the EPA's goal is pollution abatement, and it has a regulatory, top-down approach (36) (figure 6-3; 177). To date, the Office of Management and Budget has favored development of voluntary programs to reduce agrichemical contamination, based largely on economic considerations (124). Voluntary programs are seen as a form of 'cost-sharing,' whereby costs of protecting the environment are shared by the general public, rather than placed exclusively on producers who are effectively 'price-takers' unable to pass along increased costs of production. A third approach to address environmental problems in agriculture was developed in the 1985 Food Security Act: cross-compliance denies farmers government benefits unless they follow approved conservation practices.

Voluntary-Voluntary approaches involve pollution controls implemented by farmers of their own free will. Voluntary programs involve no external coercion, primarily relying on: 1) research and development of farming methods to reduce or prevent pollution; 2) farmer education to increase awareness about contamimination pathways and pollution-reducing practices; and 3) demonstration and technical assistance to show farmers how to implement new practices and to convince them of their benefits (97,37,101). Farmers incur no legal penalty if they do not adopt proposed practices, but unfamiliar practices may be associated with some level of economic risk.

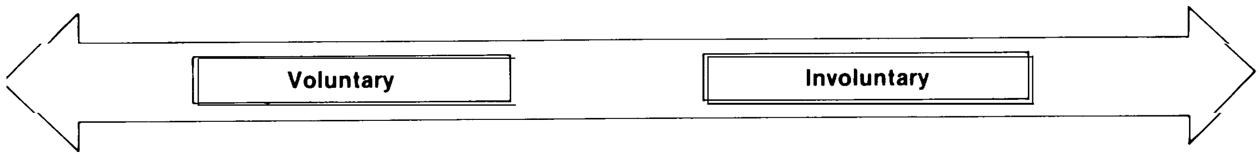
Of the three approaches, voluntary programs allow the farmer greatest flexibility in choosing crops, field sites, and farming practices. Examples of voluntary approaches include information dissemination and field demonstrations of practices by CES and SCS and in federally funded programs such as the Model Implementation Program and Rural Clean Water Program (97,146).

The main advantages to voluntary approaches are their political acceptability and flexibility. Farmers and their representatives have long opposed regulation in agriculture, which explains in part why voluntary pollution control programs have prevailed as part of agricultural policy (107). Voluntary program flexibility also allows for easier adjustment to changes in technical knowledge (180).

Voluntary programs' main disadvantages, however, are low participation rates and ineffectiveness due to inadequate or non-uniform implementation (97,47). Participants may reduce pollution originating from their own lands significantly, but nonparticipants continue to pollute, especially in the absence of adequate incentives to change. Furthermore, cost-share incentives for implementing practices are subject to local approval and interpretation as to what is politically, technically, and economically feasible (180). As a result, such practice-based voluntary programs are ineffective in areas with inadequate public support (83).

One hundred percent participation in voluntary programs, however, still may not achieve sufficient pollution reduction to attain desired water quality goals or standards. Only minor reductions in sediment and nutrient losses have been achieved through most voluntary programs, for example, even in areas with intensive information and demonstration campaigns (182,154,47,129). Compared to regulatory approaches, voluntary programs also have high costs in personnel, time, and finding (143). As a result, researchers, public interest groups, and some farmers have begun to criticize voluntary pollution control programs in agriculture because 50 years of voluntary soil conservation programs have not achieved societal goals for reducing erosion (47).

Figure 6-3-Range of Approaches to Agricultural Programs



Educational
Public presentations
School programs
Household chemical cleanup days
Waste 011 collection programs
Free water analysts programs
Aquifer hotlines
Publicity tactics
-Bumper stickers
Mascots
Poster contests
Billboards
-Aquifer area roadsigns

Operational
Contamination hotlines
Agricultural practices
Soil conservation
-Limit chemical application
Engineering practices
industrial practices
Contingency programs
-Hazardous material spill teams
Water system ınterconnection
Construct Ion practices

Economic
Water use taxes
Phased capital improvements
Purchase of development rights
Land purchase
Watersheds
-Sensitive areas
Public land retention
Eminent domain
Conservation/scenic easements
Property tax Incentives
Tax abatements
-Water conservation
-Water saving device installation
Letters of record to landowners

Regulatory
Special management districts
Zoning regulations
-Special zoning & overlay districts
• Floodplain
• Conservation
• Well field
Permits and waivers
Transfer of development rights
-Performance standards
Cluster zoning
Reduced density zoning
Subdivision and plannted unit Development ordinances
-Building and landscape codes
• Double plumbing
• Grading & soil restoration
• Water & sewer hookup
Well development standards
Aquifer penetration restrictions
States and federal designations (Critical areas or sole source)
Watershed rules & regulations

Many approaches exist to address agricultural nonpoint pollution. In general, USDA tends to use a voluntary, bottom-up approach and EPA follows a regulatory, top-down approach.

SOURCE: U.S. Department of Agriculture, Soil Conservation Service, "Principles of Groundwater for Resource Management Systems: Field-Level Training Manual," SCS South National Technical Center, Fort Worth, TX, August 1987.

Cross-compliance-Cross-compliance approaches involve pollution controls implemented by farmers (e.g., use of specific Best Management Practices—BMPs--or plans based on specific BMP combinations) in order to be eligible for certain program benefits. Cross-compliance programs are composed of: 1) specified pollution-reducing management practices; 2) a government-based program that provides benefits only to those using specified practices; and 3) verification and enforcement mechanisms to ensure eligibility of program beneficiaries.

The first cross-compliance programs to control agricultural nonpoint pollution from soil erosion were contained in the 1985 Food Security Act (FSA), representing the only Federal-level step taken so far toward making agricultural pollution control approaches more restrictive. The FSA requires farmers to implement approved conservation plans for highly erodible lands as a condition for receiving Federal farm program benefits. Cross-compliance approaches still rely on voluntary adop tion of pollution-reducing practices; they limit farmers' options only if the farmer chooses to participate in the government programs. Moreover, only certain commodities are covered by government programs, so only producers of these commodities are potential cross-compliance participants.

Cross-compliance programs, like the voluntary programs, tend to be more politically acceptable than regulatory programs. However, the main disadvantage to cross-compliance programs is that their implementation depends on base program participation, not on the severity of pollution problems (l). Base-program dependence also means that cross-compliance incentives mirror base-program incentives, which may not be great enough to induce participation in the first place. For example, were payments reduced to bring down farm program costs, the penalty for non-compliance with conservation provisions also would decrease (38). Cross-compliance incentives could also disappear altogether if the base program is discontinued. Cross-compliance programs have other disadvantages, also associated with voluntary programs, in that they depend on local public and administrative support and local interpretation of USDA pollution control regulations (123).

Cross-compliance programs also are subject to regulatory modification by the department or agency administering the base program, influencing the types of pollution controls that are implemented. In the FSA's conservation compliance program, for example, USDA regulations were changed to allow farmers to implement ''Alternative Conservation Plans" (ACPs) on their highly erodible lands and remain eligible for farm program benefits.

Regulatory and local administrative changes thus affect the extent and uniformity of pollution control achieved through cross-compliance programs, and the extent of such changes is likely to reflect the intensity of commodity crop production in local areas. The greater the intensity of commodity crop production in an area, the more pressure is placed on administrators and congressional members to permit continuance of highly polluting practices as ''technically, politically and economically feasible. " Administrative ''malleability also has implications for groundwater pollution control, because groundwater contamination is likely to be worse in hydrogeologically vulnerable areas with high agrichemical-use intensity. Local administrators may be responsive to pressures from agricultural interests to weaken pollution control requirements unless countered by high levels of interest expressed by non-farm populations. Cross-compliance programs alone are thus unlikely to achieve significant reductions in agrichemical contamination of groundwater in these areas.

Regulatory—Regulatory approaches involve pollution controls implemented by farmers in response to laws or rulings that impose penalties for noncompliance. Regulatory approaches require: 1) clear specification of what must be done or not done; 2) clearly defined penalties; and 3) verification and enforcement mechanisms. Examples of extant regulatory approaches are complete or partial pesticide bans, prohibitions on fall application of fertilizers, and requirements to triple-rinse pesticide containers prior to disposal. Regulatory approaches give farmers the least flexibility by requiring them to act in specified ways to avoid penalties.

Regulations have the advantage of allowing farmers and agricultural firms to know what is expected of them and to achieve economies of scale based on these expectations. However, uniform national regulations applicable to a wide range of hydrogeologic conditions would place excessively strict controls on areas where groundwater contamination may not occur or insufficient controls on areas where contamination potential is severe. An alternative would be to implement regulations only in vulnerable ''target' areas. However, such "target' area regulation may increase the cost of crop production in these areas thus placing these farmers at an economic disadvantage. Highly restrictive regulations in the most severely affected areas have the potential to cause people in these areas to go out of business, which makes strong support of such regulatory approaches unlikely. The challenge for regulatory programs is to specify farming practice requirements that are stringent enough to reduce pollution but that do not prohibit management strategies that will maintain farm economic viability.

A key disadvantage to the regulatory approach in agriculture has been opposition from farmers and their representatives, and this may have unintended adverse impacts (e.g., farmers may refuse to provide information voluntarily on agrichemical use and management to research and extension staff (91)). Regulation is rarely a popular policy, especially in the case of agriculture. In the last 20 years, however, farmers may have moderated their opposition to regulation, particularly in relation to agrichemicals (130). In some studies, farmers made distinctions among combinations of regulatory practices and did not universally reject regulation (175,70,81). Reduced farmer opposition, combined with recent public concern about health effects of nitrate and pesticide pollution, may result in more serious consideration of regulatory measures in integrated pollution control approaches to reduce groundwater contamination.

Other key disadvantages to regulation are the cost and feasibility of enforcement. If regulations are not designed realistically, if enforcement monitoring is unlikely, or if penalties are small, farmers may simply disobey the law (139). Regulatory enforcement is difficult in agriculture with potentially polluting activities ranging over wide areas, and enforcement is not a significant or well-accepted function for most State and local agricultural agencies. Thus, the lack of institutional mechanisms to enforce regulations in agriculture is another reason why regulatory approaches to pollution reduction have been difficult to advance. However, the potential for regulatory penalties may be a significant inducement for farmers to voluntarily adopt contamination-reduction practices.

Another disadvantage is that regulatory approaches tend to be medium- or resource-specific, lending themselves easily to prohibition of specific practices that adversely affect a single resource. Regulatory approaches to address multiple resource concerns are more difficult to design, because integration of numerous practices, each designed to protect a specific resource, into an appropriate management system for a particular site is difficult. Documented implementation plans and follow-up audits could serve as regulatory enforcement mechanisms for ''mandatory systems' in hydrogeologically vulnerable areas, but these would be costly in terms of personnel and time.

Integrated Approaches To Reducing Agrichemical Contamination of Groundwater-Past response to voluntary nonpoint-source pollution control programs indicates that "doing more of what has been done in the past' will not adequately address soil erosion and surface-water quality problems (47). It is unlikely that practitioners will widely adopt new practices, with attendant new risks, without significant incentives or penalties for noncompliance. Thus, solely voluntary programs are likely to have even greater shortcomings in addressing groundwater contamination, which is invisible and more difficult to measure than erosion and surface-water pollution. Considering the advantages and disadvantages of voluntary, cross-compliance, and regulatory approaches, it seems likely that an effective approach would combine elements of all three strategies.

An integrated groundwater pollution reduction program for agriculture could emphasize voluntary and cross-compliance approaches on the national level to improve agrichemical management, reduce point-source contamination, and spur adoption of technologies that replace agrichemicals or reduce waste associated with their use. In hydrogeologically vulnerable "target" areas, however, agricultural impacts on groundwater may need to be regulated to a greater extent along with intensified voluntary efforts and defined, nonmodifiable standards for allowable practices in cross-compliance programs. The challenge will be to devise appropriate mixes of the three approaches in these areas.

For example, following the model established in Nebraska, "Natural Resource Districts" or "Agro-ecological Regions' might be identified based on agricultural and hydrogeologic characteristics. A tiered program could be established for each region based on actual risk to water consumers and the environment (1 19). In areas where contamination is low or unlikely, education and voluntary programs might be emphasized. Districts with higher actual or potential contamination risk might require farmers to participate in certain programs (e.g., showing receipt of attendance at a nutrient management program prior to purchasing nitrogen fertilizers). In areas showing severe contamination, use of particular chemicals or farming practices might be banned entirely. With such a program, Federal, State, regional, and local roles would have to be closely coordinated.

Potential Solutions to Common Problems

A wide range of organizations have influence over policy, programs, and farming practices that may have potential to reduce agrichemical contamination of groundwater, and a broad range of policy instruments exists that can be haphazardly implemented, or integrated into a comprehensive package. However, development of a comprehensive approach **will** require:

- congressional leadership,
- clarification of roles,
- coordination/integration of programs and approaches,
- dealing with the legacies of agency histories,
- evaluating adequacy of authority, and
- evaluating resource (staff, funding, information) adequacy.

Taking the Helm: Options for Congress

Identification of national goals, and determination of the national agenda, for agricultural and environmental issues is the province of the Congress. The special properties of agrichemical contamination of groundwater, its relationship to integrating agricultural and environmental policy, and the need to coordinate Federal and State efforts, have until recently been neglected under the pressure of providing immediate public safety (12). Foresight—the "systematic process of bringing lateral and long-range implications into policy decisions" (71)--has not been formally brought to bear in consideration of agrichemical contamination of groundwater.

On the other hand, the House of Representatives has developed rules that require it to incorporate foresight into its processes: 1) multiple referral of important bills to several interested committees ensures that multiple viewpoints are incorporated into legislative debate; 2) requirements that each committee ''shall on a continuing basis undertake futures research and forecasting" on matters within its jurisdiction (160); and 3) requirements that inflationary impact and long-term budget estimates accompany each bill (71). Still, multiple referral of bills has served to impede passage of key legislation, eventually allowing the budget process to force passage of 'least-controversy" bills (e.g., "FIFRA-Lite';[2] cf: **4),** and committee staff largely are too enmeshed in day-to-day committee work to undertake much futures research. Congressional research offices can serve to focus debate on issues, but cannot serve as forums for resolution of controversy over national goals.

Integration of agricultural and environmental policy requires the Congress to give full consideration to the effects of policies on the objectives of other sectors. Successful integration also presupposes an administrative structure designed to anticipate conflicts, determine acceptable trade-offs, and foster selection and implementation of a coherent set of instruments that will achieve joint objectives (127,128). The agricultural-environmental agenda has grown substantially in the last two decades; concern over groundwater quality is just the latest manifestation of that agenda.

POLICY ISSUE: Lack of a Central Forum for Congressional Consideration of Agriculture and Environmental Issues

The U.S. Congress does not have a filtering or integrating mechanism to ensure that all components of agricultural legislation consider potential for unintended impacts on agricultural productivity, agrichemical use, groundwater quality, the rural environment, or other areas in which there is a public interest. Similarly, no centralized forum exists to ensure that environmental legislation does not conflict with legitimate public interests in agriculture. A congressional-level organizational unit might provide such a forum, ensuring that open debate, integration or determination of priorities, and foresight are incorporated into decisionmaking on agriculture and the environment.

Option: Establish New Congressional Committee

Congress could establish a Joint Committee on Agriculture and the Environment (or a Natural Resources and Environment Committee with a broader mandate) with specific jurisdiction to bring goals for agriculture and the environment, beginning with agrichemical contamination of groundwater, into open debate, to review the Federal role in U.S. agriculture, and to review all extant and proposed legislation for possible implications for the environment.

Alternate Option: Establish Alternate Congressional Forum

Congress could establish a temporary Selector Ad Hoc Committee on Agriculture and the Environment, or a National Agricultural Policy Study.

Either body would be formed of congressional Members and staff representing interested committees, whose express mandate is to provide to the Congress analysis of: 1) relevant trends, 2) changing goals for agriculture and the environment, and 3) potential conflicts in extant and proposed legislation. Such a committee, or a facsimile thereof, would need at least the following attributes: 1) not historically tied to any particular constituency, 2) not tied exclusively to a narrow subdivision of environmental or agricultural policy, and 3) not hindered by jurisdictional narrowness from considering the full

[2] "FIFRA-Lite" is a term coined to refer to the 1988 amendments to the Federal Insecticide, Fungicide, and Rodenticide Act which deleted reference to the controversial issues of reimbursement liability, and groundwater contamination (cf: 4).

realm of relevant questions. As such this entity might begin to promote congressional consideration of the range of national goals and Federal roles in agriculture and the environment,

Establishment of a Joint Committee allows coordinated consideration of issues by both chambers of Congress, and may be necessary for an issue covered by widespread jurisdiction in both chambers. Although establishment of a Joint Committee may be more cost-effective than creation of committees or policy study groups in each chamber, consideration of integration of agricultural and environmental legislation may require only a temporary congressional forum.

Either chamber may create a temporary Select Committee to conduct continuing comprehensive reviews or to resolve issues fragmented jurisdictionally among several standing committees. For example, a Select Committee To Investigate the Use of Chemicals, Pesticides, and Insecticides in and with Respect to Food Products was created in 1950 because the House Committee on Agriculture "was occupied with other matters and because that standing committee did not have jurisdiction over public health questions' (188). The Select Committee issued its final report in 1953, and was disbanded.

Select committees are expected to be of temporary duration, with clearly defined subject matter and method of inquiry, and shall deliver products (e.g., reports, bills) to standing committees with jurisdiction over parts of the issues as well to to the House. However, a House Committee on Rules report (1 88) on establishment of Select Committees lists concerns with proliferation of congressional committees, including increasing congressional costs and space problems, imposing additional committee burdens on Members, and potential interference with the standing committee system. Therefore, the Subcommittee established guidelines for establishment of new committees, including:

- the proposed select committee must deal with *a* significant and major issue;
- the present committee system does not address the issue effectively, for reason of fragmentation of jurisdiction over subject matter, or because of lack of staff resources for investigation, or to permit a broad perspective not available through any one standing committee.

Developing a comprehensive approach to agriculture and the environment clearly fits within these guidelines.

The House of Representatives also has the option of creating an Ad Hoc Committee expressly to consider one or a certain group of bill(s) (188,132). The first such committee was the Ad Hoc Committee on the Outer Continental Shelf, established in the U.S. House of Representatives in 1975, including representatives from major House committees with a role in energy development and environmental management of the outer continental shelf. This Ad Hoc Committee was created to "prevent major jurisdictional problems involving six or more standing committees' and was considered a **success** (188).

A National Ocean Policy Study was created in the Senate in the early 1970s, with the purpose of providing a forum for ocean-related matters that have multiple committee jurisdiction. Although not technically a subcommittee, and not a recipient of legislative referrals, the Policy Study was composed of Senators with an interest in the development of a comprehensive oceans policy, and developed numerous pieces of legislation for consideration by relevant Senate committees. It also aggregated an interdisciplinary group of congressional staff who could devote full time and effort to consideration of the complete range of ocean issues. Were a National Agricultural Policy Study established, it could be accompanied by a non-congressional National Agricultural Policy Review Commission established to assist in analysis and presentation of viewpoints on goals.

Clarification of Public Roles

The relative roles of the Federal agencies, and State and local governments, have not yet been detailed. Clearly all levels of government will have to work with the private sector and individuals to reduce agrichemical contamination of groundwater. To date, agencies at all levels of government have been attempting to undertake virtually all types of activities.

As States undertake initiatives to address water quality and agriculture, it will be necessary to sort out Federal, State, and local roles more clearly. This will be a difficult task. For example, arguments for regulatory uniformity, consistency of standards, and balanced treatment of farmers among different

Box 6-G—Rationales for Federal v. State/Local Jurisdiction Over Issues

Justification for Federal level program	Justification for State/local program
National problem or interstate/inter-local problem	Regional/local problem
Need for detailed scientific/technical information	Need for detailed information on local circumstances
Substantial externalities, information requirements, or economies of scale	All benefits and costs are within the jurisdiction
Need for uniform treatment of individuals, polluters, or municipalities	Flexibility and ability to provide more innovative solutions
Need to resist pressures to attract or keep industry by reducing environmental standards	Relatively homogeneous taste (goal) of local population
Need for minimum standard of health or ecological protection	Problem pervasive enough to be of major concern to the community
To reduce duplication and ease industry compliance for industries that engage in much interstate commerce	Need for rapid implementation
To reduce absolute burdens on municipalities	Need for more assured funding (e.g., earmarked tax v. general revenue)
To compensate losses aggregated in time or space by decisions made prior to the pollution control law	

However, "it is not clear which levels of government are more likely to represent the desires of future generations, particularly in a mobile society. "

AFTER: F.G. Sussman, "Environmental Federalism: Allocating Responsibilities for Environmental Protection" Staff Working Paper (Washington DC: Congressional Budget Office, September 1988).

regions provide a rationale for a strong Federal role. However, diversity of hydrogeology, farmer characteristics, and farming practices suggests a need to tailor approaches to local conditions (1 11) (see box 6-G).

Most likely, a tiered approach, involving actions at all levels of government, maybe most appropriate. For example, the Executive Director of the Association of State and Interstate Water Pollution Control Administrators suggested that States should have primary responsibility for managing groundwater quality and quantity, and identifies the Federal role as:

- providing technical assistance, research and development, and information dissemination to the States;
- assisting States in the review and definition of geologic and climatic conditions controlling groundwater quality and quantity, but having no responsibility in groundwater quantity management;
- involving States in Federal activities and providing adequate financial support for State programs addressing interstate groundwater quality; and
- developing useful mechanisms for States to translate research results, risk analysis, and guidelines into meaningful groundwater standards (73).

A consensus on the appropriate allocation of roles among Federal, State, and local organizations will be necessary to ensure that a coordinated, nonduplicative, and comprehensive system is developed to achieve the multiple public objectives of agriculture and environmental quality.

Even with substantial Federal involvement in program development, it seems likely that a majority of actions will be implemented by the States, given the site-specificity of groundwater vulnerability and the diversity of agricultural practices. Congress needs to ensure that a framework exists so that Federal directives actually can be implemented.

POLICY ISSUE: Lack of Clear Federal Agency Leadership

Confusion exists over leadership within and among Federal agencies with responsibilities for agriculture and environment. In the absence of top agency leadership, some lower level officials may be reluctant to develop or implement groundwater protection policy (1 19).

The question of leadership roles among the agencies similarly can produce difficulties in re-spending to policy initiatives. An often-raised issue in numerous groundwater quality hearings of the 100th Congress was which of the Federal agencies should be designated as the "lead agency" in groundwater protection. Given specialized expertise among a number of the agencies (e.g., USGS-data collection and coordination; EPA—standards and regulatory structure; USDA--crop and farm management, education and technical assistance, research; TVA—nutrient management) designation of a single lead agency probably is undesirable.

Executive agency reorganization could aggregate relevant authorities and responsibilities in a single agency, such as the oft-proposed Department of Natural Resources. This would allow clear identification of authority and accountability. However, it probably would not be appropriate for one organization to hold both regulatory and assistance responsibilities. Further, even if such an organization did not include regulatory authority currently held by EPA, large-scale reorganization involves serious disruption of programs and does not necessarily result in improved coordination. It may be more appropriate to assign specific domains of groundwater protection responsibilities to each of the agencies that complement the assignment of specific goals (1 19) including a mechanism to ensure interagency coordination.

Option: Identify Lead Role Responsibilities For Multiple Agencies

Congress could specifically identify lead agencies for subsets of the issue. Based on historical specialization in certain areas related to agriculture, to environmental protection, and to hydrogeology, agencies could be assigned specific lead roles to coordinate data collection, data management, information dissemination, and research program development.

Congressional identification of agencies or programs that could lead efforts in certain sub-areas of the issues probably is unnecessary. The OMB and the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) efforts serve to identify natural roles for the agencies to take, and identification of lead agency status is at least partially defined via the Memoranda of Understanding already established among the agencies. However, congressional recognition of the established roles, and explicit oversight of completion of activities within those areas, might encourage coordinated action.

Alternate Option: Require Development of an Interagency Plan by Federal Agencies

Congress could require that USDA, EPA, USGS, and TVA/NFERC develop an Interagency Proposal for Groundwater Protection in Agriculture detailing needs, roles, means for communication and coordination, etc Congress may wish to request that the relevant agencies put together an interagency proposal, and perhaps an interagency budget, to develop and implement comprehensive groundwater protection programs.

The agencies are already somewhat experienced in developing groundwater protection budgets for OMB. The agencies also already have developed documents that could serve as the foundation for an integrated interagency plan. However, given the current extent of confusion over definition of roles and approaches, and bureaucratic slowness in adopting new approaches or programs, this is unlikely to provide a timely analysis, nor a comprehensive view.

Moreover, an integrated interagency plan and budget proposal would require review and approval by each of the congressional authorization and appropriations subcommittees related to the agencies. Thus, the resulting budget and plan would have to be modular, so that each agency's component could be reviewed and approved by the appropriate congressional subcommittee, or Congress would have to develop the capacity for intercommittee authorization, appropriation, and oversight.

Legislative Authority and Flexibility

USDA has broad organic authorities to address all issues related to American agriculture; its authorizing legislation, commonly called the Farm Bill, is reconsidered by the Congress every 5 years. Consequently, programs to protect groundwater from agricultural chemicals have developed within offices that have broader historical mandates and functions. Other offices have programs specifically directed towards protecting groundwater quality.

Like USDA, USGS has broad organic authorities to pursue its primary missions. According to an OMB Circular A-67 (1964), USGS is charged with responsibility for interagency and intergovernmental ground- and surface-water data coordination, and with encouraging consistency in data collection and storage. In addition, the Water Resources Research Act authorizes USGS to provide finding to States, although such funding has been declining (197). However, additional authorizing legislation could serve to give agencies specific direction and priorities within their broader range of activities, and to legitimize specific activities (1 19).

POLICY ISSUE: National Fertilizer & Environmental Research Center Activities Dependent on TVA Oversight and Appropriations

TVA authority is based upon the 1933 Tennessee Valley Authority Act. The National Fertilizer & Environmental Research Center (NFERC) was created to assist with modernization of agriculture in the River Basin, but has since established itself as a national ''center of excellence' in fertilizer research and development (76). However, funding continues to be allocated to the NFERC under appropriations for the regional authority and, thus, can be strongly affected by decisions made with regard to the organization as a whole.

Option: Make NFERC an Independent National Center of Excellence

Congress could separate NFERC authorization and appropriations from the Tennessee Valley Authority, and redefine it as an agricultural research center of excellence, perhaps as part of the land-grant system, or as a stand-alone center based on the model of the National Center for Atmospheric Research (NCAR) or the National Institutes of Health. An independent NFERC could be created that would have explicit authority to undertake, sponsor, or direct national research, development, extension, information dissemination, and education efforts related to agricultural nutrient management and development. The center could continue to focus on commercial fertilizers and livestock waste management, or could be expanded to include additional agricultural nutrient-related issues, such as basic agroecosystem research.

Incorporation in the land-grant system might allow NFERC to define protocols for experiments to be replicated by other land-grant research centers on differing hydrogeologic sites. However, if NFERC becomes part of the land-grant university system, its funds would be allocated under the Hatch Act, and the avenue for special allocations may be narrow.

If the new organization were modeled on NCAR, a joint Federal-university consortium organization, it might focus more strongly on basic research and on computer simulation modeling of environmental fate of chemicals and modeling of the nitrogen cycle, for example. Similarly, funding could be allocated from USDA, EPA, the National Science Foundation, and other Federal research agencies. As a National Center, it may be joined in the future by other such "centers of excellence" focusing on other agricultural issues, and comprise one part of a coordinated group of research centers such as the National Institutes of Health,

As an independent center of excellence, funding and personnel decisions could be made related to nationally -identified needs. Separation of NFERC from TVA probably would require increased appropriations to NFERC to cover costs of support services currently obtained from TVA, in addition to those required to expand programs or develop new efforts. Separation of NFERC also could entail a reduction in appropriations to TVA. However, in light of TVA's experience and expertise with various forms of power-generating utilities, it might profitably reorient its environmental programs towards those more directly relevant to power generation, such as management of hazardous waste, or reduction in greenhouse gas emissions.

POLICY ISSUE: Lack of Comprehensive EPA Authority

EPA is unique among the four primary agencies in that all of its programs are specifically mandated by law. It does not have the broad organic authority available to the other agencies, and hence has less flexibility to develop programs. Existing legislative mandates set the tone for the agency's agenda and program development. Thus, perhaps the piecemeal approach contained in the mandates themselves work against a comprehensive or integrated response to environmental problems (152). Because legislation tends to focus on specific media, EPA and its programs are organized to address these specific media, rather than to track pollutants as they move among media. In addition, by their nature, regulatory programs require specific authorizing language, and little clear authority exists for EPA to regulate privately -owned drinking-water wells (119).

Option: Provide a Systems Approach in Organic Legislation For Environmental Protection

Congress could establish clear means to coordinate regulatory programs relating to protection of water quality throughout the entire hydrologic cycle, and clear authority to undertake a preventative approach, in an organic act for a Department of Environmental Protection. Several legislative proposals have been put forth in an effort to elevate EPA to Department level. Proponents argue that the associated increase in flexibility and ability to operate proactively defend elevation to Cabinet-level status (152). It has been suggested that EPA's level in the bureaucratic hierarchy works against its ability to coordinate effectively with other key agencies despite a clear cause for EPA concern in the interests and activities of these agencies. Supporters of proposals to elevate EPA to Department level also argue that equal footing with other departments is needed to promote widespread integration of environmental policy in other programs (152).

It has been suggested that EPA's lack of Cabinet standing indicates a lack of understanding regarding U.S. environmental problems: environmental protection could be viewed as a temporary governmental responsibility and not a long-term effort to protect the public interest meriting a change in bureaucratic structure (152). However, elevation to Cabinet level alone may not ensure that EPA activities would be enhanced: funding must be assured and potentially increased, and the organic legislation will need to provide EPA the authority and flexibility to deal with agriculture and water quality issues in a comprehensive, coordinated, systems fashion.

Formal congressional recognition of the continuous nature of the hydrologic cycle, and thus of the myriad pathways of water contaminants, in an organic act for EPA, might assist that agency to develop coordinated water quality protection programs. A clear mandate to undertake preventative programs, in addition to its regulatory responsibilities, could assist EPA to reorient its activities from a contaminant- or media-specific focus towards more comprehensive water quality protection.

POLICY ISSUE: Fragmented Legislative Authority for Water Quality Protection

At present, water quality concerns are addressed in a number of separate pieces of distinct and often uncorrelated legislation. Failure to integrate the provisions of these distinct laws into a coordinated set of statutes may lead to problems and conflicts in their implementation. For example, since anhydrous ammonia fertilizer can volatilize into the atmosphere, be washed into surface waters, or percolate into groundwater, use of this fertilizer could be covered not only by the diverse groundwater protection provisions already enacted, but also by laws to protect surface waters, reduce air pollution, and protect the global climate. The time may be approaching when a farmer who applies fertilizer on a field may have to comply with the provisions of more than a dozen separate pieces of legislation (1 19). The demands of each of these separate Acts could require different and sometimes contradictory behaviors.

Option: Evaluate Water Quality Laws for Coordinated, Comprehensive Approach

Congress could create a "blue-ribbon" panel of lawyers, administrators, and scientists to evaluate current water-quality laws, to identify areas of conflict and overlap, and to suggest legislation that would integrate extant laws into a rational and consistent structure. Each law could be **modified in reauthorization accordingly, or an omnibus water** quality **bill** could be developed that encompasses earlier legislation. Evaluation of current legislation and authority could be undertaken concurrently with development of organic legislation for a Department of Environmental Protection, or could be conducted independently. Reauthorization of water quality laws based on the evaluation could assist in development of a comprehensive, coordinated approach to water quality protection, but would not provide an ongoing framework to ensure maintenance of such an approach as new water-related issues emerge.

Development of omnibus water quality legislation would allow for continued comprehensive consideration of water quality issues, however, this would require the integration of laws developed and supported by separate committees within Congress. Each committee responds to somewhat different constituencies, each likely has a different set of priorities, and sometimes fierce competition exists between committees for jurisdiction. A comprehensive, integrated and rational set of groundwater laws may be difficult to create under these circumstances.

legacies of Organizational History

Each Federal agency has a unique history and set of resources for protecting groundwater. USGS has a history of 'pure science and research, ' and limits its activities to providing data and coordinating data collection for other agencies. TVA/NFERC and USDA combine data collection and monitoring with basic and applied research, technology transfer, and technical assistance. EPA engages to some extent in the preceding activities, but also has regulatory and enforcement responsibilities. Each agency has some combination of ''top-down' and "bottom-up' approaches with the well-known ensuing conflict between addressing local or regional needs and establishing programs based on visible national priorities.

Jurisdictional issues among agencies also may hinder effective programs. For example, EPA has appropriations and authority to conduct pesticide applicator training programs, but lacks the rural infrastructure and communications network necessary to deliver the program. Consequently EPA contracts with the USDA Extension Service for delivery through its extension network. However, funding has declined, and neither EPA nor USDA may be committed to make investments in a program where their respective responsibilities and authorities appear vague.

USDA and TVA have greater experience in outreach and technical support, but both are wary of direct involvement in enforcement programs. Conversely, EPA has demonstrated a repeated interest in participating in education, outreach, and demonstration programs, and has some degree of experience in each of these areas. Further, EPA has critical information on pesticide management and handling that may not currently be extended through USDA's channels. EPA lacks the outreach communications infrastructure and personnel present within USDA.

Differences in administrative structure, approach to environmental protection, and general wariness by both agencies has hindered cooperative ventures. Little research has been conducted on the efficacy of various institutional structures or approaches to protecting groundwater quality (192), so few conclusions can be formed.

POLICY ISSUE: Program Implementation Based on Political Boundaries Rather Than Hydrogeological Regions

The arrangement of decentralized (regional or field) offices of each of these organizations tend to be based on political boundaries that rarely correspond with natural resource boundaries (e.g., groundwater basin, watershed). One early attempt to subdivide the nation into meaningful water regions (figure 6-4) shows little correlation between State or county boundaries and water-resource boundaries. This complicates agency coordination efforts: groundwater protection programs must link local, State, regional, and Federal activities into a coherent, coordinated action to be effective. Each of the major agencies will have to develop national programs that can be administered through hydrogeologically meaningful regions, potentially necessitating reorganization of field activities. However, efforts may more easily be based on water-resource boundaries, as illustrated by the SCS studies of groundwater contamination within 37 "high risk" hydrologic regions identified based on hydrogeological factors.

Option: Implementing Programs Based on Natural Resource Systems

Congress could require that the relevant information collection, research, and outreach programs conducted by each of the major agencies (e.g., USDA, EPA, USGS) be directed to hydrogeologically defined "ecoregions." Most implementation organizations have jurisdictions determined by political boundaries. This will hinder establishing programs based on' ecoregions, and may require development of new organizational coordination mechanisms, or restructuring of some organizations. Thus, this may require that SCS, ES, and EPA outreach services be combined into one massive service; that outreach personnel be located within the same facilities to aid coordination; or it may require cross-training of SCS, ES, and EPA outreach personnel.

Coordination of Interagency Activities

Given the many water quality protection programs underway, it is not surprising that widespread concern exists regarding the extent of potential duplication of effort and the level of cooperation and coordination among Federal agencies. Some duplication may be desirable, as a way to ''check the system, " but wasteful duplication of basic functions and responsibilities should be avoided. Despite the increase in agency coordination that has already occurred (106), many believe that Federal programs should be better coordinated, especially to provide

Figure 6-4-Comparison of Water Resource Boundaries and State Boundaries

The lack of correlation between State or county boundaries and water-resource boundaries may complicate the development of comprehensive water quality protection schemes.

SOURCE: U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000,* vols. *1-3, In:* **Nipp, 1989.**

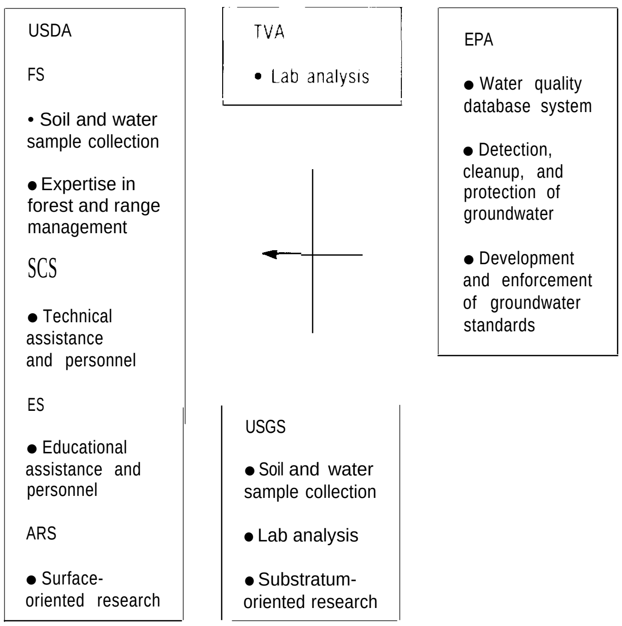
consistent advice and assistance to States and individuals (cf: 119,46,197).

The Office of Management and Budget (OMB) initiated the Interagency Task Force on Groundwater in 1987 to catalog Federal agency activities to protect groundwater quality and to develop a coordinated interagency groundwater protection strategy. These efforts culminated in the President's Water Quality Initiative for fiscal year 1990. The OMB and Congress have cited needs for more detailed and cooperative planning efforts to facilitate coordination within and among Federal agencies, resulting in new coordinating mechanisms (56, 119). Subsequently, the Subcommittee on Groundwater of the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) was made responsible for:

> . . . coordinating Federal nonregulatory groundwater efforts related to research, resource assessment, information management and dissemination, technology demonstration, technical assistance, training, and education, The membership of the subcommittee includes the Departments of Agriculture, Commerce, Defense, Energy, and Interior; the Council on Environmental Quality; the Environmental Protection Agency; the National Aeronautics and Space Administration; the National Science Foundation; the Nuclear Regulatory Commission; and the Office of Management and Budget (56).

The Subcommittee also has responsibility for facilitating implementation of existing Memoranda of Understanding and other cooperative agreements that exist among agencies (see figure 6-5). It seems that, as water quality program staff interact, there is a growing effort to plan and develop new programs

Figure 6-5-Network of Primary Federal Interagency MOUs on Water Quality



The primary Federal agencies, and a number of other Federal, State, and local organizations, have signed Interagency Memoranda of Understanding (MOU) allocating responsibilities for various components of groundwater research, monitoring, data management, and program activities.

SOURCE: Office of Technology Assessment, 1990

jointly, such as the independently planned but cooperatively merged USGS Mid-Continent and USDA Midwest Initiatives to study effects of herbicide use on groundwater.

Option: Prepare and Maintain Management Matrices of Agency Roles and Responsibilities

Congress could require that the OMB/FCCSET Subcommittee on Groundwater prepare such matrices showing clearly the activities undertaken by each relevant Federal agency or office to protect groundwater from agrichemical contamination; and provide an accompanying report detailing agency roles and responsibilities. One tool that may allow ready identification of roles and activities is the management matrix (1 19,120). Such a matrix can show agencies and offices on one axis and issues, components of the hydrologic cycle, research topics, or similar categories on the other axis. Responsibilities of each agency or office can be listed in the resulting form. This procedure should show readily where duplication is occurring, or where important topics are not addressed.

Submatrices may be similarly constructed, such as a research matrix. For example, the USGS-sponsored Technical Integration Group--composed of technical program managers from USDA, USGS, EPA, and TVA/NFERC-has developed a research matrix showing components of the hydrologic continuum on one axis and the physical processes affecting movement through the continuum on the other axis (table 6-4). The resulting research matrix can be used to identify which scientific disciplines are pertinent to each hydrogeologic component, and assists in identification of lines of coordination and communication.

POLICY ISSUE: Coordinating Federal and State Actions

Based on the 1984 Groundwater Protection Strategy, EPA has provided the States with roughly $40 million in grants since 1985 to support development and implementation of Ground Water Protection Programs (184). These programs are intended to provide a State with a cohesive, resource-oriented perspective to underpin the many federally directed (e.g., Resource Conservation and Recovery Act; Federal Insecticide, Fungicide, and Rodenticide Act; Superfund) and State-initiated programs that address specific sources of groundwater contamination. A State Ground Water Protection Program provides consistent policies, approaches, and information within each State on groundwater vulnerability assessments, resource use and value classifications, State groundwater standards, and protection priorities. Centralizing these functions in one program helps achieve consistency in groundwater protection and cost-effectiveness in avoiding unnecessary duplication among different State agencies and programs.

In 1988, EPA proposed a strategy to specifically address the concern for pesticides in groundwater (183). The key component of this source-specific strategy is the development of pesticide/groundwater management plans by a State as the basis for continued EPA registration for State use of pesticides posing groundwater concerns. The Agency's pesticide strategy builds on the 1984 strategy by requiring the State's lead agency for pesticide regulation (usually the State Agricultural Agency) to develop its pesticide/groundwater management plan in cooperation with the State's lead agency for groundwater protection (usually the State Water Quality Agency or Public Health Agency). In this

Table 6-4—Sample Program Management Matr x[a] of Research Responsibilities

	Department of Agriculture							Geological Survey					State and local institutions			
	CSRS					ES										
	ARS	SAES	ERS	FS	SCS	CES	Other	WRD	GD	NMD	EPA	Other Federal agencies	Natural resources	Agriculture/ Water research	Other	Special interest group
Fundamental process research:																
Water and solute transport	X	X						X	X		X			X		
Transformation processes	X	X						X	X		X			X		
Sorption processes	X	X						X	X		X			X		
Biological processes	X	X						X			X			X		
Evaluation of farming systems:																
Farming systems managment	X	X														
Technology evaluation	X	X	X					X								
Effects on soils	X	X														
Socioeconomic consequences		X	X												X	
Development of systems:																
Management systems	X	X	X												X	
Chemical application	X	X									X					
Diagnostic tools	X	X						X								
Spatial data:																
Compile, integrate, transfer	X	X						XX	X					XX	X	
Evaluate	X	X							X							
Develop decision aids:																
Evaluate and develop models	X	X						X			X			X	X	
Target decision aids	X	X														
Economic decision aids		X	X												X	
Technology transfer:																
Transfer to E&TA agencies	X	X						X	X		X					
Service functions:																
Laboratory and sampling	X	X						X	X		X			X		
Standards and glossary	X	X						X			X					
Impacts on ecosystems:																
Surface water	X	X						X	X		X			X		
Terrestrial	X	X						X	X		X			X		

S—A
S—C Ext
S—C
S—
Ext
S—F
D—G
MD—N M
S—St
S— Se
W D—Wa
es
M M ed ud W M grichem ca
dwa ec cal Man ed Oc M pp

reamer, protection objectives and approaches for pesticides will more likely be consistent with other groundwater protection efforts, and can build on the work underway within the States on groundwater resource mapping and monitoring (10).

EPA also has responsibility for overseeing State NonPoint-Source Programs as established by Section 319 of the Clean Water Act. The Act requires the States to develop assessments of their nonpoint-source pollution problems and Management Programs to address these problems. In EPA's guidance to the States, the Agency requested that States include information on any known or suspected groundwater problems caused by nonpoint-sources and that such information be consistent with each State's Ground Water Protection Program (181). EPA's Regional Offices also were requested to encourage the States to incorporate the groundwater policies, approaches, and information of their Ground Water Protection Programs in their NPS Management Plan submissions to the Agency.

Congress has appropriated $40 million to EPA for implementation of the Section 319 NPS Program in 1990, the first monies appropriated for implementation of the section. The Agency is providing grants to States for demonstration and implementation of best management practices (BMPs) for nonpoint-source control; some of these projects are aimed at groundwater protection (10). However, section 319 gives neither EPA nor the States additional enforcement authority, such that compliance is voluntary (57).

Coordination of a State's NPS Program with the State's Ground Water Program is intended to help assure consistency in a State's approach to groundwater protection across a wide variety of point and nonpoint sources of contamination. Concomitantly, such an approach allows the NPS Program to integrate groundwater protection priorities of the State's Ground Water Program with those for surface water, to develop an overall priority plan for addressing nonpoint sources within the State. EPA has underway a study to profile the degree of coordination between these two programs that has been achieved by the States.

Recent policy papers from EPA's Ground Water Task Force call for assuring consistent and coordinated groundwater policies and efforts across all groundwater programs within or supported by EPA and among other Federal agencies (185). The Task Force also stated that the key means for achieving such consistency and coordination is to ensure the implementation of Comprehensive State Ground Water programs (186). Many of EPA's source-specific regulatory programs affecting agriculture already have been coordinated with States' Ground Water Protection Programs, or plans for their coordination are underway.

Given that many of the BMPs developed and demonstrated under the NPS Programs and the USDA Initiative likely will be proposed as components of, or alternatives to, regulatory programs, it is important that these programs and efforts are each coordinated with the States' Ground Water Protection Programs. EPA and USDA currently are working to link States' NPS Programs to the selection of research and demonstration projects that USDA will fund under the President's Water Quality Initiative (see box 6-D).

Option: Multiple Referral of State Agrichemical and Groundwater Plans

Congress could have each State plan evaluated by each relevant agency (USDA/ES, USDA/ERS, EPA, USGS, etc.) or, alternatively, could establish a joint, interagency group to review State plans. Because of the site-specific nature of groundwater contamination by agrichemicals and the concomitant site-specificity of farming practices likely to reduce contamination, and because of the lead role the States have taken in response to agrichemical contamination of groundwater, coordinated development and approval of State Groundwater Protection Plans and Pesticide Management Plans may provide one avenue for coordination of Federal/State activities. However, having as many as 100 plans reviewed sequentially or iteratively by up to 10 agencies likely would stall the planning process.

An alternative method of coordinating Federal and State activities would be to have the State plans reviewed by an Interagency Review Board comprised of representatives from the major Federal agencies to ensure that plans consider all information available from the agencies, and to assist in coordination of Federal and State activities within each State. Regular reappraisals of plans and activities could allow readjustment of Federal and State activities to achieve increasing coordination as programs are implemented.

Option: Develop a Coordinated Farmland Resources Management Program

Congress could establish a program based on the Coastal Resource Management Act model to achieve coordinated use and protection of farmland resources and reduction of adverse environmental impacts associated with agricultural production. The Coastal Zone Management Act (CZMA) of 1972 (Public Law 92-583) (30) established coastal zones as areas of special significance to States and the Federal government, and authorized establishment of State Coastal Management Programs (CMP) (box 6-H). The CMP model encourages voluntary State participation, promotes centralization of State planning, establishes a clear line of State-Federal communication and assistance, and focuses on specific land areas and associated resources and multiple pollution sources.

The CZMA could serve as a model for development of an Agricultural Resource Management Act promoting development of State Agricultural Resource Management programs (ARMP). As coastal and nearshore resources clearly have been deemed of special significance ecologically and economically, farmland has been determined to be of national importance (cf: 54,22,131). And off-site impacts of agricultural activities are of growing concern just as the offsite-impacts of land-based activities became of concern in coastal areas and nearshore waters. Just as under a CMP, certain areas may need to be protected from agricultural development (e.g., wetlands, riverine fringes, and other agriculturally related highly vulnerable areas), but agricultural use of the area also may need to be allowed in balance with environmental protection goals.

An ARMP could be designed to protect farmland resources and manage potential adverse environmental impacts (e.g., groundwater contamination). Voluntary participation by States could be encouraged through a Federal grant-in-aid approach, as in

Box 6-H-Coastal Resources Management Program

The Coastal Zone Management Act of 1972 (CZMA) established coastal zones as areas of special economic and ecologic significance to the States and Federal government. The CZMA set Federal guidelines, however, it lacked regulatory powers and thus its success depended on voluntary participation. This Act established precedence for a Federal grant-in-aid program to encourage the protection and management of coastal resources while fully recognizing State primacy over the identified resource.[1] The 1976 amendments to the Act clearly articulated". . .a national interest in the effective management, beneficial use, protection, and development of the coastal zone" (Section 302 (a)).

The Act further recognized that the competition over resource use generated by population growth and economic expansion commonly resulted in the biological and physical degradation of the coastal environment and, thus, the Act was crafted as a mechanism to mitigate/ameliorate such adverse impacts (27).

Consequently, each of 32 coastal States, 3 territories, and 2 commonwealths developed Coastal Management Programs (CMP) that:

1. identify boundaries and evaluate coastal resources requiring management or protection;
2. examine policies with respect to their ability to accomplish this task, or develop new policies that will addresss the identified needs;
3. determine specific uses and geographic areas to be managed based on resource capability and suitability analyses and socio-economic and public interest considerations;
4. consider the national interest in planning and siting of facilities that meet more than local requirements; and
5. include sufficient legal authority and organizational arrangements for program implementation and to ensure compliance (55).

In addition to State coastal management programs, a national program for CZM is administered by the Office of Ocean and Coastal Resource Management (OCRM) (previously the Office of Coastal fine Management) under the Department of Commerce. The mission of this office is to encourage comprehensive and unified consideration of land and water uses that are sensitive to maintaining the integrity of the coastal ecosystems (27).

[1] "'[t]he key to more effective protection and use of the land and water resources of the coastal zone is to encourage States to exercise their full authority over the land and waters in the coastal zone, and, that this should include unified policies, criteria, standards, methods, and processes for dealing with land and water use decisions of more than local significance'(Section 302 (h))" (27).

the CZMA, with grants for planning and plan development, program implementation, and related education activities. However, if protection of groundwater resources is deemed of significant importance, a stronger, regulatory approach might be used. The planning phase of State ARMP development could include components such as:

- identification of areas of particular concern (e.g., aquifer recharge zones, areas deemed to be highly vulnerable to groundwater contamination) to be eligible for the program;
- development of program goals and steps for implementation (e.g., Indiana's "T by 2000" program);
- analysis of existing policies and programs for potential conflicts with program goals, and development of new policies to support program goals; and
- demonstration of sufficient State authority and organizational structure to implement the program.

A national program for agricultural lands could be established within USDA to provide funds for planning and plan implementation by States as well as monies for acquiring lands that are clearly identified as integral to maintaining the viability of groundwater resources (e.g., aquifer recharge zones). The office could provide a central location for review and approval of State programs and ensure comprehensive, integrated State approaches in program development.

An analog to the land acquisition approach was found within certain legislative proposals seeking to make aquifer-recharge zones eligible under the Conservation Reserve Program (CRP). Lands eligible on a groundwater protection basis would be removed from agricultural production for a specified contract period. Given the nature of aquifer protection, and the site-specific nature of agrichemical movement through the soils and underlying sediments and rocks, a long-term approach such as outright State purchase of land or land-development rights, may be in the best interests of groundwater resource protection. State purchases of land-development rights need not be held in perpetuity, and would allow other land uses that are determined benign in terms of groundwater contamination potential.

If an Agricultural Resources Management Act were enacted, it might be necessary to invest additional resources to expand certain agencies in order to support the Act's implementation. Previously, SCS maintained an office responsible for providing technical assistance to States and local governments regarding farmland protection.[3] The SCS computer-assisted Land Evaluation and Site Assessment system (LESA) developed in 1981 has been adopted by several States to facilitate their farmland preservation programs. The SCS effort, however, was discontinued in 1984 concurrent with a USDA decision that farmland conversion was greatly exaggerated (22).

State and local governments have developed data collection and analysis, monitoring, incentive, and zoning programs to implement farmland-preservation programs. Five states (Hawaii, Utah, Illinois, Delaware, and Virginia) have developed LESA systems since 1982 and a national survey identified 36 operational LESA systems in 19 States; the number has increased since the completion of the survey. Geographic Information Systems (GIS) are the newest trend in land-use planning. Although these systems are not used widely yet, they allow multiple variables (e.g.,hydrology, topography, soils, land cover, land tenure, and other variables) related to farmland to be displayed and analyzed together (22). These capabilities would be invaluable in implementing ARMPs that would require identification of vulnerable areas and development of indirect and direct approaches to encourage program participation. Thus, ARMP programs may best be established in States where a farmland protection program already exists.

Numerous approaches have been taken by the States for selective protection of farmland. Information gathering and analysis methods are equally diverse. Among the tools used by State and local governments to monitor change and develop farmland protection programs are: farmland mapping inventories, satellite tracking of landuse changes,

[3]The Farmland Protection Policy Act (Public Law 97-98) (FPPA) enacted in 1981 (regulations completed in 1984) identified farmland as an important national resource and required Federal agencies to consider adverse impacts of policies on farmland preservation (13 1). This Act was in part a response to a concern that metropolitan expansion was converting prime farmland to nonagricultural uses (131). However, the FPPA has not been highly effective in decreasing farmland conversion except where State farmland-protection programs exist. The Act itself does not require that a project be changed based on its potential impact on farmland conversion only that such impacts be examined and alternatives considered (22).

computer-assisted decision-making programs (e.g., GIS), and land capability analyses (22).

Tax and financial incentives, land-use controls, regulation, and acquisition or transfer of land or partial interest in land currently are the major State and local approaches used to protect farmland. All States but Nevada use at least two of these approaches; tending to progress from the indirect (e.g., tax incentives; right-to-fare laws) to the more direct approaches that require a strong public constituency. Direct approaches may include purchase or transfer of development rights, agricultural districting programs, property tax credits, agricultural-land tax relief programs, comprehensive land-use programs with farmland preservation as major goal; and statewide zoning programs. Agricultural zoning ordinances have been on the rise in 25 States. For example, Oregon's statewide land-use planning program (begun in 1975) requires local governments to identify prime agricultural land, usually by SCS Class I-IV farmland, and apply exclusive farm-use zoning, meaning restrictions on home construction or land partitioning unless it is shown to increase productivity (1 15).

Agricultural districting programs are voluntary programs designed to preserve a certain amount of farmland. These programs involve organization of a farmland district as a legally recognized entity, whereby the farmers agree not to develop the land for a specific time period. The government offers benefits to the district such as protection from annexation or nuisance suits. Thirteen States have enacted districting programs and New York alone now protects nearly 8 million acres in this manner. The approach is popular largely because it affords long-term protection at low costs (22).

Expertise housed in ARS, ES, and SCS would be integral in the implementation of ARMP. These management programs would likely rely heavily on the development of whole-farm agrichemical best management plans. ES and SCS already have experience in current application of Best Management Practices and Resource Management Systems respectively, designed to address protection or conservation of specific resources (e.g., soil, surface water). Appropriate whole-farm agrichemical management plans would need to be developed on a site-specific basis, however, and this may translate into high costs in terms of additional personnel and time. Further, the issue of groundwater protection is relatively new and increased research efforts may need to be directed towards development of practices designed to protect and conserve groundwater resources.

POLICY ISSUE: Development of Combined Technical/Policy Expertise

Interagency and Federal/State/local program coordination or integration probably will require unique talents and capabilities. Farmers and producers deal with one domain of priorities and problems. Scientists communicate in their dialects of jargon in a somewhat separate domain of priorities. Administrators function in yet another realm. Policymakers struggle to broker public sentiment into public law. Rare and few are the individuals that are fluent in the dialects of each of these communities and fewer are those that can travel freely among them.

A new "hybrid class" is needed of integrators (e.g., scientist-farmers, scientist-administrators, and scientist-policymakers) trained to communicate and facilitate communication up and down the management continuum, as well as laterally among agencies (1 19). The integrator needs a technical understanding of the issues under consideration, a grasp of policy implications of the issues, the capability of transcending the mindset of particular disciplines or administrations, and the capacity to speak the languages of the different specialties that are party to the decision (66).

Development of policy-educated scientists, and science-educated policymakers can be facilitated by sharing personnel from professional associations with Federal agencies or the Congress. The American Association for the Advancement of Science has perhaps the largest such program, detailing approximately 40 individuals to congressional and Federal offices each year. However, such sharing occurs much less commonly in the case of professional associations related more specifically to agriculture and the environment. For example, for the last several years the American Society of Agronomy provides a Congressional Fellow detailed to the Congress, commonly working with the House Committee on Agriculture. The Fellow provides a means of direct communication between the Society and congressional deliberations of agricultural issues. Such associations could be expanded to include Congressional Fellows detailed from other professional societies such as the American Geological

Institute to congressional committees or to Federal agencies.

Option: Encourage Interagency St@ Details

Congress could facilitate sharing of staff among Federal agencies. One means to facilitate communication among agencies and offices is for them to "borrow" each others' staff. To some extent this already is occurring. For example, the USDA has stationed Soil Conservation Service employees at each of EPA's regional office, and a USDA employee is detailed to EPA headquarters to assist with interdepartmental coordination (106). Some agencies also have detailed staff to congressional offices and to OMB. However, the total number of staff thus ''shared' is small and positions may not be continuously filled. Formal mechanisms and reward systems could be established to ensure continuity in interagency ''cross-fertilization. '

Another mechanism might be to encourage the development of "Technical Integration Groups" related to agrichemical contamination of groundwater; or to broader agriculture and environment issues. One Technical Integration Group (TIG) has been promulgated by the USGS and is now formally recognized by EPA and TVA; USDA is involved in the TIG although it has not formally recognized it as a coordinating mechanism.

The TIG actually is composed of three levels of groups: Strategy Teams, the Technical Integration Group proper, and the Headquarters Group, each comprising representatives from the participating agencies, State organizations, and academic organizations. The four Strategy Teams, composed of researchers from a variety of fields, regularly convene to identify and determine research needs, protocols, etc. The Technical Integration Group is an interdisciplinary team of technical program managers who ensure coordination of activities, many suggested by the Strategy Teams, and have authority to allocate resources to the programs. The Headquarters Team, still in formation, is expected to authorize research plans developed by the Technical Integration Group (133).

The primary activity of the current TIG has been to coordinate the Midwest (USDA)/Midcontinent (USGS) Initiative. This research program is a prototype cooperative research program on herbicide leaching in agricultural systems, focusing on the 11 States forming the 'Corn Belt. " The methodologies for research and research coordination are expected to be transferable to other regions and other cross-agency research issues (133). Establishment of other such interagency working groups probably would improve interagency coordination and interdisciplinary, systems-approaches to research, program implementation, and policymaking.

Congress could facilitate development of technical-policy expertise by supporting development of training and education programs for "hybrid-studies, aimed at increasing interdisciplinary understanding in Federal agency personnel. However, development of such expertise will take considerable time and money, and may do little to ensure improved communication among Federal agencies or Federal, State and local levels of government.

Coordination of Intra-Agency Activities

Complexity of programs and approaches and multiplicity of actors occurs within as well as among Federal agencies. The major Federal agencies have developed mechanisms to identify and coordinate programs relevant to water quality. The USDA has the largest number of organizational units related to agriculture and environment issues. However, coordinating systems may not include all relevant offices within the agency, and coordination systems developed commonly are not easily amenable to congressional oversight. Centralizing coordinating responsibilities in single offices or committees might improve responsiveness to congressional requests and directives.

Option: Centralizing USDA Accountability for Coordination

Congress could require USDA to establish a central person, office, or coordinating committee that will be held accountable for coordination of USDA activities related to agriculture and the environment. Improving inter-office coordination within the USDA might increase its flexibility in response to emerging issues. A USDA Working Group on Water Quality has been established within the Secretary's Policy and Coordination Council to oversee implementation of the Water Quality Program Plan and to improve intra-agency and interagency coordination relevant to agrichemical contamination of groundwater. This could be formalized and expanded to comprise a coordinating committee to address environmental issues at large, reporting directly to the Deputy Secretary. Water quality programs could be one set of issues coordinated by this committee. Alternately, a formal position could be created in the Office of the Secretary with express responsibility for coordinating all agency environmental protection efforts.

Means for Congress and the Federal agencies to rapidly and accurately identify activities within certain agencies are necessary for effective coordination and oversight of programs to protect groundwater from agrichemical contamination. Thus, agencies need to develop 'vertical' information systems that provide information flow from field agents to agency administrators (119). For example, a national program leader in Washington DC may need to know what kind of nitrogen management programs are underway in Lancaster County, Pennsylvania. In such a case, the administrator can call the relevant field agent for response, but what if the request is for a concise summary of all nitrogen-related program activities underway in 100 counties in the northeast? As efforts are targeted towards areas of high hydrogeologic vulnerability, such requests become more likely,

At present, USDA has computerized systems listing extension service activities (the Program Document Data Base) and federally funded agricultural research programs (the Current Research Information System). However, these systems were not designed to readily provide answers to questions now being asked by policymakers and program managers. Both have received criticism in recent reports (cf: 158,121) calling for standardized classification systems and reporting formats.

For example, the Current Research Information System (CRIS), maintained by the CSRS, catalogs ongoing research conducted by the Agricultural Research Service and the land-grant universities. The CRIS system tends to categorize research programs on the basis of commodity, following the historical concern of the agricultural community with production of an abundant and inexpensive food supply. The system has been expanded to monitor some broadly defined natural resource and environmental issues, but is not yet capable of categorizing projects on the basis of their contribution to groundwater quality protection or similar issues. The CRIS system provides a ''fwst cut' at isolating potentially relevant projects, but the resultant list must be manually searched and evaluated for extent of research program relevance to the issue of concern.

Option: Improving Program Tracking System

Congress could require that USDA expand the CRIS system, specifically to categorize ongoing research on the basis of current issues of public and congressional concern and, perhaps, also to include activities other than research promulgated or sponsored by the USDA. Alternately, Congress might request that similar tracking systems be fully developed for data collection, education, and technical assistance following the same type of reporting structure required by the CRIS system.

A system is needed that can track the diverse programs underway in dispersed offices so that they can be integrated with national programs. Further, the program information needs to be stored in such a way that desired information is easily searched and retrieved. However, a tracking system should not create paperwork such that the resulting burden is greater than the information benefits that result.

In order to accomplish this, some standardized classification system, and a list of the relevant issues of concern, must be generated. The list of issues could focus solely on those relevant to agrichemical contamination of groundwater, or could be expanded to include other issues of broad public concern such as other environmental issues, rural development, and trade issues. Congress could develop the list of issues, or might require USDA to develop the list as a first report on the CRIS modification.

A classification system of current research or programs would essentially constitute an agreed-upon set of rules for defining the different type of groundwater research and programs that are underway. For example, the criteria might determine whether work is relevant to groundwater protection or not, and under this, whether it is primarily: 1) collection of data and samples, 2) analysis of research and data collection, 3) management of people involved in the above, or 4) development of policy or regulations resulting from the preceding activities (120). The research categories identified by the Technical Integration Group could serve as a starting point for developing a list of categories of groundwater protection work (133). Congress could require that an interagency body such as the

FCCSET Subcommittee on Groundwater or the Technical Integration Group develop a classification system that would be relevant across all agencies.

The list of issues of concern, and the classification system probably will have to be reconsidered on a regular basis. Programs and research, particularly basic research can be relevant to a broad array of popular issues. In addition, the issues themselves change over time. Therefore, Congress might require regular reporting on potential new issues to add, or 'old' issues that might be dropped from the list. Providing for public discussion of the issue list might allow for foresight on additional issues of public concern. USDA activities related to those issues could be identified, prior to their development into public ' 'crises. ' With the use of agreed-upon classification systems, it would be possible for Congress to ask USDA or other agencies how much is spent on groundwater data collection, research, education, and technical assistance, and to receive numbers that are likely to be more defensible than those provided now.

Congress also could require that the agencies jointly support an evaluation of current program tracking databases and their relative utility. Based on this evaluation, an optimal ''Program Tracking System" might be designed, using one standard classification system. If the system were designed specifically for groundwater protection from agrichemical contamination, the system might be coordinated through the National Agricultural Library. However, if Congress decides the system should track the larger array of environmental and social issues related to agriculture, it may be more appropriate for FCCSET, OMB, or some other neutral agency to manage the system.

Adequacy of Resources

Groundwater protection will be an ongoing process. It will require the development of a number of products and investigation of numerous practices, and these efforts will have to be sustained over a number of years (1 19), In an era of diminishing Federal fiscal resources, difficult decisions need to be made about the public's commitment to protecting groundwater from contamination compared to other social concerns. No set of groundwater protection programs will succeed with sporadic, haphazard, and inadequate funding. For example, meeting USDA's stated commitment to water quality improvement will require a consistently high level of effort for a number of years. This commitment probably will require funding of agency groundwater programs over competing priorities and providing adequate staff resources (197).

Provision of this funding and staffing already is under question. For example, the Extension Committee on Organization and Policy reported that 'the conventional problems of personnel limitations and the need for staff training" hinder the Extension Service's ability to extend groundwater education programs to practitioners (52). These 'conventional problems '' include inadequate funding, inadequate numbers of personnel, and inadequate resources to train and prepare extant personnel.

Furthermore, Extension Service and Soil Conservation agents operating at the county level have multiple responsibilities; it is difficult for them to allocate the time and resources to attend groundwater training programs, particularly if the issue is not a high priority for the residents of their particular county. The majority of the funds available to these field agents comes from county and State governments, whose priorities thus take precedence. If the Federal Government wants a large role in directing the priorities of these systems, it probably will have to share a larger part of the funding burden.

These problems extend beyond education and extension. Water quality research in general, and groundwater protection research in particular, is long term and expensive. For example, one report estimates that study of the movement of agricultural chemicals through the soil profile into the groundwater usually requires drilling wells for sampling, each of which may cost several thousand dollars. Processing and analyzing one water sample for agricultural contaminants, following EPA protocols, costs several hundred dollars. Each site will require a number of samples to follow fluctuation and movement of the chemicals over time. If one sample is taken from a well every 2 weeks in the course of a year, analyzing these samples will cost $7,000 to $8,000. Conservatively, if only 10 sampling sites are chosen, then $70,000 to $80,000 a year would be spent on sampling costs, $20,000 to $30,000 in drilling costs, and further funds would be required to cover labor and other costs (40).

Option: Substantially Increasing Funding for Programs Directly Relevant to Agrichemical Contamination of Groundwater

Congress could increase funding for extant Federal research, education, and extension programs, and grants to States for such programs, based on direct relevance to reducing agrichemical contamination of groundwater. Many of the groundwater research and education programs developed under the President's Water Quality Initiative have ‘‘matching funds” requirements, where State or local governments must match the Federal allocation to receive funds.

Despite the lead role States have taken, financial resources are sufficiently scarce that States seem willing to comply with Federal guidelines in order to secure new dollars. Moreover, State readiness to respond to Federal dollars seems widespread. For example, in fiscal year 1989, after discounting congressionally earmarked projects, CSRS received about $1.8 million in new funds for groundwater research to be carried out across the nation. Nearly 240 research proposals were submitted, of which only about 20 could be funded. State researchers and educators have developed proposals, but finding from the Federal government probably is necessary to conduct these programs, and to leverage the coordination of the diverse State programs into an integrated national program (193).

Expansion of research, education, and extension programs to incorporate the whole suite of agriculture and environmental issues may be costly. For example, the National Research Council recently released a report that called for a $500 million increase in funding for agricultural research, in part to address public concerns about the effects of agricultural production on the environment (1 13). Water quality is explicitly identified, and research areas are specified:

- developing cost-effective agricultural and silvicultural systems that minimize or, preferably, eliminate surface and groundwater pollution from both point and nonpoint-sources;
- devising land management practices that reduce or eliminate the transport of pollutants through surface and subsurface flows and assessing the quantitative effects of such practices;
- developing methods for increasing water yields and availability while minimizing water quality degradation;
- using irrigation waters more efficiently;
- designing innovative systems for restoring water quality and preventing contamination from nonpoint-sources;
- developing cost-effective remediation systems; and
- understanding the economic and social effects of possible abatement, remediation, and agricultural production strategies (1 13).

Research on groundwater protection, as well as other environmental and natural resources issues, could fit into this new funding framework should it become available. However, increasing funding substantially beyond that already provided by the President's Water Quality Initiative is likely to pose difficulties in a time of fiscal austerity. Therefore, evaluating and reorienting existing programs, and existing appropriations, may be more appropriate than massive new infusions of funds.

REDIRECTING FEDERAL AGRICULTURAL PROGRAMS

Introduction

Agricultural policy represents a complex “web” of programs governing commodity production, risk management, resource conservation, and agricultural research and education. Federal agricultural programs provide farmers with a variety of benefits including commodity program price supports, income supports, and supply controls; crop insurance subsidies and disaster payments; storage payments; market enhancement subsidies; credit subsidies; and conservation land rental and cost-share payments.

Farm policies affect cropping practices and related agrichemical use primarily by conferring different relative benefits on commodities. Income and price supports, for example, reduce economic risks associated with growing seven major commodities, which encourages farmers to grow these crops preferentially over other crops which are not “protected” by farm programs (e.g., some small grains and perennial legumes useful in crop rotations).

Farm policies are criticized for creating certain commodity surpluses and huge Federal outlays of entitlement payments to farmers who are growing a limited range of crops. In fiscal years 1987 and 1988, for example, subsidies to farmers totaled $25.5 billion and $20.3 billion, respectively (174). Critics charge that such subsidies inflate the Federal deficit, distort production incentives, increase farmer de-

pendence on Federal payments, and make U.S. agriculture generally less competitive (7,77).

Differences in cost of agricultural production in many regions also has been altered by subsidization of agricultural inputs, such as irrigation water, as well as through protection from liability for environmental damages (14). Federal programs affect farmers' implementation of conservation practices to reduce soil erosion and improve water quality, but programs tend to make production a higher priority than resource conservation (34). On one hand, some program provisions encourage conservation through cross-compliance requirements, voluntary cost-share incentives, and technical assistance programs encouraging conservation. On the other hand, commodity and risk-reduction programs can conflict with conservation provisions by imposing short-term planning horizons for production decisions and discouraging long-term planning for resource conservation. Thus, in addition to restricting cropping options, commodity and risk reduction programs may provide disincentives to implementing conservation practices.

Furthermore, Federal programs are blamed for subsidizing unnecessarily high levels of aggregate agrichemical use by supporting agrichemical-intensive commodities, encouraging production of crops in areas that may not be suitable for their growth, encouraging production practices that require higher agrichemical inputs, and delaying development of reduced-chemical or nonchemical alternatives. Certain program crops, such as corn and cotton for example, use higher amounts of nitrogen fertilizers or pesticides than non-program crops (169). Incentives to increase program crop acreage to the extent possible under farm programs discourages farmers from rotating crops or integrating non-program crops into rotation systems (60).

Alternatives to current Federal farm programs are being debated, ranging from modifications that maintain the general framework of price and income supports (e.g., expanding current cross-compliance requirements on soil erosion control to include nutrient and pesticide management plans) to more drastic approaches involving elimination of Federal farm payments based on production output (i.e., "decoupling"). Proponents favoring the maintenance of support programs recognize the associated problems and trade-offs but prefer the stability these programs afford; they fear that "decoupling' would cause severe disruptions in production patterns and expose producers to commodity markets that may not be self-correcting and that are highly distorted by the concentration that has occurred among commodity buyers.

Proponents of decoupling, on the other hand, believe that elimination of price and income supports would allow farmers to be more responsive to market signals and encourage them to grow a more diversified range of crops rather than being encouraged to specialize in program commodity crops. A third alternative would be to follow up "decoupling' with a "recoupling" of Federal payments to adoption of approved conservation practices. The Federal government under this approach would then be paying farmers to steward the nation's agricultural resources, rather than intervening in commodity markets. *Any* changes in farm programs are likely to affect farmer choice of crop, production practice, and agrichemical management strategy, all of which may affect the potential for agrichemical contamination of groundwater.

Major Programs Affecting Farmers' Decisions

Groundwater protection from agrichemical contamination is a cross-cutting issue and will be influenced by all three types of agricultural programs-production, risk reduction, and conservation. Some of these programs may directly cause intensified agrichemical use, or they may conflict with other programs indirectly leading to increased use. Policy options addressing conflicts within and among all three types of programs may help remove barriers to improved agrichemical management or reduced agrichemical use.

Production Programs

Agricultural production programs are comprised of separate commodity programs outlined in the commodity titles of Federal farm bills authorized every five years. Commodity programs guide national production of at least 13 different commodities, with 7 commodities commanding the greatest portion of farm program benefits: wheat, feed grains (corn, sorghum, oats, and barley), cotton, and rice. Assistance is also provided to producers of sugar, wool, mohair, honey, peanuts, tobacco, peas, dairy products, and soybeans (15). The Secretary of Agriculture has the authority to add to the list of

program commodities if deemed necessary to achieve legislative goals.

Commodity production programs are intended to help farmers, processors, and distributors obtain prices that result in an orderly, adequate, and steady supply of agricultural products for the nation's consumers (3). Commodity programs vary in price support levels, producer requirements, and producer participation rates, and any program changes tend to generate different benefits, price ratios, and input substitution possibilities for farmers (14). Commodity programs also influence the amount and locations of cropland planted to various program crops (49). Thus, commodity programs strongly affect farmers' decisions related to crop choice, agrichemical use, and farming practices and resulting potential for agrichemical contamination of groundwater.

Commodity programs partially buffer farmers from market price fluctuations through three main types of programs: 1) price support; 2) direct payment; and 3) supply management (155). The first two of these programs account for approximately 80 percent of Federal farm program outlays (156). Certain features of each type of program have been criticized as encouraging the production of agrichemical-intensive crops or discouraging crop rotation. Policy options that address these features thus assume that the general framework of price and income supports will be maintained as agricultural policy.

Price Support Programs—Price supports guarantee that farmers will be able to sell their commodities at a price, or loan rate, set by Congress. Price supports are provided through ''nonrecourse loans' from the USDA Commodity Credit Corporation (CCC) in which the farmer uses his crop as collateral. If the commodity's market price is lower than the loan rate when the loan matures (usually after 9 to 12 months), the farmer can forfeit the crop to the CCC instead of repaying the loan in cash (15). Thus, nonrecourse loan rates provide a price floor for commodities when market prices drop.

Direct-Payment Income Support Programs— Income supports are provided to farmers through direct payments, called ' 'deficiency payments," when commodity market prices fall below ''target price' levels set by Congress. Deficiency payments make up the difference between a commodity target price and its market price or government nonrecourse loan rate, whichever is higher. To frost qualify for deficiency payments for a specific program crop, a farmer must have planted that crop on a portion of the farm for the last 5 consecutive years. This is the farmer's "crop acreage base" for that commodity, which is thereafter calculated using a 5-year rolling average of the number of acres planted to that crop (171). A farmer's total deficiency payment depends on which program crops are grown, the number of acres eligible, and average "program payment yields" per acre established by USDA/ASCS. Annual deficiency payments per farmer are limited legislatively to $50,000, but certain exceptions allow some persons to receive considerably more (155,16).

Supply Control Programs—To receive price or income supports for any commodity, farmers must agree to reduce their acreage in that commodity by a percentage set by USDA as part of an acreage reduction program (ARP). Also known as "set-sides,' ARP requirements in recent years have ranged from 5 to 30 percent of base acreage (170). USDA rules stipulate that acreage set-asides be planted to soil conserving crops. Thus, acreage eligible for deficiency payments for a specific commodity in any given year is that crop's base acreage minus the required ARP, or the crop's "permitted acreage. "

Commodity programs are included among the ''institutional factors' that are likely to influence farmers' decisions related to resource protection (109), Choices made with regard to commodity program may have environmental effects sufficient to overwhelm efforts made through traditional conservation programs (38). Production program constraints may be especially felt by participating farmers in hydrogeologically vulnerable areas who could reduce groundwater contamination through changes in cropping practices. Commodity program issues and options relating to cropping patterns and associated agrichemical use are discussed here.

POLICY ISSUE: Current Federal Farm Programs Restrict Cropping Flexibility and Discourage Crop Rotation

Federal farm programs provide price and income supports for only a few crops and thus limit participating farmers' crop choices and planting flexibility. Even among the program crops, Federal price and income supports are greater for crops using higher levels of agrichemical inputs (e.g., corn, cotton, and wheat) than for crops that are less agrichemical-intensive (e.g., oats and barley). Federal programs also discourage farmers from diversifying because deficiency payments are based on the number of program crop acres averaged over the past 5 years. For example, farmers currently wishing to receive Federal benefits for more than one program crop can establish multiple bases, but these farmers' deficiency payments will drop due to: 1) lower ''acreage base' for currently enrolled crop in the following years; and 2) 5-year period required for ''new' crop bases to be established before any payments can be obtained.

Consider the farmer currently growing continuous corn and who wishes to start a 3-year crop rotation by planting a third of the current crop base in corn, a third in soybeans, and a third in oats. This farmer faces the strong disincentives of a reduction of corn base acreage eligible for deficiency payments reaching 66 percent in the fifth year of the rotation. Further, no payments are received for oats for 5 years, and no payments for soybeans (although soybean price supports would be available). Even if this farmer wanted to plant total acreage to soybeans for only 1 year and then return to continuous corn production, a 20 percent reduction in base acreage would be incurred for each of the following 5 years (114). Farm programs thus encourage farmers to plant the maximum number of base acres possible to their current program crops in order to maintain acreage base and deficiency payments.

Some crop flexibility is currently provided through the 0/92 and 50/92 provisions for feed grains, wheat, and cotton in the 1985 FSA and subsequent amendments (126). The 50/92 program allows farmers to receive almost all (92 percent) of their deficiency payments for that commodity in return for planting only 50 percent of permitted acreage. However, Congress limited the crops that could be grown on the remaining permitted acreage and did not allow for alfalfa or clover, which are soil-building legumes useful in rotations.[4] Alternatively, the 0/92 program allows farmers to receive 92 percent of their deficiency payments without planting any permitted acres to the commodity crop, as long as their entire permitted acreage is planted to conservation uses. Although conservation uses include establishing vegetative cover by growing sod or legume crops, farmers cannot harvest these crops as hay or pasture forage. This harvesting prohibition may discourage farmers from utilizing the 0/92 option because it eliminates the possibility of sale or on-farm use of conservation crops.

Limited increases in cropping flexibility have also been provided in recent years through USDA rules related to conservation compliance and disaster assistance. For certain commodities, for example, some farmers have been allowed 'base exchanges to meet conservation compliance requirements, where base acres planted to low-vegetative-cover crops are replaced by acres planted to crops having more vegetative cover to reduce soil erosion (170). The Disaster Assistance Act of 1988 also provided for base exchanges and base protection for oats, soybeans, and sunflowers in 1988 and 1989 (43). Furthermore, USDA in 1989 allowed up to 20 percent of a farm's permitted acreage to be planted to non-program crops without a payment reduction, although this rule may not be extended after 1990.

Increased cropping flexibility can be beneficial to farmers faced with new environmental requirements or drought conditions. Greater cropping flexibility could also be extended as a result of the need to protect groundwater resources from agrichemical contamination. However, national changes in farm programs permitting increased cropping flexibility across the board would not benefit all farmers equally. Local soil, climatic, and topographic conditions constrain some farmers' cropping options more than others. Kansas dryland farmers, for example, have few options to grow anything but wheat (67)-if other farmers begin to grow it, the resulting increase in wheat supply would depress the market for established farmers who have specialized in that crop. Farmers in the Southeast, on the other hand, would probably enjoy greater benefits from cropping flexibility, because weather conditions in this region make it possible to grow a wider range of crops. Changes in farm program flexibility will thus benefit some farmers more than others and some changes may have adverse indirect impacts on certain farmers (67). Regions with limited crop choices may require special policy attention and additional analysis to identify potential impacts of program changes.

[4] The Food Security Improvements Act of 1986 allowed triticale, rye, flaxseed, sweet sorghum, guar, sesame, safflower, sunflower, and castor beans among other crops which do not have ''established markets."

The following options could increase cropping flexibility in Federal commodity programs. These options could be authorized as provisions affecting commodity production nationally, or they could provide the basis for special rulings specific for geographic areas designated as vulnerable to groundwater contamination.

Option: Increase Cropping Flexibility in Targeted Areas

Congress could authorize USDA to designate special groundwater-protection area adjust ments for base acreage formulas that would allow farmers in these areas to use crop rotations and less agrichemical-intensive crops as one strategy to reduce groundwater contamination. Program participants in hydrogeologically vulnerable areas may be ‘‘locked’ into growing agrichemical-intensive crops, especially if they depend on price and income supports to increase potential net returns and reduce risk. For example, constraints may be particularly severe for producers growing continuous corn in sandy areas, such as the central Platte River valley in Nebraska, where extensive groundwater resources are contaminated by nitrate and herbicides (145). Constraints resulting from base acreage requirements of existing farm programs could limit the effectiveness of voluntary or semi-regulatory programs to reduce contamination in hydrogeologically vulnerable areas, especially where significant contamination reductions are needed for groundwater to meet drinkingwater standards. This option would allow commodity program participants, particularly those in hydrogeologically vulnerable areas, to implement crop rotation systems designed to reduce agrichemical use and thus potential for agrichemical contamination.

Option: Increase National Cropping Flexibility

Congress could increase cropping flexibility under commodity programs on a nationwide basis. Under this approach Congress could:

End crop-specific bases altogether and reinstate ‘‘whole-farm bases. ” A whole-farm base program would be similar to the “Normal Crop Acreage” (NCA) program used between 1978-81 (45). One approach would be for the USDA to assign one base to each farm according to its cropping history and allow any combination of the major commodities to be grown. The farmer would then receive price and income supports based on the commodities grown that year. Although this approach would increase flexibility, it would not necessarily ensure groundwater protection or less agrichemical use in hydrogeologically sensitive areas, especially if price and income supports for agrichemical-intensive row crops continue to be higher than for less agrichemical-intensive commodities. Also, alfalfa and other nitrogen-fixing crops are not commodity program crops, and their acreage still would not be included in support programs.

Another approach would be to assign whole-farm bases nationally but designate more specific cropping combinations for whole-farm bases in hydrogeologically vulneralble areas. Thus, farmers in these areas could only receive price and income supports for commodities grown in environmentally beneficial rotations suited to local groundwater vulnerability conditions.

Protect the base of any farmer **wishing to grow non-program crops on crop acreage base.** Base protection could bean ongoing feature of commodity programs or Congress could allow all farmers a one-time base exchange, e.g., 10 acres of corn base with 10 acres of base in another crop. This would allow farmers to keep their commodity program base acreage while being able to plant legume and small grain crops in crop rotations, giving them the option of using beneficial rotations if they so desire. A disadvantage to increasing cropping flexibility in current farm programs is that it would not ensure that farmers choose cropping patterns that are environmentally beneficial. If flexibility is increased through any of the above options, groundwater protection benefits are likely only if cropping flexibility is coupled with incentives to adopt environmentally-beneficial cropping patterns and removal of incentives to intensify agrichemical use.

Congress could authorize a new, national rotation-based “commodity program. ” Congress could create another farm bill title based on crop rotations and environmental stewardship and covering a variety of program and non-program crops. Like other commodity programs, this program would have voluntary enrollment but could provide higher relative incentives for farmers to grow soil-building or conservation crops. Participation would require all participants to comply with crop rotation standards. The advantage to this approach would be that cropping flexibility changes would be directed toward supporting environmentally beneficial crop rotations.

One disadvantage to such a program would occur if numerous farmers chose to institute ''forage legumes" (e.g., alfalfa, clover) in crop rotation systems. If enough farmers should enter such a rotation, the livestock feed market-currently the largest market for those commodities-might not be capable of absorbing the suddenly-increased stock, especially without a substantial reduction in commodity price. Thus, under the options listed above, legumes could be instituted as program crops with all the attendant incentives for production and increases in farm commodity program payments, or a concomitant program to expand the market for legume-crop products (e.g., pelletized alfalfa might serve as a replacement for road salts) might be instituted.

POLICY ISSUE: Current Farm Programs Encourage Intensification and Production of Agrichemical-Intensive Crops

Among the seven major commodities supported by farm programs, the more agrichemical-intensive commodities, such as corn and wheat, have higher target prices than other commodities such as oats and barley. The differences in returns afforded by current target prices is reflected in the different participation rates for the commodity programs. In 1988, for example, corn commodity programs enjoyed about 90 percent participation of all corn producers while oats programs had only 30 percent participation. Current target price differentials therefore encourage farmers to plant more acres in corn and wheat (103). Increased acreage planted to crops that use relatively higher amounts of fertilizers and pesticides, particularly in continuously-cropped fields, contribute to greater potential for agrichemical contamination of groundwater in hydrogeologically sensitive areas.

Options: Increase Incentives for Growing Less Agrichemical-Intensive Crops

Congress could align target prices among program commodities. Reduced price and income supports for erosive, agrichemical-intensive row crops such as corn would reduce incentives to grow these crops in hydrogeologically sensitive areas. Higher price and income supports for small grains are likely to increase acres planted to these crops and would encourage their use in environmentally beneficial crop rotations.

Congress could conditionally authorize haying and pasturing of conservation crops in some areas. Authorization of such harvest probably should be dependent on an analysis of the impacts of commodity programs on agrichemical use in hydrogeologically vulnerable areas. This analysis should include an examination of the potential impacts of allowing harvesting of conservation crops, such as clover and legumes, planted on ARP set-asides. Harvesting is typically prohibited for fear that it will have adverse impacts on hay producers. However, harvest might be permitted on hydrogeologically vulnerable areas as an incentive to include such crops in rotations. Conversely, repeated harvesting of these crops can severely reduce the amount of nitrogen returned to the soil, such that annual harvests may have to be limited in number or volume.

Congress could require inclusion of nitrogen-fixing crops in 50/92 and 0/92 programs. Such an approach could encourage producers to adopt crop rotation given the potential for increasing soil fertility through incorporating legumes in crop rotation. Thus, alternating planting of the legume and commodity crop could provide additional benefits in terms of reduced fertilizer and pesticide use.

Options: Remove Incentives for Intensification on Non-Set-Aside Acres

Farmers who participate in commodity programs typically set aside their least productive or most marginal acres, and they may keep these same acres out of production year after year (32). Since deficiency payments are calculated in part on base acreage and partly on historical yield of those acres, incentives are strong to boost production on the acres planted to the program crop. This commonly entails high agrichemical inputs, planting high-yielding varieties, and planting in close formation. Thus, overall production of specific commodities has increased in some cases, despite set-aside provisions implemented to reduce crop supplies (153,174).

Congress could redefine set-asides or acreage limitations to a multi-year (3-to 5-year) program. Such an approach could encourage planting of perennial crops that provide greater benefits in terms of soil-building and soil erosion control. This could encourage some producers to adopt crop rotation in order to derive additional benefits from enhanced soil characteristics. Further, the more marginal agricultural lands would remain out of production for a longer period of time. Evidence indicates that crop production on marginal lands generally requires greater agrichemical inputs, thus, some benefits may also be generated by associated use-reduction. However, set-asides are designed for production control and thus this option would entail making long-term decisions relative to commodity production levels.

Congress could address production control through reducing the intensity of agrichemical use rather than land diversion. The incentives for maximizing production on cultivated acreage remain significant, frequently encouraging overapplication of agrichemicals. Establishment of a maximum "bushel per acre" for commodity program payments may have potential for reducing overall chemical use. Such a calculation could be made based on general production in a given region, similar to the methods used for calculation of deficiency payments. With such a limit established, there might be little incentive to overfertilize or apply ''insurance' pesticides. Alternatively, the maximum yield level could be set based on a realistic yield goa1[5] on afield-by-field basis and thus take into account the site-specific aspects of agricultural production. Program flexibility, perhaps in the form of regular reevaluations, must be incorporated to allow revision of identified maximum levels as technological advances allow yield increases without adverse environmental impacts.

POLICY ISSUE: Current Farm Programs May Be Subsidizing Practices That Contribute to Agrichemical Contamination of Groundwater

Some Federal commodity programs tend to support agrichemical-intensive practices, virtually resulting in subsidies for agrichemical contamination of groundwater. Another significant development in the agricultural sector is the passage of conservation compliance provisions in the 1985 Food Security Act (Public Law 99-198) (62). Conservation plans for highly erodible lands (HEL) are projected to rely on conservation tillage, residue management, and cropping practices.

Options :Expand Cross-Compliance to lnclude Groundwater Protection

Congress could expand cross-compliance requirements to include groundwater protection by requiring nutrient and pesticide management plans for eligibility. Congress could prevent subsidization of groundwater contamination by expanding cross-compliance requirements for participation in commodity programs to include documentation that agrichemicals are being used properly and judiciously. However, this would require substantial time, staff, and funding for the SCS alone or in combination with other UDSA agencies (e.g., ES, ARS, CSRS, ASCS, ERS) to develop new plans and integrate the new plans with extant conservation plans developed for current cross-compliance programs.

Congress could target base and payment protection for farmers adopting environmentally beneficial rotations. Congress could allow farmers to receive full deficiency payments when they plant up to one-third of their permitted acreage to nitrogen-fixing or conservation crops. One disadvantage to this option is that it rewards farmers who have not already implemented crop rotations and penalizes farmers whose current crop acreage bases are lower due to established crop rotations. Program benefits could be adjusted to compensate farmers who have established crop rotations or conservation cropping practices through cropping history documentation.

Congress could require environmentally beneficial rotations and management plans in hydrogeologically vulnerable areas. Congress could authorize base protection for any farmer wishing to grow non-program crops on crop acreage base (189), but not protect the deficiency payment outlay for these farmers, *unless they start* a transition to approved, environmentally beneficial rotations.

Congress could prohibit any Federal farm program benefits for commodities grown under continuous cropping practices. Significant reductions in insecticide and herbicide use can be achieved by going from continuous corn, for example, to growing corn in rotation with soybeans. A prohibition on continuous cropping is unlikely to affect large numbers of farmers: continuous cropping is not a prevalent practice among producers of major field crops, except for some crops in certain

[5]Realistic yields are determined b, averaging production from a given field over a 5-year period (see ch. 4).

regions (39). However, producers of certain crops (e.g., rice) might need special programs (e.g., a program akin to the 0/92 program or wetlands protection payments similar to the Conservation Reserve Program). Prior to authorizing this prohibition Congress could request a study to assess potential impacts of a nationwide ban on continuous cropping as a farming practice.

Conservation Programs

Federal farm programs contain agricultural con**servation components that could** also be used as tools to address the need for groundwater protection from agrichemical contamination. Besides conservation cross-compliance provisions, two voluntary agricultural conservation programs could be pertinent to groundwater protection: 1) conservation cost-share and technical assistance provided on an ongoing basis through SCS and ASCS; and 2) the 10-year Conservation Reserve Program (CRP) of the 1985 FSA. However, each of these programs would need to be modified to reorient traditional objectives to serve better as groundwater protection policy tools.

Conservation cost-share programs, for example, traditionally have focused more on facilitating implementation of structural changes (e.g., terracing) rather than on modifying land-uses or farming practices that would be needed to protect groundwater. Furthermore, the rationale for long-term land retirement programs would have to be expanded from the current primary focus on retiring erosive marginal lands to include hydrogeologically vulnerable areas or aquifer recharge zones.

A groundwater protection approach based on modifying conservation programs to include groundwater concerns, however, may not achieve significant groundwater quality impacts, for two reasons. First, allocating soil conservation funding to more severely affected ''target' areas has been difficult and largely unsuccessful (154,68). Similar difficulties are likely to be encountered in allocating groundwater protection assistance to hydrogeologically sensitive areas. Second, even intensified education and cost-share programs have not resulted in significant reductions in soil erosion or water quality degradation (47). The overall poor record of voluntary conservation programs in reducing soil erosion rates is considered largely due to the fact that government programs and economic pressures impose conservation disincentives that are greater than conservation program incentives.

Conservation disincentives are built into farm programs that have historically served production rather than resource protection objectives. As a result, land conservation programs have been used more as a production control tool to reduce commodity surpluses than as a means to modify land use or to meet national goals to reduce soil erosion and protect water quality.

Thus, groundwater protection efforts conducted solely within an expanded conservation program are not likely to reduce groundwater contamination any better than conservation programs have reduced soil erosion. Rather, effective groundwater quality protection may not be achieved unless other features of agricultural and economic policies are adjusted to ''create a climate in which natural resources are wisely used because people are both willing and able to use them wisely' (142). In the absence of broader changes in government programs, however, conservation programs could be expanded to include groundwater protection assistance.

Conservation Cost-Share and Technical Assistance Programs-Conservation cost-share programs traditionally have focused more on facilitating implementation of structural changes (e.g., terracing) than on modifying land-uses or farming practices. Cost-sharing programs also have tended to have a narrow focus (e.g., erosion reduction, tree planting). Furthermore, budget reduction imperatives have tended to reduce assistance levels provided under Federal cost-share programs, and many States have implemented State and local cost-share programs to maintain assistance levels.

State and local policies and programs greatly influence conservation cost-share and technical assistance programs, and will be highly instrumental in protecting groundwater from agrichemical contamination (see ch. 5, app. 5-l). Federal funding and direction of SCS and ASCS activities, however, affect these agencies' capacities to staff, train, and coordinate programs to serve as significant groundwater protection mechanisms.

Option: Review Federal Cost-Sharing Programs for Impacts on Agrichemical Management and Water-Quality Protection

Congress could require USDA to review extant cost-share programs to determine their impacts

on **agrichemical management and water-quality protection, and their potential as incentives to improve agrichemical management. Based on** such a review, Congress could earmark funds for extant conservation programs such as the Agricultural Conservation Program, or for expanded integrated conservation cost-sharing, such as the ASCS Integrated Crop Management Program. In addition, Congress could require a review of State cost-share programs and grant funding provided to States for cost-share programs. This review might identify opportunities for more cost-effective provision of cost-share programs, and could provide assistance to States to find alternative funding mechanisms.

Development of an expanded Federal cost-sharing program that integrates multiple environmental concerns (e.g., soil-erosion reduction, wetland and wildlife preservation, protection of water quality) might provide significant benefits without substantially increasing funding levels. A simultaneous program to expand State cost-sharing programs, via grants and assistance in identifying funding mechanisms, while potentially requiring increased expenditures in the short-run, might alleviate some budget concerns in the long term.

Long-Term Cropland Retirement Programs for Conservation-Federal cropland retirement programs serve as production controls as well as means to reduce soil erosion through long-term voluntary contracts with farmers to retire erosive cropland. Farmers in these programs convert cropland into grasslands, woodlots, or wildlife-forage plantings in return for government payments and cost-share assistance to establish permanent vegetative cover. Under any long-term cropland retirement program, the total amount and distribution of lands retired under such programs depend on a variety of factors:

- national program missions specified in legislative or administrative language;
- State- or county-level restrictions on amounts of land to be retired;
- amount of funding allocated to implement the program;
- degree of implementation by State and local administrators; and
- degree of program participation, which is influenced by attractiveness of cost-share and other program incentives to landowners.

The long-term cropland retirement program currently in effect is the 10-year Conservation Reserve Program (CRP) established by the 1985 Food Security Act. To participate in the CRP, farmers petition to put highly erodible croplands identified by the SCS into grasses, trees, or other vegetative cover for at least 10 years in return for annual rental payments. Farmers follow locally approved conservation plans to convert their CRP lands, which cannot be grazed, harvested, or used for other commercial purposes during the 10-year contract period (150).

POLICY ISSUE: Cropland Retirement Incentives May Be Too Low To Achieve Adequate Participation

Farmer incentives in land retirement programs for conservation purposes, however, must be attractive enough to provide similar or greater benefits compared to potential returns fkom cropland. Otherwise, farmers are less likely to enroll cropland acres. The 34 million acres enrolled in the Conservation Reserve Program between 1986-90, for example, fell short of the program's original policy goal to enroll 40 million acres. One of the factors involved in the enrollment shortfall was stronger farm prices relative to those of the early 1980s (94).

The impacts of long-term land retirement programs on agrichemical use depends on the types and amounts of cropland enrolled, and the choice of long-term vegetative cover. Agrichemical use on CRP lands is generally much lower than on croplands, although farmers might apply agrichemicals to establish permanent vegetative cover in the first year of the program. Aggregate agrichemical use is therefore expected to decrease with increased acreage enrolled in long-term land retirement programs (150).

Federal policies related to agricultural production and conservation also have impacts which vary by region. Agrichemical applications due to reduced planted crop acreage are more likely to decline in areas of heavier fertilizer and pesticide use (69). However, because the CRP was designed to reduce soil erosion, its criteria for enrollment did not include identification of lands most vulnerable to groundwater contamination or those receiving heavy agrichemical use.

Options: Expand the Conservation Reserve Program

Congress could expand the CRP to include hydrogeologically vulnerable areas. This approach has been examined to some extent in certain legislative proposals put forth in the 100th Congress (e.g., H.R.4137 and S.2045 proposed to establish 20 million acres of groundwater recharge eligible for CRP, however no action was taken). Inclusion of aquifer recharge areas or highly vulnerable areas in the CRP could generate significant benefits to preventing groundwater contamination from agricultural practices. However, the lack of understanding of subterranean water movement may hinder effective targeting of eligible areas.

Such an approach assumes the ability to identify highly vulnerable areas when such information and current targeting methods (e.g., DRASTIC) are still contested. Further, areas currently identified as highly vulnerable may represent high-cost farmland and thus payments for such conservation approaches may be prohibitive. An expansion of this program clearly will require additional funding given the current inability to reach target enrollment for CRP because of lack of funds. Furthermore, expanding acreage reduction may have adverse effects on commodity production, commodity prices and thus food prices as well.

Another consideration is whether or not the 10-year term contained in current CRP contracts would be sufficient to generate benefits to groundwater. Expansion of CRP based on a short-term contract period likely would result in a reduction of chemical input to groundwater for a similarly short term. This aspect is particularly important given the variability in rate of agrichemical movement through the soil profile and the potential for chemicals applied many years ago to continue moving. Thus, chemical contamination of groundwater may well continue during or beyond the contract period. Another consideration is the effects of plow-down and subsequent decomposition of conservation crops potentially creating a "nitrate pulse" through the soil profile, possibly reducing overall groundwater protection benefits.

Congress could extend the terms of CRP contracts in hydrogeologically vulnerable areas beyond the 10-year limit. This would be especially beneficial if accompanied by promotion of tree-planting with its associated nutrient-scavenging and carbon storage benefits. However, costs associated with tree-planting may be much higher than for sod or legumes and, thus, may pose a disincentive for practitioners. Still, the potential benefits in reduced agrichemical use with respect to protection of national (e.g., groundwater) or global (e.g., atmosphere) resources may argue for increasing payments for those acres planted to trees.

Risk Reduction Programs

Federal farm programs also provide some measure of economic security and risk-reduction through programs combined here under the category of "security" programs. These include farm credit programs, crop insurance, disaster assistance, and marketing programs.

Farm Credit Programs—Fanners obtain credit through two main charnels: the Farm Credit System (FCS), and the Farmers Home Administration (FmHA). Farm credit policies and practices may in some cases make it difficult for farmers to take actions to protect groundwater resources. Major farm credit programs are briefly described here, along with options to remove obstacles to enhanced groundwater protection.

The FCS is congressionally chartered to provide production credit and farm real-estate financing to farmers through a national network of cooperatively owned banks and local-lending associations **(26). A** Federal Farm Credit Board approves rules **and** regulations governing operations and oversight of FCS institutions and supervises the Farm Credit Administration (FCA), which regulates all FCS lenders (136). The FCS administers its programs through 12 Farm Credit Banks reorganized under the Agricultural Credit Act of 1987. Farm Credit Banks make real estate loans and long-term loans to Production Credit Associations (PCAs), which in turn make short- or intermediate-term loans to farmers. PCA loans usually have maturities coinciding with production or marketing periods.

The Farmers' Home Administration (FmHA) is a Federal farm credit institution authorized by the Consolidated Farm and Rural Development Act to provide credit to farmers who are unable to obtain credit from private lenders. FmHA has a number of farm loan programs which include:

- farm ownership loans, which finance farm purchases and improvements or additions to farms; these loans may also be used to finance non-farm enterprises and refinance debt;

- farm operating loans, which are short- to intermediate-term loans for machinery or equipment, annual operating expenses, refinancing of debts, or creditor payments;
- emergency disaster loans, which provide financial assistance to farmers sustaining substantial losses from a natural disaster; and
- soil and water loans, which finance land and water development, use, and conservation; these may be used for construction and maintenance of terraces, dikes, reservoirs, ponds, and waste disposal facilities for compliance with pollution control laws.

FmHA makes two types of loans: 1) insured direct loans, which are made and serviced by FmHA from a government revolving fund; and 2) guaranteed loans, which are made, financed, and serviced by a private or cooperative lender, but with FmHA guaranteeing the lender against a 90 percent loss on the loan if the borrower defaults (63). Because FmHA is agriculture’s “lender of last resort, ” it holds the largest number of high-risk loans. The 1985 Food Security Act made several significant changes in FmHA lending policy to reduce government costs from loan delinquencies, including the curtailment of FmHA insured direct loans in favor of guaranteed loans.

In 1988, 118,000 FmHA borrowers were delinquent and facing possible foreclosure. The Agricultural Credit Act of 1987 required FmHA to modify delinquent loans to the maximum extent possible in order to keep borrowers on their farms and avoid government losses (26). FmHA is required to restructure a severely delinquent loan if the cost to restructure is less than foreclosure action. Loan rescheduling can include reamortization, lower interest rates and deferral of payments, and debt reduction or ‘‘write-down, ’ which includes debt reduction through conservation easements. An easement is a 50-year contract between a landowner and an outside party to restrict the type and extent of development that may take place on the property, with the landowner retaining title. FmHA easements may be used for conservation, recreation, and wildlife purposes. However, FmHA has not used the conservation easement option to its potential. A portion of the farmers who still face foreclosure after all other loan servicing and debt restructuring options might be able to save their farms with an easement (42).

POLICY ISSUE: Some Farm Credit Mechanisms May Be Generally Under-Used and Could Provide Innovative Mechanisms To Protect Hydro - geologically Vulnerable Areas

Given the problems associated with attempting to protect groundwater solely through changes in commodity or conservation programs, other mechanisms may be more appropriate to protect severely affected areas. An alternative mechanism, for example, would be the use of farmland easements (195). Property easements involve a transfer of certain use rights of private property, yet allow owner retention of title to the land; easements may be based on conservation or other values. The earliest government-sponsored long-term conservation easements were established in the 1930s and 1940s to protect scenic views and wetlands, and have been a major component of certain private-sector conservation groups (e.g., Nature Conservancy, American Farmland Trust). The primary benefits of using conservation easements to restrict certain uses of farmland are: 1) easements are less transitory than zoning ordinances and other land-use controls, and 2) they have only a modest impact on government revenues (largely through tax credits).

Congress first enacted benefits for the gifts of “less than fee” interests in land in 1964 (195). Benefits derived from a longstanding precedent for using tax policy ‘‘to further non-revenue national objectives’ (87).[6] The Federal Government established rewards for land donations to qualified private-sector organizations capable of protecting the easement in perpetuity with a tax deduction worth the value of the property rights surrendered, and by conferring significant estate tax benefits on conservation easement donors and their heirs. However, tax reform diluted the incentive for easements: the appreciated value of a donated easement is no longer tax deductible.

Options: Authorize Alternative Mechanisms To Protect Groundwater Resources

Congress could authorize tax deductions for farmland easements for groundwater protection purposes. Section 170(h) of the tax code could be

[6] Tax policy is another potential avenue of influencing landowner, farmer, and agricultural investor decisions related to agrichemical use and agricultural management systems. For further information, see Ward, Benfield, and Kinsinger (195).

changed to complement the CRP. Such a reform could allow persons enrolling hydrogeologically vulnerable land in the CRP to obtain a charitable tax deduction provided they donate a permanent agrichemical-control easement on the affected property.

Current Federal government-sponsored farmland easements are conducted largely through restructuring FmHA loans. Section 1318 of the 1985 Food Security Act allowed FmHA borrowers to exchange conservation easements for partial debt forgiveness, but FmHA has yet to take any conservation easement for such purposes (195). A recent FmHA rule proposal would elevate conservation easements to a "primary loan service program" and FmHA would accept easements on wetlands, highly erodible lands, and certain "uplands" with "environmental significance." If a farmer could put hydrogeologically vulnerable land into an easement and be allowed to deduct the difference between the field's market value as cropland and its value under a less chemically intensive management regime, this might lend economic stability to rural communities as well as assist in surplus reduction.

Congress could expand acceptability criteria for conservation easements. Congress could implement more authority for conservation easements to satisfy farm debts, using soil, wetland, and groundwater vulnerability criteria for easement acceptability. State and private-sector programs also might be encouraged to purchase development rights or conservation easements. State and local governments already have established programs to purchase easements requiring the retention of farmland in agriculture. For example, the RIM (Minnesota) gives direct payments in exchange for either a 20-year or permanent development easement. Such programs also could be reoriented to include establishment of easements on hydrogeologically vulnerable lands. Partial easements might require the sealing of contaminated agricultural drainage wells, changes in tillage or irrigation practices, or reduced chemical use.

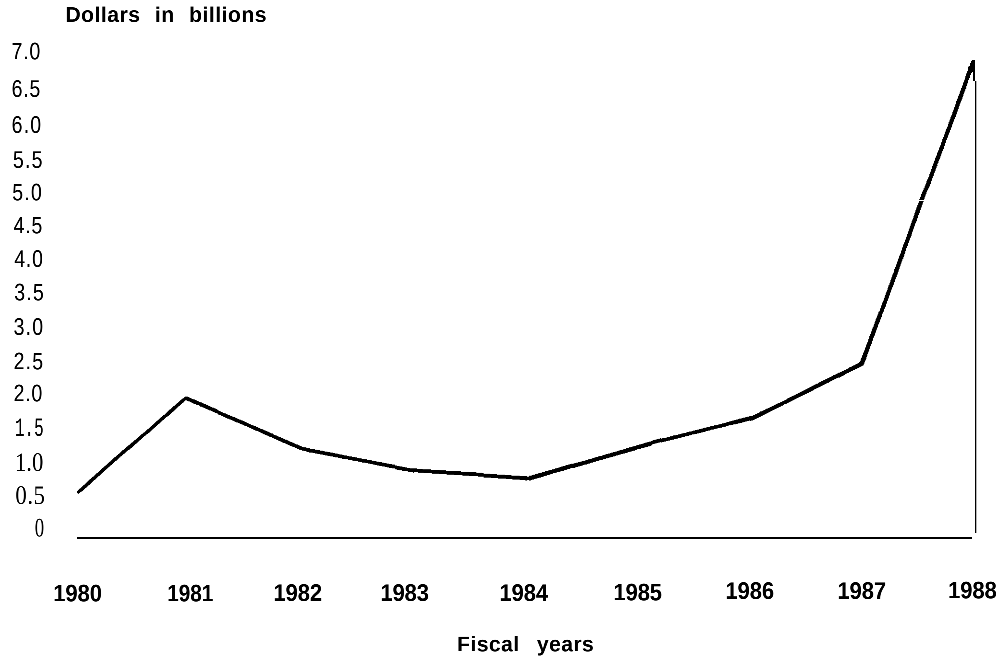
Congress could authorize grants to State and local governments for purchase of conservation easements. The Land and Water Conservation Fund (the primary mechanism for funding Federal acquisition of parks, forests, refuges, and recreation areas) also has a State grants component that provides funding for expansion and enhancement of State and local land preservation programs (137). This program, or an analog, could be used to provide grants to State and local governments for purchase of conservation easements.

Disaster Assistance—Disaster assistance provided to farmers by USDA takes the form of: 1) direct payments, 2) emergency loans, and 3) crop insurance. Although provisions vary among the programs, most provide cash to disaster victims in the event of natural disaster (see figure 6-6). The direct payment program has replaced the Disaster Assistance Payment Program that was phased out in the early 1980s; its most recent use was in response to the 1988 drought emergency (43). As of March 1989, certain aspects of the program covered 472 crops and livestock.

The emergency loan program is conducted through FmHA and provides loans at subsidized interest rates to producers sustaining a crop or livestock loss as a result of natural disaster. Loans are made in disaster areas specifically declared by the President, Secretary of Agriculture, or the FmHA Administrator. A minimum of 30 percent loss of the normal annual production must be sustained by the producer in order to be eligible for an emergency loan. The original intent was to subsidize growers' return to farming operations after a disaster, however, the program has been modified to extend loans for operation expansion. Physical loss loans are also available under this program to cover damage or destruction of property essential to farm operations. It is estimated that nearly 80 percent of emergency loans are for production loss and the remainder are for physical losses (157).

Under the crop insurance program, farmers can purchase subsidized crop insurance for most commodities through the Federal Crop Insurance Corporation (FCIC) (155). With the insurance, a farmer with crop loss is guaranteed payment for a certain amount of his production per acre, ranging from 50 to 75 percent coverage. Farmer participation in Federal crop insurance programs has been generally low, however, averaging at about 25 percent of all eligible acreage in 1987. Participation rates vary widely by crop, ranging from O to 60 percent, with participation typically lower with low-risk crops and in low-risk areas (155). Reasons for low participation include poor program marketing, high premium costs, self-insurance of farmers, and farmers' conviction that the Federal government will come to the rescue anyway in disaster situations (155). However,

Figure 6-6-Government Costs for Agriculture Disaster Assistance Programs



Significant Federal resources are directed towards disaster assistance to agricultureal producers. Low participation in crop insurance programs has been attributed to the availability of Federal disaster assistance programs that provide direct cash payments for agricultural losses.

SOURCE: U.S. Congress, General Accounting Office, *Disaster Assistance: Crop Insurance Can Provide Assistance More Effective/y Than Other Programs,* **Report to the Chairman, Committee on Agriuclture, U.S. House of Representatives, GAO-RCED-89-211, September 1989.**

farmers argue that coverage is too costly and inadequate and private insurance companies serving as marketing agents for the FmHA add that required paperwork is too complex (29).

The most recent crop insurance legislation, the Federal Crop Insurance Act of 1980, allows the FCIC to employ a variety of private insurance agencies and farm cooperatives in its attempts to publicize and sell crop insurance. This Act was intended to phase out and eventually replace the Disaster Payments Provisions established in the Agricultural Act of 1949, which provide government insurance against yield losses due to drought, flood, hail, wind, frost, fire, excessive rain, insect infestation, plant disease, and other ''unavoidable causes' (2).

POLICY ISSUE: Crop Insurance and Disaster Assistance Programs May Encourage Agrichemical-Intensive Practices in Hydrogeologically Vulnerable Areas

Prior to 1980, USDA disaster assistance was conducted primarily through cash payments totalling nearly $436 million annually between 1974 and 1980 (157). Consequently, the direct payment program was criticized for being costly and encouraging production of crops in unsuitable areas. Thus, Congress expanded the scope and availability of crop insurance in an effort to reduce the need for disaster assistance programs. However, provision of disaster assistance through direct payments and emergency loans continued through the 1980s. Experts and farmer groups attributed the low participation in crop insurance programs to the availability of Federal disaster assistance that provides direct cash payments to producers at no cost and thus send the message that crop insurance is unnecessary.

From 1980-88, USDA provided nearly $17.6 billion to support all three disaster assistance programs (direct assistance $6.9 billion; emergency loans $6.4 billion; and crop insurance $4.3 billion). Annual increases are noted under each program (157). Clearly, significant Federal resources are directed towards disaster assistance to agricultural producers and thus may offer a potential mechanism for affecting or modifying agricultural practices.

Option: Cross-Compliance in Risk-Reduction Programs

Congress could restrict crop insurance subsidies and disaster payments to those farmers who have approved nutrient and pesticide management plans. This approach would essentially create a cross-compliance situation, linking disaster payments with implementation of approved agrichemical management plans. Effectiveness of such an action would depend on producers believing that lack of compliance would in fact result in ineligibility for Federal assistance. Strong congressional sentiment that farmers should buy crop insurance to be eligible for other Federal programs may offer some potential for convincing producers that their behavior may in fact affect eligibility for Federal assistance (29). For example, legislation was passed in 1988 that required farmers to purchase crop insurance in order to be eligible for drought emergency assistance payments. The Chairman of the House Committee on Agriculture stated in response to the 1988 drought relief measure that: "Given the budget situation, the only thing riskier than betting on the weather is betting on the Federal Government to come to the rescue again. " However, it may appear that undue hardship or penalty is being placed on the part of producers, particularly since production or physical losses are incurred as the result of natural disaster and not personal mismanagement.

Option: Liability Insurance for Groundwater Contamination

Congress could provide liability insurance for groundwater contamination for farmers with approved nutrient and pesticide management plans. Liability for agrichemical contamination of groundwater has been established by several States (e.g., Connecticut, California). Liability insurance for agrichemical contamination of groundwater could be provided through various farm credit mechanisms (FCS, FmHA, FCIC) for producers in States where liability statutes are in place.

Marketing Orders—Marketing orders were originally authorized in the Agricultural Marketing Agreement Act of 1937 with the purpose of regulating the "handling" of agricultural commodities in interstate and foreign commerce to ensure that consumers receive "an adequate supply of a commodity at stable prices' (41). They are primarily used for fruit, nut, vegetable and milk production. The government sanctioned farmers in such regions to form cartels that set controls on the amount and quality of products that may be imported to these regions, thus enhancing local production of these commodities.

For example, although transportation technologies now enable marketing of Wisconsin dairy products in Southern Florida at competitive prices with local producers, marketing orders still restrict importation of products from outside the area (cf: 41). The two largest dairy farms in the United States are located near the Okeechobee (Taylor Creek-Nubbin Slough watershed) in Florida, a resource that is currently threatened by phosphorus inputs. These dairies cover nearly 14,000 acres with 9,000 head (0.642 cows per acre); the phosphorous output may lead to hyper-eutrophication of the lake and eliminate its usefulness as a source of drinking water, recreation, and wildlife habitat (96). Thus, it has been suggested that such marketing orders may in fact contribute to commodity production in unsuitable areas (41).

POLICY ISSUE: Obsolete Marketing Order Programs May Encourage Inappropriate Agricultural Production in Hydrogeologically Sensitive Areas

Obsolete marketing orders may encourage or protect agricultural production in regions where it otherwise might not be economically viable. Further, agricultural production of crops in regions not suited to them commonly requires greater external inputs, most commonly agrichemical, to create conditions conducive to production. In some of these areas, potential adverse impacts on surface- and groundwater resources then may be a significant concern.

Option: Review Marketing Orders

Congress could direct USDA to conduct a review of marketing order programs for possible contributions to groundwater quality degradation. Based on such a review, regions where extant marketing orders may pose a risk to the environment could be evaluated for alternatives to continuing the marketing order or development of alternatives to current production practices. Elimination of marketing orders that seem to promote production in unsuitable regions is one option. However, this approach offers no assurance that producers might not simply begin producing a commodity that may generate equally adverse environmental impacts (e.g., exit dairy and enter sugar production). Alternately, the programs could be revised to include an environmental component, one requiring participating producers in sensitive areas to implement production practices designed to reduce potential for agrichemical contamination of surface- and groundwater.

Factors Hindering Effectiveness of Minor Changes in Farm Programs

Some farm program modifications, such as increasing cropping flexibility under commodity programs, can remove disincentives to the adoption of crop rotations and reduce the need for intensive agrichemcial use. Other farm program modifications, such as expansion of cross-compliance to include improved nutrient and pesticide management practices, would also provide incentives to encourage more efficient and judicious agrichemical use, However, fundamental conflicts inherent in farm programs and general agricultural policy work against the simultaneous achievement of production and resource protection objectives (21). These conflicts could impede significant progress in the development of public and private-sector capacities to protect resources in agriculture, and the resulting implementation of programs and cropping systems that integrate resource protection into agricultural production processes.

Since the 1930s, farm program modifications have represented the typical approach to resolving problems within and among agricultural production sectors, and this same approach was used in the 1985 Food Security Act in an attempt to integrate production and soil erosion control objectives. Farm programs face further modification with other environmental problems, including agrichemical contamination of groundwater and emerging ones such as atmospheric pollution by agrichemicals. One concern is that constant attempts at “fine tuning’ result in an uncoordinated set of conflicting laws and regulations that in turn create more problems requiring yet more ‘‘ fine tuning (90). If agricultural policies are to address agricultural resource degradation issues effectively over the long term, a more fundamental approach to policy reform may be needed, evaluating and addressing the following conflicts:

- conservation and production titles of the Farm Bill tend to be developed separately;
- legislation on agriculture and the environment tends to be handled by separate committees; and
- congressional hearings provide the only formal mechanism to include the public in the development of agricultural policy.

Emerging environmental issues in agriculture will confront the same inherent conflicts.

U.S. agricultural policy has been first and foremost an agricultural *production policy*, shaped by the interests of commodity producers, which has made resource conservation a voluntary, and perhaps secondary, consideration for most farmers. Agricultural policy’s production emphasis may have been appropriate in the past, because it was based on the assumption that the U.S. public expects and demands an inexpensive, consistent food supply. Recent Gallup polls suggest that this assumption of public desire for a ‘‘cheap food supply” may no longer be correct, and the U.S. public may now be willing to support higher food prices to protect the national resource base and support less-polluting farming practices. If agricultural policy is to truly include resource protection and environmental stewardship as *publicly demanded* objectives for U.S. agricultural production, integration of environmental and production objectives must involve some mechanism for deciding how the costs of resource protection efforts will be shared among farmers, government, business, and consumers. The process by which agricultural legislation is developed will thus have to be opened to wide debate.

Educating for the Future

Considering the high level of public concern about agriculture’s environmental impacts, ensuring that agricultural producers, researchers, and policymakers have sufficient knowledge of relationships between agriculture and the environment to anticipate adverse environmental impacts from practices, programs, or policies is likely to become increasingly important. Similarly, environmental scientists and policymakers will need to have increased knowledge of U.S. agriculture in order to integrate agriculture and the environment in research and policy. A firm basic education in agroecology probably would benefit both groups.

Increasing exposure to environmental sciences could help agricultural students and professionals to become more aware, knowledgeable, and skilled in addressing environmental problems. However, several constraints exist to the strengthening of environmental studies components in agriculture and natural resource school (ANR) curricula. United States educational policies give primary responsibility for education to the States, despite continued calls for increased Federal attention to education. The secondary role of the Federal Government in education makes it difficult to promote widespread curricular changes among the broad range of programs found at different institutions.

POLICY ISSUE: Integrating Agriculture and Environment in Education

Curricular change is difficult because the professional and college reward systems tend to emphasize research over teaching. Individual efforts to develop course and curriculum materials take considerable time and effort. However, scholarly efforts aimed at course and curriculum renewal seldom are rewarded, especially at the larger institutions (93,88). Many faculty, particularly those in the land-grant system, have the majority of their salary support for research, rather than teaching. Finally, little funding in general is available for college program modification activities; one exception is private grant tiding, such as the Kellogg Foundation grants for agricultural curriculum renewal at the University of Minnesota (105) and University of Wisconsin (89).

Another means of encouraging students and graduates to achieve specific environmental knowledge and skills is through certification programs established by professional societies, such as the American Registry of Certified Professionals in Agronomy, Crops, and Soils (ARCPACs). Some States (e.g., Indiana) have approved ARCPACs certification programs and standards to be used in certifying agricultural professionals (138).

Other methods of encouraging understanding of agriculture and the environment are provided through Federal programs to expose teachers and students to agricultural research or to Federal agency functions. For example the USDA Agricultural Research Service conducts the Teachers Research Fellowship, providing temporary employment for secondary school science teachers in agricultural research projects. The Research Apprenticeship program offers the same opportunities to high school students. Cooperative Education provides part-time work with ARS to high school through graduate program students during school vacations. More broadly, the Federal Junior Fellowship Program encourages high school students to work with a variety of Federal agencies. These and similar programs could be oriented toward giving future producers, educators, researchers, and policymakers a basis from which to consider the integration of agriculture and the environment.

Option: Review U.S. Education System for Ability To Provide Agricultural/Environmental Expertise

Congress could require the USDA Office of Higher Education, jointly with the Department of Education, to conduct an evaluation of the U.S. education system to determine its capacity to provide graduates who are adequately trained in agricultural and environmental sciences to address national needs in environmental research, pollution control, and technology development in agriculture. Such an evaluation, however, would be difficult to do for several reasons. First, the environmental sciences encompass a broad group of disciplines and professions, ranging from ecology to atmospheric sciences to wastewater treatment. No clear definitions exist for the environmental sciences in general, nor for agricultural **courses covering** environmental impacts specifically. Specific definitions and classification of training programs by objective and content would aid in assessment programs.

Second, organization, degree programs, and instructional requirements are determined within each institution and vary considerably from college to college. Currently, agricultural students in ANR colleges are educated primarily to address problems and concerns in agricultural science, production, and business. Although most land-grant colleges offer environmental studies courses as electives, few require agricultural science students to take these courses (105). Many agricultural science courses incorporate material on environmental impacts, but no standard criteria exist for the amounts and types of environmental information to be included in these courses.

Finally, the USDA Office of Higher Education at present does not have the resources to conduct such an evaluation, and the Department of Education conducts few programs related to environmental education relative to other programs. Thus, Congress could request such an evaluation from a congressional research agency, or from a special commission established for that purpose.

THE BOTTOM LINE: QUESTIONS FOR CONGRESS

Given the: 1) level of public controversy (based on public interest in agricultural development and in environmental quality), 2) levels of uncertainty related to agrichemical contamination of groundwater (on the problem, the causes, and the potential solutions), and 3) existence of technologies (extant and emerging) that have strong potential to reduce agrichemical contamination of groundwater, the ultimate determinant of potential policy directions depends on the answer to one question: *how will Congress choose to deal with the uncertainty and, thus, define the problem?*

What action(s) Congress opts to take to protect the Nation's groundwater from agrichemical contamination may depend as much on how it chooses to approach the problem as on the state of science and technology. For example, groundwater contamination could be viewed simply as an additional target of environmental concern (along with surface water) and extant conservation programs could be modularly expanded to include groundwater protection provisions, or to increase the priority already given to such provisions.

Groundwater contamination also could be considered an outcome of farm programs that create disincentives for farmers to protect the environment. Strategies for dealing with the problem could then involve program modifications to reduce or remove disincentives and provide incentives for conservation. However, the basic program structure would be preserved. This approach is reflected in the 1985 Food Security Act provision related to soil erosion and wetland preservation.

A broader approach than either of these is to view groundwater contamination as one of many symptoms of the need to integrate environmental protection into agricultural policy as a whole. Rather than make piecemeal efforts to address soil erosion, surface-water quality, or groundwater quality, and rather than focus on a few culpable programs, Congress could review and modify the entire agricultural policy/program structure to balance a goal of environmental protection with that of agricultural production.

This view reflects potential for a changed Federal view of the relationship between agriculture and the environment. Historically, agricultural policies and programs have placed major emphasis on increasing production. However, in the future, protecting environmental and public health could be considered as important as that of enhancing agricultural production. Choosing this approach would require reconsideration of national goals for agriculture and for environment, clarification of the Federal role in agriculture, and review of the congressional separation of agriculture and environment in committee structure. The tone is set for increased legislative and executive attention to agriculture's impact on the environment.

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Appendixes

Appendix A

Major Federal Programs and Activities Related to Water Quality and Agriculture

U.S. Department of Agriculture

1985 Food Security Act Provisions

Conservation Reserve Program (CRP) provides annual rental payments to land owners and operators who voluntarily retire highly erodible and other environmentally critical lands from production for 10 years. It also provides technical assistance and cost-sharing payments of up to 50 percent of the cost of establishing a soil-conserving cover on retired land. Rental payments to any person may not exceed $50,000 per year. County enrollment is limited to no more than 25 percent of cropland, unless USDA grants a special waiver, To date, approximately 30 million acres of cropland have been enrolled.

Conservation Compliance requires that farmers who produce agricultural commodities on highly erodible cropland have approved conservation plans by Jan. 1, 1990, and finish implementing them by Jan. 1, 1995, or lose eligibility for USDA program benefits.

Sodbuster provisions require that farmers who convert highly erodible land to agricultural commodity production do so under an approved conservation system, or forfeit eligibility for USDA program benefits,

Swampbuster provisions bar farmers who convert wetlands to agricultural commodity production from eligibility for USDA program benefits, unless USDA determines that conversion would have only a minimal effect on wetland hydrology and biology.

Continuing Assistance Programs

Agricultural Conservation Program (ACP) provides financial assistance through the Agricultural Stabilization and Conservation Service (ASCS) to farmers for implementing approved soil and water conservation and pollution abatement practices. Cost-sharing payments to a given farmer may not exceed $3,500 per year on 1-year agreements, and may not average over $3,500 per year on multi-year agreements, Except for Water Quality Special Projects, conservation priorities are set by States and counties based on local soil and water quality problems. Program initiated in 1936. ASCS also administers the Integrated Crop Management (ICM) program, a pilot ACP project to improve agrichemical management through cost-share assistance for crop advisory and soil testing services. Program initiated in 1990.

Conservation Technical Assistance (CTA) provides technical assistance by the Soil Conservation Service (SCS) through Conservation Districts to farmers for planning and implementing soil and water conservation and water quality improvement practices. Program initiated in 1936.

Great Plains Conservation Program (GPCP) provides technical and financial assistance in Great Plains States to farmers and ranchers who implement total conservation treatment of their entire operation. Cost-sharing assistance is limited to $35,000 per farmer contract. Program initiated in 1957.

Small Watershed Program provides Federal technical and financial help to local organizations for flood prevention, watershed protection, and water management. Program initiated in 1954.

Resource Conservation and Development Program assists multicounty areas to enhance conservation, water quality, wildlife habitat and recreation, and rural development. Program initiated in 1962.

Emergency Conservation Program provides financial assistance to farmers in rehabilitating cropland damaged by natural disasters. Program initiated in 1978.

Rural Clean Water Program is an experimental program implemented in 21 selected projects. It provides cost-sharing and technical assistance to farmers voluntarily implementing best management practices to improve water quality. Cost-sharing is limited to $50,000 per farm. Program initiated in 1980; ends in 1995.

Forestry Incentives Program provides cost-sharing of up to 65 percent for tree planning and timber stand improvement for private forest lands of 1,000 acres or less.

Water Bank Program provides annual payments for preserving wetlands in important migratory waterfowl nesting, breeding, or feeding areas. program initiated in 1970.

Extension Service provides information and recommendations on soil and water quality practices to land owners and operators, in cooperation with SCS and Conservation Districts.

Farmers Home Administration provides loans to farmers and associations of farmers for soil and water conservation, pollution abatement, and building or improving water systems that serve several farms. It may acquire 50-year conservation easements to help farmers reduce loan payments.

National Agriculture Library collects and distributes information on all aspects of U.S. agriculture, and has received special funding to develop a new information program on agriculture and water quality.

Research Programs

Agricultural Research Service conducts research on new and alternative crops and agricultural technology to reduce agriculture's adverse impacts on soil and water.

Cooperative State Research Service coordinates conservation and water quality research conducted by State Agricultural Experiment Stations and land-grant universities. This agency allocates and administers funds appropriated for special and competitive grants for water quality research.

Economic Research Service estimates economic impacts of existing and alternative policies, programs, and technology for preserving and improving soil and water quality. With National Agricultural Statistics Service, collects data on farm chemical use, agricultural practices, and costs and returns.

Forest Service conducts research on environmental and economic impacts of alternative forest management policies, programs, and practices.

Environmental Protection Agency

FIFRA Pesticide Programs

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) gives EPA responsibilities for registering new pesticides and for reviewing and re-registering existing pesticides to ensure that, when used according to label directions, they will not present unreasonable risks to human health or the environment. Under FIFRA provisions, EPA may restrict or cancel use of any pesticide determined to be a potential hazard to human health or the environment.

National Survey of Pesticides in Drinking Water Wells

The National Survey is underway to determine the presence and concentration of 127 commonly used agricultural chemicals in 1,350 statistically selected wells in all States. Water samples were analyzed and questionnaires filled out by well owners, operators, and local area experts on well construction and locale, and cropping and pesticide use patterns. EPA expects to issue a draft report on the survey in early 1991.

Safe Drinking Water Act Programs

The Safe Drinking Water Act (SDWA) requires EPA to publish *maximum contaminant levels* (MCLs) for any contaminants, including pesticides, which may have adverse health effects in public water systems (those serving over 25 persons or with 15 connections). Standards established by EPA under the SDWA are also being used as guidelines to assess contamination of ground water in private wells. The EPA also sets nonregulatory health advisory levels on contaminants for which MCLs have not been established.

The SDWA also established a *Wellhead Protection Program* to protect wells and wellfields that contribute drinking water to public supply systems. Each State must prepare and submit to EPA a Wellhead Protection program delineating the recharge areas around public water, identifying potential sources of groundwater contamination within these areas, and addressing identified potential sources to protect the public water supply. Although funds have been appropriated for the WHP Program, the EPA Administrator testified to the Senate that only 30 States have submitted proposed programs for review and approval by EPA.

1987 Water Quality Act Nonpoint Programs

Section 319 of the Act requires States and Territories to file assessment reports with EPA identifying navigable waters where water quality standards cannot be attained or maintained without reducing nonpoint source pollution. States must also file management programs with EPA identifying steps which will be taken to reduce nonpoint pollution in those waters identified in the State assessment reports. The Act authorizes up to $400 million total in Federal funding for implementing the programs. To date, 43 States and Territories have submitted nonpoint-source pollution assessments to EPA, and 36 have submitted final management programs.

1987 Water Quality Act Clean Lakes Program

Section 314 of the Act requires States to submit assessment reports on the status and trends of lake water quality, including the nature and extent of pollution loading from point and nonpoint sources. Also, methods to control pollution and to protect/restore the quality of lakes impaired or threatened by pollution must be described.

Financial assistance is given to States to prepare assessment reports and to implement watershed improvements, as well as to conduct in-lake restoration activities. Several USDA small watershed projects (PL-566) have been coordinated with Clean Lakes projects.

1987 Water Quality Act National Estuary Program

Section 320 of the Act provides for identification of nationally significant estuaries threatened by pollution, preparation of conservation and management plans, and Federal grants to prepare the plans. Twelve major estuaries have planning underway.

Near Coastal Waters Strategy

Through its Near Coastal Waters Strategy, EPA is integrating its water quality programs to target priority programs and prevent pollution in near coastal waters. This includes the implementation of nonpoint source management programs in coastal counties and will, in several cases, encompass accelerated implementation of agricultural conservation programs.

Regional Water Quality Programs

The EPA and other Federal agencies are cooperating on several regional programs to reduce nonpoint source pollution, including the Chesapeake Bay Program, the Colorado River Salinity Control program, the Great Lakes Program, the Gulf' of Mexico Program, and the Land and Water 201 Program in the Tennessee Valley Region.

U.S. Geological Survey

The U.S. Geological Survey is engaged in a broad array of information collection, information management, and research projects pertinent to groundwater management and protection.

Coordination and Dissemination of Federal Information on Groundwater

The USGS releases a comprehensive report on water resources annually: the National Water Summary, This report includes comprehensive documentation on water resource quantity and quality for each State, and includes case studies of nonpoint source contamination. It also summarizes studies on managing and coordinating Federal and State water protection efforts. USGS also maintains a computerized National Water Storage and Retrieval System (WATSTORE) and a computer-based National Water Data Exchange (NAWDEX).

National Water Quality Assessment Program

Since 1986 the NAWQA program has conducted assessments of national and regional status of groundwater resources and monitors trends in factors that can affect groundwater quality. Agrichemical nonpoint source contamination problems are under study in seven pilot projects.

Regional Aquifer Systems Analysis Program

The RASA program was established in 1978 to gather data on the quantity of water resources available in the nation's aquifers. RASA's objectives for each aquifer system study are to determine the availability and chemical quality of stored water and discharge-recharge characteristics, and to develop computer simulation models that may assist in understanding the groundwater flow regime and changes brought about by human activities. Twenty-eight aquifer systems have been identified for study; fourteen of which have been completed.

Federal-State Cooperative Program

USGS supports local efforts to collect data on ground and surface waters through cost-sharing arrangements with State and local governments. For example, USGS has provided support for mapping State aquifers, for monitoring pesticide contamination problems, and has assisted in developing wellhead protection programs.

Toxic Substances Hydrology Program

Under the TSHP, USGS conducts research on transport and fate of groundwater contaminants to develops information on means to improve waste disposal practices and mitigate contamination problems.

State Water Resources Research Institutes

Under this program USGS provides grants to 54 State and Territory Water Resources Institutes for research, information dissemination, and for training students in water resources fields. Approximately 35 percent of the Institutes' work is related to groundwater protection. Reauthorization of the Institutes has been hindered by their incorporation in broad and controversial groundwater protection bills.

Mid-Continent Initiative

USGS also is working in cooperation with the USDA's Midwest Initiative on a "Mid-Continent Initiative, " a 5-to 10-year research program characterizing the environmental fate of the widely-used agricultural herbicide atrazine. The area under study, roughly bounded by the Upper Missouri and Ohio River Basins, was chosen largely because of the coincidence of hydrologic boundaries with a region of intensive agrichemical-use cropland.

National Fertilizer & Environmental Research Center (TVA)

NFERC adopted a new mission along with a new name in 1990 (originally it was titled the National Fertilizer Development Center). Over its nearly 60 year history, the Center has served as a national laboratory for fertilizer research and demonstration. As many as 75 percent of fertilizer formulations and manufacturing processes used today are based on technology originating at the Center. The new mission expands NFERC's national role in agriculturally related environmental issues.

Fertilizer and other Agricultural Chemicals

Research, development, and commercialization of improved fertilizer technologies and agronomic research on nutrient use efficiency will continue to be a core effort for NFERC. However, a new emphasis has been placed on environmental protection in development and management. For example, research on fertilizer interrelationships with other agricultural chemicals is planned.

Renewable Fuel and Chemical Technologies

Biotechnology and bioconversion technology research is planned for production of ethanol and other chemicals from cellulose and agricultural waste materials.

Environmental/Waste Management

Initial efforts will be aimed at helping fertilizer dealers meet environmental regulations. Research, development, and demonstration will focus on degradation of pesticides and other contaminants, recycling and reuse of agricultural and other wastes, and related technologies. For example, NFERC is exploring the use of constructed wetlands to treat chemical wastes from fertilizer dealerships.

Education and Demonstration

NFERC is closely allied with the fertilizer manufacturing industry and dealers through its National Field Program, and with agricultural universities and other organizations through its Test-Demonstration Program. The programs are supervised by area directors distributed throughout the continental States, who work with cooperating dealers and distributors in planning fertilizer introduction, providing information on use, and supplying technical assistance (e.g., computer software to help dealers offer least-cost formulations and match fertilizer treatments with soil test recommendations). NFERC personnel also conduct Improved Management Practices for Dealers and Site Remediation projects for small fertilizer dealerships across the country. In addition, NFERC personnel participate in State fertilizer education programs, and conduct regional and national seminars and demonstrations.

Selected State Programs

States increasingly are enacting innovative and sometimes stringent environmental laws. These are 'having an indirect impact on Federal policy as States put pressure on the Federal Government to take similar action or as industry goes to Congress in search of uniform Federal laws to replace the patchwork of conflicting State requirements."[1]

Ground Water Quality Protection Programs

Twenty-two States have developed comprehensive programs to protect or improve groundwater quality. Most include one or more common program elements: 1) classification, assessment, and mapping of groundwater sources; 2) groundwater quality standards, 3) groundwater quality monitoring; 4) control of farming practices; 5) control of land uses; 6) economic incentives; and 7) education programs. Specific examples include:

- *Iowa's Ground Water Protection* uses pesticide registration fees and fertilizer taxes to finance sustainable agriculture research and demonstration activities.
- *Massachusetts Wellhead Protection Program* established land use control and restricts pesticide use in critical recharge areas around wells; and
- *Wisconsin's Risk Assessment Program* based on numerical groundwater standards.

Best Management Practices (USDA/ERS)

Thirty-six States provide financial or regulatory incentives for installing and maintaining best management practices (BMPs) to promote soil conservation and protect surface water quality.

- *Financial incentives* include: cost-sharing programs (26 States); income or property tax credits or deductions (7 States), no- or low-interest loans (5 States); and purchasing conservation easements or development rights in agricultural lands (3 States).
- *Approved plans or permits* for activities that could cause soil erosion or pollution discharges into waterways, or compliance with established permissible soil-loss limits are required in 17 States. Ten States give farmers cost-sharing assistance specifically to help them meet the requirements.

Innovative State Financing Mechanisms

States will face competing demands for funding of groundwater, drinking water, and surface water programs in the coming decade, potentially requiring many to develop alternative funding mechanisms. Some States already have created innovative financing mechanisms, including: 1) user and impact development fees; 2) dedicated tax revenue; 3) State revolving loan funds; and 4) special water quality districts and utilities.

- *Iowa's Groundwater Protection Fund*, established under the 1987 Groundwater Protection Act, is capitalized by user and producer fees on pesticides, fertilizers, and other products contributing to nonpoint source pollution.
- The *Minnesota Environmental Trust Fund* is capitalized with one-half of the proceeds from the State lottery. The fund is expected to reach $100 to $200 million by the end of 1993.
- A *Washington State sales tax on cigarettes* at $0.08 per pack finances water pollution control programs. Half of the funds are designated for wastewater treatment; 20 percent for groundwater protection; and 10 percent each for nonpoint source pollution, lake management, and discretionary purposes.

[1] M.E. Kriz, "Ahead of the Feds," *National Journal*, Dec. 19, 1989, pp 2989-2993.

Appendix B
List of Acronyms

ACP	—Agricultural Conservation Program
ACS	—Agricultural Cooperative Service, USDA
AFM	—Alternative Financing Mechanisms
ARS	—Agricultural Research Service, USDA
ASCS	—Agricultural Stabilization and Conservation Service, USDA
BMP	—Best Management Practice
CES	--Cooperative Extension Service
CMA	--Crop Management Association
CRIS	-Current Research Information System
CRP	-Conservation Reserve Program
CSRS	-Cooperative State Research Service, USDA
DOA	—Department of Agriculture
DOC	—U.S. Department of Commerce
EPA	—U.S. Environmental Protection Agency
ERS	—Economic Research Service, USDA
ES	—Extension Service, USDA
FmHA	—Farmers Home Administration
GAO	--General Accounting Office
GIS	-Geographic Information System
ICM	—Integrated Crop Management
IPM	—Integrated Pest Management
LISA	—Low-Input Sustainable Agriculture program
NFERC	—National Fertilizer & Environmental Research Center, TVA
NOAA	—National Oceanic and Atmospheric Administration, DOC
OMB	-Office of Management and Budget
OTA	---Office of Technology Assessment, U.S. Congress
RAES	—Regional Agroecosystem Experiment Station
RASA	—Regional Aquifer System Analysis
RCD	—Resource Conservation District
RMS	—Resource Management System
RUP	—Restricted Use Pesticide
SAES	-State Agricultural Experiment Station
SCS	-Soil Conservation Service, USDA
SWCD	-Soil and Water Conservation District
TIG	—Technical Integration Group
TVA	—Tennessee Valley Authority
USDA	—U.S. Department of Agriculture
USGS	—U.S. Geological Survey

Appendix C[1]

Commissioned Papers

Overviews

Primer on Hydrogeology
Susan J. Wintsch
Clay Minerals Society
Bloomington, IN

Introductory Overview
Stuart Z. Cohen
Biospherics, Inc.
Beltsville, MD

Strategies To Reduce Pesticide and Nutrient Contamination of Groundwater

Farmstead Assessments: A Means To Manage Farm Sources of Groundwater Contamination of Groundwater
Gary Jackson
Bruce Webendorfer
Susan A. Jones
University of Wisconsin
Madison, WI

Improving Pesticide Management Practices
Franklin Hall
Ohio State University
Wooster, OH

Integrated Pest Management: Potential for Reducing Agrichemical Contamination of Groundwater
Frank G. Zalom
Michael Stimman
Janet Smilanick
University of California Statewide IPM Project
Davis, CA

Legumes as a Nitrogen Source: Implications for Nitrate Contamination of Groundwater
Gary Heichel
University of Illinois
Urbana, IL

Improving Livestock **and Poultry Management Practices To Reduce Nutrient Contamination of Groundwater**
John M. Sweeten
Texas A&M University
Lubbock, TX

Sludge, Slurry, and Compost: Management of Land Application
James A. Moore
Oregon State University
Corvallis, OR

Irrigation/Chemigation: Implications for Agrichemical Contamination of Groundwater
E. Dale Threadgill
University of Georgia
Athens, GA

Agrichemical Application Technology: Potentials To Reduce Groundwater Contamination
Maurice Gebhart
U.S. Department of Agriculture/Agricultural Research Service
Columbia, MO

Farmer Decisionmaking and Technical Assistance To Reduce Agrichemical Contamination of Groundwater

Farmers' Views on Groundwater Quality: Concerns, Practices, and Policy Preferences
Steven Padgitt
Iowa State University
Ames, IA

Farmer Adoption of Conservation Practices: Lessons for Groundwater Protection
Ted Napier
Ohio State University
Columbus, OH

Local Agricultural Information and Assistance Networks Relative to Ground Water Protection
Peter J. Nowak
University of Wisconsin
Madison, WI

Agricultural **Best** Management **Practices: Implications for Groundwater Protection**
Terry J. Logan
Ohio State University
Columbus, OH

Low-Input/Sustainable Agriculture Research and Education: A Review of Selected Private Organizations' Activities
Ron Kroese
Mary Turck
Land Stewardship Project
Marine, MN

Holistic Resource Management as a Groundwater Protection Strategy in Agriculture
Cliff Montagne
Brian W. Sindelar
Ronald R.H. Kroos
James W. Bauder
Patrick C. Jobes

[1] Microfiche or paper copies of commissioned papers may be available from the US. Department of Commerce, National Technical Information Service (NTIS), Springfield, VA 22161. In ordering, the paper author, title, assessment title, and Office of Technology Assessment should be specified.

James R. Sims
Montana State University
Bozeman, MN

Computer-Based Decision Support Systems for Farmers: Applications for Groundwater Protection

Roy Black
Bernard Knezek
Michigan State University
East Lansing, MI

The Role of Retail Fertilizer Dealers in Reducing Groundwater Contamination: A Focus on Educational Needs

Ronald J. Williams
James M. Ranson
Tennessee Valley Authority/National Fertilizer & Environmental Research Center
Muscle Shoals, AL

Extension Education for Agrichemical Dealers

Keith Kelling
Keith Wedberg
University of Wisconsin
Madison, WI

Public Influences on Agrichemical Contamination of Groundwater

Agriculture/Environment organization, Coordination, and Systems

Terry J. Nipp
National Association of State Universities and Land Grant Colleges
Washington, DC

The Federal Role in Reducing Agrichemical Contamination of Ground Water

Laura A. Dye
Private Consultant
Washington, DC

Disciplinary Integration in Agricultural Research

Harry Kunkel
Texas A&M University
College Station, TX

Systems Approaches in Agricultural Research: Applications for Groundwater Protection

A. Dale Whittaker
Texas A&M University
College Station, TX

Integrating Agriculture and Environment in Education

Richard Merritt
University of California-Davis
Davis, CA

Mapping Groundwater Vulnerability to Agricultural Uses on a National Scale in a Geographic Information System

Margaret Maizel
Kelly Chan
National Center for Resource Innovations
Washington, DC

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