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PROTECTING GROUND WATER: PESTICIDES AND AGRICULTURAL PRACTICES

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FOREWORD

State and local governments throughout the country are seeking to address the problem of pesticide contamination as part of their ground-water protection programs. Encouraging the sound choice and management of pesticides is generally recognized as an important element of these programs, but very little information has been readily available to aid in selecting management practices to help reduce the risk of pesticide contamination. As part of a continuing effort to provide information to officials in State and local government involved in ground-water protection, the Office of Ground-Water Protection of the U.S. Environmental Protection Agency initiated a project to identify and evaluate the potential impacts on ground water of various agronomic, irrigation, and pesticide application practices. The results of the study are presented in this report, "Protecting Ground-Water: Pesticides and Agricultural Practices."

Since site conditions, crop and pest patterns, and agricultural practices vary widely, no single set of recommendations can be developed that would be appropriate for all situations. The purpose of this report is to explain the principles involved in reducing the risk of pesticide contamination and describe what is known about the impact of various agricultural practices on pesticide leaching. With this basic understanding, it is hoped that water quality officials can work with their colleagues in the agricultural community to design and implement protection programs suited to specific conditions in their areas.

PREFACE

This report, "Protecting Ground-Water: Pesticides and Agricultural Practices," was prepared by the Office of Ground-Water Protection (OGWP), U.S. Environmental Protection Agency. Donna Fletcher, Senior Analyst, OGWP, served as the Task Manager and Project Officer. Ron Hoffer, Director, Guidelines Implementation Staff, OGWP, provided additional guidance. The project was conducted as part of a continuing effort led by Marian Mlay, Director of OGWP, and Susan Wayland, Deputy Director of the Office of Pesticide Programs, to address the problem of pesticides in ground water.

An EPA technical committee comprised of Dr. Robert Holst of the Office of Pesticide Programs, Robert Carsel of the Office of Research and Development, Carl Myers of the Office of Water Regulations and Standards, and Ken Adler of the Office of Policy Analysis provided technical support and participated in the review of preliminary drafts. Drafts were also reviewed and discussed by a panel of experts from Federal and State water quality and agricultural agencies and the industrial, academic, and environmental communities who are listed on the next page.

The report was developed with technical support from Dames & Moore under EPA Contract No. 68-03-3304. The principal contributors to the report from Dames & Moore were Surya S. Prasad, Ph.D., CPSS, CPAg, Senior Soil Scientist and Project Manager, and Robert Kalinski, Hydrogeologist.

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PART I

OVERVIEW AND OBJECTIVES OF MEASURES TO REDUCE PESTICIDE CONTAMINATION OF GROUND WATER

Part I describes the context for ground-water protection efforts addressing pesticides, the factors influencing the leaching of pesticides, and the objectives of measures to reduce pesticide contamination of ground water

CHAPTER ONE

INTRODUCTION

Pesticides and Ground-Water Protection Programs

Increased awareness of the need to protect the nation's vital ground-water resources has led to the development of programs at the Federal, State, and local levels to control potential sources of contamination. One of the principal goals of the U.S. Environmental Protection Agency's (EPA) Ground-Water Protection Strategy, issued in 1984, was to control sources of contamination of particular national concern. In the Strategy, pesticides were named as a source needing additional national attention. Since that time, the Agency has increased efforts to review the potential ground-water impacts of pesticides and take regulatory action on specific chemicals found to pose a risk to ground water. The Agency has also initiated a National Survey of Pesticides in Well Water to better characterize the problem. In addition, the Agency conducted an extensive review of the magnitude, sources, and potential health impacts of pesticides in ground water and the statutory and program authorities available to help address the problem. This work led the Agency to select the topic of agricultural chemicals in ground water for a major strategic initiative that is still underway.

During this same period, many States also began efforts to understand and address pesticide contamination of ground water. These efforts have been stimulated, in part, by the development of State ground-water protection strategies. EPA has supported State strategy development through grants under Section 106 of the Clean Water Act as a means for strengthening the capacity of State governments to protect ground-water quality, another principal goal of EPA's Ground-Water Protection Strategy. Nearly all of the State strategies recognize the need to address pesticides as part of the ground-water protection program. However, because the pesticide contamination problem is a relatively recent discovery and involves complex technical and institutional questions, programs to address pesticides in ground water are less developed than for other sources of contamination.

The enactment of amendments to the Safe Drinking Water Act (SDWA) in 1986 provided EPA with a statutory basis for promoting comprehensive protection of the nation's ground water as a vital resource. Under the new Wellhead Protection

Program, States will be delineating areas around public water supply wells and instituting management programs to protect these wells from all sources of potential contamination. EPA may provide financial and technical support. Another SDWA amendment establishes a demonstration program for protecting critical aquifer protection areas in designated Sole Source Aquifers. Since pesticides are a potential source of contamination for public water supply wells and critical aquifer protection areas, EPA anticipates that many State and local governments will seek to develop programs that address this source.

The recent reauthorization of the Clean Water Act provides additional impetus for addressing pesticide contamination as a nonpoint source for both surface and ground water. Under the new Nonpoint Source Management Program, States can be eligible to receive funding for ground-water protection activities. EPA expects that many States will seek to control pesticide contamination as part of their comprehensive nonpoint programs.

Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), EPA has regulatory responsibility for determining whether a pesticide can be or remain registered and also for specifying, by label, how the pesticide can be used. This authority is being used to evaluate the leaching potential of individual chemicals. Regulatory actions such as label changes, restricted use classification, and cancellation will continue to be made when needed to protect ground water. These actions on a chemical-by-chemical basis will define the chemicals posing a risk to ground water and establish requirements for using these chemicals.

While regulatory actions on specific chemicals are a fundamental element of efforts to control pesticide contamination, State and local governments will also be seeking to address pesticides in the broader context of their ground-water protection programs and in a way that is suited to the agricultural conditions in their areas. These programs will be looking beyond the pesticide regulatory process for ways to manage pesticide use to minimize risks to ground-water resources.

The Agency recognizes that technical information on practices to reduce these risks is needed to help in the design and implementation of programs addressing pesticide contamination at the State and local levels. To help meet this need, EPA's Office of Ground-Water Protection undertook a study to evaluate the potential ground-water impacts of various agronomic and pesticide application practices. Since there has been only limited research in this area, the Agency also drew together experts in the field to gain their insights into what steps can be taken to reduce risks of pesticide contamination. This report presents the findings of the study and expert panel discussions.

Background of the Project

As mentioned earlier, the Agency is now developing a strategy for agricultural chemicals in ground water as an outgrowth of preliminary investigations to understand the scope of the problem and identify policy issues. Findings of the initial working group on pesticides in ground water, co-led by the Office of Pesticide Programs and Office of Ground-Water Protection, were published in a 1986 report entitled "Pesticides in Ground Water: Background Document." Readers seeking a detailed discussion of the extent and causes of pesticide contamination, its potential environmental and human health impacts, and the statutory authorities and programs available to address it should obtain a copy from the Office of Ground-Water Protection, U.S. Environmental Protection Agency, WH-550-G, Washington, D.C. 20460.

In exploring potential solutions, it soon became apparent that little information was readily available to aid in selecting management practices that would help reduce the risk of contaminating ground water from pesticide use. Recognizing that encouraging sound choice and management of pesticides would be an important element of ground-water protection programs at all levels of government, the Office of Ground-Water Protection initiated a project to identify and evaluate the potential impact of various agronomic and pesticide application practices on ground water.

This report presents the results of an extensive literature review and interviews with experts in several disciplines. The draft report was reviewed by a panel of experts from the research community, Federal and State agriculture and water quality agencies, and industry and environmental organizations who participated in a three day workshop to discuss the findings to assure that they represent the best professional judgement now available on this topic.

Scope of the Project

The problem of pesticides in ground water is extremely complex. Pesticides can enter ground water from activities at any point in their manufacture, commercial distribution, storage, use on land or in industrial settings, and disposal.

The leaks, spills, and other releases that can occur wherever bulk pesticides are stored, handled, or disposed of can result in ground-water contamination; several laws and regulations already address these potential sources.

By far, pesticides are most commonly used to control insect and weed pests on the land. While they are also used on lawns and gardens, forest lands, and rights of way, the greatest use of pesticides is on land in crop production. Under certain conditions, some pesticides applied to the land can leach to the ground water from normal application. The focus of this report is on reducing leaching from agricultural use of pesticides; some practices to minimize on-farm releases and spills are also addressed. It should be noted that many of the considerations and practices suggested may also apply to non-agricultural use of pesticides.

It is recognized that long-term solutions to the problem of pesticides in ground water could involve changes in how and where crops are grown, implementation of pest control methods that are less chemically dependent, and development and use of new chemicals that present a lower risk to ground water and human health. This report, however, assumes that in the more immediate term, farmers will continue growing crops in areas where ground water may be vulnerable to contamination and will be using chemicals that have some potential to leach. The purpose of the report is to provide State and local regulatory officials with technical information pertaining to measures for reducing pesticide leaching to ground water that can aid in the design of programs to prevent ground-water contamination from pesticides.

Organization of Report

Part I of this report contains background information on the pesticide properties, site conditions, and other factors influencing the likelihood of pesticide contamination. It also contains an overview of basic principles for reducing pesticide contamination that provides a framework for developing and implementing protection measures.

Part II of the report contains detailed discussions of the potential impacts of various farming, pesticide application, and irrigation practices on pesticide leaching. This information can be used as a starting point for development and fostering use of management practices that are appropriate to the conditions in a particular area.

The appendices contain references, national maps of soils and climatic conditions, and a list of other sources that can provide information useful in the development of ground-water protection programs addressing pesticides.

CHAPTER TWO

OVERVIEW OF FACTORS CONTROLLING PESTICIDE LEACHING

A complex set of factors influence the likelihood of pesticide contamination of ground water in a given location: the physical and chemical properties of the pesticide, natural hydrogeologic and man-made features at the site of application, and the agronomic and pesticide application practices employed. The following summary of pesticide properties and site conditions most conducive to leaching is provided as background for the more detailed discussion of practices influencing leaching potential that are the primary focus of this report.

Pesticide Properties Conducive to Leaching

Although ground-water contamination by pesticides is a relatively recent public concern, a significant amount of research on the environmental fate of pesticides has either directly or indirectly provided some understanding of the problem. In particular, a great deal of work addresses the fate of pesticides in soil. As a result, a better understanding of the relative leaching potential of various pesticide classes exists than perhaps any other aspect of the problem. Recent monitoring of ground water has provided data that have improved and confirmed understanding of what makes a pesticide more likely to leach. The following are the important physical and chemical characteristics of a pesticide that may make it conducive to leaching, based on current scientific understanding (EPA, 1986).

> Water solubility: the propensity for a pesticide to dissolve in water. The higher a non-ionic pesticide's water solubility, the greater the amount of pesticide that can be carried in solution to surface water and ground water. Water solubility of greater than 30 ppm has been identified as a "flag" for the possibility of a pesticide to leach.
>
> Soil adsorption: the propensity of a pesticide to adhere to soil particles, which is defined as the ratio of the pesticide concentration in soil (C_s) to the pesticide concentration in water (K_d; $C_s/-C_w$). There are different mechanisms for

pesticide adsorption in soils, with particularly important differences between clays and soil organic matter. A second measure, K_{oc}, is used to help characterize the mechanism of adsorption. K_{oc} is a measure of the pesticide adsorption to the organic component of the soil. The lower a pesticide's K_d and K_{oc} values, the less likely these chemicals will be adsorbed to soil particles and the more likely they will leach to ground water. Of the pesticides found in ground water to date, most have had K_d values of less than 5, and usually less than 1. These ground-water contaminants have also generally been shown to have K_{oc} values of less than 300.

- Volatility: the propensity for a pesticide to disperse into the air. Volatility is primarily a function of the vapor pressure of the chemical and is strongly influenced by environmental conditions (e.g., temperature, wind speed, etc.). Aqueous volatility of pesticides is determined by dividing the chemical's vapor pressure by its solubility; this value is termed Henry's Law Constant (H). Certain compounds have a high vapor pressure but are also water soluble. High water solubility can cause pesticides with high vapor pressure to remain in the soil, particularly when these chemicals are applied just before irrigation or rainfall.

- Soil dissipation: a simplified general measure of a pesticide's dissipation in soil, usually measured as the length of time required for dissipation of one-half the concentration of a pesticide and often referred to as a pesticide's soil half-life.

The persistence of pesticides in soil is dependent on a number of environmental processes, including vaporization, and several decomposition processes that cause chemical breakdown, particularly hydrolysis, photolysis, and microbial transformation. Hydrolysis is the reaction of a chemical with water. Photolysis is the breakdown of a chemical from exposure to the energy of the sun. And, microbial transformations result from the metabolic activities of microorganisms within the soil. When a pesticide resists these decomposition processes and does not readily evaporate, it will have a long soil half-life, increasing its potential as a threat to ground water. This is particularly true if the same pesticide is highly soluble and does not readily adsorb to the soil particles. Generally, pesticides with half-lives greater than two or three weeks may have a higher potential to leach to ground water.

Concern for ground-water contamination by pesticides has led EPA to focus more attention on identifying those having the greatest potential to leach through the Agency's pesticide registration and re-registration process. EPA has begun to examine every pesticide for chemical and physical properties that would, as described above, indicate their potential to leach. Table 2-1 provides a summary of the threshold values for those key factors indicating that a pesticide has a high potential to leach. It is important to note, however, that no single threshold will indicate leachability.

Presently, insufficient data exist to state with certainty which pesticides have the greatest potential to leach from normal application to land. In preparing for the National Survey of Pesticides in Well Water, however, EPA developed a list of pesticides suspected of having a potential to leach based on their properties, use patterns, and available monitoring data. The pesticides shown in Table 2-2, along with selected pesticide metabolites or degradation products, are the pesticides included in the National Survey. Pesticides marked with an asterisk on the list are those for which monitoring data shows the pesticide has leached as a result of normal use. Other pesticides shown are those that EPA considers, based on current knowledge, to have the potential to leach to ground water.

Soil Conditions Conducive to Leaching

The site conditions at the area receiving a pesticide can greatly affect the likelihood of any leaching. The composition and properties of the soil are the two most important factors affecting leaching potential. These factors are discussed below.

Soil Composition

- Clay minerals content: contributes to cation exchange capacity (CEC), the ability of the soil to adsorb positively charged ions or molecules (i.e., cations). Positively charged pesticides may be adsorbed to soil containing negatively charged clay particles.

- Clay soils: defined as soils with a predominance of particles less than 2 micrograms in size; particle size is generally proportional to the amount of clay mineral contained. They have a high surface area which contributes further to adsorption capacity. Adsorption onto clay colloids leads to chemical degradation and inactivation of some pesticides, but it inhibits degradation of others.

TABLE 2-1: PHYSICAL AND CHEMICAL CHARACTERISTICS OF PESTICIDES INFLUENCING LEACHING POTENTIAL

Pesticide Characteristic	Value or Range*
Water solubility	Greater than 30 ppm
K_d	Less than 5, usually less than 1
K_{oc}	Less than 300 - 500
Henry's Law Constant	Less than 10^{-2} atm-m^{-3} mol
Speciation	Negatively charged, fully or partially at ambient pH
Hydrolysis half-life	Greater than 25 weeks
Photolysis half-life	Greater than 1 week
Field dissipation half-life	Greater than 3 weeks

*Parameter for indicating the potential for ground-water contamination.

Source: U.S. EPA, 1986

TABLE 2-2: PESTICIDES AND RELATED CHEMICALS INCLUDED IN EPA's NATIONAL SURVEY OF PESTICIDES IN WELL WATER

PESTICIDES	
Acifluorfen (H)	Dinoseb (H)
Alachlor (H)	Diphenamid (H)
Aldicarb (I)	Disulfoton (I)
Ametryn (H)	Diuron (H)
Atrazine (H)	Endrin (I)
Bromacil (H)	Ethylene dibromide (I,N)
Butylate (H)	Fluometuron (H)
Carbaryl (I)	Heptachlor (I)
Carbofuran (I)	Hexachlorobenzene(s)
Carbofuran-3-OH	Methomyl (I,N)
Carboxin (F)	Methoxychlor (I)
Chloramben (H)	Metolachlor (H)
alpha-Chlordane (I)	Metribuzin (H)
gamma-Chlordane (I)	Oxamyl (I)
Chlorothalonil (F)	Pentachlorophenol (H)
Cyanazine (H)	Picloram (H)
Cycloate (H)	Propachlor (H)
2,4-D (H)	Propazine (H)
Dalapon (H)	Propham (H)
Dibromochloropropane (N)	Propoxur (I)
DCPA (H)	Simazine (H)
Diazinon (I)	2,4,5-T (H)
Dicamba (H)	2,4,5-TP (H)
3,5-Dichlorobenzoic acid (H,I)	Tebuthiuron (H)
1,2-Dichloropropane (N)	Terbacil (H)
Dieldrin (I)	Trifluralin (H)

These pesticides and related chemicals are considered by EPA to have the greatest potential for leaching to ground water.

F - Fungicide
H - Herbicide
I - Insecticide
N - Nematicide
S - Seed Protectant

TABLE 2-2 (continued)

PESTICIDE METABOLITES

Aldicarb sulfone	Fenamiphos sulfoxide
Aldicarb sulfoxide	Heptachlor epoxide
Atrazine, dealkylated	Hexazinone
Carboxin sulfoxide	Methyl paraoxon
DCPA acid metabolites	Metribuzin DA
5-Hydroxy dicamba	Metribuzin DADK
Disulfoton sulfone	Metribuzin DK
ETU	Pronamide metabolite, RH 24850
Fenamiphos sulfone	

Source: U.S. EPA, 1986

- Organic matter content: contributes to adsorption of pesticides in soil. Organic matter content affects biological activity, bioaccumulation, biodegradability, leachability, and volatility of pesticides. Soils with high organic content adsorb pesticides and therefore inhibit their movement into ground water.

Soil Physical Properties

- Soil texture: refers to the relative proportion of different sizes of soil particles (i.e., percent sand, silt, and clay). Leaching is more rapid and deeper in coarse or light (sand textured) soils than in fine or heavy (clay) soils.

- Soil structure: refers to the way soil grains are grouped together into larger aggregates - platy, prismatic, blocky, or spheroidal (granular and crumb). Structure is affected by texture and percent of organic matter. Pesticides and water can seep, relatively unimpeded, through seams between the aggregates.

- Porosity: is a function of pore size and pore size distribution determined by soil texture, structure, and particle shape. Pesticides are more likely to be transported to a greater degree through more porous soils, all other things being equal.

- Soil moisture: refers to the presence of water in soil. The soil water ultimately transports pesticides that are not adsorbed onto soil particles in the unsaturated bone to the water table below. Upward movement may also occur through capillary action and evapotranspiration (evaporation from open bodies of water and soil surfaces and the uptake of soil moisture and release to the atmosphere by plants).

The factors described above are considered important in evaluating leaching potential at a site based on standard concepts of water and chemical movement through porous media. However, recent studies (Hallberg, 1986) indicate that preferential flow (of water and solutes) through soil macropores may be a major cause of pesticide leaching to ground water under various soil and climatic conditions.

Under standard concepts of flow through porous media, sandy soils should provide a higher potential for pesticide leaching than clayey soils. However, clayey soils may tend to be well structured and contain a high number of macropores which may enhance the potential for rapid leaching. In addition, dessication of clayey soils may result in prominent shrinkage cracks. Rainfall or irrigation, water flowing preferentially along such features may promote leaching, even when other pesticide properties and site conditions are not conducive to leaching.

Appendix C contains a national map prepared by the Soil Conservation Service of the patterns of soil orders and suborders of the United States. More detailed local information on soils is available from State and district offices of the Soil Conservation Service.

Other Factors

Several other factors also affect pesticide leaching potential and the likelihood for ground water contamination. Depth to ground water and permeability of the material in the vadose (unsaturated) zone are considered particularly important in determining vulnerability to pesticide contamination. Areas of karstic hydrogeologic conditions, found in many regions of the United States are also particularly vulnerable to contamination. Hydrogeologic information may be available from State geological survey offices and/or district offices of the U.S. Geological Survey in some areas of the country. Well drilling logs are another possible source of information, although they tend to be of inconsistent quality.

The amount and seasonal variation in the amount of recharge--rainfall and irrigation--is another important factor influencing leaching potential. Areas with high rates of infiltration from rainfall or irrigation water have large amounts of water passing through the soil, and therefore are more susceptible to leaching. Average monthly precipitation data are recorded at numerous stations around the country and are available from several publications, including van der Leeden and Troise (1974). Several methods of calculating evaporation and evapotranspiration are given in Dunne and Leopold (1978). One of the more common methods is the Thornthwaite method, which uses air temperature as an index of the energy available for evapotranspiration. Average monthly air temperature for numerous stations is also available from van der Leeden and Troise (1974).

Man-made site features such as poorly constructed water supply wells, agricultural drainage wells, and faulty check valves on chemigation systems also influence whether a pesticide will reach ground water. These features can lead to "short circuiting" or the creation of pathways for pesticides to enter ground water without filtering though soil.

CHAPTER THREE

OBJECTIVES OF MITIGATION MEASURES TO REDUCE PESTICIDE CONTAMINATION OF GROUND WATER

Since site conditions, pest and crop patterns, and agricultural practices vary widely, no specific recommendations for practices to reduce the risk of pesticide contamination can be developed that are appropriate for all situations. Generally, however, measures to protect ground water from pesticides achieve one or more of the following objectives:

- --Reduction of the quantity of pesticides used.
- --Use of pesticides with less potential to leach.
- --Avoidance of pesticide application when conditions are most likely to promote leacning.
- --Prevention of spills and elimination of pathways for entry of pesticides to ground water.

The potential impacts on leaching of various farming, pesticide application, irrigation, and other agricultural practices are discussed in detail in Part II of this report, along with suggestions for measures that can be taken with each practice to minimize leaching. Many agricultural practices are "fixed";* that is, they are either impractical to change or serve another important environmental purpose such as reducing soil erosion or surface runoff. Other practices are "variable"; that is, they are more amenable to changes in management such as timing or rate of pesticide application.

Designing a program to promote the use of good practices to reduce pesticide contamination risks requires an understanding of the type(s) of agriculture and agricultural practices that are common or typical in the area. This knowledge forms the basis for identifying specific practices that might be promoted as well as the particular technical assistance needs of the area's agricultural producers.

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* No practice is ever completely "fixed," since there is always the potential to change crops, tillage equipment, etc. The term is used because of the major investment likely to be involved in changing or because they are in place to achieve other important benefits.

Minimizing Pesticide Usage

An obvious part of any plan to reduce the potential for leaching of pesticides into ground water is minimizing the amount of pesticides used. This can be accomplished by, among other things: careful timing of pesticide application relative to climate, crop economic thresholds, and pest cycles; eliminating persistent and recurring insects and weeds with crop rotation; the use of pest resistant varieties of crops; proper maintenance and calibration of application equipment; and using mechanical cultivation to control weeds, when possible. Many or all of these factors can be included in an integrated pest management (IPM) system.

IPM is an integrated approach to pest control that involves the application of basic farming practices, ecological principles, and biological and chemical pest control methods. Case studies have shown that pesticide use can be greatly reduced in some field situations with IPM. An effective IPM system requires extensive knowledge of the crop and its surrounding ecosystem. Steps involved in an IPM system include identifying key pests; identifying the environmental factors that influence those pests; and after considering the concepts, methods, and materials that will help in the restraint or elimination of those pests, implementing the most economically and environmentally sound approach. An IPM system generally requires monitoring of pests and weeds and the help of Extension specialists or pest consultants.

Using Pesticides with Lower Leaching Potential

As described in Chapter Two, studies have shown that certain chemical properties of a pesticide can have a significant impact on the potential for that pesticide to leach into ground water. Numerous pesticides have been proven effective for nearly all types of insects and weeds. In many cases, a group of pesticides with different potentials for leaching may be similarly effective in eliminating a particular pest. When available, the use of alternative pesticides with lower leaching potential should be encouraged, particularly in areas with vulnerable conditions.

Reducing Pesticide Application at Times Most Likely to Promote Leaching

While many of the site conditions conducive to leaching are naturally occurring, various farming and irrigation practices can increase or decrease the likelihood that pesticides will leach. When soils are at or near saturation or have many macropores or cracks, conditions are particularly conducive to leaching.

Some farming practices can help reduce the potential for pesticide leaching by enhancing the soil's ability to retain moisture or adsorb or degrade pesticides. Other practices, however, may promote leaching. Ponding of runoff water high in pesticides may promote infiltration into the ground. Certain tillage practices may foster the formation of macropores which enhance infiltration. Chapter Five in Part II describes the impact of a variety of tillage and other farming practices on leaching.

The method and timing of irrigation and pesticide application can also create site conditions that are conducive to pesticide leaching. With some irrigation methods, soils are kept at or near full saturation. This condition can promote pesticide leaching when normally adsorbed pesticides desorb from soil particles and become available to leach into ground water. In addition, improper and/or excessive irrigation can promote leaching of surface-applied or soil-incorporated pesticides by moving dissolved pesticides through soil. The potential impact of various irrigation methods and timing of pesticide applications are discussed in Chapter Four of Part II.

In many areas of the United States, site conditions may be conducive to leaching either naturally or as a result of irrigation. In general, site conditions that are conducive to leaching occur when ground-water recharge rates are high and significant quantities of water move downward. This can occur in areas where infiltration is significantly higher than evapotranspiration, and/or where soils are highly permeable. This is particularly a problem in irrigated semi-arid or arid regions of the United States where infiltration of irrigation water leaching from agricultural fields is the primary source of ground-water recharge. High ground-water recharge rates alone, however, do not necessarily indicate that concentrations of pesticides will reach levels of concern because the pesticides may be sorbed to soil or degraded before reaching ground water.

Preventing Accidents, Spills, and Pathways for Pesticides to Reach Ground Water

Contamination of ground water can also be avoided by proper pesticide handling and by eliminating pathways for pesticides to enter ground water from the ground surface or from surface water. Contamination by <u>any</u> pesticide, regardless of its leaching potential, can result from spills and leaks or entry by direct pathways.

In the steps between the purchase and application of pesticides, pesticides may be spilled or released into the environment at any time or place during transport, storage or handling. Depending on site conditions and the amount of pesticide involved, movement of the released pesticide to ground-water can occur. Ground water contamination is a particular concern if spilled pesticides build up in soil, such as can happen if application equipment is loaded or cleaned in one designated area repeatedly. Careful storage and handling of pesticides can help to minimize spillage and waste.

Improperly constructed or abandoned irrigation or drinking water wells can provide a direct pathway for pesticides to enter ground water. In ungrouted wells, especially those located in topographic depressions susceptible to surface runoff, water may be able to run down the outside (or even the inside) of the well casing directly into ground-water supplies. In addition, pesticide-laden surface runoff water may enter ground water through abandoned wells that are not sealed properly or covered. Pesticides may also enter ground water via irrigation wells connected to chemigation systems unequipped with check valves to prevent back-siphoning of chemicals into the well.

In developing measures to reduce the impacts of pesticides, the relationship between ground water and surface water should also be considered. Surface water bodies that are susceptible to runoff from agricultural fields, such as irrigation reuse pits or farm ponds, may contain high amounts of pesticides. Although such surface water bodies may not serve as direct sources of drinking water, they may recharge ground-water supplies. Futhermore, where ground water discharges to surface water, it is possible for any ground water that is contaminated with pesticides to adversely impact surface water supplies.

Measures to avoid contamination from leaks and spills and to reduce direct pathways for contamination are discussed in Chapter Seven of Part II.

Selecting Combinations of Practices

While the broad objectives described in this chapter set forth an overall framework for reducing the risk of pesticide contamination from crop production, determining which practices can and should be promoted involves analysis of the particular conditions, needs, and capabilities of farms in the area of concern. Design of specific measures may ultimately need to be done at the individual farm level. Technical assistance in determining appropriate measures is available from a variety of agencies (see Appendix D).

In the development and external review of this report, one overriding recommendation emerged that is appropriate for all conditions: pesticide use should be reduced to only that which is essential. While biological methods of pest control have not yet been developed for all crop and pest situations, the principles of integrated pest management, which include a variety of chemical, biological, and non-chemical methods, should be applied to the extent feasible. Reducing pesticide use protects not only ground water, but also the environment in general--and particularly, the farm family and farm community. Reduced chemical inputs can also improve farm profitability, and may help in addressing the increasing pest resistance problem.

Selection of appropriate measures is influenced to a large extent by the topography and soil type of the site. For example, flat fields of sandy soils with low adsorptive capacity and high permeability, where ground-water is recharged primarily from infiltration of irrigation water, require specific mitigation measures. In such cases, one should concentrate on reducing the quantity of pesticides used, carefully managing water use, timing applications for when site conditions are less likely to promote leaching, and increasing the ability of the soil to adsorb and/or degrade pesticides.

By contrast, for a hilly site with clay-rich soils of low permeability and high adsorbtive capacity, where the ground water is generally of low vulnerability to contamination, practices to reduce soil erosion and control surface runoff are likely to be in place. Here, leaching is less likely, so mitigation would focus on other pathways to ground-water. For these settings, mitigation measures should concentrate on reducing the quantity of pesticide used (so that both surface and ground-water are protected) and minimizing the potential for pathways such as farm ponds and irrigation re-use pits to adversely affect ground water.

In Part II, the potential impact on ground water of a wide range of agricultural practices is discussed in detail. The information is presented to suggest possible measures that, when tailored to local conditions, can be incorporated into ground-water protection efforts. Appendix D contains a description of agencies and organizations with expertise in agriculture, soil science, and hydrogeology who can provide more detailed information on conditions and practices on a more localized level.

PART II

POTENTIAL IMPACT OF AGRICULTURAL PRACTICES ON PESTICIDE CONTAMINATION OF GROUND WATER

This part contains discussions of the potential impact of pesticide application, farming, irrigation, and other practices on pesticide contamination of groundwater. Each section separates "fixed" practices, which are impractical to change or otherwise essential, from "variable" practices, which are more amenable to change to accomplish ground water protection (and/or other) objectives. Note that no practice is ever completely "fixed"; the term is used because of the major investment likely to be involved in changing or because such practices are in place to achieve other important benefits.

CHAPTER FOUR

PESTICIDE APPLICATION FACTORS

A carefully adopted plan for pest management can play a significant role in helping reduce the potential for pesticide leaching to ground water. The plan should include choosing the most appropriate pest control method. Whenever possible, consider factors such as: choosing a pesticide with low leaching potential; properly timing pesticide application relative to climate, crop stage, and weed and insect populations; controlling the volume and frequency of application; and using the correct form of pesticide. Potential impacts of these factors on pesticide leaching are discussed individually in the sections that follow.

Fixed Practices

The method of application is generally considered a fixed practice because it is dependent upon the equipment available to the farmer and is specific to the type of crop and the type of pest being treated.

Application Methods

The method of pesticide application refers to how the pesticide is applied on the crop or field. A pesticide can be applied to a crop by aerial application, ground application, or through chemigation. Ways in which the method of application can impact pesticide leaching to ground water are described below.

Aerial Application

Aerial application involves the foliar or surface application of pesticides from a small airplane or helicopter. Pesticides applied by this method may not always be applied uniformly over a field and can drift away from the target site to nearby fields or surface water. Localized areas may receive more or less of the application of pesticides, which can result in over-concentrated areas from which pesticides may leach.

Aerial application of pesticides, however, is often the only available method, such as at times of advanced crop stages when ground application is not feasible. Methods that may be used to increase the uniformity of application and decrease drift include applying pesticides only at times when winds are calm, applying the pesticides at as low an altitude as possible, using swath analysis to evaluate distribution, and adjusting spray nozzles and drop sizes to account for air turbulence (propwash) (Maas, et al, 1984).

<u>Ground Application</u>

Ground application involves applying pesticides through land based vehicles. Pesticides applied by ground application can be foliar applied, surface applied, or soil incorporated.

With foliar applied pesticides, the quantity of pesticides used can be reduced by adjusting spray drop sizes relative to the surface of the plant to which they are being applied. This helps pesticides stick to plant surfaces and not run off onto soil. The drop sizes should be small enough to avoid runoff, but not so small that they are susceptible to drift and inadequately cover plant surfaces (Roberts, 1982).

The quantities of pesticides used can also be reduced through the use of methods that help foliar applied pesticides cling to plant surfaces, such as by adding crop oil or surfactants to the pesticide mixture. Electrostatic sprayers, or sprayers that use ultra-low volumes of pesticides by recirculating pesticides that do not become attached to the plant surface, are also effective. With electrostatic sprayers, pesticide drops are negatively charged before they are applied to plant surfaces. The negatively charged pesticide can then more easily attach to the positively charged surfaces of the plant. In some sprayers, the negatively charged pesticides that do not attach to plant surfaces can be collected and recirculated, thus reducing the quantities of pesticide used (Mass, et al, 1984).

The potential for pesticide leaching to ground water is higher with surface applied and soil incorporated pesticides an for foliar applied pesticides. This is particularly true if the pesticide is applied where site conditions are most conducive to leaching. However, for many insects and weeds, surface application or soil incorporation are the only effective means of control. In irrigated agriculture, the potential for pesticide leaching with these application methods depends, in large part, on the method of irrigation being used (See Chapter Six).

Where surface application and/or soil incorporation is necessary, uneven application of the pesticide can cause an increase in the potential for pesticide leaching. The uniformity of the application depends, in part, on the uniformity, calibration, spacing, and height of the nozzles (Roberts, 1982). Improper calibration can lead to concentrated bands of pesticide.

Chemigation

Chemigation involves mixing the pesticide with water flowing through an irrigation system. The irrigation system used is most often a spray or drip system, although chemigation can also be practiced with flood irrigation. The potential impacts of chemigation on pesticide leaching are discussed in Chapter Six.

Variable Practices

By choosing appropriate pest control methods and carefully managing the amount, volume, and timing of pesticide applications, the risk of ground water contamination can be reduced significantly.

Choice of Pest Control Method

Subsequent sections describe many ways to control pest populations through management practices that either eliminate or reduce the need for pesticides. Further, an overall recommendation regarding the use of pesticides is to implement integrated pest management (IPM) techniques, which consider non-chemical methods of pest control and prescribe the use of pesticides only as they are needed to keep pest populations below economic thresholds (see discussion of IPM in Chapter Five). Reductions in the use of pesticides will result in the greatest protection for all environmental media.

Selection of Pesticide

When use of a pesticide is necessary to control damaging pest populations, careful selection can help avoid contamination of ground water. As described in Chapters Two and Three, persistent pesticides with high water solubility that do not adsorb readily to soil have the highest potential to leach. Table 2-2 (Page 11) lists the pesticides EPA has determined as having greatest potential to leach based on current data and understanding. The Agency will monitor these pesticides in the National Survey of Pesticides in Well Water. Until better information is available, this list represents the pesticides for which there is some concern that they may leach to ground water as a result of normal application to the land.

Form of Pesticide

The form of pesticide can affect the potential for leaching into ground water. Pesticide forms include powders, dusts, granules, timed-release encapsulated forms, concentrated emulsions, liquid concentrates, and aqueous solutions. The particular form used is generally dictated by the pesticidal effect desired.

Different spraying formulations may be prepared by dissolving a solid in water, by mixing a liquid solution with water, by mixing a wettable powder to form a suspension, by mixing an emulsifiable concentrate with water to form an emulsion, or by mixing an oil-miscible formulation with an oil. All these forms of application have variable impacts on the leaching potential of pesticides. For example, surfactants made of oils are added to foliar-applied herbicide/insecticide sprays to increase the penetration and translocation of the chemicals within the plant tissue. This process increases the effectiveness of the pesticide, thus allowing a smaller application of the active ingredient. These additives also help the pesticide stick to the plant surfaces, thus reducing the amount washed off onto the soil and the potential for leaching to ground water. However, the surfactants may increase the potential for pesticide leaching of washed off pesticides by decreasing their ability to adsorb to soil particles.

Pesticide solubility can also impact leaching potential. Pesticides with low solubility and high adsorbtive capacity are prone to be transported in the sediment phase rather than in dissolved runoff and thus have lower potential to leach. More soluble pesticides can be carried to ground water in solution where runoff is not significant.

Because of their high solubilities, wettable powders, dusts, and microgranules are generally susceptible to surface runoff or to leaching. These solid forms of pesticides also do not volatilize as readily as do pesticides in liquid and aqueous solutions and may persist in soil, potentially affording more time when leaching might occur.

Application Timing

The time that a pesticide is applied can be a major factor in pesticide leaching potential, depending on local environmental conditions, temperature, and rainfall. Leaching potential is minimized when the applied pesticide is fully utilized or when the soil conditions promote degradation.

Timing of pesticidal application should be relative to climatic conditions, crop stage, and weed and insect populations. Figure 4-1 presents, for illustration purposes, a summary of the concepts presented in this discussion; note that actual timing decisions will vary based on climate, crop, and pest control needs.

Climatic Conditions

The degree of pesticide leaching at a particular site depends on the amount and nature (e.g., drizzle vs. downpour) of local precipitation events. The temperature of the soil and surrounding air at a site can also greatly affect the processes that result in a pesticide's movement and degradation in the environment. These climatic factors are governed by the season and the geographical location. In general, pesticides are more likely to leach below the root zone when the soil is at or near full saturation after heavy precipitation. This condition can result in pesticide desorption from soil particles, or downward movement of dissolved pesticides. As such, leaching can be minimized by limiting pesticide application during wet seasons. Leaching potential can also be minimized by observing weather patterns and avoiding pesticide application before major precipitation events. In either situation, proper timing of pesticide application relative to climatic conditions involves knowledge or understanding of the period(s) of heavy precipitation for the geographical area in general (e.g., late spring or fall). The immediate weather forecast, is, of course, of primary importance in making a specific application decision.

Crop Stage

Pesticides are usually applied at pre-planting, at pre-emergence, or during post-emergence. Pesticides applied during pre-planting and pre-emergence stages have higher potentials to leach than those applied post-emergence. The potential for post-emergent applied pesticides to leach depends upon the crop stage. In general, mature crops have a higher capacity for uptake of pesticides. During this stage of crop growth, water is absorbed at the root zone, thus limiting downward movement of water and the potential for pesticide leaching. For some weeds and pests, however, the benefits of pre-plant and pre-emergent application may outweigh the higher potentials for leaching associated with these methods. This would be true when, for example, a single application per season is effective in controlling weeds that would otherwise require multiple applications.

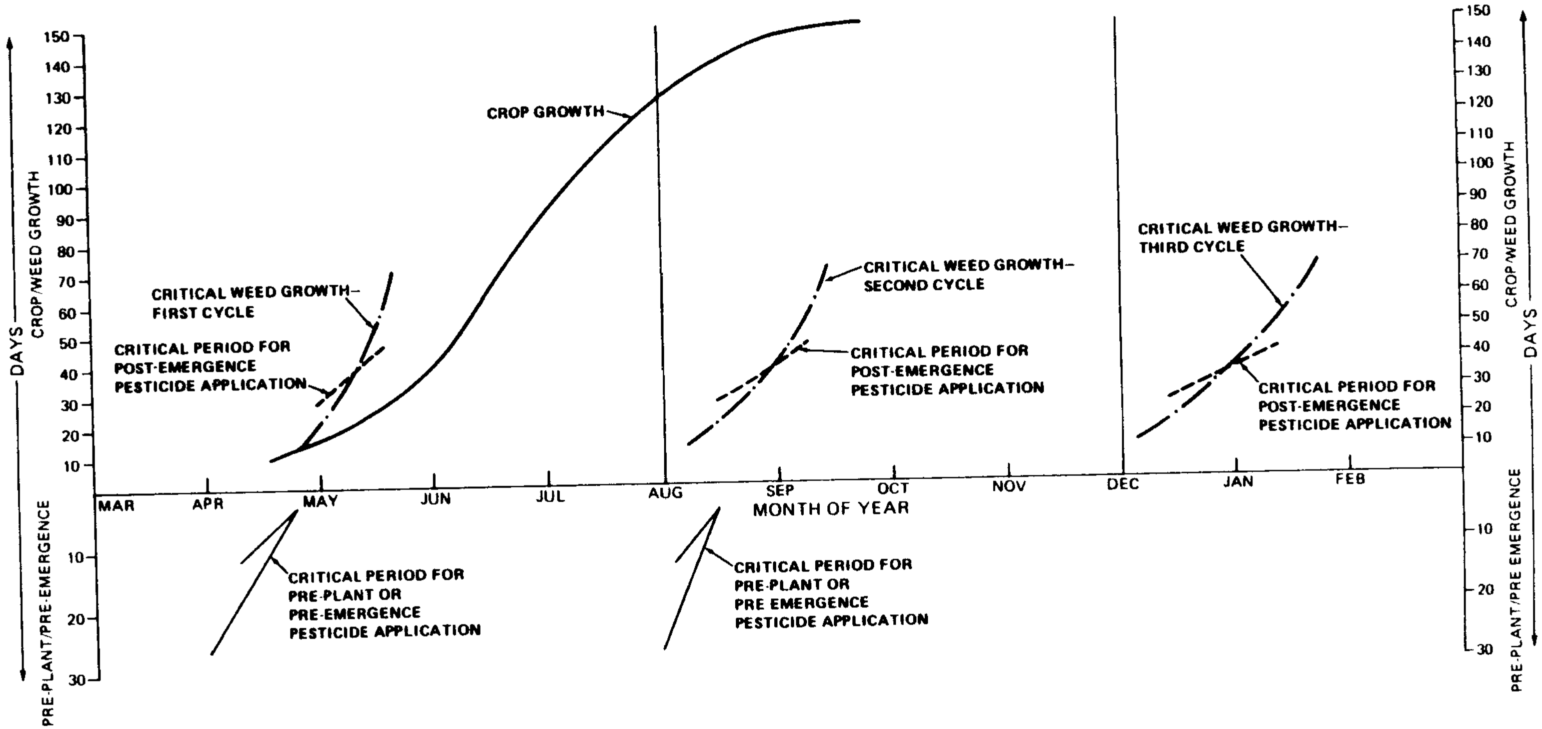

FIGURE 4-1
PESTICIDE APPLICATION RELATIVE TO CROP GROWTH STAGE, WEED AND PEST OCCURRENCE (ILLUSTRATION ONLY; ACTUAL WILL VARY BASED ON CLIMATE, CROP AND PEST CONTROL NEEDS)

For post-emergent application, the timing of pesticide application relative to crop stage should consider the interaction between growth stages of the crop and the time that the pest species does the most damage. Many pests cause damage to crops only during a specific period of the crop cycle (Maas, et al, 1984). The alfalfa seed-crop, for example, can be best protected from the lygus bug, which attacks alfalfa buds, floral parts, and immature seeds, by application of insecticide during the early bud stage of the crop (Martin and Leonard, 1967). In addition, pesticide application can be reduced by eliminating application at crop stages where pests do not feed on the crop. For example, the tobacco budworm, which only affects buds, cannot cause economic damage to tobacco after plant leaves emerge, thus eliminating the need for insecticide application after that point (Maas, et al, 1984).

Thresholds and Pest Cycles

Pesticide application can be reduced through insect and weed scouting and by being aware of economic thresholds--that is, the levels at which pest numbers become economically injurious to crops. Proper timing of pesticide application relative to economic thresholds and pest cycles can significantly reduce the quantity of pesticides applied. With the new pest resistant varieties on the market, most crops can generally tolerate a high number of pests before yields and/or crop quality are affected. In addition, many weeds and insects reach critical growth stages where their numbers can be drastically reduced with a relatively low amount of pesticides. Extension specialists with expertise in weed and insect monitoring can provide advice on proper timing of pesticide applications.

In several studies, pesticides were found to have been applied unnecessarily at times when pest scouting indicated that economic thresholds had not been reached (Maas, et al, 1984). A four-county study in Illinois found that 19 and 11 percent of corn acreage actually required insecticide usage while 67 and 57 percent, respectively, received it (Luckman, 1978). In addition, a three-year study in the Midwest showed that only 9 percent of corn fields even contained wireworm, a commonly treated pest, and only 1.2 percent actually had wireworm damage (National Science Foundation, 1975). Studies with soybeans have shown that this crop can have a remarkably high ability to tolerate insects without significant loss of yield (Newsom, 1978), thus requiring the use of only small quantities of pesticides.

Application of pesticides relative to pest growth cycles can also be useful in reducing the quantities of pesticides used. The times in pest cycles where they can be best controlled can be identified with the help of Extension specialists, by consulting pesticide label directions, or from the reports "Weed Control Manual and Herbicide Guide" and "Insect Product Guide" (published by Ag Consultant and Fieldman, respectively). For example, Canada thistles and many broadleaf weeds in corn fields can be effectively controlled only by applying herbicides in early weed or pre-emergent stages (Ag Consultant, 1986). In fact, nearly all weeds can be most effectively controlled by application of pesticides at times early in growth stages when they are most susceptible. In addition, pests such as cutworm, corn earworm, cottom bollworm, sorghum headworm, soybean podworm, tobacco budworm, and tomato fruit worm are best controlled when the larvae first appear (Ag Consultant, 1986).

Application Rate and Volume

Proper choice of pest control method and application timing can reduce the quantity of required pesticides as described in the previous sections. In addition, other measures help assure the most effective use of minimum amounts of pesticides, including proper maintenance and calibration of pesticide application equipment, consideration of recommended ranges of pesticides, and band application of pesticides.

Proper Mixing

Label directions for mixing the pesticide should be carefully followed to assure the most efficient use. Under-dilution of the pesticide will result in use of excessive quantities; more pesticide may be available to leach since normal degradation processes are likely to be less effective.

Equipment Maintenance and Calibration

Pesticide application equipment should be maintained and properly calibrated to ensure even application of pesticides and to ensure that pesticides are applied at volumes intended by the user. Poorly maintained and/or calibrated equipment can discharge excessive quantities of an improperly diluted mixture of pesticides which can result in inefficient use and subsequent leaching into ground water. Ensuring the proper rate and volume of pesticide application can be made easier with the use of automatic volume regulating devices which cause spray pressure to vary accordingly with change in speed of the application equipment.

Pesticide application equipment should be maintained and calibrated on a periodic basis to achieve the desired application rates and volumes. The Agricultural Training Board of England recommends that calibration should take place at the beginning of each season; after every 100 hectares sprayed; and after changes of tractor wheels, nozzles, or pressure (Roberts, 1982).

Detailed information on calibration procedures can be obtained from Extension specialists and equipment manufacturers. The calibration procedure for spray equipment should first include selecting nozzles to give the required application rate at the intended pressure and speed, based on the label instructions of the pesticide being applied. The sprayer should then be adjusted to the intended spray pressure, and the nozzles should be checked for visual alignment. All worn or bent nozzles should be repaired or replaced. The nozzle output should then be checked for uniformity with flow-measuring devices or by recording the time it takes each nozzle to fill a container to a specified depth. In a trial run with the pesticide application equipment filled with water, the spray width of the nozzles should be checked for the desired width. If the desired width is not obtained, the boom height or nozzles can be adjusted accordingly.

Consideration of Dosage Recommendations

Pesticide label instructions recommend a specific dosage, which is generally expressed in a range of active ingredients per acre. If pest numbers are relatively low, the lower end of the recommended range may give adequate results while resulting in lower quantities of pesticide used. It is illegal to use greater than the maximum dose shown on the label.

Band Application

Applying pesticides in a band on crop rows rather than on the entire field is an effective method for reducing the amount of pesticides used. Band application with corn, for example, can be used to apply pesticides along the crop row at the time of planting with a sprayer located behind the planter. Drop nozzles can also be used to spray below the crop canopy, allowing use of less pesticide and more effective application. The band application will control weeds along the row, while mechanical cultivation or lesser amounts of pesticides can be used to control weeds between the rows (Martin and Leonard, 1967).

CHAPTER FIVE

FARMING PRACTICES

Farming practices can help reduce the quantities of pesticides used and make site conditions less conducive to leaching. Farming practices employed at a given farm are usually influenced by soil conditions, topography, rainfall pattern, cropping pattern, economic status of the farmer, and individual knowledge of various agricultural practices. A combination of farming practices can be used to set up an integrated pest management (IPM) system, in which the quantities of pesticides used can be greatly reduced.

Many farming practices are also used for the purposes of preventing soil erosion and surface runoff. Because in some situations there may be tradeoffs, the choice of farming practices should consider impacts on all environmental media. For example, one farming practice may be useful in reducing the leaching potential of pesticides, but may promote soil erosion, with subsequent negative impacts on surface water quality.

Fixed Practices

Since different tillage methods require different types of capital equipment and are often selected as a means for controlling erosion and surface runoff, tillage practices are considered, for this publication, to be "fixed" practices. When a decision to change tillage method is being made, however, the potential impact of alternative methods on both ground and surface water should be considered.

Tillage Practices

The fundamental purposes of tillage are to: provide a suitable seedbed, reduce competition from weed growth, and make conditions in the soil more favorable for crop growth (Martin and Leonard, 1967). Tillage practices can impact the potential for pesticide leaching by influencing the quantity of pesticides used and by making the site more or less conducive to pesticide leaching. Details of how conventional and conservation tillage can impact the potential for pesticide leaching to ground water are discussed below.

Conventional Tillage

In conventional tillage, land is cultivated mechanically often in both fall and spring prior to planting for seed bed preparation. Mechanical cultivation is also one of the oldest forms of weed control known. In addition to weed control, cultivation between crop rows provides aeration to crop roots and can help in reducing insect numbers by exposing insects to the surface where they can be controlled by natural predators. Conventional tillage can be effective in the control of weeds that grow between crop rows before the crop can shade the ground (Martin and Leonard, 1967).

Herbicide use can be relatively low with conventional tillage, although herbicides are generally used in conjunction with mechanical cultivation to control weed competition. In addition, conventional tillage may be useful in eliminating macropores and animal burrows through which pesticides can rapidly infiltrate into ground water.

However, because the soil is left exposed, conventional tillage can promote soil erosion and surface runoff if practiced on steep slopes (greater than 3%) without contouring or terraces. Erosion is particularly a problem in areas of the United States where steep slopes are combined with soils of relatively low permeability, and rainfall amounts are high and occur in high-intensity events (storms).

Conservation Tillage

Conservation tillage is defined as any tillage practice that leaves at least 30 percent of the soil surface covered with crop residues after planting (Conservation Technology Information Center, 1987). Conservation tillage is generally employed as an inexpensive, effective method for reducing soil erosion and surface runoff. At the present time, considerable controversy exists over the impact of conservation tillage on ground water.

The term conservation tillage encompasses five basic methods: no-till, ridge-till, strip-till, mulch-till, and reduced-till. With no-till, the soil is left undisturbed prior to planting, and the planting is completed in a narrow seedbed. With ridge-till and strip-till, the soil is left undisturbed prior to planting, although a portion of the soil surface is tilled at planting. With ridge-till, however, planting is completed on ridges which are higher than the row middles, and cultivation is used to rebuild ridges. In mulch-till, the total soil surface is disturbed by tillage prior to planting with tillage tools such as chisels, field cultivators, discs, sweeps, or blades. Reduced-till refers to any conservation tillage practice not covered above. With conservation tillage practices, weed control is accomplished with a combination of herbicides and cultivation (Conservation Technology Information Center, 1987).

The controversy surrounding the effects of conservation tillage on pesticide leaching centers around the fact that conservation tillage may require additional herbicides, in some cases, compared to conventional tillage (Maas, et al, 1984). However, experience has shown that much of the increase is due to a desire for a hedge against uncertainty. Some producers are using less herbicides than they did when practicing conventional tillage, often after they have gained experience and confidence in the new system. Studies on corn have shown that more herbicides may be required with reduced tillage compared to conventional tillage (Hanthorn and Duffy, 1983). For soybeans, however, only no-till was found to cause an increase in herbicide usage, while there was no significant differences in herbicide use between reduced till and conventional tillage.

Different methods of conservation tillage require different quantities of herbicide and have different effects on leaching potential. Generally, it appears that no-till requires the greatest herbicide usage and may lead to site conditions most conducive to leaching when compared to other conservation tillage methods. If no-till is used continuously for several years on the same land, the likelihood for the presence of soil macropores is higher than for other conservation tillage methods, thus increasing the potential for pesticide leaching (Dick, et al., 1986). Ridge-till and mulch-till may generally require the least amount of herbicides because some mechanical cultivation is done with these methods.

In some instances, higher amounts of insecticides may also be required with conservation tillage, compared to conventional tillage (Smith, et al., 1979). The additional amounts involved are generally greater for no-till.

Although conservation tillage may require the use of more pesticides in some cases, the overall impact of this practice on the potential for pesticide leaching remains unclear. Studies have also shown that conservation tillage, although sometimes requiring the use of more pesticides, can also help in reducing the potential for pesticide leaching by making site conditions less conducive to leaching by enhancing microbiological activity and degradation of pesticides in the upper three inches of the soil layer (Helling, 1986).

Contour Farming

Contour farming involves the planting of crops along contour lines across slopes. Contour farming is effective at reducing soil erosion by slowing water movement on the soil surface and allowing for increased infiltration. It is most effective on fields of moderate slopes (less than 8 percent) that are free of depressions and gullies. Runoff volumes may be reduced up to 50 percent depending on crop and soil type (Maas, et al., 1984) in comparison to other farming practices.

Although contour farming can decrease surface runoff, this practice can cause ponding of runoff between rows. Subsequent increases in infiltration may increase the potential for leaching of soluble pesticides (Maas, et al., 1984).

Terracing

Terraces are ridges and channels constructed across a slope. They are divided into two general classes--graded terraces and level terraces. Graded terraces divert water to a grassed waterway or to some other non-erosive drain. Level terraces hold water on the field, thereby increasing infiltration water and allowing redeposition of eroded soil. Both types of terraces help reduce surface runoff, with the greatest reductions occurring in dry areas with level terraces (Maas, et al., 1984).

Increased infiltration from terracing may result in an increased potential for leaching of pesticides to ground water. This is due to the minimized surface runoff, which allows more water to infiltrate into the ground. Level terraces are often used in semi-arid areas to supplement the general lack of moisture in the root zone; in such areas the depth to ground water is greater so the likelihood of pesticides reaching the water table is reduced.

Contour Stripcropping

Stripcropping consists of alternating rows of the main crop with strips of either a grain crop, sod, or a legume. It is effective in controlling surface runoff and soil erosion by wind and water (Maas, et al., 1984). Stripcropping can also help in reducing insect, nematode, and weed problems in some cases, thus reducing the amounts of required pesticides (National Science Foundation, 1975). Stripcropping also helps reduce the total area of land to which pesticides are applied, thus reducing the quantity of pesticide used.

Cover Crops

The purpose of cover crops is to provide vegetative cover to the soil to control soil erosion during the non-growing season. Insecticide requirements are generally unchanged from those with conventional tillage, although with no-till, a contact herbicide may be required to kill the cover crop (Smith, et al., 1979).

Variable Practices

Farming involves making a large number of choices regarding where, when, and how crops are planted and harvested; the variety of plants to be grown; and pest management. Depending upon the tillage practices used, such variable practices can have different impacts on the quantities of pesticides used, and thus, the amount that might be available to leach. Table 5-1 shows the possible impacts of each variable practice on insecticide and herbicide use when practiced with each of the fixed practices. The table shows whether pesticide use would likely increase or decrease as compared to not employing the particular variable practice.

Crop Rotation

Crop rotation involves periodically changing the crops grown on a particular area. This practice can reduce the quantities of pesticide used when practiced with any of the tillage methods. In addition, crop rotation can help to improve soil structure, organic matter content, and infiltration, thereby making conditions more favorable for crop growth (Smith, et al., 1979). The principle behind crop rotation and pest control is to eliminate insect pests of a specific crop by introducing non-host crops into the crop rotation program. Crop rotation is most effective in reducing numbers of pests that are poor competitors and have low survivability and mobility.

Crop rotation has proven to be especially effective against corn rootworm. Corn rootworm numbers have been found to be dramatically reduced by rotating crops with corn on consecutive years (Maas, et al., 1984). Crop rotation has also proven useful in controlling nematodes and billbugs in wheat (Martin and Leonard, 1967).

TABLE 5-1: POSSIBLE EFFECTS OF FARMING FACTORS ON QUANTITIES OF PESTICIDES USED*

Practice	Conservation Tillage		No-Till		Ridge-Till		Other Conventional Tillage	
	In	H	In	H	In	H	In	H
Crop Rotation	D/3	D/1	D/3	D/3	D/3	D/2	D/3	D/1
Contour Stripcropping	D/2	D/2	D/2	D/2	D/2	D/2	D/2	D/2
Cover Crops	N	N	I/1	I/1	N	N	N	N
Pest Resistant Varieties	D/2	N	D/1	N	D/2	N	D/2	N
Adjusting Planting and Harvest Times	D/2	D/1	D/1	D/3	D/2	D/1	D/2	D/2
IPM	D/3	D/1	D/2	D/2	D/2	D/1	D/2	D/2

In - Insecticide
H - Herbicide

I - Increase
N - No Significant Impact
D - Decrease

1 - Minor Impact
2 - Moderate Impact
3 - Major Impact

* The table shows generally whether pesticide use would likely increase or decrease compared to not employing the practice. The effect on actual amounts used at a given location is dependent on site-specific conditions.

Planting Pest-Resistant Varieties

A non-chemical pest control method that is steadily increasing is the planting of pest-resistant varieties. About 75 percent of the total U.S. acreage is planted with pest- and disease-resistant crop varieties. Insecticide use in the United States was significantly reduced between 1971 and 1982 (Maas, et al., 1984), partly due to the use of pest-resistant varieties. Resistance can help the plant to either inhibit pest growth or recover from injury inflicted by the pest. However, to reduce the quantity of pesticides used with pest-resistant varieties, pest scouting and monitoring are still necessary to ensure that pesticides are applied only when pest numbers approach economic thresholds.

Adjusting Planting and Harvesting Times

Planting can often be timed to give crops a competitive edge over insects and weeds, thus decreasing the requirement for pesticide use. A study in Wisconsin, for example, showed that corn planted before weed emergence required minimal use of herbicides. Herbicides were needed in only two out of ten locations investigated. The study showed that early crop canopy, particularly in narrow rows, gave the corn a competitive advantage over weeds and slowed water movement in soil, thus reducing the potential for pesticide leaching (Kogan, 1982).

Adjustments in planting and harvesting times can also help in reducing damage from insects and the use of insecticides. Planting as soon as the soil is warm enough to permit rapid plant growth can help corn to avoid corn borer attack. Planting of winter wheat late enough for the main brood of hessian flies to have emerged and died can reduce damage from these pests (Martin and Leonard, 1967). For soybeans, early planting is encouraged so that a plant canopy can form before the flight of second generation moths of the corn earworm (Maas, et al., 1984).

Timing of harvesting can also reduce the need for pesticides. Early harvesting, before insects reach economic thresholds, has proven effective for a variety of pests, including sugarcane borers, sweet potato weevils, potato tuber worms, and cabbage loopers (Maas, et al., 1984).

Integrated Pest Management

All farming practices discussed above can be incorporated into an integrated pest management (IPM) system of controlling pests with minimal use of pesticides. IPM is a pest control strategy that utilizes appropriate control methods to keep pest populations below economic thresholds with the least undesirable impacts on the environment. It includes both chemical and non-chemical means of pest control.

Practicing IPM can reduce the overall quantities of pesticides used, leading to a decreased potential for pesticide leaching to ground water and transport to other environmental media. It has been estimated that a 40 percent reduction in current pesticide use may result from IPM programs that are now available, with an estimated projection to a 60 percent reduction in the next decade by continuing these programs (USDA, 1985).

An effective IPM system requires extensive knowledge of the ecology of the system of interest (Maas, et al., 1984) and generally will require the use of Extension specialists or pest consultants. One text that includes discussion of IPM (van der Bosch, 1978) suggests the following general guidelines for setting up an IPM system:

1) Understand the biology of the crop, and how it is influenced by the surrounding ecosystem.

2) Identify the key pests; know their biology; recognize the kind of damage they inflict; and initiate studies on the economic impact of these damages.

3) Identify the key environmental factors that impinge upon the pest.

4) Consider concepts, methods, and materials that individually or in combination will help suppress permanently or restrain pest species.

5) Structure IPM programs so that they will have the flexibility needed to adjust to ecosystem changes.

6) Anticipate unforeseen developments; expect setbacks; move with caution; and remain aware of the ecosystem complexity.

7) Seek the weak links in the key pest life cycle and narrowly direct control practices at these weak links, avoiding broad ecosystem impacts.

8) Whenever possible, use methods that preserve, complement, and augment biotic and physical mortality factors of the pest.

9) Whenever feasible, attempt to diversify the ecosystem.

IPM systems for reducing pesticide use have proven effective for a number of crops including corn, soybeans, and cotton (Maas et al., 1984). Crop rotation has been combined with pest scouting and monitoring to help eliminate corn rootworm beetle populations (Luckman, 1978). Monitoring and scouting, optimal planting dates, natural control agents, resistant varieties, trap crops, selective use of insecticides, and treatments based on economic thresholds have proven effective for controlling pests (Rudd, et al., 1980).

Note: At present, IPM methods for insect pest control, while still not available for all crops and all pests, are generally more developed than for weed control. Since many of the commonly used herbicides are considered to have significant leaching potential, many workshop participants and reviewers from the agricultural and environmental communities noted a particular need for research to develop IPM methods for weed control.

CHAPTER SIX

IRRIGATION PRACTICES

Irrigation is the practice of applying water to the land to provide sufficient moisture for crop production. Irrigation is needed because rainfall is either insufficient for crop needs or does not occur at the ideal time during the growing season. Proper use of irrigation can increase crop yields and quality by counteracting high or low temperatures, eliminating short droughts, and aiding germination and continuous plant growth (Soil Conservation Service, 1983).

A proper irrigation strategy can also help to make site conditions less conducive to pesticide leaching and help reduce the quantities of pesticides used. The goals of the strategy are to apply pesticides when site conditions are less likely to promote leaching and to ensure the most efficient use of the pesticides.

With all methods of irrigation, water inputs should be managed to limit the potential for pesticide leaching (Helling, 1986). Water conservation practices, such as the use of soil moisture monitors to determine field water requirements, will help avoid over-watering and minimize the potential for dissolved chemicals to leach with the excess water.

Irrigation practices that can influence the potential for pesticides to leach to ground water include the method of irrigation (fixed practice) and the timing, volume, and frequency of irrigation (variable practices). The potential for pesticides to leach is also dependent upon the relationship between the method of irrigation and the method of pesticide application (See Chapter Four). Table 6-1 shows the potential for pesticide leaching of various irrigation methods practiced with various pesticide application practices. For leaching potentials listed in Table 6-1, it is assumed that the applied pesticide has a high potential to leach, based upon its physio-chemical properties.

Fixed Practices

Methods of Irrigation

Irrigation methods commonly used in commercial agriculture can be categorized generally into three basic types:

TABLE 6-1: POTENTIAL FOR PESTICIDE LEACHING WITH VARIOUS METHODS OF IRRIGATION AND PESTICIDE APPLICATION*

	Irrigation Method - Soil Type								
	Sprinkler			Drip			Flood		
Application Method	Clay	Loam	Sand	Clay	Loam	Sand	Clay	Loam	Sand
Foliar Application	L	M	M	L	L	L	L	L	L
Surface Application									
Pre-Plant/Emergent	L	M	M	L	L	M	M	M	H
Post Emergent	L	M	M	L	L	M	M	M	M
Soil Incorporated									
Pre-Plant/Emergent	M	M	H	L	M	M	M	H	H
Post Emergent	L	M	H	L	M	M	M	M	H
Chemigation	L	M	H	L	M	M	M	H	H

L - Low Leaching Potential
M - Moderate Leaching Potential
H - High Leaching Potential

* The table assumes that a pesticide with chemical-physical properties indicating leaching potential is being used. Actual leaching potential will depend on the specific pesticide and site properties.

flood or furrow, sprinkle, and trickle or drip. There are many variations within these categories and there are other methods designed for specific crop needs and site conditions. A growing practice, known as chemigation, is to apply pesticides and/or fertilizers through the irrigation systems.

Flood or Furrow Irrigation

In this method of irrigation, water is retained within some type of ridge or dike and infiltrates into the ground in response to gravity. Water is pumped or allowed to flow from ground or surface sources into the ridged or diked area. In level or graded basin irrigation, for example, all or part of the crop is flooded temporarily until the soil absorbs the water. In furrow irrigation, water is ponded between crop rows in furrows created during planting and cultivation (Soil Conservation Service, 1983). Flood or furrow irrigation may promote leaching of soil incorporated and surface applied pesticides because it is difficult to avoid over-application of water with this method (Helling, 1986). Over-watering may promote downward movement or desorbtion of pesticides, particularly where soils are highly permeable.

Sprinkle Irrigation

In sprinkle irrigation, water is sprayed into the air through perforated pipes or nozzles operated under pressure. Sprinkle systems can be classified into three broad categories: portable, solid-set, or self-propelled (Soil Conservation Service, 1983).

Sprinkle irrigation offers the greatest potential to promote pesticide leaching when it washes foliar applied pesticides from crop and weed surfaces before they are effectively utilized. When foliar applied pesticides are used with sprinkle irrigation, therefore, proper timing of irrigation with regard to pesticide application is essential.

Trickle or Drip Irrigation

In trickle irrigation, water is applied slowly on or beneath the surface layer--usually as drops, tiny streams, or miniature spray--through emitters or applicators placed along a water delivery line. Trickle systems are normally designed to apply light, frequent applications of water and to wet only part of the soil (Soil Conservation Service, 1983).

Since trickle irrigation is a relatively conservative user of water, the potential for over-application of water and subsequent leaching of pesticides can also be relatively low.

Chemigation

With chemigation, pesticides (or fertilizers) are mixed with irrigation water before they are applied to the field, and irrigation and application is done simultaneously. Chemigation can be done with any irrigation system and method as long as the pesticide and the method of application are compatible. For example, surface applied pesticides should only be applied with drip or flood irrigation. While it is common practice to irrigate at the same time as pesticide application, some experts recommend that only the amount of water needed to activate the pesticide should be applied when chemigating (see Irrigation Timing, below).

Although research is limited on this subject, there is some concern that the practice may promote leaching because the pesticide (or fertilizer) is being applied continuously or in pulses when it is already dissolved (Helling, 1986). The potential impact of chemigation when practiced with drip irrigation systems, however, may be lower because less water is used with this method compared with flood and sprinkler irrigation, and the pesticide is being applied in localized areas nearer the crop. Another possible source of ground-water contamination associated with chemigation is faulty, leaky, or non-existing anti-back-siphoning devices (see section on Chemigation Back-Siphoning Devices in Chapter Seven).

Variable Practices

Irrigation Timing

The proper timing of irrigation relative to pesticide application can enable the pesticides to be utilized most effectively. Under relatively dry conditions, soil incorporated or surface applied pesticides will remain in the root zone or be adsorbed onto soil particles before significant leaching can occur. However, when excessive water is applied before pesticides degrade or can be taken up by plants, mobile pesticides may move with infiltrating irrigation water and leaching may occur. Because of this possibility, irrigation should be delayed, when practical, following pesticide application. The delay time is a function of, among other factors, the rate of plant uptake of the pesticide and the pesticide degradation rate.

The rate of plant uptake of soil applied pesticides is generally a function of the transpiration rate of the plant. In addition, plant uptake also increases as the root zone depth increases (Carsel, et al., 1984). Therefore, for post-emergent pesticides applied to mature crops, a shorter delay time is necessary than for post-emergent pesticides applied to young plants or pre-emergent or pre-plant applied pesticides. The necessary delay time is also shorter for pesticides with faster degradation rates in soil, which is an inverse function of the pesticide half-life. Appendix B shows degradation rates for selected pesticides in soil.

For foliar applied pesticides which rely on contact with the plant surface for effectiveness, sprinkle irrigation too soon after application may wash pesticide off onto the soil before the full benefit of the pesticide is obtained. Again, by delaying irrigation which may wash pesticides from plant surfaces, the pesticide can be fully utilized and the potential for pesticide leaching reduced. The delay time between foliar application and irrigation is generally a function of the degradation rate of the pesticide on foliage. For pesticides with short half-lives, the necessary delay time is shorter. Appendix B shows degradation rates for selected pesticides on foliage.

Irrigation Volume and Frequency

As stated earlier, avoiding excess water inputs can be an effective method of limiting the potential for pesticide leaching. Studies have shown that fields are often irrigated at unnecessarily high volumes and frequencies (University of Nebraska, 1984), and irrigation amounts can almost always be reduced with no significant impacts on yield.

Irrigation volumes and frequencies can be limited through soil moisture monitoring and with the help of various water conserving best management practices (BMPs). Soil moisture monitoring can be done with portable moisture meters and probes that indicate soil moisture levels. This practice can help determine the water requirement in a field and will identify when water contents become low enough to cause crop stress.

CHAPTER SEVEN

OTHER PRACTICES TO REDUCE CONTAMINATION POTENTIAL

In many areas of the country, natural hydrogeologic conditions make pesticide leaching to ground water more likely to occur than in other areas. Factors that are generally conducive to pesticide leaching include high ground-water recharge rates, highly permeable soils, soils with low capacities to adsorb or biologically degrade pesticides, and shallow ground water depths. In karst areas, ground water can also become contaminated by surface water running into sinkholes.

The potential for pesticides entering ground water can be increased by man-made alterations to the land such as poorly constructed, improperly sealed currently used or abandoned wells, and agricultural drainage wells. The potential can also be increased from chemigation systems that are improperly equipped.

This chapter describes actions, not all strictly management practices, that can be taken either to minimize the likelihood of pesticides entering ground water or to minimize the impact on water supplies if contamination should occur.

Note: Workshop participants and reviewers generally agreed that the practices described in this chapter should be employed <u>everywhere</u>, regardless of hydrogeologic vulnerability.

Handling and Disposal of Pesticides and Pesticide Products

Spills and improper disposal of <u>any</u> pesticide, not just those pesticides considered to have high leaching potential, can result in ground-water contamination. If a spill or release occurs, "slugs" of the pesticide can overwhelm normal decomposition processes and soil adsorption capacity, resulting in a high potential for pesticide leaching. Careful handling and disposal of pesticides are critical parts of an overall effort to reduce the risk of ground water contamination.

Studies in Wisconsin, Iowa, California, North Carolina, and other states suggest that incidents in which pesticide concentrations in ground water exceed State standards are often the result of pesticide spills and leaks during loading, handling, or storing of pesticides, and from pesticide equipment rinsing.

Pesticide storing, mixing, or loading activities should be conducted as far from wells as possible to prevent contamination. These activities should take place, whenever feasible, on an impervious foundation or on a ground cover to retain spilled materials. The USDA Soil Conservation Service can provide information to farmers interested in constructing special facilities for mixing and loading designed to minimize the potential for ground water contamination. Care should be taken that storm drains and any routes of runoff from the area are protected by berms or diking.

Closed-system transfer, mixing, and loading of pesticides can substantially reduce worker exposure and facilitate pesticide handling. In these systems the chemical is delivered through gravity flow, suction, or pumping, thus eliminating the need to open and handle pesticide containers. Closed systems meter and transfer pesticide products from shipping container to mixing or application tanks, and often rinse the emptied containers as well. Closed systems can also provide greater accuracy in measuring the dosage, and reduce or eliminate fill site contamination from spillage. Mechanical failures such as hose breaks, and backsiphoning into water sources, however, may occur with these systems, depending on their design and operation.

Recommendations for pesticide handling have been summarized by the University of Wisconsin (1987):

1) Open pesticide containers carefully.

2) When adding water to a spray mixer, the hose or pipe should remain above the level of the mixture at all times to avoid the possibility of back-siphoning into the water source. An input line should be submerged in the mix only when it is equipped with a reliable anti-siphoning device.

3) If an emulsifier or spreader-sticker is used, it should be added before the tank is full because these materials tend to cause foaming.

4) Be careful to avoid overflow and never leave a spray tank unattended while it is being filled.

5) Always have materials for containing or cleaning up a spill close at hand. Know ahead of time what to do to contain a spill of the particular chemical being used. A spill must be controlled, contained and cleaned up. Since different chemicals require different actions, it is a good idea to have on hand the "Emergency Response Information Sheets" or "Safety

Data Sheets" from manufacturers that have them available. These provide detailed information about what to do in case of a spill.

Significant ground-water contamination can result if pesticide containers break from rough handling, weathering, corrosion, or age. Proper storage can help avoid these problems. The label instructions for each registered pesticide contain brief but explicit instructions regarding storage and disposal. Pesticide containers and materials may be stored ideally in a separate fire-resistant facility on a pallet or on a raised impervious or concrete platform. The storage facility should be hydrologically downgradient and a safe distance from the drinking water well and any other sensitive areas. Spill containment measures, such as paving and diking the area, will prevent releases to the environment. Routine inspection of the condition of pesticide containers and the storage facility can minimize the potential for leaks or spills. Additionally, maintaining an inventory of stored and used pesticides can be helpful in this regard.

Damage to containers and spills can occur during transportation. Precautions should be taken to avoid such accidents, for example, by examining the condition of the containers, fastening containers to prevent shifting and damage, and protecting against weather conditions.

Steps should be taken to minimize pesticide-related waste and reduce disposal problems. Reduction in left-over tank mixes, rinse water, and the number of pesticide containers requiring disposal will enhance ground water protection efforts. In all cases, label directions should be followed exactly. Only the required amount of pesticide solution should be mixed and equipment must be carefully calibrated. Rinse water can be sprayed on cultivated fields where feasible and consistent with label directions. Fresh water can be carried and used to flush spraying equipment in the field.

Federal law requires triple rinsing of pesticide containers, or jet-spray cleaning, before disposal (Federal Insecticide, Fungicide and Rodenticide Act). Rinsed containers should be stored securely prior to disposal to minimize the chance of inadvertent exposure to humans or the environment. Metal containers may be recycled through scrap metal dealers; those not suitable for recycling or refilling by distributors should be disposed of in a sanitary landfill.

The potential for pesticide contamination of ground water may be significantly reduced by employing common sense, caution, and the methods and procedures discussed above.

Chemigation Anti-Backsiphoning Devices

A growing practice in many areas of the country is the application of fertilizers and pesticides through irrigation systems, often termed "chemigation". Although there are systems specifically designed for chemigation, in most cases an existing irrigation system is modified to mix the chemical with irrigation water for application to crops. Pesticides (or fertilizers) are generally stored in large tanks located near wells drawing ground-water for irrigation. Pesticides flow from the storage tanks into the irrigation water (see Figure 7-1).

Concerns about pesticide ground-water contamination from this practice rise from two potential problems: (1) if the system is not well designed and therefore not operating properly, the chemical-laden water may be applied unevenly or at an improper rate, resulting in inefficient use of the chemical and a greater potential for leaching; and (2) accidental backflow or siphoning of chemicals into the well may occur when the irrigation pumping system shuts down unexpectedly (Schepers and Hoy, 1987).

The importance of careful timing and application of pesticides and irrigation water in reducing risks of pesticide contamination due to leaching are discussed in Chapters Four and Six. Because of the potential for ground-water contamination from backflow into wells, this section discusses requirements for anti-backsiphoning equipment on irrigation systems used for pesticide application.

Many States already require the use of anti-backsiphoning devices on chemigation systems. The State of Nebraska requires also that chemigation systems contain inspection ports built into the chemigation system pipelines to allow visual inspection of the check valves (State of Nebraska, 1986). In addition, EPA recently notified pesticide registrants that they must place specific chemigation use directions on the label of any pesticide they wish to be eligible for use in such systems.

Unless the pesticide user's equipment meets these EPA label requirements, it will be a violation of the Federal pesticide law to use the pesticide in the chemigation system. Labeling requirements, PR Notice 87-1, for chemigation systems connected to sprinkler, flood, and drip irrigation systems include:

1) The system must contain a functional check valve, vacuum relief valve, and low pressure drain appropriately located on the irrigation pipeline to prevent water source contamination from backflow.

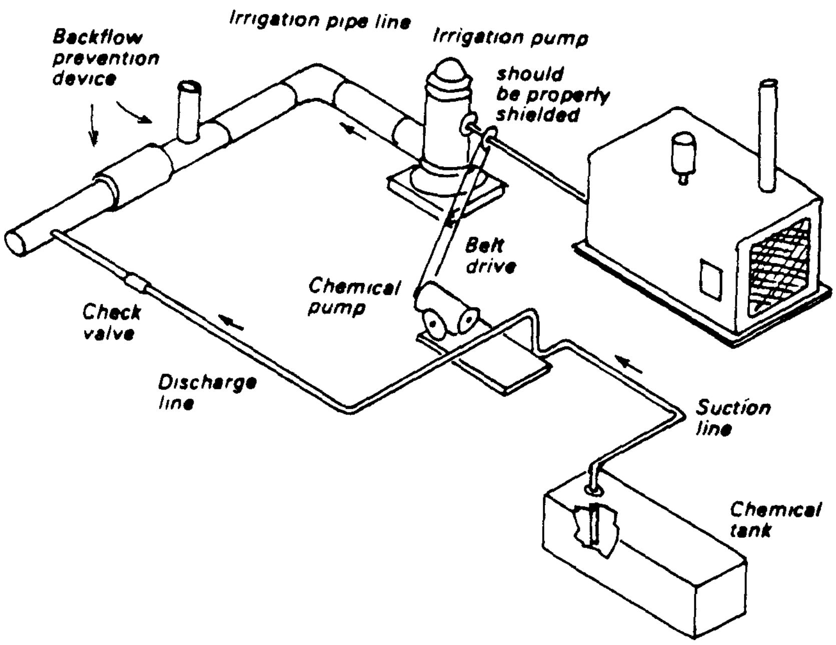

FIGURE 7-1
CHEMIGATION SYSTEM WITH ANTI-BACKSIPHONING DEVICE

SOURCE: ASAE 1980

2) The pesticide injection pipeline must contain a functional, automatic, quick-closing check valve to prevent the flow of fluid back toward the injection pump.

3) The pesticide injection pipeline must also contain a functional, normally closed solenoid-operated valve located on the intake side of the injection pipe and connected to the system interlock to prevent fluid from being withdrawn from the supply tank when the irrigation system is either automatically or manually shut down.

4) The system must contain functional interlocking controls to automatically shut off the pesticide injection pump when the water pump motor stops.

5) The irrigation line or water pump must include a functional pressure switch, which will stop the water pump motor when the water pressure decreases to the point where pesticide distribution is adversely affected.

Readers who wish to obtain a copy of the EPA labeling requirements for pesticides to be used in chemigation should write to the Registration Division, Office of Pesticide Programs, TS767C, U.S. Environmental Protection Agency, Washington, D.C. 20460 and refer to PR Notice 87-1.

Buffer-Zone Establishment

A buffer zone is an established area or distance between a polluting activity (e.g., nonpoint source of entry of pesticides into ground water) and a point of ground-water discharge such as a well. The purpose of the buffer zone is to allow adequate space and/or time for dilution, dispersion, or degradation of the pesticide before it reaches the ground water to minimize its potential adverse impacts. The concept of altering activities to protect the ground water in portions of the recharge area to a well is fundamental to the new Wellhead Protection Program established under the 1986 Safe Drinking Water Act amendments. While buffer zones are generally useful, they protect primarily existing wells, not future or potential sources of drinking water (some future wells may be located in wellhead protection areas).

Establishing a buffer zone adequate in size and configuration to provide protection against pesticides entering into ground water that supplies a well depends upon a number of factors. First, pesticides vary in the speed and degree to which they degrade in ground water. Also important are hydrogeologic conditions--such as the depth to ground water, ground-water flow velocities, ground-water flow patterns, ground-water recharge rates, aquifer types, recharge and withdrawal rates, and assimilative capacity of the aquifer. A larger buffer zone may be required for groundwater that is particularly vulnerable to contamination. Vulnerable ground-water resources may include aquifers with shallow ground water or permeable soils with little or no adsorptive capacity and/or high recharge rates. In addition, consolidated rock aquifers that are highly fractured present particular challenges to protection, in many cases comparible to the karst problem discussed later. Readers interested in more information regarding methods for determining size of wellhead areas (buffer zones) should obtain a copy of "Guidelines for Delineation of Wellhead Protection Areas," published by the Office of Ground-Water Protection, U.S.Environmental Protection Agency, WH-550G, Washington, D.C. 20460.

Drinking water wells most likely to be impacted by pesticides leaching to ground water are the domestic supply wells located in rural areas near agricultural fields and community supply wells where there is a high degree of interface between agricultural and residential land use. Wells that are hydrologically downgradient from crop lands have the greatest potential to be impacted. For private wells at risk to pesticide contamination, stopping the use of pesticides in the area around the well can be an effective means of providing extra protection to current sources of water supply. Of course, other practices, such as those described in this report, should be used to protect all other ground water to help assure its quality for future use.

Many experts recommend that pesticides should not be mixed, stored, handled, or applied in the immediate vicinity of a well (e.g., 25 to 50 feet) to avoid direct well contamination and run-in from the land surface.

Proper Well Sealing and Abandonment

Water wells with improper sealing around the well casings can provide a direct conduit for pesticides to enter ground water from the land surface (Exner and Spalding, 1985). If a well casing is backfilled with gravel, sand, or other permeable materials, pesticides can run down the side of the casing and into ground water. Inadequate grouting and sealing can also lead to contamination of confined aquifers which would otherwise be protected from surface contaminants. Inadequate grouting and sealing can be a problem particularly if the well is located in a topographically low area susceptible to surface runoff.

State standards for well construction should be followed. Generally, to prevent ground-water contamination via improperly sealed wells, the well should be sealed with bentonite grout or some other form of relatively impermeable material. In addition, the well should be sealed with concrete for at least two feet below ground surface.

As is the case with wells that are inadequately grouted and sealed, abandoned wells can also provide a direct conduit for pesticides to reach ground water, particularly if the well is located in an area susceptible to runoff or chemical spills. Also, abandoned wells may be used to dispose of chemicals by parties unaware of the environmental or legal implications.

Although many States have strict codes regarding the abandonment of wells, these codes are difficult and sometimes impossible to enforce. Proper well abandonment often requires pressure grouting and the blocking of casing perforations to adequately seal off different aquifers and to prevent movement of water through annular spaces. It may involve removal of the well casing or the pump above the ground.

Avoiding Sinkholes in Areas of Karst or Subsidence

Karstic hydrogeologic conditions are found in agricultural areas, especially in the midwest and southeastern United States. Under so called "conduit karst" conditions, ground water may flow through openings (see Figure 7-2) such as caves, rather than through porous or highly fractured material as diffuse flow (Quinlan and Ewers, 1985). In karst areas, sinkholes may form at the surface allowing runoff water to flow into ground water in underground conduits (Hallberg and Hoyer, 1982). Subsidence due to excessive ground water extractions can cause fractures and cracking in the ground, increasing opportunity for movement of pesticides into ground water.

Sinkholes, when located in areas susceptible to runoff from agricultural fields, provide a direct path for pesticides to reach ground water. Also, pesticides entering ground water in karst areas can travel for long distances with little or no dilution or attenuation.

Several methods are available to help ensure that pesticide-contaminated surface runoff does not enter sinkholes. Runoff can be channeled away from the sinkhole; cover crops not requiring pesticides can be planted around the sinkhole; and pesticide use in the immediate area of the sinkhole can be stopped by use of a buffer strip made of grass or non-crop vegetation.

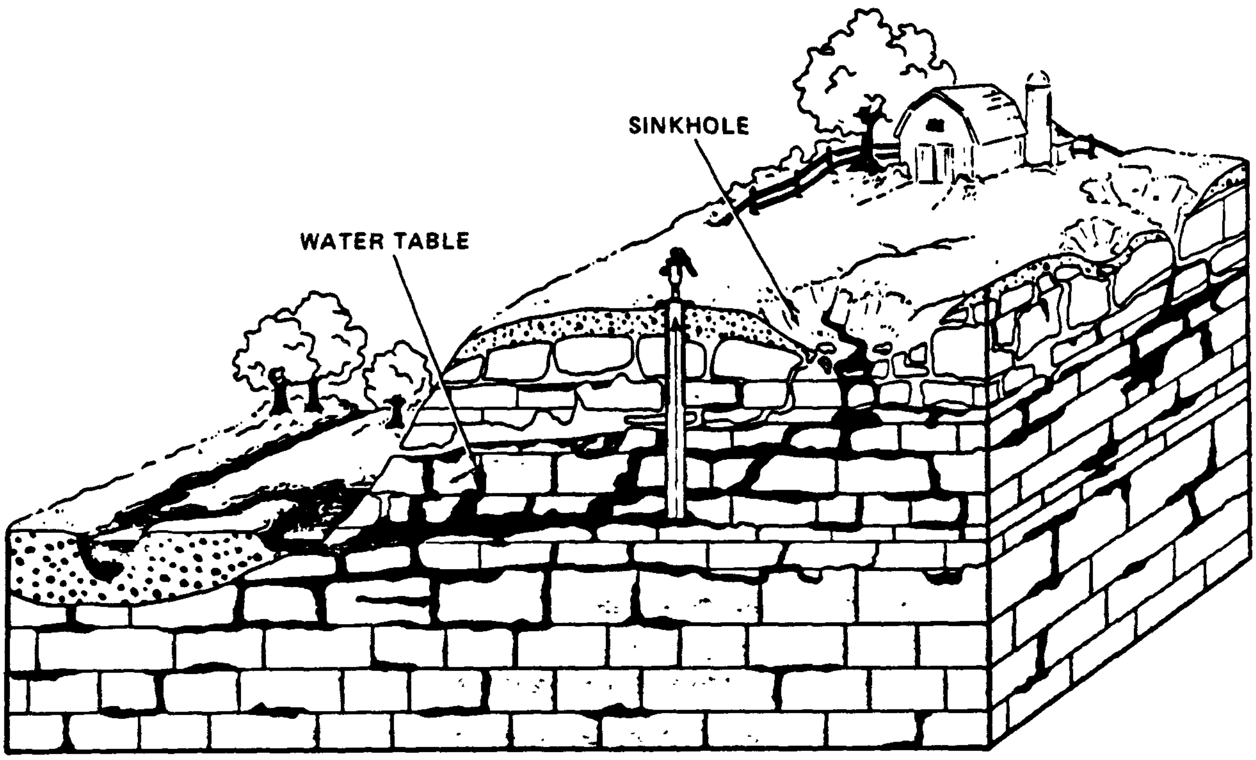

FIGURE 7-2
KARSTIC GROUND-WATER CONDITIONS

SOURCE Hallberg, et al, 1984

Sealing of Agricultural Drainage Wells

Agricultural drainage wells (ADWs) are sometimes used to drain excess water from fields, particularly during wet seasons, providing a direct route for pesticides to enter ground water (Grahm, et. al., 1977). Although installation of new ADWs is illegal in most States, many old wells still exist.

ADWs are usually located in topographically low areas susceptible to surface runoff. The wells generally consist of a cistern or basin to collect water and a well that drains directly into the ground. Generally, ADWs are found in areas that have underlying consolidated aquifers with high secondary porosities. Relatively few are found in unconsolidated aquifers because those wells frequently clog.

To prevent ground-water contamination from ADWs, new wells should not be constructed and old wells should be properly abandoned. Proper abandonment involves removal of old well casing where possible, overreaming the borehole to greater than its original diameter, and plugging the boring with impermeable materials.

Subsurface Drainage and Treatment

Subsurface drains are often used to draw off excess water from agricultural fields (Hallberg, et. al., 1986). The drained water is then discharged to surface water or allowed to drain into ground water through agricultural drainage wells (see the discussion of ADWs above). When subsurface drainage contains high concentrations of contaminants, treatment, such as carbon treatment, may be needed before final discharge of the drainage water to minimize adverse impacts on either ground or surface water (Stryk, et. al., 1977).

Tile drains can be used to drain large areas without disrupting the natural soil structure (Stryk, et. al., 1977). The tile drains are designed to lower the water table to allow drainage and cultivation and to improve plant rooting. Tile drains are used extensively throughout the corn belt States to improve soil drainage in seasonally or perennially wet soils. Tile drains help to collect unused or excessive pesticides applied to a crop land. The leachate may be recycled for use as irrigation water, or it may be diverted to grass waterways where soil adsorption and degradation processes can take place. (Note that some herbicides will kill the grass, however.)

Farm Ponds and Irrigation Re-Use Pits

Farm ponds are often constructed on farm facilities by damming up small streams. These ponds form reservoirs of water for irrigation, for livestock use, or for fish culture. They often collect surface runoff which may contain high concentrations of pesticides. Since the ponds may be deeper than the water table, the possibility of contaminating adjacent ground water exists.

A measure to reduce risks that may result from pesticide contamination of farm ponds is to establish a buffer zone between the pond and nearby drinking water wells. The potential for ground water contamination from the ponds can also be minimized by limiting pesticide use in nearby fields.

Irrigation re-use pits are often built in topographic low areas adjacent to agricultural fields. The pits are used to store runoff from fields for re-use as irrigation water. Because the pits contain direct runoff, the water often contains high concentrations of pesticides.

Lining of irrigation re-use pits with low permeability clays such as bentonite can help minimize the potential impacts the pits may have on ground-water quality. In addition, mitigation measures should also include locating the pits as far as possible from drinking water wells.

APPENDIX A

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APPENDIX B

DEGRADATION RATE CONSTANTS FOR SELECTED PESTICIDES

Tables B-1 and B-2 present degradation rate constants for selected pesticides on foilage and for selected pesticides in soil respectively. These constants express the rates at which pesticides decay or breakdown when present on plant surfaces or in the soil. Knowledge of these degradation rates can aid in preventing ground-water contamination. Pesticides which degrade relatively fast should be chosen over those which degrade slower, assuming that performance and applicability are consistent with intended use.

TABLE B-1: DEGRADATION RATE CONSTANTS FOR SELECTED PESTICIDES ON FOLIAGE

Class	Group	Decay Rate ($days^{-1}$)
Organochlorine	Fast	0.231 - 0.1386
	(aldrin, dieldrin, ethylan, heptachlor, lindane methoxychlor).	
	Slow	0.1195 - 0.0510
	(chlordane, DDT, endrin, toxaphene).	
Organophosphate	Fast	0.2772 - 0.3013
	(acephate, chlorpyrifos-methyl, cyanophenphos, diazinon, dipterex, ethion, fenitrothion, leptophos, malathion, methidathion, methyl parathion, phorate, phosdrin, phosphamidon, quinalphos, alithion, tokuthion, triazophos, trithion).	
	Slow	0.1925 - 0.0541
	(azinphosmethyl, demeton, dimethoate, EPN, phosalone).	
Carbamate	Fast (carbofuran)	0.630
	Slow (carbaryl)	0.1260 - 0.0855

TABLE B-1: DEGRADATION RATE CONSTANTS FOR SELECTED PESTICIDES ON FOLIAGE (Continued)

Class	Group	Decay Rate ($days^{-1}$)
Pyrethroid	(permethrin)	0.0196
Pyridine	(pichloram)	0.0866
Benzoic acid	(dicamba)	0.0745

Source: Knisel, 1980.

TABLE B-2: SOIL DEGRADATION RATE CONSTANTS FOR SELECTED PESTICIDES

Chemical Name	Degradation Rate Constant ($days^{-1}$)	Reference
Alachlor	0.0384	a
Aldicarb	0.0322 - 0.0116	a
Atrazine	0.0149 - 0.0063	a
Benanyl	0.1486 - 0.0023	a
Bifenox	0.1420	a
Carbaryl	0.1196 - 0.0768	a
Carbofuran	0.0768 - 0.0079	a
Chlordane	0.0020 - 0.0007	
Chloropropham	0.0058 - 0.00267	d
Cyanazine	0.0495	c
Dalapon	0.0462 - 0.0231	d
Diazinon	0.0330 - 0.0067	a
Dicamba	0.2140 - 0.0197	a
Dichlobenil	0.0116 - 0.0039	
2,4-Dichlorophenoxy-acetic Acid	0.0693 - 0.0231	d
Dinoseb	0.0462 - 0.0231	d
Diuron	0.0035 - 0.0014	d
Fenitrothion	0.1155 - 0.0578	a
Fluometuron	0.0231	c
Linuron	0.0280 - 0.0039	a
Malathion	0.291 - 0.4152	a
Methoxychlor	0.0046 - 0.0033	a
Methyl Parathion	0.2207	a
Monuron	0.0046 - 0.0020	d
Parathion	0.2961 - 0.0046	a
Permethrin	0.0396	e
Phorate	0.0363 - 0.0040	a
Picloram	0.0354 - 0.0019	a
Propachlor	0.0231 - 0.0139	d
Propanil	0.693 - 0.231	d
Propazine	0.0035 - 0.0017	d
Simazine	0.0539 - 0.074	a
Toxaphene	0.0046	e
Trifluralin	0.0956 - 0.0026	a
Zineb	0.0512	a

TABLE B-2: SOIL DEGRADATION RATE CONSTANTS FOR SELECTED PESTICIDES (Continued)

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a Nash, R.G., 1980. Dissipation Rate of Pesticides from Soils. Chapter 17. IN CREAMS: A Field Scale Model for Chemicals Runoff, and Erosion from Agricultural Management Systems. W. G. Knisel, ed. USDA Conservation Research Report No. 26. 643 pp.

b Smith, C.N., Partition Coefficients (Log K_{OW}) for Selected Chemicals. Athens Environmental Research Laboratory, Athens, GA. Unpublished report, 1981.

c Herbicide Handbook of the Weed Science Society of America, 4th ed. 1979.

d Control of Water Pollution from Cropland, Vol. I, a manual for guideline development, EPA-600/2-75-026a.

e Smith, C.N. and R. F. Carsel. Foliar Washoff of Pesticides (FWOP) Model: Development and Evaluation. Accepted for publishing in Journal of Environmental Science and Health - Part B. Pesticides, Food Contaminants, and Agricultural Wastes, B 19(3), 1984.

Source: Carsel, et al. 1984

APPENDIX C

DOMINANT SOIL ORDERS OF THE U.S.

Figure C-1 shows patterns of dominant soil orders and suborders of the U.S. and identifies crops and topographic conditions that are associated with each. This figure provides information useful in the identification of topographic and soil conditions which is necessary for the selection of mitigation measures to reduce pesticide leaching. How these factors should be considered in the selection of mitigation measures is described in Part I of this report.

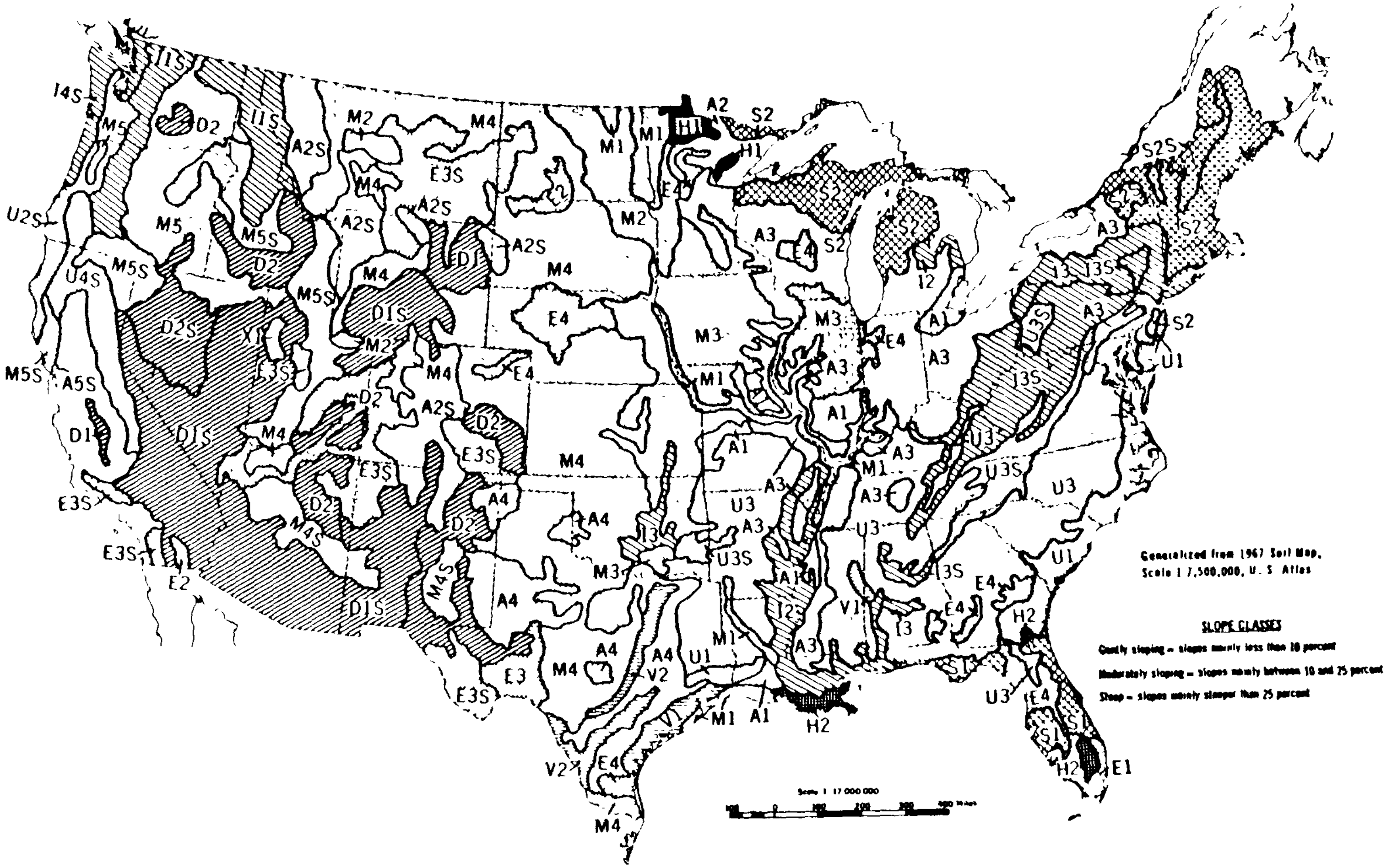

FIGURE C-1
PATTERNS OF SOIL ORDERS AND SUBORDERS OF THE U.S.

SOURCE U.S. Soil Conservation Sevice

U S DEPARTMENT OF AGRICULTURE

LEGEND

Only the dominant orders and suborders are shown. Each delineation has many inclusions of other kinds of soil. General definitions for the orders and suborders follow. For complete definitions see Soil Survey Staff, Soil Classification, A Comprehensive System, 7th Approximation, Soil Conservation Service, U. S. Department of Agriculture, 1960 (for sale by U. S. Government Printing Office) and the March 1967 supplement (available from Soil Conservation Service, U. S. Department of Agriculture). Approximate equivalents in the modified 1938 soil classification system are indicated for each suborder.

ALFISOLS Soils with gray to brown surface horizons, medium to high base supply, and subsurface horizons of clay accumulation; usually moist but may be dry during warm season

A1 **AQUALFS** (seasonally saturated with water) gently sloping; general crops if drained, pasture and woodland if undrained (Some Low-Humic Gley soils and Planosols)

A2 **BORALFS** (cool or cold) gently sloping; mostly woodland, pasture, and some small grain (Gray Wooded soils)

A2S **BORALFS** steep; mostly woodland

A3 **UDALFS** (temperate or warm, and moist) gently or moderately sloping; mostly farmed, corn, soybeans, small grain, and pasture (Gray-Brown Podzolic soils)

A4 **USTALFS** (warm and intermittently dry for long periods) gently or moderately sloping; range, small grain, and irrigated crops (Some Reddish Chestnut and Red-Yellow Podzolic soils)

A5S **XERALFS** (warm and continuously dry in summer for long periods, moist in winter) gently sloping to steep; mostly range, small grain, and irrigated crops (Noncalcic Brown soils)

ARIDISOLS Soils with pedogenic horizons, low in organic matter, and dry more than 6 months of the year in all horizons

D1 **ARGIDS** (with horizon of clay accumulation) gently or moderately sloping; mostly range, some irrigated crops (Some Desert, Reddish Desert, Reddish-Brown, and Brown soils and associated Solonetz soils)

D1S **ARGIDS** gently sloping to steep

D2 **ORTHIDS** (without horizon of clay accumulation) gently or moderately sloping; mostly range and some irrigated crops (Some Desert, Reddish Desert, Sierozem, and Brown soils, and some Calcisols and Solonchak soils)

D2S **ORTHIDS** gently sloping to steep

ENTISOLS Soils without pedogenic horizons

E1 **AQUENTS** (seasonally saturated with water) gently sloping; some grazing

E2 **ORTHENTS** (loamy or clayey textures) deep to hard rock; gently to moderately sloping; range or irrigated farming (Regosols)

E3 **ORTHENTS** shallow to hard rock; gently to moderately sloping; mostly range (Lithosols)

E3S **ORTHENTS** shallow to hard rock; steep; mostly range

E4 **PSAMMENTS** (sand or loamy sand textures) gently to moderately sloping; mostly range in dry climates, woodland or cropland in humid climates (Regosols)

HISTOSOLS Organic soils

H1 **FIBRISTS** (fibrous or woody peats, largely undecomposed) mostly wooded or idle (Peats)

H2 **SAPRISTS** (decomposed mucks) truck crops if drained, idle if undrained (Mucks)

INCEPTISOLS Soils that are usually moist, with pedogenic horizons of alteration of parent materials but not of accumulation

I1S **ANDEPTS** (with amorphous clay or vitric volcanic ash and pumice) gently sloping to steep; mostly woodland; in Hawaii mostly sugar cane, pineapple, and range (Ando soils, some Tundra soils)

I2 **AQUEPTS** (seasonally saturated with water) gently sloping; if drained, mostly row crops, corn, soybeans, and cotton; if undrained, mostly woodland or pasture (Some Low-Humic Gley soils and Alluvial soils)

I2P **AQUEPTS** (with continuous or sporadic permafrost) gently sloping to steep; woodland or idle (Tundra soils)

I3 **OCHREPTS** (with thin or light-colored surface horizons and little organic matter) gently to moderately sloping; mostly pasture, small grain, and hay (Sols Bruns Acides and some Alluvial soils)

I3S **OCHREPTS** gently sloping to steep; woodland, pasture, small grains

I4S **UMBREPTS** (with thick dark-colored surface horizons rich in organic matter) moderately sloping to steep; mostly woodland (Some Regosols)

MOLLISOLS Soils with nearly black, organic-rich surface horizons and high base supply

M1 **AQUOLLS** (seasonally saturated with water) gently sloping; mostly drained and farmed (Humic Gley soils)

M2 **BOROLLS** (cool or cold) gently or moderately sloping, some steep slopes in Utah; mostly small grain in North Central States, range and woodland in Western States (Some Chernozems)

M3 **UDOLLS** (temperate or warm, and moist) gently or moderately sloping; mostly corn, soybeans, and small grains (Some Brunizems)

M4 **USTOLLS** (intermittently dry for long periods during summer) gently to moderately sloping; mostly wheat and range in western part, wheat and corn or sorghum in eastern part, some irrigated crops (Chestnut soils and some Chernozems and Brown soils)

M4S **USTOLLS** moderately sloping to steep; mostly range or woodland

M5 **XEROLLS** (continuously dry in summer for long periods, moist in winter) gently to moderately sloping; mostly wheat, range, and irrigated crops (Some Brunizems, Chestnut, and Brown soils)

M5S **XEROLLS** moderately sloping to steep; mostly range

SPODOSOLS Soils with accumulations of amorphous materials in subsurface horizons

S1 **AQUODS** (seasonally saturated with water) gently sloping; mostly range or woodland; where drained in Florida, citrus and special crops (Ground-Water Podzols)

S2 **ORTHODS** (with subsurface accumulations of iron, aluminum, and organic matter) gently to moderately sloping; woodland, pasture, small grains, special crops (Podzols, Brown Podzolic soils)

S2S **ORTHODS** steep; mostly woodland

ULTISOLS Soils that are usually moist, with horizon of clay accumulation and a low base supply

U1 **AQUULTS** (seasonally saturated with water) gently sloping; woodland and pasture if undrained, feed and truck crops if drained (Some Low-Humic Gley soils)

U2S **HUMULTS** (with high or very high organic-matter content) moderately sloping to steep; woodland and pasture if steep, sugar cane and pineapple in Hawaii, truck and seed crops in Western States (Some Reddish-Brown Lateritic soils)

U3 **UDULTS** (with low organic-matter content; temperate or warm, and moist) gently to moderately sloping; woodland, pasture, feed crops, tobacco, and cotton (Red-Yellow Podzolic soils, some Reddish-Brown Lateritic soils)

U3S **UDULTS** moderately sloping to steep; woodland, pasture

U4S **XERULTS** (with low to moderate organic-matter content, continuously dry for long periods in summer) range and woodland (Some Reddish-Brown Lateritic soils)

VERTISOLS Soils with high content of swelling clays and wide deep cracks at some season

V1 **UDERTS** (cracks open for only short periods, less than 3 months in a year) gently sloping; cotton, corn, pasture, and some rice (Some Grumusols)

V2 **USTERTS** (cracks open and close twice a year and remain open more than 3 months) general crops, range, and some irrigated crops (Some Grumusols)

AREAS with little soil

X1 *Salt flats*

X2 Rockland, ice fields

NOMENCLATURE

The nomenclature is systematic. Names of soil orders end in sol (L. solum, soil), e.g. ALFISOL, and contain a formative element used as the final syllable in names of taxa in suborders, great groups, and sub-groups.

Names of suborders consist of two syllables, e.g. AQUALF. Formative elements in the legend for this map and their connotations are as follows:

- and – Modified from Ando soils; soils from vitreous parent materials
- aqu – L. aqua, water; soils that are wet for long periods
- arg – Modified from L. argilla, clay; soils with a horizon of clay accumulation
- bor – Gr. boreas, northern; cool
- fibr – L. fibra, fiber; least decomposed
- hum – L. humus, earth; presence of organic matter
- ochr – Gr. base of ochros, pale; soils with little organic matter
- orth – Gr. orthos, true; the common or typical
- psamm – Gr. psammos, sand; sandy soils
- sapr – Gr. sapros, rotten; most decomposed
- ud – L. udus, humid; of humid climates
- umbr – L. umbra, shade; dark colors reflecting much organic matter
- ust – L. ustus, burnt; of dry climates with summer rains
- xer – Gr. xeros, dry; of dry climates with winter rains

AUGUST [illegible]

FIGURE C-1 (cont.)
PATTERNS OF SOIL ORDERS AND SUBORDERS OF THE U.S.

APPENDIX D

INFORMATION SOURCES

To design an appropriate State or Local program to reduce risks of pesticide contamination, consideration must be given to hydrological conditions, cropping patterns, agricultural practices, pest control needs, and alternatives. Information on these topics is available from a variety of sources; the guide which follows describes several sources including key agencies and organizations and the information they can provide (see Figure D-1 for a summary).

The Cooperative Extension Service (CES), a joint program of the U.S. Department of Agriculture (USDA), States, and counties, serves the American agricultural community through dissemination and application of information generated by research efforts. The CES is the most extensive and readily available source of information on agriculture and plays an important role in educating pesticide users. Local offices of the CES may be found in the telephone directory, usually listed under the U.S. Department of Agriculture.

The U.S. Soil Conservation Service (SCS), among other activities, provides direct technical assistance to landowners in designing and carrying out plans for conserving soil and protecting water quality. SCS soil surveys provide detailed information on soil type and distribution as well as other data useful in assessing the potential for ground water contamination from pesticides. Local offices of the SCS may also be found in the telephone directory, usually under U.S. Department of Agriculture.

Land Grant Universities generally have major agriculture and science programs and represent excellent sources of information. Federal and State governments and industry sponsor many projects conducted by leading researchers at these institutions. Firsthand knowledge of local or regional agricultural practices may be obtained through contact with these investigators. Land Grant Universities are also linked to the Cooperative Extension Service.

Agricultural Experiment Stations and Water Resources Research Institutes are sources of local and regional information and are usually associated with major universities or colleges. Results of research typically are available as technical reports documenting findings and observations of agricultural and water resource investigations.

States generally have a Department of Natural Resources, Water Quality, Environmental Protection, or similarly named agency responsible for managing and protecting ground water. These agencies are potential sources of information, as are State Soil and Water Conservation Agencies. Offices of State agencies can be found in the telephone directory. State Geological Surveys generally have major ground water programs, and in light of the recent interest in pesticide contamination, many may have ongoing research projects in this area. State surveys are sometimes located in capital cities but may also be associated with colleges or universities.

The U.S. Geological Survey (USGS) is the principal Federal agency conducting ground water resources investigations. Technical details concerning the geology and water resources of many areas of the country are presented in USGS Water Supply Papers. These reports, usually available at major college or university libraries, provide information essential for evaluating the vulnerability of the study area to ground water contamination. The USGS headquarters is located in Reston, Virginia, with numerous offices in other locations.

U.S. Geological Survey
12201 Sunrise Valley Drive
Reston, Virginia 22091
(703)860-7000

The Conservation Technology Information Center is a clearinghouse for information encouraging conservation systems for soil and water on croplands. Information relating to conservation tillage and water quality protection is currently available; fact sheets on pesticide and nitrate contamination of ground water are under development at the time of this writing. For specific information, contact:

The Conservation Technology Information Center
1220 Potter Drive
Room 170
Purdue Research Park
West Lafayette, Indiana 47906-13314
(317)494-9555

The National Agriculture Library publishes a series of commodity-oriented environmental bibliographies. Two recent bibliographies -- "Conservation Tillage and "Chemigation" -- include the latest available information from United States publications involving commodity protection relating to these two aspects of ground water contamination, pesticides use, and alternative agricultural practices. These, and other publications, can be obtained through:

National Agricultural Library
U.S. Department of Agriculture
Beltsville, Maryland 20705

Resources For The Future, a non-profit research association, has compiled a data base of pesticide use estimates for a typical year in the 1980s. It details the percent of acreage treated with pesticides and the application rate per acre on a State and county level. Information concerning this data base can be obtained from:

Resources For the Future
1616 P. Street, N.W.
Washington, D.C. 20036
(202)328-5000

National Pesticide Information Retrieval System (NPIRS) is a data base produced by Purdue University. It contains pesticide chemical and registration data for 50,000 products registered by EPA, as well as thousands of State registrations. Facts sheets for each registered pesticide contain data on product names, pesticide use patterns, EPA registration numbers, formulations, active ingredients, and sites and crops where the pesticides are used. Information on NPIRS, including accessing information, can be obtained by contacting:

User Services Manager, NPIRS
Entomology Hall
Purdue University
West Lafayette, Indiana 47907
(317) 494-6614

The Institute for Alternative Agriculture is an organization dedicated to advancing agricultural economics, resource conservation, and environmental protection. Information on alternative farming practices which may be implemented to reduce the potential for ground water contamination from pesticides is available from the Institute:

Institute for Alternative Agriculture
9200 Edmonston Road
Suite 117
Greenbelt, Maryland 20770
(301) 441-8777

Farm Chemicals Handbook, published annually, is a directory and reference for fertilizer and pesticide users. It contains information on specific pesticides, including chemical names, trade names, common names, chemical properties, toxicity, applications, and formulation. The handbook can be obtained by contacting:

Meister Publishing Company
37841 Euclid Avenue
Willoughby, Ohio 44094
(216) 942-2000

The Weed Science Society of America produces the "Herbicide Handbook." It contains an alphabetical listing of all available herbicides and includes information on common names; chemical names; chemical and physical properties, including structural and molecular formulae, vapor pressure, and adsorption parameters; herbicide use, including application methods, associated crops, and application rates; toxicology; and behavior in soil and general potential for leaching. This publication can be obtained by contacting:

Weed Science Society of America
309 West Clark Street
Campaign, Illinois 61820
(217) 356-3182

Weed Control Manual and Insect Product Guide contain listings of insecticides and herbicides by various crop types. Also included are mixing instructions, use instructions, and lists of weeds and insects controlled by each pesticide. The guides can be obtained by contacting:

Ag Consultant and Fieldman
37841 Euclid Avenue
Willoughby, Ohio 44094
(216) 942-2000

TABLE D-1
SOURCES OF INFORMATION

SOURCES	GEOLOGY AND SOIL	WATER QUALITY	PESTICIDES	AGRICULTURAL PRACTICES	ALTERNATIVE TECHNOLOGY	CONSERVATION
	TYPES OF INFORMATION					
COOPERATIVE EXTENSION SERVICE	●	●	●	●	●	●
SOIL CONSERVATION SERVICE	●	●		●	●	●
LAND GRANT UNIVERSITY	●	●	●	●	●	●
STATE AGRICULTURAL EXPERIMENT STATION	●	●	●	●	●	●
STATE WATER RESOURCES RESEARCH INSTITUTE		●				
STATE GEOLOGICAL SURVEY	●	●				
STATE GROUND WATER AGENCY	●	●	●			
STATE SOIL AND WATER CONSERVATION AGENCY	●	●		●		●
U.S. GEOLOGICAL SURVEY	●	●	●			
CONSERVATION TECHNOLOGY INFORMATION CENTER		●		●	●	●
NATIONAL AGRICULTURAL LIBRARY	●	●	●	●	●	●
RESOURCES FOR THE FUTURE			●			
NATIONAL PESTICIDE INFORMATION RETRIEVAL SYSTEM			●			
INSTITUTE FOR ALTERNATIVE AGRICULTURE			●	●	●	●
FARM CHEMICALS HANDBOOK			●	●		
HERBICIDE HANDBOOK			●	●		
INSECT PRODUCT GUIDE			●	●		