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Report to the Chairman, Subcommittee on Superfund, Ocean and Water Protection, Committee on Environment and Public Works, U.S. Senate

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GROUNDWATER PROTECTION

Validity and Feasibility of EPA's Differential Protection Strategy

148291

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Program Evaluation and
Methodology Division

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December 9, 1992

The Honorable Frank R. Lautenberg
Chairman, Subcommittee on Superfund, Ocean and Water
Protection
Committee on Environment and Public Works
United States Senate

Dear Mr. Chairman:

In your letter of February 27, 1991, you asked us to evaluate the feasibility of differentially protecting groundwater from pesticide contamination based on the relative vulnerability of different geographic areas. This approach had been set forth by the Environmental Protection Agency in its Proposed Agricultural Chemicals Strategy and has since been finalized in its Pesticides and Ground-Water Strategy. In Groundwater Protection: Measurement of Relative Vulnerability to Pesticide Contamination (GAO/PEMD-92-8), we reported on part one of our two-part evaluation and present herein our findings on part two. Specifically, we assess the validity of scientific groundwater vulnerability modeling efforts, as well as the likelihood that states will be able to perform valid assessments.

As agreed with your office, we plan no further distribution of this report until 30 days from its date of issue, unless you publicly announce its contents earlier. At that time, we will send copies to the Administrator of the Environmental Protection Agency. We will also make copies available to interested organizations, as appropriate, and to others upon request.

If you have any questions or would like additional information, please call me at (202) 275-1854 or Kwai-Cheung Chan, Director of Program Evaluation in Physical Systems Areas, at (202) 275-3092. Other major contributors to this report are listed in appendix III.

Sincerely yours,

Eleanor Chelimsky
Assistant Comptroller General

Executive Summary

Purpose

Groundwater is the drinking water source for approximately half of our population. It is essential to agriculture and industry, and it sustains aquatic and terrestrial ecosystems. In the past decade, there have been increasing reports of pesticide contamination of groundwater, and once contaminated, groundwater is very difficult to clean up. In October 1991, the U.S. Environmental Protection Agency (EPA) issued its Pesticides and Ground-Water Strategy, a new approach for protecting groundwater from pesticide contamination under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This strategy embodies the notion of differentially protecting groundwater from pesticides on the basis of the value of the groundwater and the relative vulnerability of different geographic areas.

The Chairman of the Subcommittee on Superfund, Ocean and Water Protection of the Senate Committee on Environment and Public Works asked GAO to examine the feasibility of implementing this strategy. In the first part of this two-part evaluation, Groundwater Protection: Measurement of Relative Vulnerability to Pesticide Contamination (GAO/PEMD-92-8), GAO found that (1) because of the large geological variability within many counties, the appropriate level for a differential protection strategy is generally the subcounty level; and (2) including information on the size of the population dependent on a groundwater source (that is, the population at risk) when targeting vulnerable areas would significantly alter the outcomes of many assessments of groundwater contamination risk. In the present report, GAO examines (1) the data available to states for assessing groundwater vulnerability and (2) the validity of models designed to predict groundwater contamination by pesticides.

Background

In the past, the EPA approach had been to limit groundwater pesticide contamination largely through national restrictions, using authority granted to it in FIFRA. (However, there are only two cases in which leaching to groundwater played a key role in the cancellation of a pesticide.) Under the new strategy of differential protection, if EPA determines that a pesticide poses a significant human health or environmental risk (because it may leach to groundwater) and the risk cannot be dealt with by labeling or national restricted use provisions, a state management plan (SMP) will be required for the sale and use of the pesticide in a state. The plan must describe how the risks will be addressed. As part of these plans, states will target specific areas, distinguishing those locales that warrant enhanced protection from those that merit less attention because of the lower value of the groundwater and/or their lower vulnerability to groundwater contamination.

GAO surveyed state officials to assess the readiness of states to implement the new EPA strategy. A set of three questionnaires was sent to each state. Responses were received from 45 or more states for each survey. Issues addressed included the availability of data necessary for conducting vulnerability assessments and plans for protecting groundwater.

Through a computer-based literature search, GAO identified and then reviewed 40 studies that examined the correspondence between vulnerability assessment model predictions and monitoring results. Vulnerability assessment models play a central role in EPA's new strategy. GAO found evaluations of models that represent three approaches used for assessing groundwater vulnerability: parameter-weighting, empirical, and simulation-modeling. Twenty-nine models were evaluated in the 40 studies. GAO synthesized the results of the studies to assess the suitability of using these models when developing SMPs.

Results in Brief

Based on the surveys of state officials, GAO finds that many states possess at least some of the data necessary for conducting groundwater vulnerability assessments. However, there are significant gaps in the data that do exist. Officials in only 15 states reported that data have been mapped in their state for all 8 vulnerability factors necessary for conducting valid assessments. Even when data are available, they often cover only part of the state and are not sufficiently detailed to use in preparing valid assessments. In fact, no state has been completely mapped at a sufficient resolution for every factor. Thus, in order to conduct valid groundwater vulnerability assessments, states need to collect more data.

GAO finds that the performance of vulnerability assessment models has been inconsistent. At best, existing models have been shown to predict groundwater vulnerability adequately only in some cases (that is, for some pesticides in some soils). Moreover, the model tests have generally not been conducted on the subcounty scale necessary to show whether the EPA differential protection strategy is either scientifically sound or economically viable. To be useful for regulatory purposes, both the models and their testing will have to be improved.

GAO's Analysis

Data Availability and Sufficiency

As already noted, there are gaps in the data needed to conduct valid vulnerability assessments. In addition to incomplete data for geologic mapping, approximately half of the states do not have data on the vadose and confining zones. Further, existing information does not generally possess a sufficient degree of geographic resolution to be useful in vulnerability assessments (that is, a scale of 1:62,500 or greater). Twenty-five states have mapped data for both depth and description of the confining zone. However, no state has been mapped for either of these factors at a sufficient resolution for more than 40 percent of the state. Finally, there is great variability across states in the availability and sufficiency of the data.

Despite these problems, officials in most states reported that they intended to develop SMPs and that differential protection would be part of these plans. Given the current data limitations in many states, it is unclear that groundwater vulnerability assessments can be of sufficient detail to fulfill the goals of the EPA strategy.

Model Validation

GAO identified four studies in which a parameter-weighting approach for assessing groundwater vulnerability was used. (See approach for assessing groundwater vulnerability was used. (See chapter 3 for a discussion of this approach.) All were tests of the DRASTIC method. (See table 3.2.) The most extensive tests of DRASTIC have found no positive relationship between DRASTIC scores and pesticide contamination. The failure of DRASTIC to perform acceptably is especially important since EPA had in the past promoted its use for conducting vulnerability assessments and many states have used DRASTIC when doing their own assessments.

GAO located one study in which an empirical approach was used. Specifically, discriminant analysis was used to predict groundwater contamination. Although the model was successfully tested, it has only been validated once and then for only one pesticide. In addition, the testing was done by its developers. Thus, the consistency of the model is still an open question, and independent replication is needed.

The other 35 studies used a simulation-modeling approach. Despite generally favorable reports by scientists on the models they tested, none of these mathematical models has been adequately validated to justify its use for developing SMPs. The four most tested models show some promise for particular pesticides. However, for other chemicals, the results have been inconsistent. None of the other models have been sufficiently tested to gain an understanding of their usefulness. Moreover, we found no instances in which these models had been tested at a subcounty level. Thus, the appropriateness of using them to predict at this scale is in doubt. To use these models for vulnerability assessments at this time would require site-specific validation for all pesticides to be used.

Many states have conducted vulnerability assessments. However, as differentiated from the 40 scientific studies reviewed, the states have generally used unvalidated methods for their assessments, and in most cases, model predictions have not been verified with monitoring data.

Recommendations

Based upon state data availability and model validity, GAO concludes that implementation of the new EPA strategy at this time is premature. Many states lack the data necessary to implement a differential protection strategy, and the models for predicting pesticide contamination of groundwater have not yet been successfully validated. GAO therefore recommends that the Administrator of EPA take the following steps: (1) rather than fully implement the EPA strategy, conduct pilot tests in a limited number of states to ensure that the plans can be meaningful; (2) in the interim, continue to protect groundwater through the use of uniform national standards while increasing the consideration of groundwater contamination in the regulation of pesticides; and (3) continue to support, to the extent possible, scientific development in the field, including state data gathering activities and the development and refinement of vulnerability models.

Agency Comments

EPA officials reviewed and provided oral comments on the draft report. EPA generally agreed with GAO's findings that the states lack data at a subcounty level and that vulnerability assessment methods have not been sufficiently validated. However, EPA believes that, even with these problems, differential protection is a viable and effective way of dealing with groundwater contamination from pesticides. GAO disagrees. At issue is the usefulness of implementing a strategy that, to work as intended, requires data that do not currently exist and are unlikely to exist in the near future. GAO also believes that, given the current status of vulnerability assessment methods, protective actions cannot be adequately targeted and therefore a differential protection strategy would not be effective.

Contents

Figures

Abbreviations

AGGR	Aggregate model
CMLS	Chemical movement in layered soils
CREAMS	Chemicals, runoff, and erosion from agricultural management systems
DBCP	Dibromochloropropane
DDT	1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane
DRASTIC	Depth ... recharge ... aquifer ... soil ... topography ... impact ... conductivity
EPA	Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GAO	General Accounting Office
GIS	Geographic information system
GLEAMS	Groundwater loading effects of agricultural management systems
LEACHM	Leaching estimation and chemistry model
LEACHMP	Leaching estimation and chemistry model—pesticides
MOUSE	Method of underground solute evaluation
PESTAN	Pesticide analytical model
PRZM	Pesticide root zone model
RZWQM	Root zone water quality model
SAFTMOD	Saturated zone flow and transport model
SESOIL	Seasonal soil compartment model
SMP	State management plan
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VADOFT	Vadose zone flow and transport model
VIP	Vadose zone interactive processes

Introduction

Groundwater is stored below the land's surface in saturated soil and rock formations. It is a vital and irreplaceable resource in the United States that we increasingly rely upon for a variety of uses. Approximately half of our population, as well as 90 percent of our country's rural residents, obtain drinking water from underground sources. Seventy-five percent of American cities derive their water supplies, either totally or at least partially, from groundwater. Groundwater is also essential to agriculture and industry in many areas. Ensuring the purity of groundwater is therefore of vital importance to the nation. This importance is reinforced by the cost of replacing groundwater with water from other sources and, in some cases, by the lack of alternative sources. In addition, once contaminated, groundwater is very difficult, time-consuming, and expensive—if not impossible—to clean up. Furthermore, it has been estimated that 30 percent of the flow in streams and rivers is provided by groundwater discharges. Groundwater contamination thus may affect terrestrial and aquatic ecosystems as well as human activities.

Sources of groundwater contamination include septic tanks, landfills, aboveground and underground storage tanks, and pesticide application. Indeed, the Office of Technology Assessment identified 33 generic sources of groundwater contamination.[1] Complicating the problem is the fact that protecting groundwater is much more difficult than protecting surface water. Among other things, groundwater moves more slowly than does surface water, thereby resulting in less dilution of the contaminant(s). Also, it is more difficult to monitor groundwater for contamination than it is to monitor surface water.

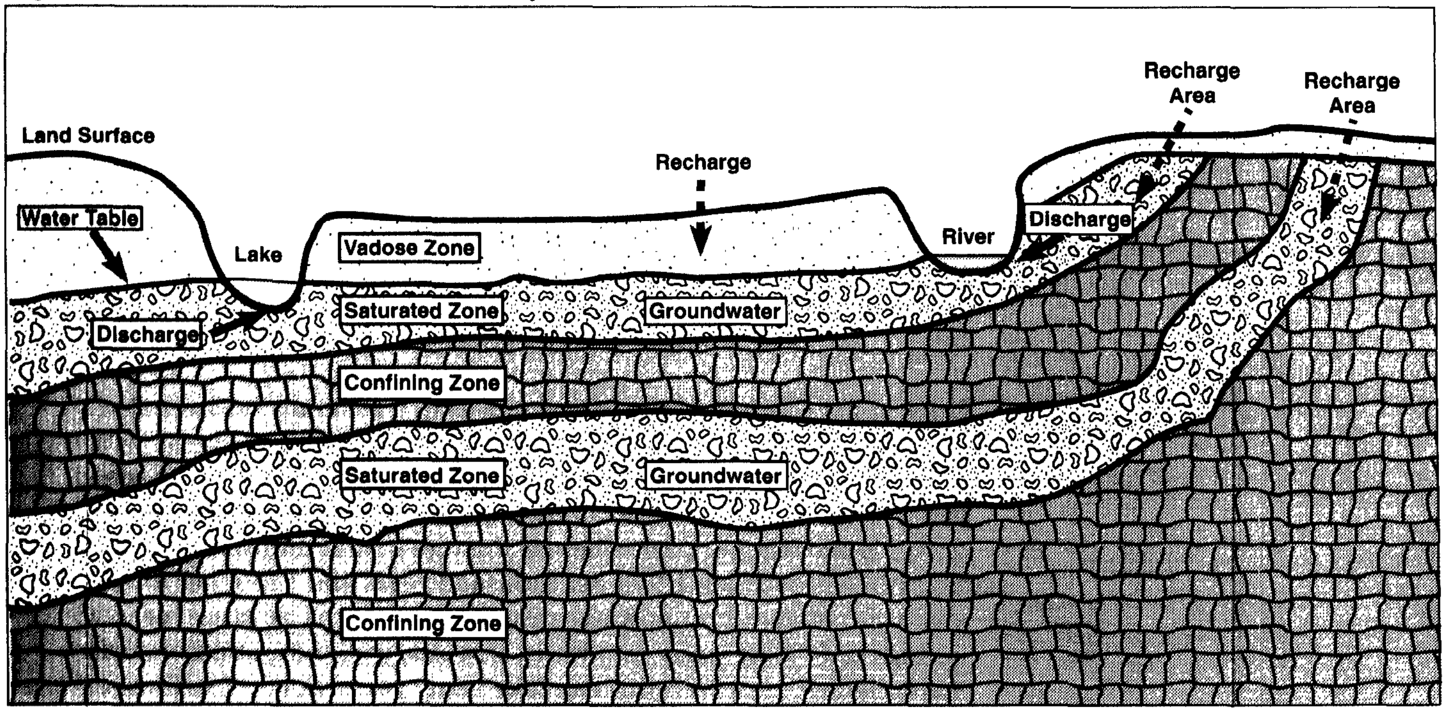
Groundwater Systems

Figure 1.1 shows some important hydrologic components of a groundwater system. Water, generally from precipitation, enters the soil and gradually moves downward to become groundwater—that is, if it is not first taken up by plants, evaporated into the atmosphere, or held within soil pores. This percolating water, called recharge, passes downward through the vadose zone until it reaches the water table and the saturated zone.[2] Eventually, the groundwater resurfaces in discharge areas. Climate, topography, and geology determine the type and location of natural areas of recharge and discharge. Prior to the pumping of groundwater to serve human needs, an equilibrium exists between long-term natural recharge and discharge rates.

[1]U.S. Congress, Office of Technology Assessment, Protecting the Nation's Groundwater from Contamination: Volume II, OTA-O-276 (Washington, D.C.: October 1984).

[2]The vadose zone is also called the unsaturated zone.

Figure 1.1: Cross Section of a Groundwater System



Source: EPA

The uppermost zone in a groundwater system is called the vadose zone. In the vadose zone, the space between the grains of soil and rock or the cracks in the rock contain both water and air. Although there can be a substantial amount of water in the vadose zone during wet periods, water in the vadose zone is not considered groundwater even though it may eventually migrate into groundwater formations. The properties of the land surface and vadose zone control the extent of recharge of water from the land surface to the saturated zone below. These properties include the slope of the land, extent of vegetation cover, thickness of the vadose zone, the inherent capabilities of the vadose zone materials to conduct water, and the presence of cracks or fractures in the zone.

The bottom of the vadose zone is the water table. At the water table, water is under pressure equal to atmospheric pressure, whereas in the vadose zone pressure is less-than-atmospheric. The level of the water table fluctuates seasonally based primarily on rainfall. However, other factors, such as well pumping, also affect the level of the water table.

The water table is also the top of the saturated zone; hence, it serves as a boundary between the vadose and saturated zones. Only when water reaches the saturated zone does it become classified as groundwater. This is the zone from which water may be obtained by pumping. The saturated zone may exist near the surface or be thousands of feet underground. In the saturated zone, all voids and cracks between soil and rock are completely filled with water (that is, the porous material is saturated with water). In this zone, water is under greater-than-atmospheric pressure.

Once in the saturated zone, water moves in a generally horizontal direction in response to gravity, friction, and pressure gradients within the zone. In general, groundwater moves quite slowly. However, its speed varies greatly. It has been estimated that the flow rate in clean sand and gravel is 100 feet per year, whereas the rate in unfractured dense limestone is between 1 foot per thousand years and 1 foot per million years. Eventually, groundwater resurfaces in discharge areas, producing springs or feeding water into wells, streams, wetlands, or other surface water bodies. However, this can take many years. Some "fossil water" has been sequestered under the soil for thousands of years.

The saturated zone is known as an aquifer if the formation yields significant quantities of water to wells and springs. [3] Two properties of geologic materials determine their ability to store and transmit water: porosity (the amount of space to store water) and permeability (a measure of the relative ease with which water can move through the material due to the connections between the spaces). An aquifer is a saturated, porous, permeable earth material from which significant quantities of water can be produced on the surface. The most productive aquifers are highly permeable formations next to streams, where the adjacent flowing water can quickly supplement the aquifer's storage.

The confining zone is a layer of relatively impermeable material that restricts the flow of water. Two major types of aquifers, based on the characteristics of the confining zone, have been defined. An aquifer with a confining zone below but not above is called an unconfined aquifer. The top of an unconfined aquifer is the water table. An aquifer with confining zones both below and above is called a confined aquifer. The top of a

[3]This is a very imprecise definition, and hence, there is no definitive distinction between what is and is not an aquifer. The minimum water content necessary to classify a rock formation as an aquifer is a relative concept dependent on the availability of other water sources in the area.

confined aquifer is usually well below the water table. A confined aquifer is less vulnerable to pollution percolating down from the surface. Recharge and hence contamination come primarily from water flowing laterally into the aquifer. These recharge zones may be many miles from where the aquifer is tapped. An unconfined aquifer may also be recharged by laterally flowing water, in addition to water leaching through soils. Well water can be drawn from both unconfined and confined aquifers.

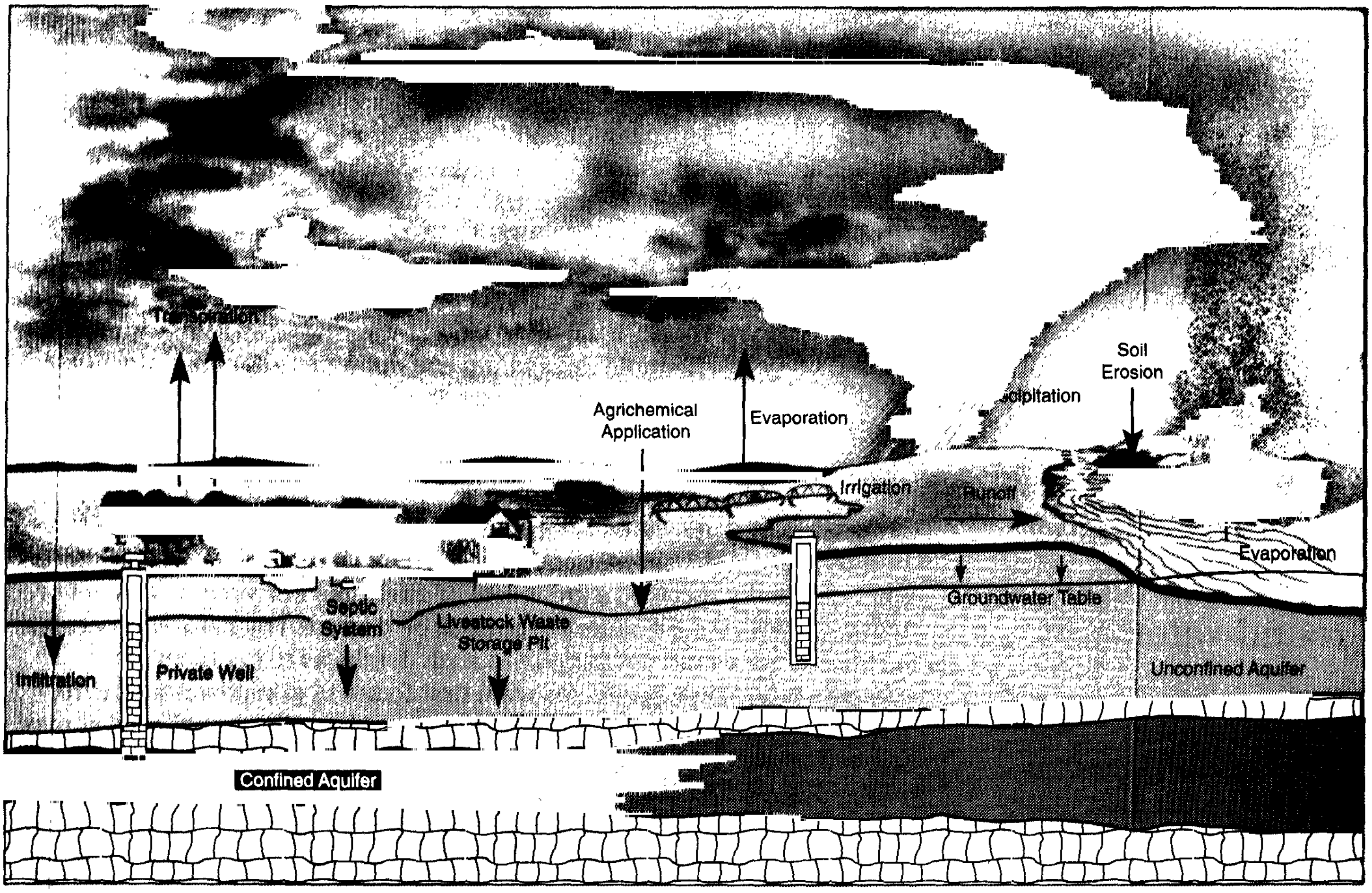
Groundwater systems vary greatly. They can vary in area, depth below the land surface, volume of water stored, permeability, interconnectedness, and velocity of flow. Some are rather small and simple, with a single aquifer having a short flow path to a nearby spring or stream. Others are quite complex, with multiple aquifers and confining zones and flow paths of over a hundred miles. For example, the Ogallala Aquifer underlies parts of eight states and ranges from South Dakota to Texas.

Pesticide Contamination of Groundwater

To what extent pesticides are currently present in groundwater and how best to prevent contamination from occurring in the future are questions that have lately received a great deal of attention. For years it was believed that pesticides would adhere to soils or be degraded by natural processes and therefore would not migrate to such depths as to contaminate groundwater. When pesticides were first found in groundwater in 1979, this notion was shattered. Since then, reports have been published across the nation concerning incidents of local groundwater contamination by pesticides.

Figure 1.2 shows the major pathways by which agricultural chemicals reach groundwater. The usual route is via downward percolation from a surface source. The chemical is transported, usually via water, through the vadose zone down to the groundwater. However, groundwater systems vary and are not equally vulnerable to contamination. Among the factors that affect vulnerability are the properties and conditions of the soil, as well as climatic and environmental variables. For instance, the temperature of the soil can affect groundwater vulnerability. The warmer the soil, the faster the pesticide breaks down, and the less likely it is to reach the groundwater. Characteristics of potential pollutants (for example, pesticides) also vary, making some more likely to reach groundwater than others.

Figure 1.2: Principal Sources of Agricultural Chemical Contamination of Groundwater[a]



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

Source: Office of Technology Assessment; adapted from Soil and Water Conservation Society, "Treasure of Abundance of Pandora's Box?: A Guide for Safe, Profitable Fertilizer and Pesticide Use," pamphlet, 1989.

Several national studies of groundwater pesticide contamination have been published recently. These studies found pesticides in a relatively small percentage of groundwater sites and, by and large, at fairly low concentrations. The most comprehensive, EPA's National Pesticide Survey of Drinking Water Wells (1990), concluded that pesticides were present in 10.4 percent of wells serving public water systems and in 4.2 percent of private wells. Sixteen pesticide ingredients and metabolites were detected at least once. However, according to the study, less than one percent of both rural domestic wells (0.6 percent) and community water system wells (0.8 percent) across the nation contained pesticides exceeding EPA's health guidelines.

Nevertheless, the fact that pesticides were found in groundwater at all and, more importantly, that in some locations they were detected at levels exceeding EPA's health guidelines, is cause for concern. Indeed, because there are approximately 10.5 million rural domestic wells and 94,600 community water system wells in the United States, the numbers of these wells containing one or more pesticides are large: about 440,000 rural and 9,800 community wells. Some of the pesticides detected are known to cause cancer or other adverse health outcomes. Moreover, some people fear that current contamination levels may herald a much larger problem in the future if current pesticide application rates continue unabated.

EPA's National Pesticide Survey focused exclusively on drinking-water wells. In a 1988 study entitled Pesticides in Ground Water Data Base: Interim Report, EPA reported that 46 different pesticides had been detected in samples of groundwater from 26 states where origin could be reasonably attributed to normal field applications. In addition, 32 pesticides had been detected in samples of groundwater from 12 states where origin was believed to be a point source (for example, spills, poor handling at mixing/loading sites, and improper disposal of containers).

EPA's Pesticides and Ground-Water Strategy

In the past, the EPA approach had been to limit groundwater pesticide contamination largely through uniform national restrictions, using authority granted to it in the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Under this authority, the most important regulatory decisions are made by the federal government and applied by states in a more or less uniform manner. However, there are only two cases—dibromochloropropane (DBCP) and ethylene dibromide—in which potential leaching to groundwater has played a key role in the cancellation of a pesticide.

When EPA acts to control pesticide contamination by registering pesticides under FIFRA, by law it must take into account the economic costs and benefits of the use of any pesticide. The recognition that vulnerability to pesticide contamination was not at all uniform across the nation led the agency to conclude that the protection of groundwater required a different approach. EPA therefore developed a strategy that emphasizes local prevention of further contamination.

EPA's new approach is embodied in its report entitled Pesticides and Ground-Water Strategy, a component of its broader groundwater protection initiatives, and is stated as follows:

"The goal of the Pesticide Strategy is to prevent contamination of ground-water resources that would cause unreasonable risk to human health and the environment resulting from the normal, registered use of pesticides, by taking appropriate actions where such risks may occur." [4]

As indicated earlier, once groundwater has become contaminated, it may not be economically or technically feasible to clean the resource. Because of this, the EPA strategy emphasizes prevention.

Rather than mandate a national ban on the use of a pesticide (out of concern for groundwater contamination), EPA officials have stated that it seems reasonable to impose controls only in geographic areas where groundwater is endangered. They contend that this approach is particularly appropriate for actions taken under FIFRA, given its requirement that the benefits of a pesticide be weighed against its risks, and given the disproportionate impact of applying a uniform national response to risks that are specifically localized. Under a policy of localized control, costs and benefits would better reflect conditions at particular sites.

Under this new regulatory scheme, states will be granted a large degree of freedom to create individual "state management plans" (SMPS) for controlling pesticide use. EPA contends that a lead role for the states is justified based on the expertise at the state level with regard to local hydrogeology, soils, agronomic practice, climate, and pesticide use, as well as the states' understanding of their local population and land use trends that help to define the future use of groundwater resources. If EPA determines that any particular pesticide could pose a health or environmental risk due to environmental leaching (and if the risk cannot be adequately addressed through labeling or national restricted use provisions), an EPA-approved SMP will be required in order for the pesticide to be sold or used in the state. The plan will explain how the risk is to be

[4]EPA, Pesticides and Ground-Water Strategy (Washington, D.C.: October 1991), p. ES-7.

managed. A separate SMP will be required for each such pesticide. In states where there is no approved plan, sale and use of the pesticide will be prohibited. It is expected that no two SMPs will be exactly the same. SMP requirements will vary by state and by pesticide, depending on aquifer sensitivity, pesticide use, and groundwater value. The greater the level of risk, the more detailed and specific this approach will have to be in order to be approved by EPA. One consequence of this approach is that pesticides which previously would have been banned nationally could be used if the state submitted a management plan acceptable to EPA.

As part of their plans, state officials will target vulnerable areas within their states, distinguishing those areas that warrant enhanced protection through pesticide use restrictions or other controls from those that merit less attention because of their lower value and/or lower probability of groundwater contamination. This component of EPA's proposed strategy is termed "differential protection." Priority for protection will be on (1) currently used and reasonably assured future drinking water supplies (both public and private) and (2) groundwater that hydrologically is closely connected to surface water.

The theoretical basis of differentially managing pesticide use rests on the fact that vulnerability varies over regions as a function of physical, hydrogeologic factors. Considerations such as depth of the groundwater supply, type of soil, and subsurface geology all influence groundwater vulnerability, as do amount of rainfall and soil temperature. For example, shallow groundwater supplies are generally at greater risk of being contaminated by a pollution source than are deeper groundwater supplies. In addition, groundwater overlaid by porous sandy soil has a greater chance of being contaminated by a pollution source than does groundwater that is overlaid by heavy clay soils.

The EPA strategy was released in October 1991. Table 1.1 contains the short-term implementation schedule that was included in the strategy.

Table 1.1: Groundwater Strategy Implementation Summary

	1991	1992	1993
Federal	EPA groundwater task force documents	EPA's strategic management systems modified to foster support of state groundwater protection programs	Grant allocation per states' comprehensive groundwater protection programs status
	Principles Federal/state relationship EPA's approach to implementation	9 final pesticide maximum contaminant levels	Final mixing/loading, disposal rules
	Final pesticides and groundwater strategy, state management plan guidance Proposed mixing/loading, storage, disposal rules	65 state pesticide groundwater grants awarded[a] Final restricted-use rule for pesticides with potential to leach	Final rule for SMP approach for some pesticides (possible) Additional final pesticide maximum contaminant levels
	Proposed restricted-use rules for pesticides with potential to leach	Reregistration continues Final procedural rules on storage and disposal for cancelled and suspended pesticides	Proposed final pesticide specific state management plan requirements Reregistration continues
	18 final pesticide maximum contaminant levels 61 state pesticide groundwater grants awarded[a] Final Phase II Report of the National Pesticides Survey State pesticide management plan support documents Aquifer sensitivity assessment technical support document Reregistration continues	Proposed rule for classifying some pesticides for SMPs	
States[a]	6 first-draft generic state management plans for EPA review	26 first-draft generic state management plans for EPA review	59 final generic state management plans for EPA approval
	State groundwater protection program profiles	13 final generic state management plans for EPA approval	40 proposed pesticide specific state management plans for EPA approval
Research	USDA: President's Water Quality Initiative (research, usage data, demonstration and education projects, multi- agency participation)	USDA: integrated pest management, low input sustainable agriculture research initiatives (per 1990 Farm Bill)	USDA, EPA, USGS: research ongoing
	USGS: basic hydrogeology research and data gathering	EPA and USGS: research ongoing	
	EPA: models, new tools to track contamination		

(Table notes on next page)

[a]"States" includes territories and Indian tribal authorities.

Source: EPA

Objectives

The Chairman of the Senate Subcommittee on Superfund, Ocean and Water Protection asked us to evaluate the viability of the EPA approach to protecting groundwater. The success of differentially protecting groundwater from pesticide contamination rests on the ability to discriminate accurately between areas in which continued pesticide use poses little or no threat to groundwater quality and areas where such use would likely result in contamination.

In responding to the request, we examined several issues believed to be keys to the success of EPA's proposed strategy. We addressed two of these issues in a previous report. [5] First, the methodology that EPA then advanced for targeting vulnerable areas did not include a measure of population-at-risk. [6] We found that including this measure when determining areas for protection would yield significantly different assessments of relative groundwater contamination risk.

Second, we found that the geographic scale at which areas are uniform enough in their degree of vulnerability to contamination to warrant their being treated differentially is on a subcounty level. Thus, we believe that vulnerability assessment methods must be valid at this scale if they are to be used successfully in a differential protection strategy.

As part of the present evaluation, we include our findings on two additional factors central to the EPA strategy. First, we assess the availability of data necessary to implement the EPA strategy. Successful implementation of a differential protection strategy requires the use of a great deal of data. Since much of the responsibility for implementing the EPA strategy falls on the states, our first evaluation question is, "Do the data to perform valid groundwater vulnerability assessments exist at the subcounty level in most states?"

[5]See Groundwater Protection: Measurement of Relative Vulnerability to Pesticide Contamination, GAO/PEMD-92-8 (Washington, D.C.: October 31, 1991).

[6]No particular methodology is advocated in the Pesticides and Ground-Water Strategy.

Second, we examine whether current vulnerability assessment methods are valid and therefore appropriate for use in a differential protection strategy. In the EPA strategy, two protective efforts are mentioned: monitoring and vulnerability assessments. Because of its expense, monitoring is impractical on a large scale. We therefore focus on vulnerability assessments. These involve assessing areas for their potential for groundwater contamination, using models that predict groundwater vulnerability. Consequently, our second evaluation question is, "Have current vulnerability assessment methods been demonstrated to be valid for use in a differential protection strategy?"

Scope and Methodology

State Activities

To gather information on state activities for assessing groundwater vulnerability to pesticide contamination, we developed three questionnaires. An expert panel was then convened to evaluate the questionnaires and address general issues relevant to the project. (See appendix I for the membership of the panel.) Among the principal questions addressed by the expert panel were the following:

1. What methods or combination of methods are available for conducting broad-scale assessments of groundwater vulnerability to pesticide contamination?

2. What factors can be used to evaluate the quality (that is, the face validity) of the studies for each type of method? (In other words, what attributes of a study are important and/or critical for judging whether the study can produce reliable information on which to base a vulnerability assessment?)

3. What types of base resource and ancillary data are needed to conduct the assessment methods identified in answering question one?

The questionnaires were pretested with several state officials, and we then made final revisions. The three questionnaires are contained in appendix II.

One set of questionnaires was sent to each state. Respondents were identified by asking EPA regional office staff to identify state officials considered well-informed concerning information sources and vulnerability assessment studies performed in their states. Distribution of the questionnaires depended on the division of responsibilities for pesticides and groundwater within each state government. In 28 cases, all three questionnaires were sent to the same official. In 21 cases, the questionnaires were divided between two officials, with the first two parts going to one official and the third part to a different respondent. In one case, the three questionnaires were divided among three officials. The questionnaires were mailed in August of 1991.

Each questionnaire addresses a different aspect of state programs for assessing groundwater vulnerability to pesticide contamination. The first two questionnaires are entitled "Survey of State Coordinators for Groundwater Vulnerability to Pesticide Contamination." Part I includes general questions about a state's groundwater programs and the availability of information relative to groundwater pesticide contamination in that state. Part II addresses studies that are considered representative of the state's efforts to identify groundwater that is vulnerable to "nonpoint" contamination by pesticides. [7] A separate questionnaire was to be completed for each representative study. For these questionnaires, we received responses from 45 states. [8]

The third questionnaire, entitled "Survey of Pesticide Management Officials on Plans to Protect Groundwater," addresses the effort undertaken by the states to identify areas overlying vulnerable groundwater. The information requested includes a report on the state's pesticide management plan (if any), vulnerability assessments, and pesticide use data. We received responses from 47 states. [9]

[7] Nonpoint sources of pollution are diffuse sources of pollution rather than pollutants discharged from a single, specific point source.

[8] We did not receive responses from Kentucky, Pennsylvania, Rhode Island, Tennessee, and Wisconsin for either of these surveys.

[9] We did not receive responses from Illinois, Pennsylvania, and Rhode Island.

Model Assessment

We conducted an evaluation synthesis of groundwater vulnerability assessment models. For this synthesis, we first conducted a computer-assisted search of the relevant data bases, using the keywords "groundwater," "model," "valid," "monitor," "sensitive," "predict," and "reliable," as well as combinations of these words. Through this search, we identified over 200 studies, for which we then obtained abstracts. After reading the abstracts, we secured copies of those studies that appeared relevant to our analysis. We then constructed a list of those studies in which vulnerability assessment techniques were evaluated by means of a comparison with monitoring data. We sent copies of this list to experts in the field, who were asked to supply us with studies that should be added to the list. In this way, we identified several additional reports, which we eventually included in our analysis. This process resulted in a total of 40 studies in which 29 models were evaluated. Citations for the studies are given in the bibliography.

Through a literature review and findings from our earlier work, we established the following criteria for evaluating the models' usefulness in preparing SMPs:

1. the author's summary assessment of the predictive validity (that is, accuracy) of the model;

2. the consistency of results across pesticides and studies;

3. the use of both statistical criteria and graphical displays for assessing model performance;

4. independent validation of the model (that is, by someone other than the developer of the model under scrutiny); and finally,

5. validation on a subcounty scale.

The first two criteria are indicators of the outcomes of the validation efforts; that is, they assess the relationship between predicted and observed values. The last three criteria address how the validations have been conducted. If a model failed any of the criteria, we concluded that it should not be used as the basis for developing SMPs at this time.

Our assessment of the reports themselves consisted of several classification steps. For each study, we characterized the sample size, the model(s), the groundwater vulnerability or the contaminant(s) concentrations predicted in each soil type tested (the dependent variable differs with the type of model being assessed), the validation method(s), the results of the validation, and the association between the study author(s) and the model author(s). These characteristics were compared to our ideal criteria. We then synthesized information across studies to form a comprehensive picture of all of the validations done for a model.

In the previously discussed survey of states, respondents were asked to report on representative vulnerability assessments that had been conducted in their state. This information was used to assess the application of these models and possible state strategies for assessing groundwater vulnerability when developing SMPs.

Responsible EPA officials reviewed this report and provided oral comments on it. We have incorporated these comments where appropriate. Our evaluation was conducted between August 1991 and July 1992 in accordance with generally accepted government auditing standards.

State Data Resources

In this chapter, we address our first evaluation question, "Do the data to perform valid groundwater vulnerability assessments exist at the subcounty level in most states?" We report on the availability and sufficiency of data in the states and evaluate these findings in light of EPA's Pesticides and Ground-Water Strategy.

We used the following criteria in conducting these assessments:

- the availability of data for eight vulnerability factors;
- how much of the state has been mapped for each of the factors; and
- the scale at which the state has been mapped.

The information for this assessment was gathered via three questionnaires that were sent to state officials who had been identified by EPA as being knowledgeable about pesticides and groundwater within their state.

Data Availability and Sufficiency

As discussed earlier, the vulnerability of groundwater to contamination varies according to the presence of particular geological attributes. We asked our expert panel (see the "Scope and Methodology" section in chapter 1) what data were necessary in order for a groundwater vulnerability study to have face validity. They concluded that there were five types of data (that is, independent variables) necessary: depth of groundwater, soil characteristics, vadose zone information, basic geologic/hydrogeologic data, and aquifer or groundwater maps with conductivity information.

In our survey, we represented basic geologic/hydrogeologic data by two dimensions: depth of the confining zone and description of the confining zone. The aquifer or groundwater-maps variable was characterized by three factors: aquifer thickness, direction of groundwater flow, and aquifer boundaries. The result was a total of eight vulnerability factors: depth to groundwater, soil characteristics, vadose zone information, depth of confining zone, description of confining zone, aquifer thickness, direction of groundwater flow, and aquifer boundaries. We assessed data availability and sufficiency by asking state officials to indicate the resolution of the data that were available for their state and the percentage of the state that had been mapped at that scale for each of the eight factors.

Data Availability

The availability of data varied by factor. For 5 of the 8 factors, at least 34 of the 45 states responding had the data available for at least a part of the state. For description and depth of the confining zone and information on the vadose zone, 26 or fewer of the state officials reported that some information was available. Officials in only 15 states (of 45 responding to the questionnaire) indicated that data had been mapped for all 8 factors. In table 2.1, we report the number of states in which data were available for each of the vulnerability factors. Subsequently, we report on the sufficiency of these data.

Table 2.1: Data Availability in the States

Factor	Number of states with some data available
Depth to groundwater	40
Soil characteristics	40
Vadose zone information	26
Depth of the confining zone	26
Description of the confining zone	25
Aquifer thickness	37
Direction of groundwater flow	34
Aquifer boundaries	37

[a]Officials from 45 states responded to this question.

Data Sufficiency

We asked officials to indicate what percentage of their state was mapped and at what resolution for each vulnerability factor. We found that the existence of some data for a state did not necessarily mean that all or even most of the state was mapped for the factor. For instance, only 11 of the 26 states that reported having vadose zone data had the information mapped for the entire state. Soil type was the factor most often completely mapped, with 27 of the 40 states with data having been completely mapped. Officials in only 3 states reported that their states were completely mapped for all 8 factors.

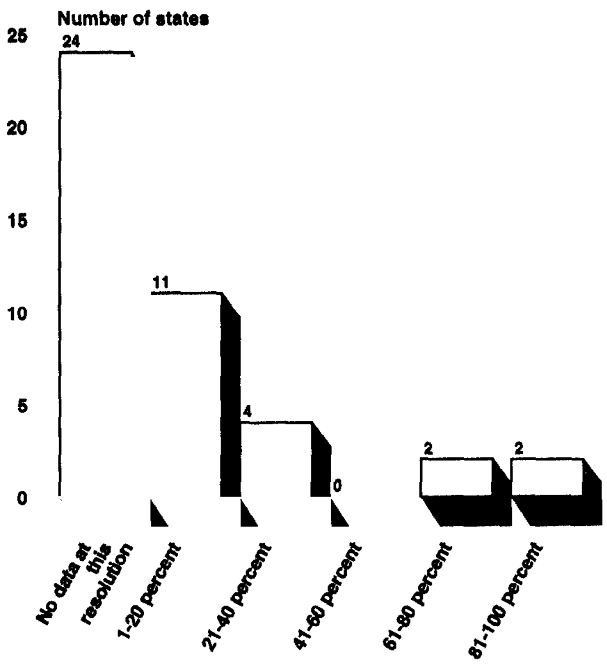
For vulnerability assessments, a map with a greater resolution would contain more detailed information on relevant geological factors and hence allow a more exact assessment of groundwater vulnerability. Four of our five expert panelists agreed that, for these assessments, all data should be at least at a resolution of 1:62,500. [1] We asked state officials to provide the resolution of their data for each of the eight vulnerability factors. In most cases, mapping had not been done at the degree of resolution considered adequate by the majority of our expert panelists

[1]The fifth panelist believed that a scale of 1:24,000 was necessary.

(that is, 1:62,500 or greater). The least often mapped factors at this resolution were depth and description of the confining zone, with only 12 states having been mapped at this scale. The most often mapped factor at a sufficient resolution was "type of characteristics of soil," with 28 states (of the 45 responding to the questionnaire) having been mapped at 1:62,500 or greater resolution. Officials in 7 states reported that parts of their states had been mapped at a sufficient resolution for all 8 factors.

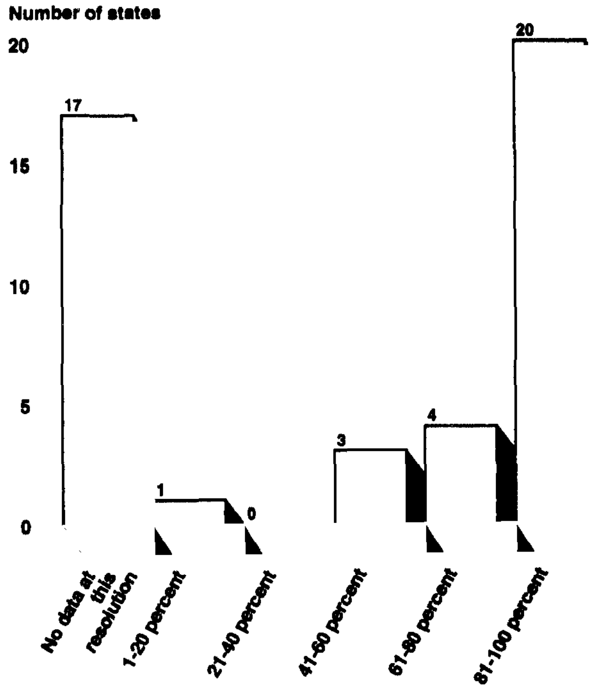
In figures 2.1 to 2.8, we display bar graphs showing the number of states mapped at a resolution of 1:62,500 or greater for each vulnerability factor, as well as the percentage of the state mapped at that resolution. It is clear from these figures that even when data are available at an acceptable degree of resolution, there are gaps for all of the factors. In fact, for both depth and description of the confining zone, no state has been mapped at a sufficient resolution over more than 40 percent of its area.

Figure 2.1: Percentages of 19 States Mapped at Sufficient Resolution for Depth to Groundwater[a]



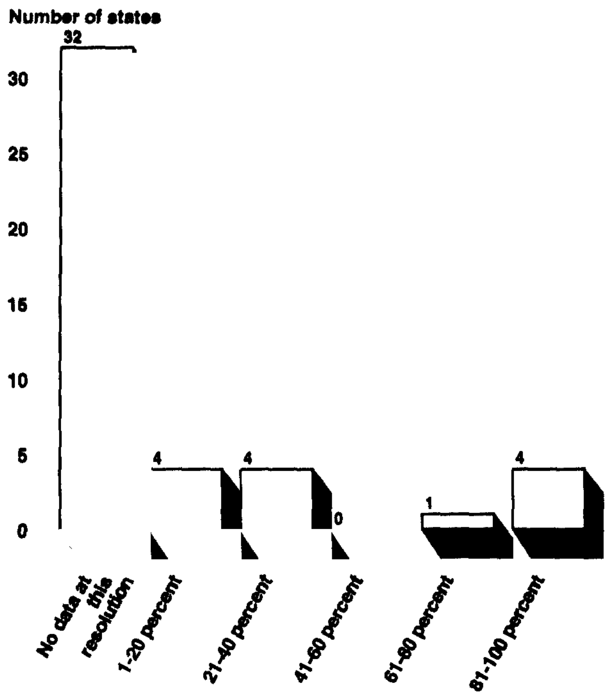
[a]Sufficient resolution is considered to be 1:62,500 or greater. Forty of the 45 states responding indicated that some data were available for the depth to groundwater vulnerability factor; 21 states had data at a resolution of 1:62,500 or greater. Officials in two states reported that maps were available at a 1:62,500 scale or greater but were unable to report what percentage of their states had been mapped.

Figure 2.2: Percentages of 28 States Mapped at Sufficient Resolution for Type of Soil Characteristics[a]



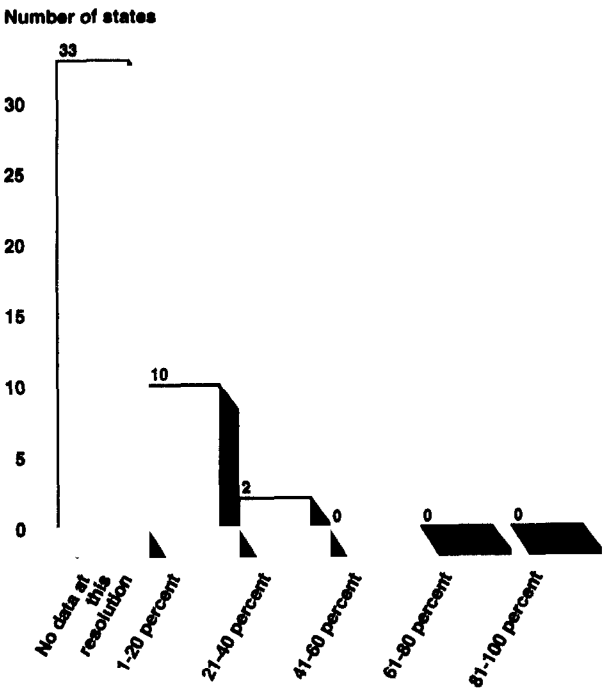
[a]Sufficient resolution is considered to be 1:62,500 or greater. Forty of the 45 states responding indicated that some data were available for the soil characteristics vulnerability factor; 28 states had data at a resolution of 1:62,500 or greater.

Figure 2.3: Percentages of 13 States Mapped at Sufficient Resolution for Type of Vadose Zone Characteristics[a]



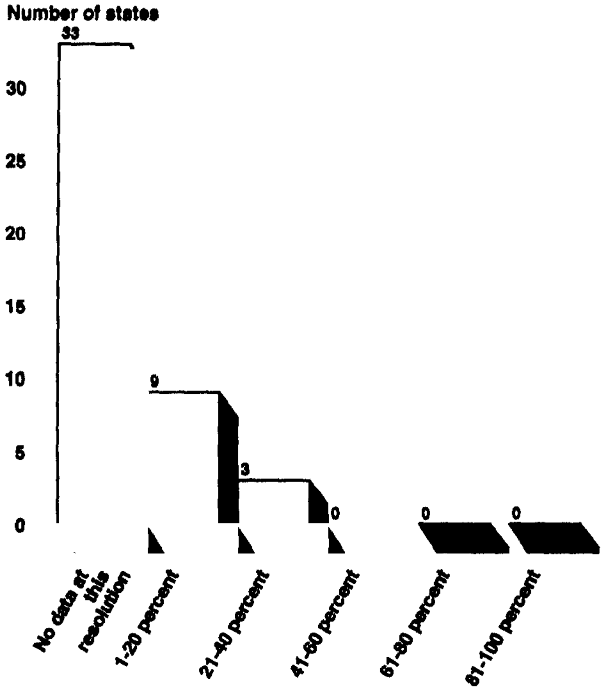
[a]Sufficient resolution is considered to be 1:62,500 or greater. Twenty-six of the 45 states responding indicated that some data were available for the vadose zone characteristics vulnerability factor; 13 states had data at a resolution of 1:62,500 or greater.

Figure 2.4: Percentages of 12 States Mapped at Sufficient Resolution for Depth of the Confining Zone[a]



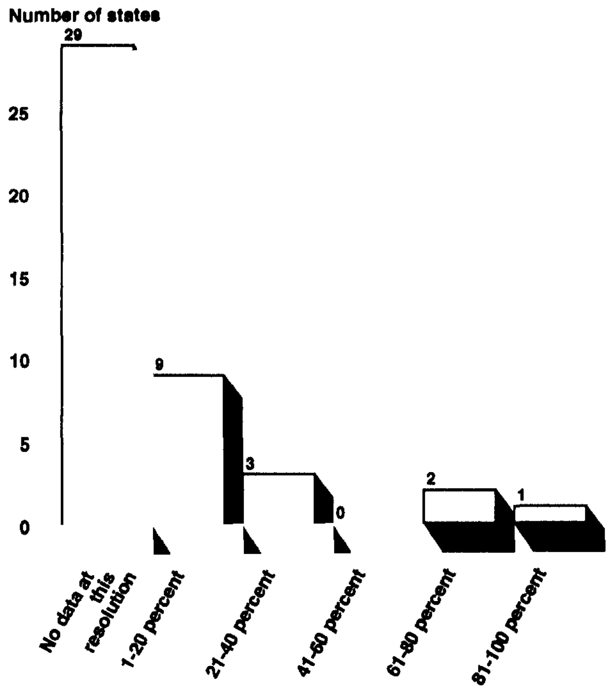
[a]Sufficient resolution is considered to be 1:62,500 or greater. Twenty-six of the 45 states responding indicated that some data were available for the confining-zone-depth vulnerability factor; 12 states had data at a resolution of 1:62,500 or greater.

Figure 2.5: Percentages of 12 States Mapped at Sufficient Resolution for Description of the Confining Zone[a]



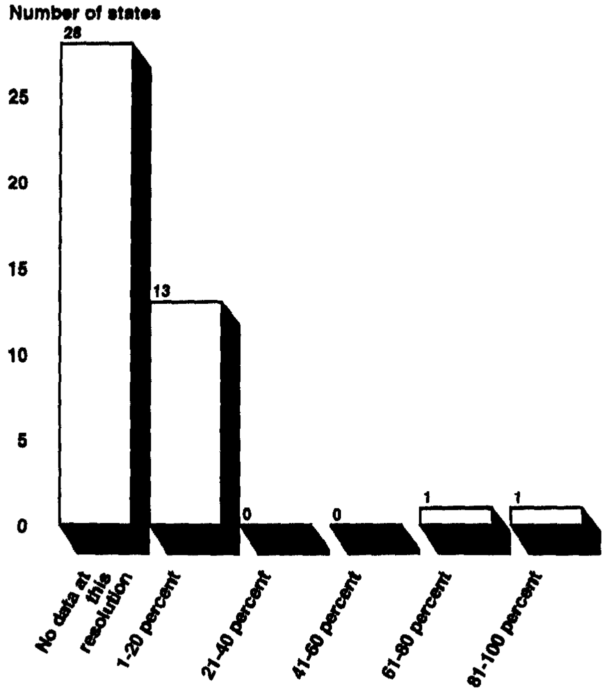
[a]Sufficient resolution is considered to be 1:62,500 or greater. Twenty-five of the 45 states responding indicated that some data were available for the confining-zone-description vulnerability factor; 12 states had data at a resolution of 1:62,500 or greater.

Figure 2.6: Percentages of 15 States Mapped at Sufficient Resolution for Aquifer Thickness[a]



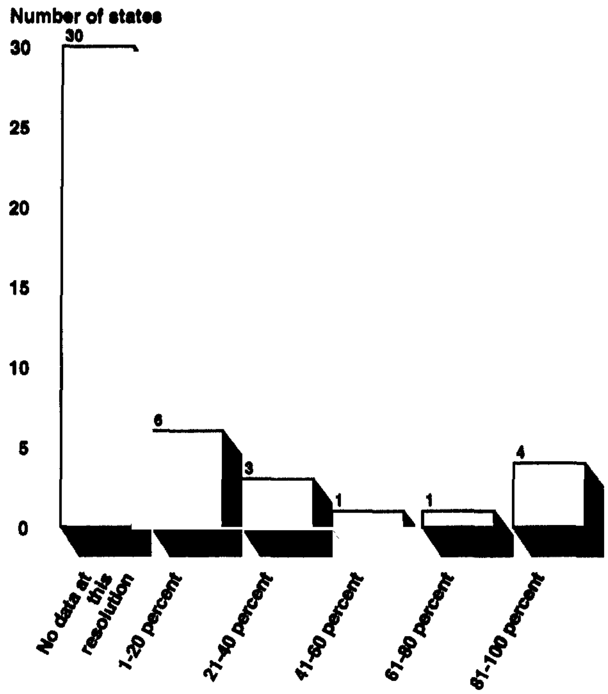
[a]Sufficient resolution is considered to be 1:62,500 or greater. Thirty-seven of the 45 states responding indicated that some data were available for the aquifer-thickness vulnerability factor; 16 states had data at a resolution of 1:62,500 or greater. An official in one state reported that maps were available at a 1:62,500 scale or greater but was unable to report what percentage of the states had been mapped.

Figure 2.7: Percentages of 15 States Mapped at Sufficient Resolution for Direction of Groundwater Flow[a]



[a]Sufficient resolution is considered to be 1:62,500 or greater. Thirty-four of the 45 states responding indicated that some data were available for the direction-of-groundwater-flow vulnerability factor; 17 states had data at a resolution of 1:62,500 or greater. Officials in two states reported that maps were available at a 1:62,500 scale or greater but were unable to report what percentage of the states had been mapped.

Figure 2.8: Percentages of 15 States Mapped at Sufficient Resolution for Aquifer Boundaries[a]



[a]Sufficient resolution is considered to be 1:62,500 or greater. Thirty-seven of the 45 states responding indicated that some data were available for the aquifer-boundaries vulnerability factor; 15 states had data at a resolution of 1:62,500 or greater.

We should note that, for some areas, mapping at this level of detail might not be necessary. For instance, if there is no pesticide use in a particular area, potential pesticide contamination would not be a concern, and thus it would not be important whether SMPs could be developed for the area. We therefore asked officials about the scope of the vulnerability studies that had been conducted in their states. In 24 cases where less than "all or almost all of the state" had been studied for groundwater vulnerability, 16 officials reported that pesticide use was moderately important or greater in determining the geographic areas chosen for analysis. In fact, pesticide use was the single factor most often cited as determining the geographic areas selected for analysis. Therefore, it is possible that areas not mapped in detail were those with low pesticide use. However, this needs to be determined on a case-by-case basis and should not be assumed.

A second possibility is that there may be large areas of geologic uniformity in a state. In this case, a less detailed map would be sufficient. However, our previous work has indicated that detailed information is required for many counties if differential protection is to be successful.[2] Moreover, even if these data are available, it may be difficult to determine whether a county is uniform enough not to require detailed mapping. Here also, judgments will need to be made on a case-by-case basis to determine whether the existing mapping is sufficient.

In addition to citing the eight vulnerability factors discussed earlier, our expert panel indicated that there are other types of data that enhance the face validity of groundwater vulnerability studies but are not absolutely necessary. We examined two of these, pesticide use data and recharge data. We found that pesticide use data were among those most often available, with 38 of 47 states having some information in this area. Our panel noted that pesticide use data should not come from sales data, since they are not always an accurate measure of the level of pesticide use. For example, pesticides are sometimes bought but then not used for years. As a result, data on sales would not accurately measure the amount of the pesticide actually used in a particular year. We found that, although 20 states did collect pesticide sales data, in all but 3 cases this was supplemented by additional information, such as surveys of farmers or agricultural extension agents. Thus, we concluded that 35 states had a valid source of pesticide use data.

Fewer states had adequate recharge data available. We asked officials how adequate the available recharge data were with regard to mapping important recharge areas in their state. Twenty-eight officials responded that the data for their state were marginally adequate or better. Eleven officials stated the data were generally inadequate or worse.

Development of State Management Plans (SMPs)

Researchers have noted that one of the biggest factors limiting the development of a science of groundwater vulnerability assessment is lack of data. Our findings support this. However, despite the gaps in the data, officials in all but five states reported to us that they plan to develop SMPs.[3] In most states, differential protection will be part of these plans. However, given the current data limitations of many states, it is clear that vulnerability assessments will not be sufficiently detailed and thus will generally be inadequate to fulfill the goals of the EPA strategy. One state official expressed skepticism about the feasibility of the SMP component of

[2]See Groundwater Protection: Measurement of Relative Vulnerability to Pesticide Contamination, GAO/PEMD-92-8 (Washington, D.C.: October 31, 1991).

[3]Officials in these five states reported either that they were waiting for EPA to publish its strategy before beginning work or that a decision had not yet been made concerning the development of a pesticide management plan.

the EPA strategy. He stated his belief that SMPs are currently viable for only 4 or 5 states. Furthermore, he also stated that, even for those states like his own that possess more developed programs, SMPs are problematic because of such difficulties as data variability (that is, data at different scales).

For the EPA strategy to be successful, more extensive and detailed data than currently exist will be required. The feasibility of collecting these data in the near future is doubtful. In the survey, we asked state officials to indicate the percentage of their state to be mapped at a particular resolution by 1996. Many officials were unable to answer this question, indicating the uncertainty of their current plans. This brings into further question the feasibility of successfully implementing the EPA strategy over the next 5 years.

Summary and Conclusions

In this chapter, we addressed our first evaluation question, "Do the data to perform valid assessments exist at the subcounty level in most states?" We found that, although in many states a great deal of data had been collected, there were large gaps in the type of data gathered, a lack of information at a sufficiently detailed degree of resolution, and less than complete coverage of individual states. To collect the data necessary to perform valid vulnerability assessments, many state programs will need to be considerably expanded. The feasibility of this expansion in the near future is questionable.

We conclude that, given the shortcomings discussed in this chapter, the usefulness of preparing state management plans (SMPs) is dubious. A lack of data means that important factors will either have to be estimated or left out of the assessments altogether. Although the importance of this lack of data varies by site, the validity of the assessments, and hence the effectiveness of the plans, will be compromised.

Agency Comments

EPA officials felt that we had collected a great deal of useful information from the states. However, they stated that, even with the data limitations discussed in this chapter, states can conduct assessments of groundwater vulnerability. They felt that it was incorrect to suggest that states cannot do some level of assessment of groundwater vulnerability with their extant data. In their opinion, states can then take useful actions on this information that will allow them to differentially manage the risks of groundwater contamination by pesticides.

While we agree that assessment of groundwater vulnerability can be conducted with data of any quality, this premise is not a sound, reasonable, or useful basis for state action. It is not even clear that increased controls on pesticide use, if undertaken by the states on this basis, would result in increased protection of groundwater. The problem lies in the fact that assessments would often contain incomplete or unrepresentative data and would be conducted on such a large geographic scale that small scale variations would be missed. This would result in the underprotection of groundwater resources. Moreover, without more detailed information, the potential effectiveness of programs cannot be projected. We question the usefulness of implementing a strategy that, to work as intended, requires data that do not currently exist and are unlikely to exist in the near future.

Validations of Groundwater Vulnerability Assessment Models

In this chapter, we address our second evaluation question, "Have current vulnerability assessment methods been demonstrated to be valid for use in a differential protection strategy?" A method is open to doubt until it has been shown to be valid. If the protective measures set forth in a SMP were based on predictions of groundwater contamination from a vulnerability assessment model, the effectiveness of the plan would necessarily be in doubt if the validity of the model was not known. In this case, it is not possible to evaluate meaningfully how well a plan addresses the groundwater contamination risk since the extent of the potential contamination is unknown.

We conducted a literature search and identified 40 studies where groundwater vulnerability model predictions were compared with actual monitoring results (that is, measured field or laboratory data). Three general modeling approaches were represented in the set of evaluation studies: parameter-weighting, empirical, and simulation-modeling. Twenty-nine different groundwater vulnerability assessment models were addressed by the studies. We abstracted information on five evaluation criteria from each study. We then synthesized this information across studies for each model. The results were then used to assess each model's suitability for supporting the development of SMPs at this time. Finally, we discuss applications of vulnerability assessment models in the states.

Monitoring and Modeling in the EPA Strategy

Prevention is emphasized in the approach for protecting groundwater set forth by EPA in its Pesticides and Ground-Water Strategy. Under this strategy, state officials are expected to develop SMPs that will reduce or eliminate the human health and environmental risks resulting from the leaching of pesticides to groundwater. The plans could be developed using a monitoring network to measure contamination, and/or a vulnerability assessment could be conducted to estimate potential groundwater contamination from pesticide use. Plans would then be evaluated by EPA on the basis of how well they manage the groundwater contamination risk.

Monitoring is typically conducted to determine if contamination has already occurred at a site and, if so, to what extent. If contamination is found, actions can be taken to prevent further pollution. However, effective monitoring is quite arduous. Wells may be too deep, too shallow, or in the wrong place. Additionally, because of hydraulic and pumping variations, contaminant levels can vary significantly within very short time periods. To be successful, a monitoring network needs to be extensive. However, monitoring is very expensive and therefore cannot practically be done on a large scale. In fact, EPA has stated that one test of the success of the strategy will be whether states "can avoid extraordinary monitoring." [1]

The one alternative to monitoring cited in the EPA strategy for assessing groundwater vulnerability and preparing SMPs is vulnerability assessment modeling. Modeling is a technique for predicting where contamination is likely to occur without requiring such expensive procedures as monitoring. Under the EPA strategy, states may forego monitoring if a vulnerability assessment shows the absence of pesticide use in an area or the likelihood that no contamination will occur. Given the expense and difficulty of monitoring for pesticide contamination, the states will most likely rely heavily upon vulnerability assessment modeling when developing SMPs.

Evaluation Criteria

We used five criteria for assessing the validity of vulnerability assessment models for their use in a regulatory framework. Four of the five criteria were developed through a review of the model evaluation literature, with an emphasis on the literature discussing validation of pesticide and groundwater models. The fifth criterion was arrived at on the basis of our findings in an earlier study. The five criteria we used to assess the models for their use in developing SMPs were

- the author's summary assessment of the predictive validity (that is, accuracy) of the model,
- the consistency of results across pesticides and studies,
- the use of both statistical criteria and graphical displays for assessing model performance,
- independent validation of the model (that is, by someone other than the developer of the model under scrutiny), and
- validation at a subcounty level.

The first criterion served as a surrogate for a more general standard. For a model to be useful for prediction, it must be able to forecast within an acceptable range of the true value. (The acceptable range is determined in great part by how the model is to be used.) Because models are not exact replications of reality and are not expected to be completely accurate, it is important to establish criteria to evaluate the usefulness of models prior to their being tested. We are unaware of any criteria established for evaluating pesticides and groundwater models in terms of desired accuracy for regulatory purposes. Because we do not have such a

[1] EPA, Pesticides and Ground-Water Strategy (Washington, D.C.: October 1991), p. 18.

standard, we instead used the authors' summary judgments of the overall predictive validity of the models and also note limitations in the success of the tests.

Our second criterion addressed the consistency of the models. We thus examined the consistency across tests for the same model using the same pesticide. However, because different pesticides and soils have different leaching characteristics, the validity of a model needs to be demonstrated for all pesticides and soils for which it will be used. We therefore also evaluated the consistency of model results for different pesticides and soils.

Our third criterion focused on the approach used to validate model performance. A comprehensive analysis of model performance requires both graphical analysis and statistical criteria. Graphical analysis helps to examine components of fit, such as locating trends, types of errors, and distribution patterns. However, visual inspection is by its nature subjective, and different viewers will see different "goodnesses" of fit. Statistical criteria provide an objective numerical measure of fit between predicted and measured values and hence are a necessary supplement to graphical displays.

Our fourth criterion was independent testing of the model. One of the tenets of science is replication. Research must be repeated by other investigators before its findings can be considered well-established.

The fifth criterion, validation at a subcounty level, emerged from the results of our earlier study.[2] We found that the geographic level at which differential protection becomes scientifically and economically viable (that is, the scale at which land is uniform enough to be appropriately assumed to be uniformly vulnerable and the cost is not prohibitive) is the subcounty level (that is, an area larger than a specific site but smaller than a county). Models must be shown to be valid at this level or their use for differential protection remains in doubt.

Vulnerability Assessment Models

We identified 40 studies in the scientific literature that examined the correspondence between vulnerability assessment model predictions and empirical monitoring results. (These studies are listed in the bibliography.) Three general approaches were used in the 29 models examined in these

[2]See Groundwater Protection: Measurement of Relative Vulnerability to Pesticide Contamination, GAO/RCED-92-8 (Washington, D.C.: October 31, 1991).

studies: parameter-weighting, empirical, and simulation-modeling. The purposes of these approaches differ. The parameter-weighting and empirical approaches are meant to characterize the vulnerability of groundwater in a geographic area based on an assessment of geological variables. The result is a general assessment of vulnerability independent of pesticide characteristics. The simulation-modeling approach results in predictions of individual pesticide contamination levels based on specified input variables (for example, amount of the pesticide applied). We will deal with each approach in turn. For each, we first give a general description of the approach being examined and then apply our evaluation criteria to the validation exercises.

Parameter-Weighting Approach (DRASTIC Method)

A parameter-weighting approach involves selecting factors that are believed to influence groundwater vulnerability and attaching weights to them in terms of their relative importance. The vulnerability of sites or areas are the weighted scores of the factors.

We located four studies in which a parameter-weighting approach was used. Table 3.1 contains summary information about these studies, including data on our five evaluation criteria. All four studies were tests of the DRASTIC method, an approach developed at EPA for evaluating groundwater vulnerability. Among the possible applications of DRASTIC is its use for preventive purposes through the prioritization of areas where groundwater protection is critical. The method uses a seven-variable equation, with each variable representing a factor thought to influence the relative vulnerability of groundwater to contamination by a source at the surface of a given area. Each factor is weighted by a constant that reflects its postulated relative influence (that is, factors considered more important receive higher weights). [3] A rating system is then used to assign numeric values to the observed characteristics for a given site for each of the variables. [4] The algorithm is then applied, and a numeric rating of

[3]The weights were determined by an advisory committee using a Delphi (consensus) approach.

[4]For instance, for depth to water, the ranges (in feet) and corresponding ratings are

Range	Rating
0-5	10
5-15	9
5-30	7
30-50	5
50-75	3
75-100	2
100+	1

For example, if the depth to ground water was 20 feet, the rating would be 7.

groundwater vulnerability is calculated for the area. DRASTIC does not provide specific predictions of pesticide contamination. Its purpose is to provide a relative rating of groundwater vulnerability to contamination (for areas of 100 acres or larger). In table 3.2, we display the factors, acronym, weight, and definitions for Agricultural DRASTIC. (Agricultural DRASTIC is a modification of DRASTIC that addresses the potential degradation of pesticides within soil. The variables are the same in both DRASTIC and Agricultural DRASTIC; however, the weights differ slightly.)

Table 3.1: Validations of Parameter-Weighting Approach

Author and date[a]	Model tested	Contaminants examined
Baker (1990)	DRASTIC	Nitrate
California Department of Food and Agriculture (1988)	DRASTIC	Pesticides detected in wells; unclear how many pesticides tested for
EPA (1992)	DRASTIC	Pesticides detected in wells; 126 pesticides and nitrate tested for (127 total analytes)
Holden and Graham (1990)	DRASTIC	Alachlor, atrazine, cyanazine, metolachlor, nitrate, simazine

Geographic area	Analytical method	Model developer[b]	Predictive validity	Observations
Private wells in Ohio counties	Statistical, graphical	No	Considerable correlation	Because of lack of national data, cannot assess accuracy in predicting relative levels of contamination
Wells in California counties	Percentage of counties with high, medium, and low DRASTIC scores with positive groundwater samples	No	Important vulnerable areas overlooked by the scores	Unclear if findings show level of pesticide use or groundwater vulnerability
Wells in 399 counties for community water system survey; 90 counties for rural domestic well survey	Statistical	Yes	Poor predictor of pesticide and nitrate detections with either county or subcounty scores	Site-specific data appear to be necessary; some variables negatively related to contamination
1,430 domestic wells in 89 counties	Statistical, graphical	No	Inadequate as predictor of chemical contamination	Some of the DRASTIC variables found to be negatively related to contamination

[a]Complete citations are given in the bibliography.

[b]Is the author of the validation exercise also the developer of the model?

Table 3.2: Agricultural DRASTIC Subcomponents and Weights

DRASTIC factor and acronym	Weight	Definition
Depth to water (D)	5	Depth to static water levels in unconfined aquifers and to base of aquitard in confined aquifers; effects of artificial recharge removed; as depth increases, score decreases
Net recharge (R)	4	Natural recharge to water table or confined aquifer; effects of artificial recharge removed; as net recharge increases, score increases
Aquifer media (A)	3	Lithology and structure of aquifer; emphasis upon attenuation and hydraulic properties; more porous media have higher scores than less porous media
Soil media (S)	5	Texture of the most significant soil layer; emphasis upon attenuation and infiltration; as permeability of soil type increases, score increases
Topography (T)	3	Degree of slope determined from large-scale topographic maps or published soil surveys; as the steepness of the topography (percent slope) increases, score decreases
Impact of the vadose zone (I)	4	Lithology of unsaturated zone for unconfined aquifer or material above confined aquifer; emphasis on attenuation and hydraulic properties; less attenuating and more porous media have higher scores
Hydraulic conductivity (C)	2	Ease of groundwater flow as inferred from well data or from lithology; as conductivity increases, score increases

Source: EPA

Predictive Validity

The tests of DRASTIC generally indicated a poor relationship between model predictions (that is, relative groundwater vulnerability) and monitoring results (that is, whether pesticides were found). The most comprehensive test of DRASTIC is discussed in a recent EPA report on pesticide contamination of drinking water wells. [5] EPA officials examined the relationship between county-level DRASTIC scores and pesticide detections, as well as that between subcounty scores and pesticide detections. Results for rural domestic wells were based on a survey in 90 counties, while results for community water systems were based on a survey in 399 counties.

[5]EPA, Another Look: National Survey of Pesticides in Drinking Water Wells, Phase II Report (Washington, D.C.: January 1992).

EPA found that, at the county level, DRASTIC was a poor predictor of detections of pesticide contamination both in rural domestic wells and in community water systems. In fact, some DRASTIC factors were found to be negatively related to nitrate contamination. [6]

Subcounty results were reported only for the rural wells. The results were similar to those reported for the county-level analyses. No positive relationship could be demonstrated between DRASTIC scores at the subcounty level and pesticide detections in rural domestic wells. EPA concluded that DRASTIC had not identified drinking water wells with a greater likelihood of detections. They went on to state that localized or site-specific assessments appear to be necessary in order to obtain adequate evaluations of the sensitivity of drinking water wells to contamination.

However, the usefulness of DRASTIC at this level is doubtful. DRASTIC was developed to characterize groundwater vulnerability in areas of more than 100 acres. Additionally, the one test of DRASTIC we located that employed site-specific data (from 1,430 wells) also found the model predictions to be either uncorrelated or negatively correlated with monitoring results. (See Holden and Graham, 1990.) [7]

In a third study, DRASTIC scores for counties in California were divided into categories of high, moderate, and low. Ten percent of counties with low scores, 46 percent with medium scores, and 67 percent with high scores were found to have wells contaminated with the pesticide aldicarb. The California official reporting on this study wrote that these results did not validate the DRASTIC approach. The only study in which the author concluded that there was a strong relationship between DRASTIC scores and contamination was one of counties in Ohio. In this study, a correlation of .55 was found between nitrate contamination of groundwater and county level DRASTIC scores.

In discussions with state officials, we found explanations for the generally poor results. Factors believed by some officials to be more important than the DRASTIC variables for predicting contamination—such as distance of wells to crops, soil temperature, and well attributes—are not included in the DRASTIC index. Other state officials noted more generally that important vulnerable areas are often overlooked by DRASTIC. Wisconsin officials gave an example of what might appear to be an area of uniform vulnerability,

[6]Nitrates are fertilizers, not pesticides. However, Agricultural DRASTIC is suitable for nitrates.

[7]Complete references are supplied in the bibliography.

but noted that in fact subtle differences in organic matter greatly affected the vulnerability of different sections within the larger area. These officials stated their belief that DRASTIC or other models were not sufficiently developed to make such fine distinctions.

Consistency of Results

Consistently positive results were not found in the validation exercises. The only positive result reported was of nitrate contamination in Ohio. However, no relationship was found between DRASTIC scores and nitrate contamination in the two other studies in which nitrate contamination was examined. (See EPA, 1992, and Holden and Graham, 1990).

Analytical Method, Independent Replication, and Geographic Area.

DRASTIC measured up well against our three criteria for judging how the validations of the models were conducted. DRASTIC has been assessed using both statistical criteria and graphical displays, there have been independent tests of the approach, and it has been tested at the subcounty level.

Summary

Given the results of the validation exercises, it is clear that DRASTIC cannot be relied upon to assess groundwater vulnerability and hence should not be used in the development of SMPs. The most extensive tests have found no relationship between DRASTIC scores and pesticide contamination. The failure of DRASTIC to perform acceptably is especially important in view of the fact that EPA had in the past promoted its use for conducting vulnerability assessments.

Empirical Approach

An empirical approach involves gathering monitoring data to test a thesis that certain attributes, such as hydrogeologic factors, influence contaminant concentrations. We located one study (Teso et al., 1988) in which an empirical method was used to assess groundwater vulnerability. In this study, a discriminant function was used to predict the presence of groundwater contamination in various sections of a California county. Discriminant analysis is used to predict into which group individual cases will fall based on a set of classifying variables. In this case, the groups were characterized by the presence or absence of a DBCP contaminated well in the area. The classifying variable was derived from soil map units.

Predictive Validity

The results were better than chance accuracy, but some inconsistent patterns were found. Approximately 70 percent of the areas were correctly classified. In general, the broader the soil taxon, the more accurate was the classification. The authors concluded that the results of the study strongly confirmed the model.

Consistency of Results

We cannot evaluate the consistency of the results for this model since this was the only test of the model and only one pesticide was examined.

Analytical Method

Both statistical criteria and graphical displays were used to evaluate the results of the validation exercise.

Independent Replication

There has been no replication study of the model.

Geographic Area

The testing of the model was done at the subcounty level.

Summary

This model meets 3 of our 5 criteria. The predictive validity of the model was judged positively by the authors. Both statistical criteria and graphical analysis were used to assess the performance of the model, and validation was conducted at a subcounty level. However, the model has only been validated once, and this was done by its developers. Thus, the consistency of the model is still an open question, and independent replication is needed. We therefore judge that this approach is not yet ready to be used as definitive support for SMP development.

Simulation-Modeling Approach

The other 35 studies are validations of mathematical models (generally computer simulations) of soil leaching. (See table 3.3.) Twenty-seven models were tested in these studies. In several cases, more than one model was examined. This approach employs a mathematical model of the processes that influence contaminant fate and transport in one or more compartments of the soil/vadose zone/groundwater/aquifer system to predict either how long it will take for contaminants to reach a given depth or the amount that will reach a given depth. The development and evaluation of these models require extensive site-specific data, such as soil characteristics and monitoring results.

Table 3.3: Validations of Simulation-Modeling Approach

Author and date[a]	Model tested[b]	Contaminant examined
Carsel et al. (1985)	PRZM	Aldicarb
Carsel et al. (1986)	PRZM	Metalaxyl
Enfield and Shew (1975)	2 unnamed models	Phosphorus
Enfield et al. (1982)	3 unnamed models (one of the models later named PESTAN)	Aldicarb, DDT
Green et al. (1986)	5 unnamed models	DBCP
Grenney et al. (1987)	VIP	Anthracene, fluoranthene, napthalene
Harter and Teutsch (1990)	GLEAMS, LEACHM, PRZM,	Atrazine, bromide,[e] terbuthylazine
Hutson et al. (1988)	LEACHM	Bromide, diazinon, simazine

Geographic area/soil[c]	Analytical method	Model developer[d]	Predictive validity	Observations
1 site, 1 soil	Graphical	Yes	Results suggest the model effectively simulates relevant processes affecting the pesticide's movement	Test not rigorous; peak depth not as deep as predicted with uncalibrated model
2 sites, 2 soils	Statistical, graphical	Yes	Successfully tested under field-averaged conditions	Accurate predictions for days 55 and 85 but not day 26
2 sites, 2 soils	Statistical, graphical	Extend a model not developed by them	Good agreement between experimental and predicted movement through the soil	Needs to be further developed to handle transient hydraulic conditions
1 site, 1 soil per pesticide	Graphical	Yes	Approach should be adequate to make environmental decisions evaluating the potential hazard of nonionic compounds to the groundwater	Underpredicted DDT's mobility; modifications would be required to evaluate ionic or charged compounds
1 or 2 sites per model, 1 soil per model	Graphical	Developers of 2 of the 5 models	Modeling efforts were only moderately successful in predicting concentration profiles	Successful predictions of the leaching and volatilization of DBCP residues require a better understanding of sorption mechanisms
1 site, 1 soil	Graphical	Yes	Closely simulates the fate and behavior of the three compounds through depth and time in the vadose zone conditions in the soil columns	Laboratory experiment; apparent decay rates were observed to vary significantly with flow rates
2 sites, 2 soils	Graphical	No	All three models accurately simulate pesticide transport to a given depth within a margin of two . . . only some of the GLEAMS estimates are less accurate	Laboratory experiments; do not necessarily reflect the accuracy of the models when applied to field situations
1 site, 1 soil	Graphical	Yes	As the role of leaching increased compared with adsorption and decay, agreement between predicted and observed chemical behavior deteriorated	Bromide values were very different from those predicted; lack of understanding of flow pathways and processes

(continued)

Author and date[a]	Model tested[b]	Contaminant examined
Huyakorn et al. (1988)	PRZM/ SAFTMOD/ VADOFT (combination of models)	Aldicarb
Jaynes et al. (1988)	Unnamed probability density function	Bromide
Jones and Back (1984)	PESTAN	Aldicarb
Jones et al. (1986)	PRZM	Aldicarb, aldoxycarb
Jones et al. (1987)	Unnamed model	Aldicarb
Jury et al. (1982)	Unnamed transfer function	Bromide
Jury et al. (1988)	Two unnamed transfer functions	Bromide, bromacil, chloride, napropamide, prometryn
Leonard et al. (1985)	CREAMS	Fenamiphos
Leonard et al. (1987)	GLEAMS	Alachlor, atrazine, bromide, cyanazine

Geographic area/soil[c]	Analytical method	Model developer[d]	Predictive validity	Observations
1 site, 1 soil	Graphical	Yes	Agreement between predicted and observed pesticide concentrations was reasonably good	Tendency to underpredict observed concentrations; lack of field data precludes rigorous validation of the model
2 sites, 2 soils	Graphical	Yes	Model shows promise for modeling field-scale solute transport	Predictions agreed strongly with concentrations for a sandy loam but were not as accurate for sand
6 sites, soils not specified	Graphical	No	The monitoring data and computer calculations demonstrate that the use of . . . aldicarb will not result in pesticide residues in Florida groundwater	Underestimated downward leaching
19 sites, varying soils; number not specified	Graphical	No	Can be effective in assessing pesticide movement in soils	Relatively good job of predicting the leaching depth of the residual profile; less accurate predictions for actual concentrations
1 site, 1 soil	Graphical	Yes	Field data along with simulation suggest current Florida restrictions are adequate	Simulated movement of aldicarb did not match observed results in the northeastern portion of the test site
1 site, 1 soil	Graphical	Yes	Good agreement between predicted and observed values of the average pulse	Further testing needed; overpredicted the amount of spreading with greater depth
1 site, 1 soil	Graphical	Yes	Good agreement, but predicting the leading edge movement of contaminants under field conditions must be regarded as unattainable with our present information base	25 percent of the recovered pesticide migrated to depths far below the maximum depths predicted
1 site, 1 soil	Graphical	Yes	Appears promising; utility of the model for long-term simulation was demonstrated	Preliminary evaluation
1 site and soil for bromide, 2 sites and soils for others	Graphical	Yes	The model simulates pesticide and bromide movement and leaching generally within the range of variability of field data	GLEAMS is not a predictive model in the sense of absolute quantities; therefore, simulated values cannot be interpreted as absolute values and only differences between management practices should be assessed

(continued)

Author and date[a]	Model tested[b]	Contaminant examined
Leonard et al. (1990)	GLEAMS	Fenamiphos
Leonard et al. (1991)	GLEAMS	Atrazine, carbofuran
Levy et al. (1990)	PRZM	Alachlor, atrazine, metolachlor, metribuzin
Loague et al. (1989a)	PRZM	Ethylene dibromide
Loague et al. (1989b)	PRZM	DBCP, Ethylene dibromide, 1,2,3 trichloropropane
Loague and Green (1991)	PRZM	Atrazine
Loague (1992)	PRZM	Ethylene dibromide
Lorber and Offutt (1986)	PRZM	Aldicarb
Melancon et al. (1986)	PESTAN, PRZM, SESOIL	Atrazine, diazinon, dicamba, 2, 4-dichlorophenoxyacetic acid, lindane, pentachlorophenol

Geographic area/soil[c]	Analytical method	Model developer[d]	Predictive validity	Observations
1 site, 1 soil	Graphical	Yes	Compared favorably with field data	Limited validation; less accurate for summer applications than for spring
1 site, 1 soil	Statistical	Yes	Successfully tested; reasonably represents field behavior of the two pesticides	Model does not specifically address groundwater contamination
7 sites, 3 soils	Comparison of observed and predicted values; no measures of fit calculated	No	Inaccuracy of the PRZM simulations reflects poorly on the applicability of PRZM as a regulatory tool	Accuracy varied widely depending on the herbicide
3 sites, 2 soils	Graphical	No	Can be used effectively; results suggest that PRZM may be useful in the future for pesticide screening and risk assessment in Hawaii but may not be suitable for general use	Addressed only deterministic aspects of model; performance hampered by data uncertainties
1 site, 1 soil	Graphical	No	Simulations laced with uncertainty but deep leaching reasonably well predicted; cannot suggest that PRZM be used for decision/management purposes until further testing has been conducted	The primary limitation of determining a conceptual simulation for pesticides is scarce data; PRZM is not well-suited to testing volatile chemicals
1 site, 1 soil	Statistical, graphical	No	Poor performance . . . simulating observed concentration profiles	Overpredicts early, underpredicts late
1 site, 1 soil	Statistical, graphical	No	Model performance is quite poor overall	Improved field data sets needed for model validation and comparison studies
3 sites, 2 soils	Graphical	Yes	Despite some differences, mass balance and trends in concentration-depth profiles were accurately portrayed	In order to force the simulated profiles to match the observed profiles, a higher adsorption partition coefficient was required for the top zone than would be calibrated based on aldicarb and soil organic matter
1 site, 1 soil	Graphical	No	PRZM and PESTAN fairly good after calibration; SESOIL performance did not improve; models need to be calibrated with site-specific data before they are used for definitive predictions	Individual model performance was highly chemical specific; laboratory experiment

(continued)

Author and date[a]	Model tested[b]	Contaminant examined
Niccoli et al. (1990)	PRZM, Opus	Atrazine, bromide
Parrish et al. (1991)	AGGR, PRZM	Aldicarb, bromide, metolachlor
Pennell et al. (1990)	CMLS, GLEAMS, LEACHMP, MOUSE, PRZM	Aldicarb, bromide
Rojas and Hjemfelt (1991)	RZWQM	Nitrate
Sauer et al. (1990)	PRZM	Atrazine, carbofuran, chloropyrifos, metolachlor
Shirmohammadi et al. (1989)	GLEAMS	Atrazine, carbofuran, cyanazine, dicamba, metolachlor, simazine
Steenhuis et al. (1987)	MOUSE	Alachlor, aldicarb, butylate, dichloropropane, metolachlor
Wagenet and Hutson (1986)	LEACHMP	Aldicarb

Geographic area/soil[c]	Analytical method	Model developer[d]	Predictive validity	Observations
1 site, 1 soil	Graphical	No	Models should not be relied upon to predict reality; able to predict relative chemical movement, not direction or magnitude	Predictions were not always close to measured values
1 site, 1 soil	Graphical	Authors of AGGR but not PRZM	Models are not sufficient to simulate precisely the dynamics of chemical transport under widely varying conditions; models more accurate in upper zones than in lower zones	Aldicarb results variable; both models reasonably accurate for metolachlor in upper 30 centimeters; both overpredicted bromide tracer movement
1 site, 1 soil	Statistical, graphical	No	GLEAMS and MOUSE underestimated aldicarb and bromide; other models provided satisfactory predictions of solute mass and pesticide degradation; none of the models accurately described measured solute concentration distributions	Models and validations limited by extensive data requirements
2 sites, 1 soil	Graphical	Yes	Capable of accurately determining movement and production of nitrate	Validation limited in scope; thorough understanding of system to be represented is required
1 site, 1 soil	Graphical	No	Can make reasonable predictions of pesticide movement in a coarse-textured soil	Acceptable agreement early in season; overprediction later in season
1 site, 1 soil	Comparison of observed and predicted values; no measures of fit calculated	No	Results support use if appropriate limitations are recognized (that is, model's predictions are only for relative comparisons between agricultural best management practices as they affect groundwater quality)	Vadose zone module capable of linking the root zone component of GLEAMS to groundwater is necessary for accurate predictions of pesticide loadings to the groundwater system
Site and soil vary by module of model tested	Graphical	Yes	Capacity to reproduce general measured patterns of subsurface water and selected pesticide concentrations over a variety of conditions	Estimated concentrations of aldicarb ranging from 10 to 50 parts per billion when the concentrations exceeded 100 parts per billion
1 site, 1 soil	Graphical	Yes	Good agreement	Next step is to extend the model to cases where volatilization is important

(continued)

Author and date[a]	Model tested[b]	Contaminant examined
Wagenet et al. (1989)	LEACHM	DBCP

Geographic area/soil[c]	Analytical method	Model developer[d]	Predictive validity	Observations
1 site, 1 soil	Graphical	Yes	Relatively poor agreement; results should not be considered an indication that LEACHM is an inadequate representation of pesticide fate in the unsaturate zone	Simulated values are always substantially larger than measured concentrations

[a]Complete citations are given in the bibliography. "Predictive validity" statements and "observations" are from listed sources.

[b]Complete model names are given in the abbreviations section of the table of contents.

[c]"Geographic area" is the number of sites at which the tests were conducted. "Soils" is the number of distinct soil types in which the tests were held.

[d]Is the author of the validation exercise also the developer of the model?

[e]Bromide is not a pesticide; however, it is commonly used as a surrogate for a very mobile pesticide.

In table 3.4, we provide a summary showing the results for each of the 27 models on the 5 criteria. The principal models tested were PRZM (pesticide root zone model), GLEAMS (groundwater loading effects of agriculture management systems), and LEACHM or LEACHMP (leaching estimation and chemistry model—pesticide).

Table 3.4: Summary of Validations of Simulation-Modeling Approach

Model[a]	Number of studies[b]	Predictive validity[c]	Inconsistent results[d]	Subcounty analysis[e]	Independent replication[f]	Graphical and statistical analysis[g]
AGGR	1	0	[h]	No	No	No
CMLS	1	1	Yes	No	Yes	Yes
CREAMS	1	1	[h]	No	No	No
GLEAMS	5	4	Yes	No	Yes	Yes
LEACHM(P)	5	4	Yes	No	Yes	Yes
MOUSE	2	1	Yes	No	Yes	Yes
Opus	1	1	[h]	No	No	No
PESTAN	3	3	Yes	No	Yes	No
PRZM	15	11	Yes	No	Yes	Yes
RZWQM	1	1	[h]	No	No	No
SAFTMOD	1	1	[h]	No	No	No
SESOIL	1	0	[h]	No	Yes	No
VADOFT	1	1	[h]	No	No	No

(continued)

Model[a]	Number of studies[b]	Predictive validity[c]	Inconsistent results[d]	Subcounty analysis[e]	Independent replication[f]	Graphical and statistical analysis[g]
VIP	1	1	No	No	No	No
Unnamed #1 (Enfield and Shew, 1975)	1	1	[h]	No	Yes	Yes
Unnamed #2 (Enfield and Shew, 1975)	1	1	[h]	No	Yes	Yes
Unnamed #3 (Enfield et al., 1982)	1	1	Yes	No	No	No
Unnamed #4 (Enfield et al., 1982)	1	1	Yes	No	No	No
Unnamed #5 (Green et al., 1986)	1	1	[h]	No	No	No
Unnamed #6 (Green et al., 1986)	1	1	[h]	No	Yes	No
Unnamed #7 (Green et al., 1986)	1	1	[h]	No	Yes	No
Unnamed #8 (Green et al., 1986)	1	1	[h]	No	No	No
Unnamed #9 (Green et al., 1986)	1	1	[h]	No	Yes	No
Unnamed #10 (Jaynes et al., 1988)	1	1	[h]	No	No	No
Unnamed #11 (Jones et al., 1987)	1	1	[h]	No	No	No
Unnamed #12 (Jury et al., 1982 and 1988)	2	1	Yes	No	No	No
Unnamed #13 (Jury et al., 1988)	1	0	[h]	No	No	No

[a]Complete model names are given in the abbreviations section of the table of contents.

[b]Number of studies in which the model was evaluated.

[c]Number of studies in which the author concluded that there were at least some positive results.

[d]For models for which some positive results have been reported, have negative results been reported either in the same study or across studies? Models that have been tested with only one pesticide in one study or for which no positive results were reported are designated not applicable.

[e]Was the model tested at a broader than site-specific scale?

[f]Has the model been tested by someone other than its developer?

[g]Has the model been evaluated using both graphical analysis and statistical measures of fit?

[h]Not applicable

Predictive Validity

Authors' assessments of the models they tested were generally positive (that is, have predictive validity). In 30 of the 35 studies, a positive evaluation of at least one of the models being tested was reported. A positive evaluation of model performance was given by at least one author for 24 of the 27 models.

PRZM is the most widely tested of the models, with 15 validation studies. Eleven of these were judged to be positive. However, adjectives used to describe this model's performance ranged from "successful" and "acceptable agreement" to "erratic" and "poor." One author concluded that, despite PRZM's being a logical conceptual model for the simulation of water and solute movement through soils, the inaccuracy of his PRZM simulation reflected particularly poorly on the use of PRZM as a regulatory tool. (See J. Levy et al., 1990.) However, other authors concluded, based on their more positive results, that PRZM could be used effectively.

GLEAMS and LEACHM have each been tested five times. For each model, four of the validations were judged to be at least partially successful.

Other models, none of which had been tested more than three times, were often judged in positive terms by the authors. In all but three cases, there had been only one test of the model. In 18 of 21 cases in which there had been only one test, the results were judged to be positive.

Harter and Teutsch wrote that predictions from uncalibrated simulation models need to be within a factor of two of measured field data to be of use. [8] (See Harter and Teutsch, 1990). The sufficiency of this criterion for regulatory purposes has not been established. Moreover, the absolute accuracy of these models has been questioned by several authors. They noted that the models provide acceptable predictions for ranking the relative leaching of different pesticides but that the models did a poor job of predicting the actual pesticide concentrations. In fact, the author of GLEAMS states that the model is not predictive in the sense of absolute quantities but should only be used to assess differences between management systems. Acceptable ranges for accuracy need to be developed and models evaluated to determine if they meet these criteria.

Consistency of Results

Consistency of results can, of course, only be assessed if there has been more than one test of the model. This can be done either in separate studies or in a single study where multiple pesticides are tested. Thirteen of the models have been tested only once and then only for a single pesticide. We assessed consistency for the other 14 models. From the

[8] An uncalibrated model is one in which model parameters have not been adjusted to approximate the prevailing site conditions. Specific site data are needed for calibration. Uncalibrated models are, perhaps, a more realistic test of predictive capability in actual regulatory applications than are calibrated models since the site-specific data are often unavailable.

results shown in table 3.4, we concluded that only one of the models had consistently predicted contamination levels accurately. However, this model, VIP, has only been tested with three pesticides and in only one type of soil. More extensive testing needs to be done to enable researchers to properly evaluate the consistency of the model.

In several cases in which different pesticides were tested in a single study, the fit between simulation predictions and monitoring results was found to be good for one pesticide but not for another. For instance, Parrish et al. found PRZM to be "reasonably accurate" for the pesticide metolachlor but "variable" for aldicarb. In other cases, results for the same pesticide varied between studies. Atrazine concentrations were accurately predicted by PRZM in some studies but not others. (See, for example, Harter and Teutsch, 1990, and Loague and Green, 1991.) Inconsistency was also found when a model was tested with the same pesticide but in different soils. In a test of an unnamed model, Jaynes et al. found that predictions were strongly related to concentrations in a sandy loam soil but not to those in sand.

However, there are some signs that consistent results can be achieved with these models. In the 35 simulation-modeling studies, we found 12 cases in which a model had been tested two or more times using the same pesticide. Four of these cases were for PRZM, 4 for GLEAMS, 2 for LEACHM, and 1 each for MOUSE and PESTAN. Authors' assessments of model performance were positive for more than half the cases for aldicarb for PRZM, LEACHM, and PESTAN, as well as for atrazine, carbofuran, and cyanazine for GLEAMS. Thus, in 6 of 12 cases in which a model had been tested more than once using the same pesticide, the majority of the results were judged to be positive. In addition, in some tests of model performance, multiple pesticides were used to assess predictive validity. In some of these studies (for example, Jones et al., 1986, and Leonard et al., 1991; see table 3.3), positive results were reported for all pesticides tested.

Despite these limited positive findings, we concluded that the consistency of these models had not been demonstrated. If the models are to be used for regulatory purposes, their validity for all pesticides and soils in question needs to be demonstrated.

Analytical Method

Graphical analyses of results were presented for all but two of the studies. However, statistical measures of fit were rarely reported. Only 6 of 35 studies contained any statistical measures of goodness of fit. Seven of the 27 models have been evaluated at least once using statistical criteria.

While we believe that statistical criteria alone are insufficient for a comprehensive analysis of model performance—for instance, graphical analysis helps to locate anomalies in the data and differences between predicted and observed values—their virtual exclusion from the literature renders aggregation or comparison of the results of different assessments impossible. It also makes it difficult to determine the quality of the fit for any single study. Therefore, we are dependent on the testers' judgments concerning the fit between model predictions and monitoring data and have little, if any, indication of how their conclusions were reached.

Independent Replication

There has also been a lack of independent testing of these models. Fifteen of the 27 models have been tested only by the developer of the model. Independent analysis of these 15 models will need to be done if confidence in them is to be increased to the point where their being considered for regulatory use is appropriate.

Geographic Area

We found no instances in which these models were run over an area broader than a specific site (for example, a township or county) and the results subsequently compared with monitoring results across such areas, although some models were validated at multiple sites. In fact, the models were developed to be used at a field-scale. Thus, it is questionable how appropriately these models can be applied over broad regions. Either expensive and extensive site-specific data collection must take place for all leachable pesticides to be used in the area (and in all soil types), or it must be demonstrated that site-specific studies can be generalized to the area in question. As has been seen, we concluded that, thus far, researchers have not been able to show that these models consistently predict groundwater vulnerability.

Summary

None of the mathematical models has been adequately validated to justify its use in developing SMPs. The four most-tested models (PRZM, LEACHM, GLEAMS, and PESTAN) show some promise for particular pesticides. However, for other chemicals, the results for these models has been inconsistent. None of the other models has been tested enough to gain a thorough understanding of its usefulness. Moreover, we found no instances in which these models had been tested at a subcounty level. The appropriateness of using them to predict at this scale is therefore in doubt. To use these models for groundwater vulnerability assessments at this time would require site-specific validation for all pesticides to be used in the area.

Vulnerability Assessments Conducted by the States

We supplemented our analysis of model validity with an examination of applications of vulnerability assessment models in the states. We believed that this examination would give us a better understanding both of the potential of the models and of state activities that likely would be involved in the assessing of groundwater vulnerability for developing SMPs. State officials were asked to report on any vulnerability assessments that had been conducted within their states. Officials in 42 states (of 45 responding) reported that at least one such study had been conducted. Fifty-six studies were reported to us. One of these studies (Teso et al., 1988) has been published and was included in our earlier analysis in this chapter. Summary statements referring to it are also included in this section. None of the other studies was included in our earlier analysis.

State officials were asked to indicate which of four approaches (parameter-weighting, hydrogeologic, empirical, simulation-modeling) was used in assessing groundwater vulnerability. Twenty-seven of the 56 studies employed a parameter-weighting methodology. Most of these studies used the DRASTIC approach or a modified version of DRASTIC (with fewer or additional variables or different weights). DRASTIC is readily available and easy to use, and EPA had promoted its use for assessing groundwater vulnerability. However, we concluded earlier that tests of DRASTIC have generally been negative. Hence, its appropriateness for vulnerability assessments is doubtful.

Twelve of the studies used an empirical approach, while nine used a hydrogeologic-setting comparison approach. The former was discussed earlier in this chapter. The latter compares sites of known contamination with other areas in terms of one or more hydrogeologic factors that are believed to influence groundwater vulnerability. Areas that are judged to possess similar hydrogeologic attributes are considered to be equally susceptible to contamination.

No cases were reported to us in which a simulation-modeling approach had been used in a state. Eight studies did not fit any of our four categories. In some cases, these were monitoring studies in which baseline data were being developed and no hypothesis was being tested.

The state studies do little to inform us about the predictive validity of the models they employed. In only seven cases were the results of the studies verified with monitoring data (that is, predictive validity assessed). In some cases, verification would have been inappropriate since no model was being tested. However, in only 2 (each) of the hydrogeologic and empirical studies and 3 of the parameter weighting studies had the results been subject to verification. In 3 of these cases, officials reported that the results of the vulnerability assessment had been either generally or strongly confirmed using monitoring data. [9] Some of the studies were not yet completed and preliminary results had not been verified (that is, compared with monitoring data). Only 4 of 18 completed studies had been verified. (For 2 other completed studies, verification was inappropriate.)

Summary and Conclusions

In this chapter, we addressed our second evaluation question, "Have current vulnerability assessment methods been demonstrated to be valid for use in a differential protection strategy?" Of the 40 studies outlined in our report, 4 used a parameter-weighting approach (using DRASTIC), 1 used an empirical approach, and the other 35 used a simulation-modeling approach. We concluded that the models examined in these studies have not been shown to predict groundwater contamination accurately. We found inconsistent results between studies and within single studies. In addition, we found shortcomings in the testing of the models. Moreover, we found that the models generally have not been tested at the subcounty level, which is the appropriate level for a differential protection strategy. It has not yet been shown that these models are or can be valid at a subcounty level. Thus, at this time, these models should not be used to support SMPS.

Our results suggest that the models suffer from a lack of sound scientific basis. In most cases, they appear to be oversimplifications and therefore cannot be used to make consistently accurate predictions. This is not to argue that the models only need to be made more complicated in order to increase their validity. Rather, the problem is that the science is not well enough developed to make accurate modeling viable. Modeling is an integral part of the scientific process, and the development of models, along with the gathering of other data, must continue if we are to gain a better understanding of groundwater vulnerability. The problem, at this time, lies in the use of the models for making regulatory decisions.

[9] The three studies are a New Jersey study in which a hydrogeologic approach was used, an Idaho study in which a parameter-weighting methodology was used, and a California study that used an empirical approach. The latter is the study conducted by Teso et al. that was discussed earlier.

Agency Comments

Agency officials generally agreed with our finding that the models have not been sufficiently validated. They also agree that more work needs to be done before the models are accurate predictors of contamination. However, they noted that it is generally accepted that the models may be used successfully in a comparative mode; that is, the models do an acceptable job of predicting the relative leaching of different pesticides and the comparative effectiveness of different management practices in reducing leaching to groundwater.

While we agree that models could be used to help determine the pesticide and management practices that would minimize groundwater contamination, the models would still not be useful in predicting actual amounts of contamination. This means that the question of whether the groundwater contamination resulting from pesticide use or management practices is above or below the level of acceptability could not be answered. Hence, proper controls on pesticide use could not be established.

Conclusions, Recommendations, and Agency Comments

Conclusions and Recommendations

In our previous report, we found no evidence of uniformity of vulnerability at any practical level of analysis. In this study, we report that (1) although many states have been active in collecting data relevant for assessing groundwater vulnerability to pesticides, there are nonetheless large gaps in the availability and sufficiency of this data, especially at the subcounty level, and (2) methods for predicting contamination of groundwater by pesticides have not been sufficiently validated for use in a differential protection strategy. These findings call into question the practicality at this time of the EPA strategy for protecting groundwater from pesticide contamination. In its Pesticides and Ground-Water Strategy, EPA acknowledges the lack of data and suspect quality of the models in this area. However, EPA also points out that the imperfect state of current knowledge concerning groundwater contamination should not be viewed as a reason for inaction. We agree with this assessment. However, we disagree with EPA about what actions should be taken at this time.

EPA has developed an ambitious strategy for protecting groundwater from pesticide contamination. We believe that the objective of the state management plans (SMPs) is theoretically reasonable insofar as they would allow regulatory actions to be targeted to the specific areas where they are appropriate. However, we question the appropriateness of implementing the strategy at this time. The SMPs, with their emphases on prediction and differential protection, seem to be several years ahead of the science. We conclude that, at this time, resources would be better used collecting data and developing models than preparing and reviewing differential protection plans based on incomplete data and unvalidated models.

Based on this conclusion, we make the following recommendations to the Administrator of EPA:

1. Implementation of the differential protection component within EPA's Pesticides and Groundwater Strategy should be delayed. EPA should assess the meaningfulness of preparing and evaluating these plans given the current state of the science. We recommend that EPA do a pilot study with a limited number of states to assess the viability of the strategy. Issues to be addressed include the states' ability to develop meaningful plans based on differential protection and EPA's ability to evaluate these plans. Until the meaningfulness of the plans can be assured, resources should not be spent on preparing them.

2. Until differential protection can be successfully implemented, EPA should continue its current approach of using uniform national restrictions

to protect groundwater from pesticide contamination and allowing states to set standards stricter than those required by EPA. However, as we recommended in a previous report,[1] EPA should increase the attention given to groundwater contamination in the regulation of pesticides. Such an approach would neither require such extensive and expensive data nor the use of models for predicting contamination.

3. EPA should continue to support, to the extent possible, the scientific development of the field, including state data gathering activities and the development and refinement (including validation) of vulnerability models. Only by doing this can EPA ensure that the differential protection component of its groundwater strategy will become viable.

Agency Comments

EPA takes issue with our recommendation that implementation of SMPs be delayed. They argue that precise scientific knowledge of where contamination is likely to occur is not necessary in order to implement a differential protection strategy to manage risks. EPA officials also stated that our focus for evaluating vulnerability assessment tools was too narrow since we examined only monitoring and modeling. They stated that there are other approaches to assessing groundwater vulnerability that could produce better assessments. In particular, they mentioned "best professional judgment."

Certainly, we agree that any increased regulation of pesticides could result in managing risk. However, that does not justify the new strategy. We have shown that data and model limitations greatly restrict the ability to assess groundwater vulnerability. While we appreciate the importance of professional judgment, we have no evidence that this method will yield better assessments, or even accurate or comparable assessments. The preparation and evaluation of state management plans (SMPs) will require extensive resources. Given our findings and the lack of evidence of the effectiveness of other approaches, it cannot be assumed that the new strategy will be more cost-effective than the earlier approach.

[1]Pesticides: EPA Could do More to Minimize Groundwater Contamination, GAO/RCED-91-75 (Washington, D.C.: April 29, 1991).

Expert Panel

Leonard Gianessi
Resources for the Future
Washington, D.C.

Don Goss
Soil Conservation Service
U.S. Department of Agriculture
Fort Worth, Texas

George Hallberg
Iowa Department of Natural Resources
Des Moines, Iowa

Harold Mattraw
U.S. Geological Survey
U.S. Department of the Interior
Reston, Virginia

Rebecca Petty
Ohio Department of Natural Resources
Columbus, Ohio

GAO Questionnaires

GAO

Survey of State Coordinators for Groundwater Vulnerability to Pesticide Contamination

Part I

The U.S. General Accounting Office has been asked by the Congress to perform an evaluation of state programs to assess groundwater vulnerability to pesticide contamination. We are conducting a survey of every state in the country. We have asked the Environmental Protection Agency (EPA) regional office to identify officials considered well informed about information sources and vulnerability assessment studies performed within your state. They recommended that we contact you to help us comply with this congressional request. Please complete the enclosed questionnaire, which provides a standardized format to describe the efforts undertaken in your state to identify areas overlying vulnerable groundwater.

This questionnaire is in two parts. Part I includes general questions about groundwater programs and the availability of information relative to groundwater pesticide contamination in your state. Part II includes separate questionnaires about each study that you consider representative of your state's efforts to identify groundwater that is vulnerable to nonpoint contamination by pesticides.

Part I of the questionnaire may take about a half hour to complete if all the information is readily available. If not, it may take a few additional hours, depending on the extent to which your records are centralized and automated and on the number of additional parties that have to be consulted.

Feel free to get assistance in completing this questionnaire from anyone you think would be helpful. If you have any questions or problems completing it, contact Steve Smith at 202-275-1895 in Washington, D.C. We would appreciate it very much if you could return the completed questionnaire in the enclosed stamped, addressed envelope within 15 days of receiving this request.

Shallow Well Population

1. Of the population in your state that draws drinking water from the ground, approximately what percentage uses shallow wells (well depth less than 50 feet)?

   ____________________(of total using groundwater, % using shallow wells)

   Note: If data are not available to provide an accurate assessment, please indicate this and give us a "best guess" estimate.

Planning

2. Do you have a statewide groundwater quality plan (and/or law) for protecting drinking water from pesticides or not? *(Check one.)*

   1. ☐ Yes. (Go to 4.)
   2. ☐ No. (Continue.)

3. If no to 2, will you have such a plan within the next 5 years or not? *(Check one.)*

   1. ☐ Yes. (Go to 6.)
   2. ☐ Probably yes. (Go to 6.)
   3. ☐ Uncertain. (Go to 9.)
   4. ☐ Probably no. (Go to 9.)
   5. ☐ No. (Go to 9.)

4. Please send us a copy of the plan. (Indicate the status of transmission.) *(Check one.)*

   1. ☐ Copy enclosed
   2. ☐ Copy to be sent within two weeks.
   3. ☐ Other. (Specify)__________

5. Have all components of the plan (or law) been implemented or not? *(Check one.)*

   1. ☐ Yes.
   2. ☐ No. (If no, please identify the components of the plan that have not been implemented and indicate the dates you expect them to be implemented.)

   ____

   ____

   ____

6. Consider protected groundwater sources. Does (will) this plan protect all sources equally or are sources (will sources be) protected according to a priority? *(Check one.)*

   1. ☐ All sources protected equally.
   2. ☐ Sources protected according to a priority. (If checked, please describe the criteria for assigning this priority.)

   Criteria: ______________________________

   ____

   ____

   ____

Natural Susceptibility

7. Does this plan currently (or will it within the next 5 years) identify and rate different parts of the state as to natural vulnerability or susceptibility to groundwater contamination or not?

   1. ☐ Yes. (Continue.)
   2. ☐ No. (Skip to question 9.)

8. If yes, are these parts mapped in accordance to their natural susceptibility to groundwater contamination or not? *(Check one.)*

   1. ☐ Yes.
   2. ☐ No.

9. Regardless of whether you have a groundwater quality plan or vulnerability plan, please indicate the data available in your state for the factors listed below that could be (or are) considered in the development of a vulnerability map. We understand that there may be data available at a number of different scales. If applicable, you may respond separately for up to three different scale levels which are classified below as broad, intermediate, or fine. You may also substitute the letters designated in the legend below for the scale ratio nearest that used in your data. The scale of map should be indicated in the first column. Indicate in column 2 the percent (or proportion) of your state mapped for each factor at each scale identified in column 1. Indicate the percent of these data that are computerized in column 3. Please do this for the current year, and if maps are incomplete, indicate what you expect will be completed by 1996 in columns 4 and 5.

Factors considered for vulnerability	Scale of map (e.g., 1:2000) (1)	% of state mapped at this scale in 1991 (2)	% of data computerized and available in 1991 (3)	% of state mapped at this scale in 1996 (4)	% of data computerized and available by 1996 (5)
1. Depth of top of water table/aquifer					
1. Broad					
2. Intermediate					
3. Fine					
2. Aquifer thickness					
1. Broad					
2. Intermediate					
3. Fine					
3. Direction of groundwater flow					
1. Broad					
2. Intermediate					
3. Fine					
4. Type of characteristics of soil					
1. Broad					
2. Intermediate					
3. Fine					

Scale Legend

A 1:2,000,000	E 1:100,000
B 1:1,000,000	F 1:24,000
C 1:500,000	G 1:15,480
D 1:250,000	H 1:2,000

9. Continued.

Factors considered for vulnerability	Scale of map (e.g. 1:2000) (1)	% of state mapped at this scale in 1991 (2)	% of data computerized and available in 1991 (3)	% of state mapped at this scale in 1996 (4)	% of data computerized and available by 1996 (5)
5. Type of characteristics of vadose zone					
1. Broad					
2. Intermediate					
3. Fine					
6. Depth of confining zone					
1. Broad					
2. Intermediate					
3. Fine					
7. Description of confining zone					
1. Broad					
2. Intermediate					
3. Fine					
8. Aquifer boundaries					
1. Broad					
2. Intermediate					
3. Fine					

Scale Legend

A 1:2,000,000	E 1:100,000
B 1:1,000,000	F 1:24,000
C 1:500,000	G 1:15,480
D 1:250,000	H 1:2,000

9. Continued.

Factors considered for vulnerability	Scale of map (e.g. 1:2000) (1)	% of state mapped at this scale in 1991 (2)	% of data computerized and available in 1991 (3)	% of state mapped at this scale in 1996 (4)	% of data computerized and available by 1996 (5)
9. Other geological considerations: *(specify)*________					
1. Broad					
2. Intermediate					
3. Fine					
10. Overall susceptibility index or rating					
1. Broad					
2. Intermediate					
3. Fine					

Scale Legend

A 1:2,000,000 E 1:100,000

B 1:1,000,000 F 1:24,000

C 1:500,000 G 1:15,480

D 1:250,000 H 1:2,000

Well Drillers Information

10. Does your state have a listing of well drillers' logs or not?

    1. ☐ Yes. (Continue.)

    2. ☐ No. (Skip to question 12.)

11. What groundwater vulnerability information is included in these logs? How long has this information been collected, and is the information accessible by computer? Finally, what is the quality of the data reported in these logs? That is, are they complete? Are they accurate? *(Please specify accuracy of depth in + or - feet.)*

	Is information recorded? (Write yes/no.) (1)	Number years information recorded? (2)	% of information readily accessible by computer (3)	Completeness: % logs with this entry complete (4)	Accuracy (+ or - feet) (5)
1. Depth to groundwater					
2. Depth to uppermost aquifer					
3. Description of land surface (e.g., soil)					
4. Description of subsurface geological materials by depth					
5. Well pumping capacity					
6. Location of well					
7. Other *(Specify.)*__					
8. Other *(Specify.)*__					

Recharge

12. How adequate or inadequate is the information currently available to map important recharge areas in your state at a 1:100,000 scale? *(Check one.)*

1. ☐ More than adequate.
2. ☐ Generally adequate.
3. ☐ Marginally adequate.
4. ☐ Generally inadequate.
5. ☐ Very inadequate.
6. ☐ No basis to judge.

Other factors

13. What factors, if any, other than those listed in question 9 does your statewide vulnerability assessment index include? *(Check one.)*

1. ☐ No other factors.
2. ☐ Recharge.
3. ☐ Other. *(Specify.)* ____

____

____

____

14. Has a Geographic Information System (GIS) been employed to store vulnerability data? *(Check one.)*

1. ☐ Yes. (Please identify the GIS used and indicate which data are included in it.)

____

____

____

____

2. ☐ No.

15. Please list your name, title, affiliation, address and telephone number.

Name: ______________________________

Title: ______________________________

Affiliation: ______________________________

Address: ______________________________

____

____

____

Phone #: ______________________________

16. If you have any comments about the questions covered in this questionnaire or if you have questions that we should have asked but did not, please use the space below to comment.

United States General Accounting Office

GAO

Survey of State Coordinators for Groundwater Vulnerability to Pesticide Contamination

Part II

In this part of the questionnaire, we would like to obtain information regarding vulnerability assessment studies (or a program of studies), analyses, or reports you are aware of that have been conducted within your state. We are particularly interested in studies employing one or more of the four following approaches: a hydrogeologic-setting-comparison approach, a parameter-weighting approach, an empirical approach, or a simulation-modeling approach. (See page 4 for more description.)

For the purposes of this questionnaire, a vulnerability assessment study is defined as a characterization of the relative vulnerability of groundwater for some or all of the state, using a single methodology. Further, a program of studies is defined as a group of studies that employ substantially similar methodologies and data sources. Both approaches to the assessment of groundwater vulnerability, as defined here, would rate or rank areas of contamination potential using a uniform set of guidelines. Finally, in neither case would field-scale assessments that have not been "mapped" to broader areas (such as townships or counties) be considered.

We request that you complete a separate questionnaire for each study (or program of studies), analysis, or report your state has conducted, or is planning to conduct, that would characterize groundwater vulnerability. Please select the studies or programs that you feel best represent your state's efforts. We have included three sets of questionnaires for Part II. However, if you feel that there are more than three such "model" studies (or programs), you are free to make copies and complete additional sets of questions. Please send a copy of each study report, or other documentation, if available.

Part II of this questionnaire is divided into the following four sections:

Section I (Questions 1-5) covers background information about the study, or program of studies, being reported on.

Section II (Questions 6-29) includes items pertaining to the approach and methodology of this study or program of studies.

Section III (Questions 30-34) seeks information about the costs and resources associated with vulnerability assessments.

Section IV (Question 35) pertains to information about the respondent.

Part II of this study may take a few hours to complete, depending on the extent to which the information is readily available. Again if you have any questions, please call Steve Smith at (202) 275-1895 in Washington, D.C. We would appreciate it if you would use the enclosed stamped and addressed envelope to return Part II and Part I, within 15 days.

Section I: Background of the Study, Report, Analysis, or Program

1. Please identify the study report, analysis, or program and the principal researcher:

   Name of study or program: ____________

   ____

   ____

   Affiliation: ____________

   ____

   Principal Investigator or Researcher: ____________

   ____

   ____

   Address: ____________

   ____

   ____

   ____

   Phone #: ____________

2. Is this a single, i.e., "stand alone," study or a program of studies, having substantially similar methodologies and sources of data? *(Check one.)*

   1. ☐ This is a single study.
   2. ☐ This is a program of studies having substantially similar data sources and methodologies that have been or are being replicated.

3. What is (are) the area unit(s) of analysis for the stud or program of studies? *(Check all that apply.)*

   1. ☐ The state.
   2. ☐ A county.
   3. ☐ A watershed.
   4. ☐ Other. *(Specify)*: ____________

4. Has the study (program of studies) identified above been completed or is it ongoing? *(Check one.)*

   1. ☐ Completed.
   2. ☐ Work is ongoing. (If you are answering for a program of studies, some individual studies may have already been completed, although the entire effort has not yet been completed.)

5. When was (will) the study (program of studies) identified above (be) completed? *(Check one.)*

   1. ☐ Before 1980.
   2. ☐ Between 1980 and 1990.
   3. ☐ 1991.
   4. ☐ 1992.
   5. ☐ 1993.
   6. ☐ After 1993.

Section II: Approach and Methodology

6. What proportion of the state will be the subject of the study or studies? *(Check one.)*

   1. ☐ All or almost all of the state. (Skip to question 8.)
   2. ☐ About 3/4 of the state. (Continue.)
   3. ☐ About 1/2 of the state. (Continue.)
   4. ☐ About 1/4 of the state. (Continue.)
   5. ☐ Less than 1/4 of the state. (Continue.)

7. How important, if at all, were the following possible threats or socioeconomic factors in determining the geographic areas selected for analysis? *(Check one column for each row).*

	Little or no importance (1)	Somewhat important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
1. High pesticide use patterns					
2. High population density					
3. Availability of cost-sharing funds from the local government					
4. Monitoring data indicated groundwater contamination by pesticides or other substances					
5. High degree of interest by individuals or groups in the community being studied					
6. Other reasons to suspect vulnerability *(Please explain)* ______					
7. Other reasons *(Specify.)*______					

8. Which of the following approaches was used by the study (program) named above? *(Check one.)*

   1. ☐ **A hydrogeologic-setting-comparison approach:** This approach compares sites that have known contamination to other areas in terms of one or more hydrogeologic factors that are believed to influence groundwater vulnerability. Areas that are judged to have similar hydrogeologic attributes are considered equally susceptible to contamination. An example would be to identify as vulnerable groundwater below sandy soils with permeability greater than six inches per hour. *(Skip to question 9.)*
   2. ☐ **A parameter-weighting approach:** This approach involves selecting factors that are believed to influence groundwater vulnerability and then attaching weights to them in terms of their relative importance. The vulnerability of sites or areas are the weighted scores of the factors. DRASTIC is an example of this approach. *(Skip to question 9.)*
   3. ☐ **An empirical approach:** This approach involves gathering monitoring data to test a thesis that certain factors, such as hydrogeologic factors, influence detections or contaminant concentrations. If verified through the monitoring study, the model would then be used to "map" areas that had not been studied. *(Skip to question 10.)*
   4. ☐ **A simulation-modeling approach:** This approach employs a mathematical model of the processes that influence contaminant fate and transport in one or more compartments of the soil/vadose zone/groundwater/aquifer system to predict either how long it will take for contaminants to reach a given depth or the amount that will reach a given depth. The model is then used to "map" areas of the state. *(Skip to question 13.)*

9. Briefly describe the basic plan, procedure, or rationale for selecting parameters; e.g., selected those conditions that facilitated leaching. *(Write answer below and skip to question 14.)*

   Brief description of parameter-selection plan, procedure, or rationale:____________________

   ____

   ____

   ____

   ____

10. How were the discrete well locations selected? *(Check one.)*

    1. ☐ Judgment sample (judged to be representative). (Continue.)
    2. ☐ Random sample. (Continue.)
    3. ☐ According to a priori criteria. (Skip to question 12.)
    4. ☐ According to cost convenience or availability. (Skip to question 12.)
    5. ☐ Arbitrarily. (Skip to question 12.)
    6. ☐ According to potential threat. (Skip to question 12.)
    7. ☐ To cover the largest portion of the vulnerable population for the least cost. (Skip to question 12.)
    8. ☐ Other. (Please specify and skip to question 12.)

       ____

       ____

11. If sampled, was the sample stratified or not?

    1. ☐ Stratified.
    2. ☐ Not Stratified.

12. How many discrete well locations were selected?

    ________ (# of well locations).

13. On what basis were the pesticides whose effects were simulated selected? *(Check all that apply.)*

    1. ☐ Pesticide mobility.
    2. ☐ Usage rates.
    3. ☐ Toxicity.
    4. ☐ Other. *(Specify.)*: ________

14. If the study (program) employs an established methodology (such as DRASTIC or PRZM) please identify the methodology. *(Write answer below.) (If not skip to question 15.)*

    Methodology: ________

15. Was a Geographic Information System (GIS) employed in this study? *(Check one.)*

    1. ☐ Yes. *(Please identify.)* ________

       GIS and variables: ________

    2. ☐ No

16. How were vulnerable areas identified at the end of the study, if at all? *(Check all that apply.)*

    1. ☐ Through a map of the study area with differential coding or coloring of areas with different degrees of vulnerability.
    2. ☐ Through a listing of vulnerable areas.
    3. ☐ Other. *(Please specify:)* ________
    4. ☐ None identified.

17. If applicable, what was the scale of resolution of the map or output data set? *(Write scale, e.g., 1:100,000 or check not applicable)*

    1. ☐ Scale of resolution: 1:________
    2. ☐ Not applicable.

18. We would like some more detailed information about the data that went into your model. For each (1) parameter in your model (e.g., depth to groundwater), please describe (2) the source of data used for that parameter (e.g., well logs), (3) the scale or resolution of the data, (4) the organization that collected the data and (5) what limitations or restrictions, if any, there are on the use of these data. In lieu of writing out data sources, scales, and organizations you may use the designated numbers and letters from the legend below. If there are other data sources please specify them in the space provided under other. Also, you may use abbreviations for organization names.

1. Variable Name	2. Data Source	3. Scale	4. Organization	5. Limitations

LEGEND

Data Sources:	Other Data Sources *(Specify)*	Scales	
1. Well logs	6. ________	A. 1:2,000	E. 1:250,000
2. Measurements	7. ________	B. 1:15,480	F. 1:500,000
3. Topographic maps	8. ________	C. 1:24,000	G. 1:1,000,000
4. Census	9. ________	D. 1:100,000	H. 1:2,000,000
5. County/state maps	10. ________		

Abbreviations:____

____

19. Preferential flow patterns are defined as conditions under which infiltration rates are highly uneven (e.g., presence of sinkholes, fractured bedrock). If new data were collected, did the study find preferential flow patterns a significant factor in your state? *(Check one.)*

   1. ☐ Yes. (Continue.)
   2. ☐ No. (Skip to question 22.)

20. If yes, was the possibility of preferential flow patterns explicitly accounted for in the study? *(Check one.)*

   1. ☐ Yes. (Continue.)
   2. ☐ No. (Skip to question 22.)

21. If yes, briefly explain how these preferential flow patterns were accounted for in the space below.

   ____
   ____
   ____
   ____

22. If you collected your own data, were the data at different locations collected in accordance with a standardized procedure or protocol, or were the data gatherers given authority to collect data in accordance with their individual discretion? *(Check one and describe.)*

   1. ☐ Collected in accordance with a standardized procedure. *(Please describe.)*

      Standardized procedure: ______________
      ____
      ____

   2. ☐ Collected in accordance with data gatherers' discretion. *(Please describe.)*

      Discretionary procedure: ______________
      ____
      ____
      ____

   3. ☐ Did not collect our own data.

23. *(Answer only if the study is completed. Otherwise skip to question 28.)* Have the results from the study been formally subjected to verification through a monitoring study? *(Check one.)*

   1. ☐ Yes. (Continue.)
   2. ☐ No. (Skip to question 28.)

24. If yes, please either (1) send us a copy of the verification report or (2) identify the chemicals that were monitored; and (3) estimate the predictive validity (e.g., R-squared). *(Check 1, and enclose a copy of the report, or check 2 and 3 and write your answers.)*

   1. ☐ Enclosed a copy of the report.
   2. ☐ Listing of chemicals monitored.

      ____

      ____

   3. ☐ Quantification of predictive validity.

      ____

      ____

25. Which of the following methods were used in the verification? *(Check all that apply.)*

   1. ☐ Random sampling of well sites.
   2. ☐ Inclusion of chemical use data as an explanatory variable.
   3. ☐ Inclusion of other explanatory variables. *(Please identify.)*
   4. ☐ Comparison of predictions with nitrate-monitoring data.
   5. ☐ Comparison of predictions with pesticide-monitoring data. *(Please identify pesticides.)*
   6. ☐ Use of contaminant readings averaged over an area, rather than, or in addition to, site-specific readings.
   7. ☐ Other. *(Please specify.)*

      ____

26. To what extent, if at all, did the results of the verification study confirm the model? *(Check one.)*

   1. ☐ Strongly confirmed.
   2. ☐ Generally confirmed.
   3. ☐ Neither confirmed nor disconfirmed.
   4. ☐ Generally disconfirmed.
   5. ☐ Strongly disconfirmed.
   6. ☐ No basis to judge.

27. Was the model recalibrated as a result of the verification effort or not? *(Check one.)*

   1. ☐ Recalibrated.
   2. ☐ Not recalibrated.

28. What groundwater sources were characterized for vulnerability by the study approach and methodology? *(Check all that apply.)*

   1. ☐ Shallow well sources (i.e., well depth less than 50 feet)
   2. ☐ Deeper aquifer sources.

29. What actions, if any, were taken to review the validity of data collection and analysis activities; e.g., data verification, independent review, etc.? *(Check 1 or write description of action taken.)*

1. ☐ No actions taken.

Description if action taken: ____________

____

____

____

Section III: Costs and Resources

30. Please list the primary areas of technical expertise of the project manager. Also identify other individuals who provided significant contributions of expertise or technical assistance to the study (program of studies) and list their area(s) of expertise.

Responsibility	Area(s) of Expertise
Project manager	
1.	
(Other contributors)	
2.	
3.	
4.	
5.	

31. Please name the organizations that provided a significant amount of information, staff, or other assistance to the planning, implementation, or review of the study and the nature of the work or information involved. Include both governmental and nongovernmental organizations.

Organization	Nature of Assistance
1.	
2.	
3.	
4.	
5.	

32. What was the approximate cost of the study (program of studies) identified in this questionnaire? Include all project functions (e.g. planning, primary and secondary data collection, interpretation and analysis, generating maps, performing QA/QC publishing, and other expenses). *(If the study is ongoing, please estimate the cost and skip to question 35.)*

$____________(total cost)

33. Approximately what percentage of the total cost was spent performing each of the following project functions?

Task	Percentage of total cost
1. Original data collection	%
2. Acquiring secondary data	%
3. Interpreting data	%
4. Generating maps	%
5. Performing QA/QC	%
6. Printing and publishing	%
7. Other significant expenses *(Please specify.)*:	%
8. Total	100%

34. How may staff years, expressed in full-time equivalents (FTEs), were expended on the study (program of studies) identified in this questionnaire? (Note: excluding publishing and printing.)

_______FTE staff yrs.

Section IV: Information About the Respondent

35. Please indicate your name, title, affiliation, address and telephone number.

Name: ____________

Title: ____________

Affiliation: ____________

Address: ____________

____

____

____

Phone #: ____________

36. If you have any comments on any of the questions presented in the questionnaire or comments about questions we should have asked or issues we should have raised but did not, please write in the space below.

United States General Accounting Office

GAO

Survey of Pesticide Management Officials on Plans to Protect Groundwater

The U.S. General Accounting Office has been asked by the Congress to perform an evaluation of state programs to control the contamination of groundwater by pesticides. We are conducting a survey of every state in the country. We have asked the Environmental Protection Agency (EPA) regional offices to identify officials considered well informed about actions taken, or currently proposed, to manage pesticide contamination of groundwater within your state. They recommended that we contact you to help us comply with this congressional request.

Please complete the enclosed questionnaire, which provides a standardized format to describe the effort undertaken in your state to identify areas overlying vulnerable groundwater. Feel free to obtain information from other knowledgeable individuals. The questionnaire may take a half hour to complete, if all the information is readily available. If not, it may take a few additional hours depending on the extent to which your records are centralized and automated and on the number of other parties that need to be consulted.

If you have any questions or problems with the form please contact Steve Smith at 202-275-1895. We would be most appreciative if you would return the completed questionnaire in the enclosed stamped, addressed envelope within 15 days of receiving this request.

Pesticide Management Plan

1. The Environmental Protection Agency is in the process of preparing a management plan to control pesticide contamination of groundwater. Which of the following choices best reflects the status of your state's efforts to develop a pesticide management plan in response to EPA's proposed strategy? *(Check one.)*

   1. ☐ Our agency has already completed our state plan.
   2. ☐ Another state agency has already completed our state plan. (If checked please identify this agency.)

      Name of agency: ____________________

   3. ☐ Our state has legislation which satisfies the EPA strategy requirement.
   4. ☐ Our agency has started preparing a plan.
   5. ☐ Another state agency has started preparing a plan. (If checked please identify this agency.)

      Name of agency: ____________________

   6. ☐ We are waiting for EPA to publish the strategy before we begin work.
   7. ☐ We do not intend to submit a state management plan. (Go to question 10.)

2. Does (or will) your state pesticide management plan (or law) protect all groundwater, or are some types of groundwater excepted? (Examples are: shallow wells, salt water deposits, etc.) *(Check one.)*

   1. ☐ All groundwater is protected.
   2. ☐ Some types of groundwater are excepted from protection. *(Please specify.)*

      ____

      ____

      ____

   3. ☐ Undecided.

3. Has your stated decided how it will assess the vulnerability of groundwater? *(Check one.)*

   1. ☐ Yes. (Continue.)
   2. ☐ Generally yes. (Continue.)
   3. ☐ Generally no. (Go to 10.)
   4. ☐ No. (Go to 10.)

4. If yes or generally yes, is your agency responsible for this assessment?

   1. ☐ Yes. (Go to 6.)
   2. ☐ No. (Continue.)

5. If no to question 4, please identify the agency(ies) in your state responsible for doing these assessments.

   Name(s) of agency(ies):____________________

6. If yes to question 4, please enclose, send under separate cover, or write below a description of the vulnerability assessment method. *(Check one.)*

   1. ☐ Description enclosed.
   2. ☐ Description being sent.
   3. ☐ Description provided below.

      Vulnerability assessment method: ________

      ____

      ____

7. Are these vulnerability assessments part o: :ur state's pesticide management plan?

   1. ☐ Yes.
   2. ☐ No.

Reports, Studies, Analyses or Programs of Vulnerability Assessments

8. Can you identify any particular report(s), study(ies), analysis(es), project(s), data source(s), or program(s) to be used in making vulnerability assessments that you will prepare in response to EPA's agricultural chemicals strategy? Include all important related studies considered even if they were not specifically developed for pesticide control/management.

   1. ☐ Yes. (Continue.)
   2. ☐ No. (Go to 10.)

9. If yes to question 8, please cite the title(s) of the report(s), study(ies), analysis(es), data source(s), or program(s) that you will draw on in designing your assessment. Also, for each please list the responsible organization(s) and the project manager(s) or responsible principal investigator(s). *(Write in space below. Use the back of the questionnaire if there are more than three reports or studies.)*

   1. Report, study or analysis:

   1. Title: ______________________
   2. Organization: ______________________
   3. Name and telephone number of study project manager or principal investigator: __________

   ____

   ____

   2. Report, study or analysis:

   1. Title: ______________________
   2. Organization: ______________________
   3. Name and telephone number of study project manager or principal investigator: __________

   ____

   ____

   3. Report, study or analysis:

   1. Title: ______________________
   2. Organization: ______________________
   3. Name and telephone number of study project manager or principal investigator: __________

   ____

   ____

Pesticide Use data

10. Does your state have information sources or methods that are used to determine agricultural pesticide use or sales? *(Check one.)*

   1. ☐ Yes. (Continue.)
   2. ☐ No. (Go to 15.)

11. Please identify these information sources by writing the number of agricultural pesticides that are monitored and tracked by each source. When counting pesticides, enumerate them by active ingredient rather than by product or trade name. *(Write the number of pesticides tracked by each source in the space provided or check "No basis to judge.")*

Sources	Number of pesticides covered by source (1)	No basis to judge (2)
1. Sales or use data from pesticide dealers or manufacturers.		
2. Pesticide use surveys of farmers.		
3. Surveys of county extension agents.		
4. Cropping data from surveys: (i.e., data on acreage by crop, or crop yield and location).		
5. Reports from farmers or commercial users on restricted use, limited use, or controlled pesticides.		
6. Other *Specify*___		

12. How may counties in your state use enough agricultural pesticides to justify monitoring or keeping track of agricultural pesticide use or sales? *(Write the number or check "No basis to judge.")*

    1. ________________(Number of counties).

    2. ☐No basis to judge.

13. How many of these counties use each of the following information sources or methods to determine agricultural pesticide use or sales? *(Write the number of counties for each information source, or check column 2 for "No basis to judge.")*

Sources	# of counties monitored by data source (1)	No basis to judge (2)
1. Sales or use data from pesticide dealers or manufacturers.		
2. Pesticide use surveys of farmers.		
3. Surveys of county extension agents.		
4. Cropping data from surveys. (i.e., data on acreage by crop, or crop yield and location.		
5. Reports from farmers or commercial users on restricted use, limited use, or controlled agricultural pesticides.		
6. Other *(Specify)* ______		
7. Other *(Specify)* ______		

14. How adequate or inadequate are each of the following information sources for agricultural pesticide monitoring in your state. By adequate we mean, does the source report on the use of all important pesticides and are these reports sufficiently accurate to monitor use? Importance considers toxicity, leaching and prevalence of use. *(Check one column to indicate either degree of adequacy/inadequacy or "No basis to judge" for each source.)*

Sources	Very inadequate (1)	Inadequate (2)	Marginally adequate (3)	Adequate (4)	More than adequate (5)	No basis to judge (6)
1. Sales or use data from pesticide dealers or manufacturers.						
2. Pesticide use surveys of farmers.						
3. Surveys of county extension agents.						
4. Cropping data from surveys: (i.e. data on acreage by crop, or crop yield and location.)						
5. Reports from farmers or commercial users on restricted use, limited use, or controlled agricultural pesticides.						
6. Other *(specify)*.						

15. Please indicate your name, title, affiliation, address and telephone number. Thank you.

Name: ______________________

Title: ______________________

Affiliation: ______________________

Address: ______________________

____

____

____

16. If you have any comments about the questions covered in this questionnaire or if you have questions that we should have asked but did not, please use the space below to comment.

Major Contributors to This Report

Program Evaluation and Methodology Division

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Stephen Smith, Project Staff

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Glossary

Aquifer	A geological formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. Also see Saturated Zone.
Aquitard	See Confining Zone.
Confined Aquifer	An aquifer separated from the groundwater table above by a layer of relatively impermeable sediment or rock and sealed at its base by another layer of materials having low permeability. The impermeable material is referred to as the confining zone. Also see Unconfined Aquifer.
Confining Zone	A geologic unit of relatively low permeability.
Discharge Area	An area in which subsurface water, including water in either the vadose or saturated zone, is discharged to the land surface, to surface water, or to the atmosphere.
Discriminant Analysis	A multivariate statistical method in which predictor (independent) variables are used for classifying individual cases into a predefined, discrete category or group.
Face Validity	That quality of an indicator that makes it seem a reasonable measure of some variable.
Groundwater	Subsurface water in the saturated zone.
Leaching	The process by which soluble constituents are dissolved and carried down through the soil by percolating fluid.
Lithology	The physical character of rocks.
Predictive Validity	The ability of a test or other instrument to produce results in keeping with some criterion that is observed at a future time.
Recharge	The process by which water is added to a zone of saturation.

Saturated Zone

A subsurface area in which all pores and cracks are filled with water under pressure equal to or greater than that of the atmosphere. Also see Aquifer and Vadose Zone.

Taxon

A taxonomic category or unit.

Unconfined Aquifer

An aquifer whose upper surface is the water table and whose lower surface is the confining zone. Also see Confined Aquifer.

Unsaturated Zone

See Vadose Zone.

Vadose Zone

The zone above the water table where the soil pores are not fully saturated, although some water may be present. This is also known as the unsaturated zone. Also see Saturated Zone.

Water Table

The level of groundwater (that is, the top of the saturated zone in an unconfined aquifer).

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