Chapter 1

Summary

CONTENTS

	Page
INTRODUCTION	3
TECHNOLOGIES	6
Point-Source Controls	6
Nonpoint Sources	7
FARMER DECISIONMAKING	10
Factors Influencing Decisionmaking	10
Decisionmaking To Protect Groundwater	10
Information Sources for Decisionmaking	11
Public-Sector Financial Assistance To Improve Decisionmaking	13
Public-Sector Coordination To Improve Decisionmaking	14
TAKING A STRATEGIC APPROACH TO REDUCING AGRICHEMICAL CONTAMINATION OF GROUNDWATER	14
STRATEGY: Define and Evaluate Roles, Goals, and Relationships of Relevant Organizations	14
STRATEGY: Build the Knowledge Base To Support Improved Decisionmaking	18
STRATEGY: Redirect Federal Agricultural Programs To Remove Disincentives and Create Incentives for Groundwater Protection	19
STRATEGY: Foster a National Effort To Reduce Agrichemical Mismanagement and Waste	20
LOOKING IN THE LONGER TERM	20

Boxes

Box	Page
l-A. Definitions	3
l-B. Uncertainty and Risk	5
l-C. Hydrogeology and Agrichemical Contamination of Groundwater	6
l-D. Aspects of Agrichemical Use and Regulation Potentially Fostering Agrichemical Mismanagement	17

Figures

Figure	Page
1-1. Primary On-Farm Pathways of Agrichemical Contamination of Groundwater.	4
1-2. Potential Farmstead Point-Source Routes of Contamination	7
1-3. Sources of Information and Advice to Farmers	12
1-4. Lost Agrichemicals Are Wasted Resources	15
1-5. Major Federal, State, and Local Organizations Influencing Farmer Decisionmaking	16

Chapter 1

Summary

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

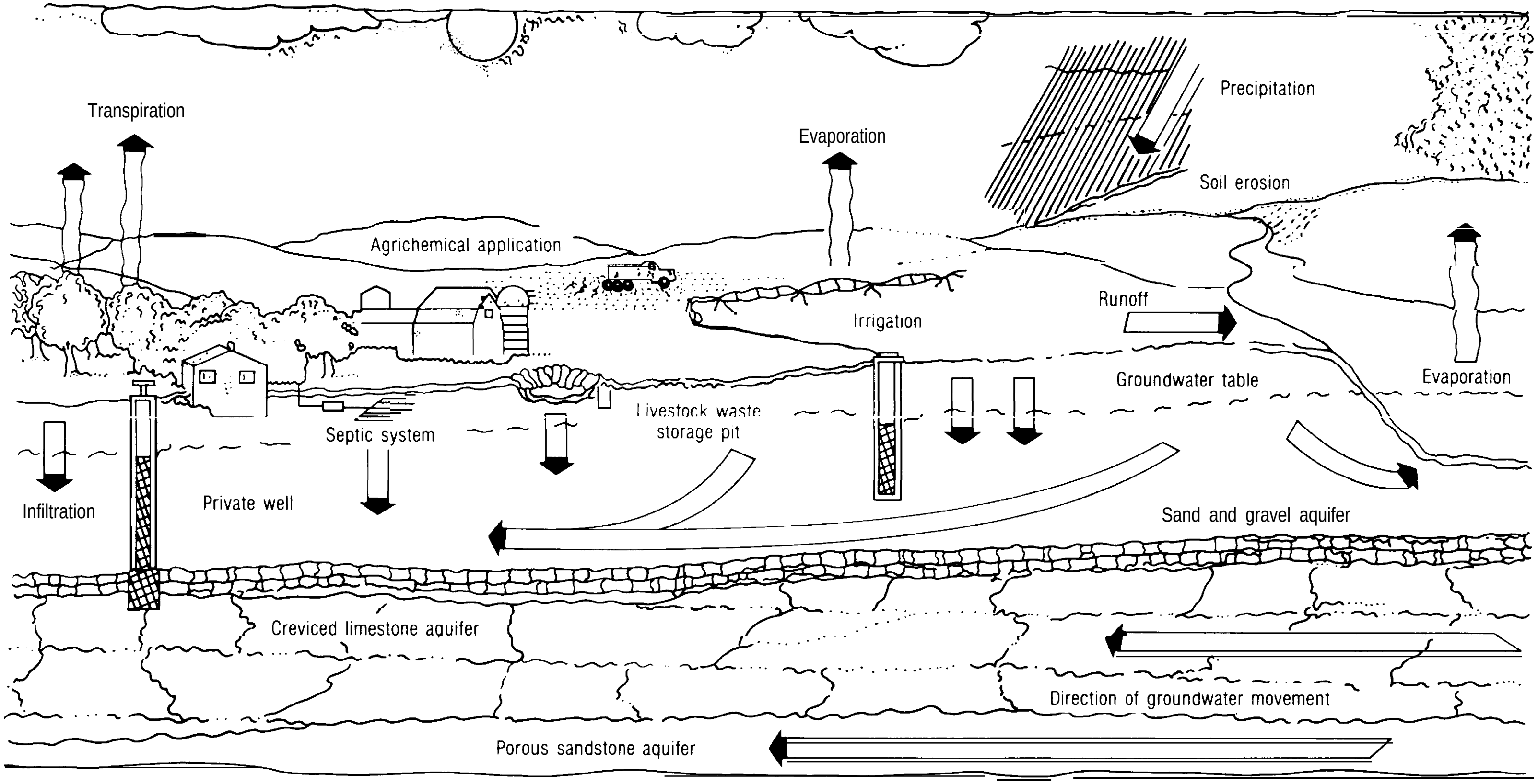
***What** is an agrichemical?* For the purposes of this assessment an agricultural chemical-agrichemical-is any chemical compound applied to an agricultural production system with intent to enhance plant productivity or prevent loss of productivity caused by disease or by pests; or produced as a byproduct 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:

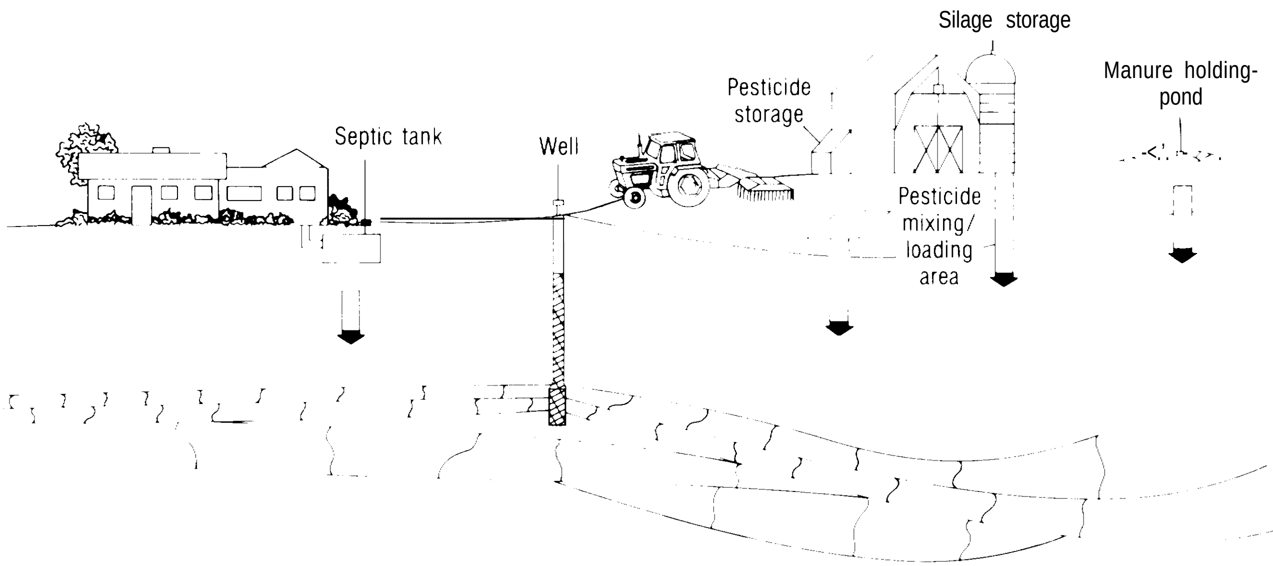
- improved agrichemical handling to reduce groundwater contamination from farmstead or dealership point sources;
- improved agrichemical efficacy and application to reduce nonpoint-source contamination;
- agrichemical use reduction; and
- incorporating nonchemical nutrient and pest management practices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

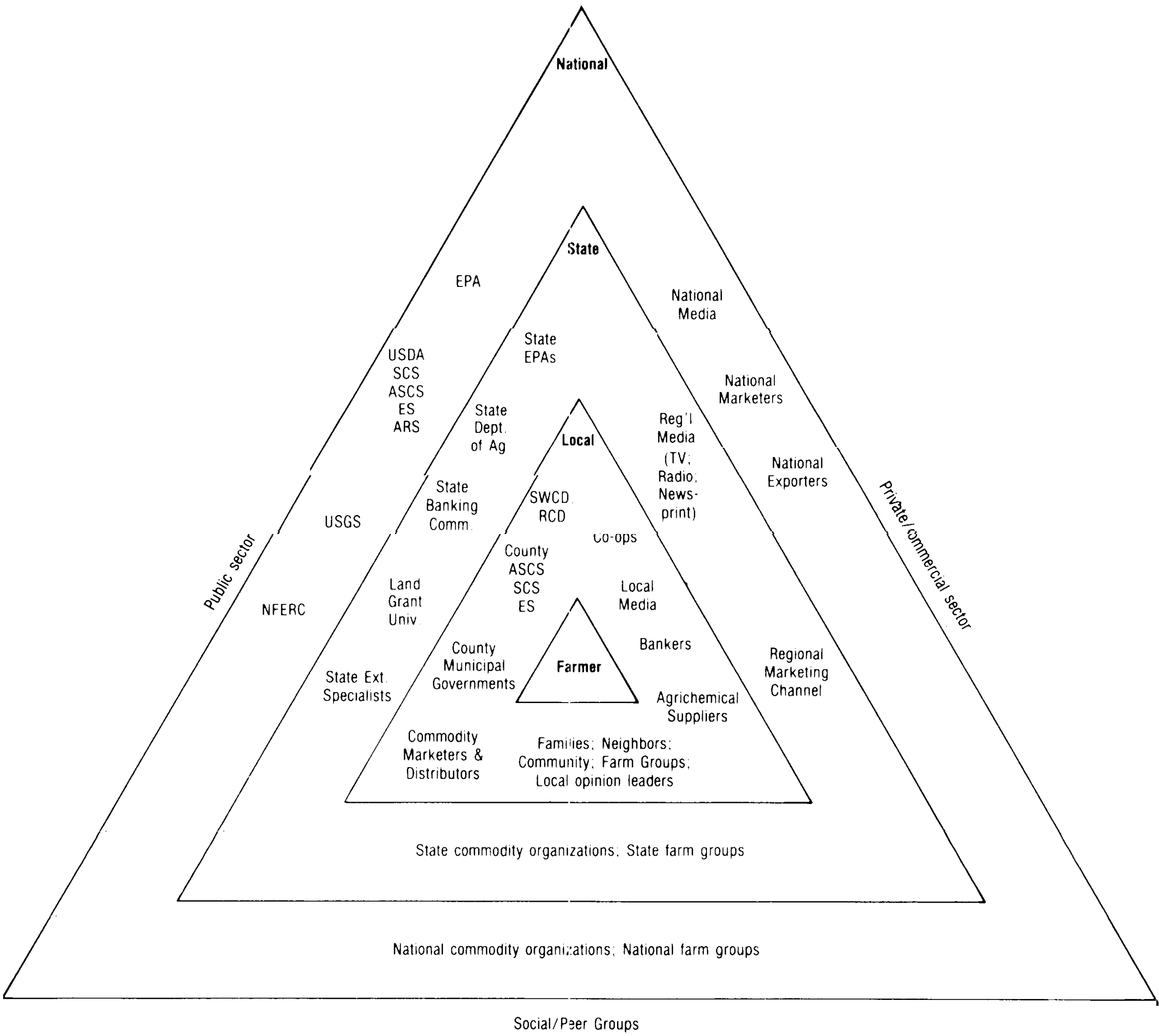
Photo credit: State of Florida ***Department of Environmental Regulation***

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?

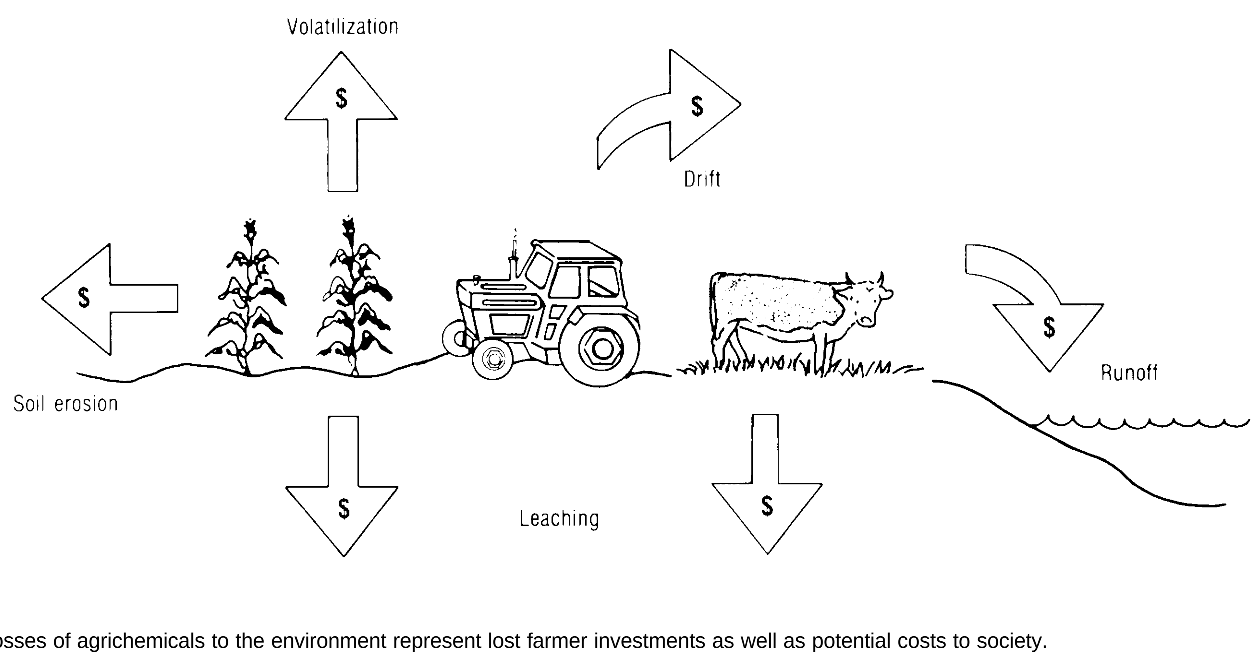
How a variety of issues relating to agriculture and the environment are handled may depend on congressional and Federal agency ability to set well-defined, achievable goals for U.S. agriculture and the environment; and on how well the roles and responsibilities of various agencies are defined in light 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 l-D).

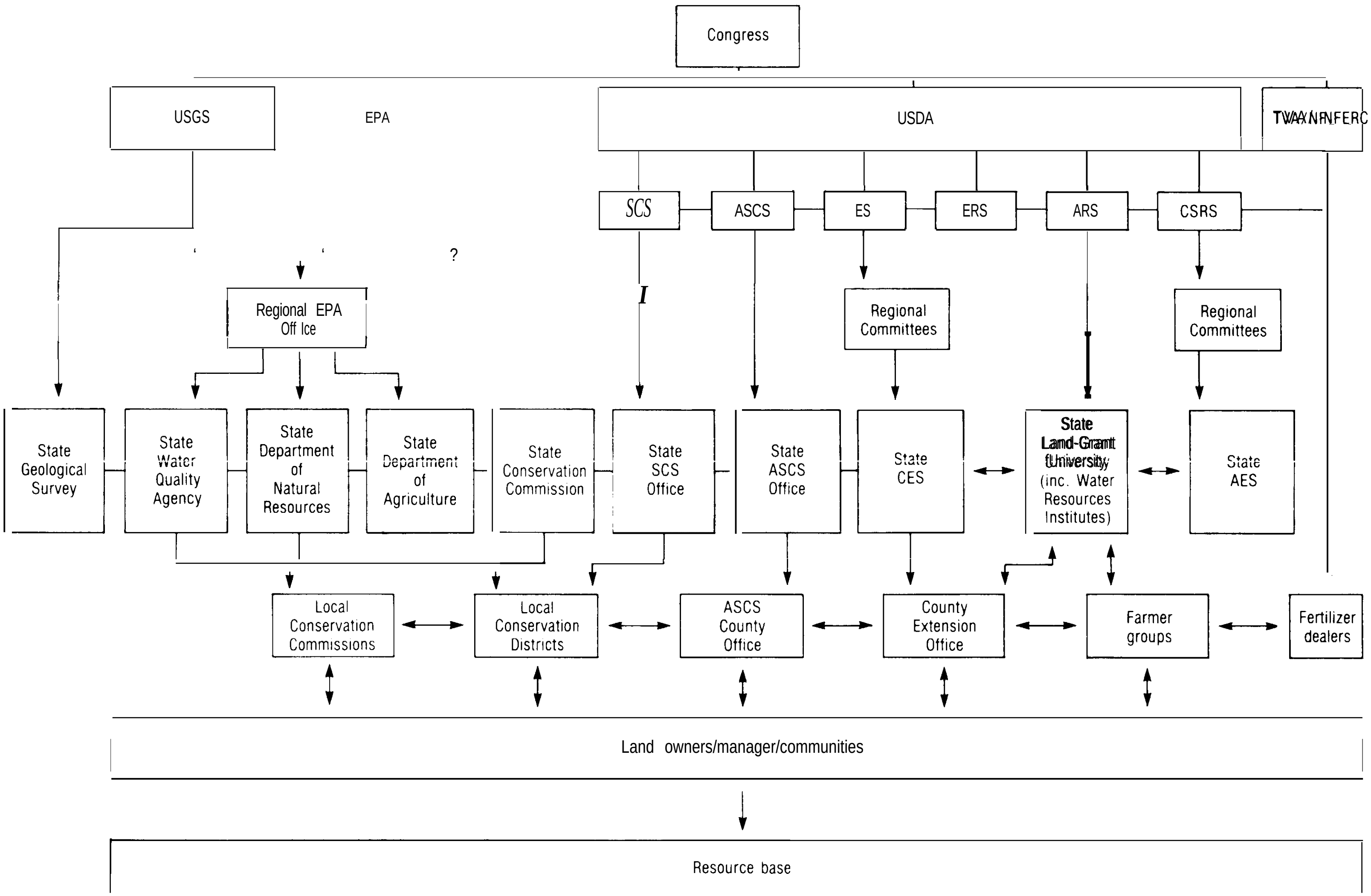
These problems could be addressed in a variety of ways. A Joint Committee or other (temporary) congressional forum could debate goals for agriculture and the environment and review Federal roles in agriculture and environmental protection. Better coordination of Federal agency activities could be realized 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.