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Potential for Agricultural Chemical Contamination of Aquifers in Illinois

Dennis P. McKenna and Donald A. Keefer

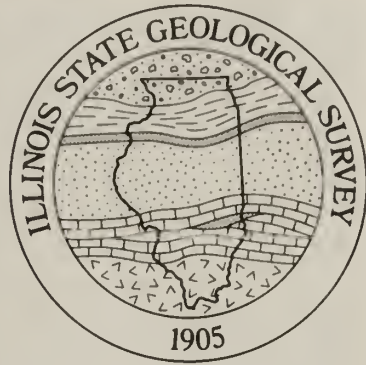
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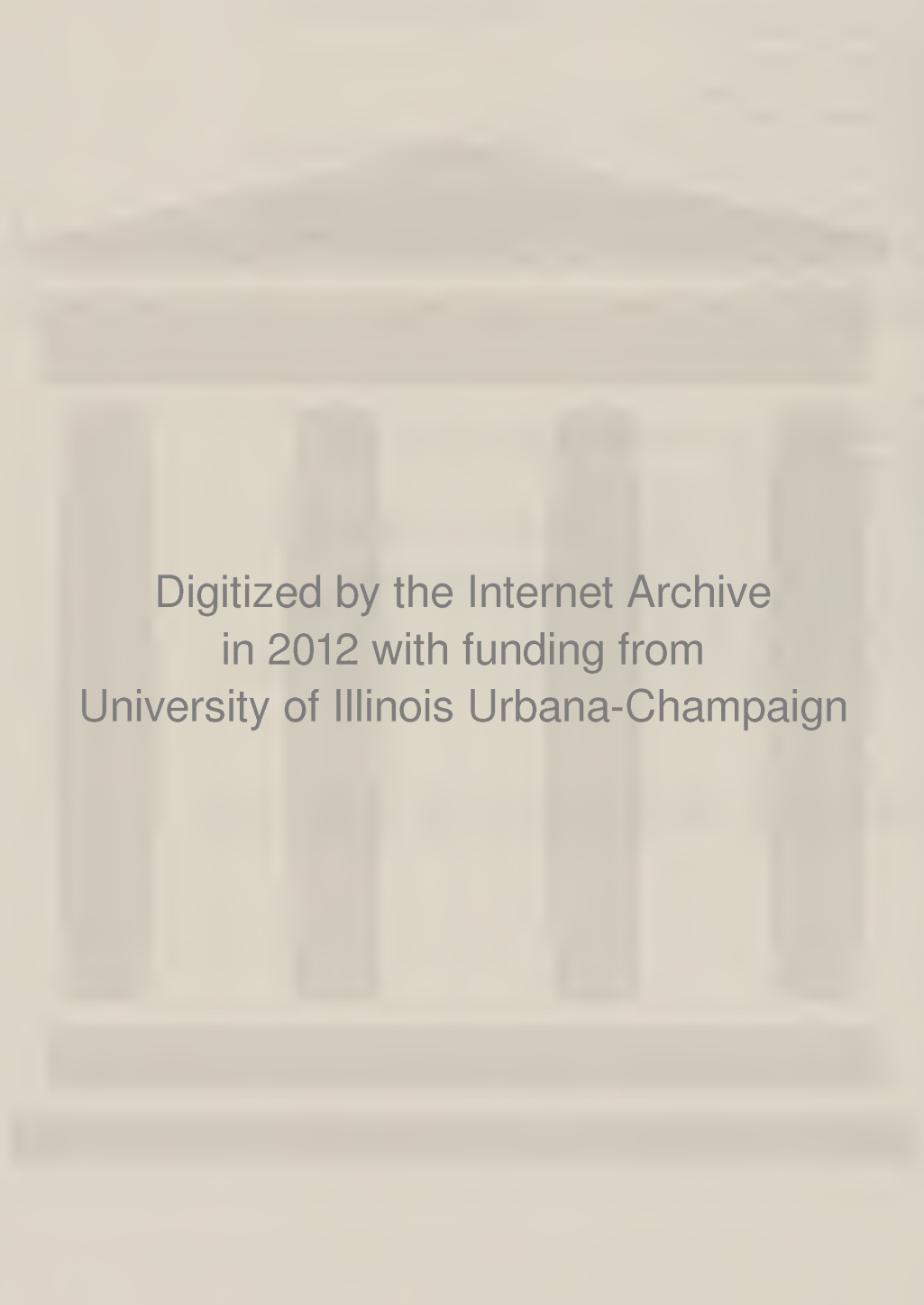
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ABSTRACT

Statewide geologic mapping of Illinois has been used to identify regions with aquifers vulnerable to contamination by agricultural chemicals. This report summarizes the factors and processes affecting the transport of agricultural chemicals to groundwater resources. Aquifer vulnerability is estimated on the basis of the thickness and character of materials overlying the aquifer. In about 60 percent of rural Illinois, aquifers are more than 50 feet deep and apparently protected from pesticide contamination. Potentially vulnerable aquifers occur throughout Illinois but are most common in the northern and southern parts of the state and along the major river valleys. This mapping can aid in targeting educational programs, technical assistance, and detailed monitoring studies of groundwater resources in Illinois.

INTRODUCTION

Accurate prediction of the vulnerability of groundwater resources to contamination from agricultural chemicals is one of the most important environmental issues facing farmers, water users, and state and federal agencies. The areas most vulnerable to contamination must be identified to effectively target educational programs, technical assistance, and detailed monitoring studies. More importantly, regulation of agricultural chemical use to protect groundwater resources must also take into account the vulnerability of these groundwater resources. The U.S. Environmental Protection Agency (USEPA) has proposed a strategy to regulate pesticide use to prevent unacceptable levels of contamination of current and potential drinking water supplies (USEPA 1991). They recommend managing pesticide use on the basis of differences in groundwater use, value, and vulnerability. They also recommend using groundwater vulnerability as a basis for county- or state-level measures, which may include canceling the use of specific pesticides. Under-protection of the resource may result in contamination of drinking water sources and potential damage to water users and the ecosystem. Over-protection, for example, use-restrictions in areas that do not require stringent protection measures, may result in economic hardship for the entire state. The optimum level of protection will balance use and protection of the groundwater resource.

Reasons for concern over the potential for agricultural chemical contamination of groundwater in Illinois include:

- Two out of three acres of rural Illinois are treated with pesticides. Illinois farmers apply approximately 50 million pounds of pesticides (Pike et al. 1991) and 1 million tons of nitrogen fertilizer yearly (IDOA 1990).
- In 1990, more than 80 percent of the corn acreage and almost 30 percent of the soybean acreage receiving preplant or preemergent weed control was treated with herbicides that pose a potential hazard to groundwater in vulnerable soil and hydrogeologic settings.
- Groundwater is the only source of drinking water for about 97 percent of the rural population in Illinois (Withers et al. 1981).
- Aquifers occur within 50 feet of the surface in about 40 percent of rural Illinois.
- State and county agencies have detected pesticides in groundwater samples from shallow aquifers. However, public water supply wells, which generally withdraw water from deep aquifers, apparently have not been significantly impacted (Clark and Sinnott 1988).

This report is accompanied by a series of maps depicting the potential for agricultural chemical contamination of aquifers in Illinois. The map series includes a statewide map at a scale of 1:500,000 (1 inch equals approximately 8 miles) and a map for each county in Illinois prepared at a scale of 1:250,000 (1 inch equals approximately 4 miles).

The method for estimating aquifer vulnerability to contamination by agricultural chemicals was originally proposed in McKenna et al. (1989b). The discussion of hydrogeologic principles and the distribution of groundwater resources in Illinois was modified from Berg et al. (1984a,b).

POTENTIAL FOR CONTAMINATION OF ILLINOIS GROUNDWATER BY AGRICULTURAL CHEMICALS

With current agricultural practices and technology, the leaching of agricultural chemicals, particularly nitrates derived from fertilizer nitrogen and the more mobile pesticides, into groundwater (the saturated zone) may be impossible to prevent (McKenna et al. 1989a). More than one-third of the soils in the state have water tables within 5 feet of the surface during the spring and fall (Drablos and Moe 1984). Through most of Illinois, groundwater occurs within 20 feet of ground surface. However, in about 60 percent of the state, aquifers are more than 50 feet deep and probably not vulnerable to contamination. Thus, agricultural chemicals may be found in shallow groundwater, such as the water flowing from drainage tile, while the source of well water, the aquifer, remains unaffected. Making the distinction between groundwater in fine-grained (non-aquifer) materials (such as clay) and groundwater in permeable (aquifer) materials is important when establishing compliance points for regulatory monitoring.

Agricultural Chemical Use

The widespread use of agricultural chemicals in Illinois presents a large potential source of contamination. The distribution of corn and soybeans can be used to predict where pesticides are used most intensively in the state. In 1990, an estimated 47.2 million pounds of herbicides and more than 3.7 million pounds of insecticides were applied to the 19.9 million acres of corn and soybeans (Pike et al. 1991). In more than 80 percent of the townships in Illinois, more than 25 percent of the total land area is devoted to corn and soybeans (fig. 1). Herbicides were applied to 98 percent of the corn and soybean acreage, but only a small percentage of the small grain and hay or pasture acres received herbicide applications. In 1990, insecticides were applied to 33 percent of the corn. In most years only a small percentage of other crops, including soybeans, are treated with an insecticide. Illinois farmers also apply approximately 1 million tons of nitrogen fertilizer yearly. Almost all corn acres receive applications of nitrogen fertilizer; the average application rate in 1989 was 160 pounds per acre (IDOA 1990). Nitrogen is applied to most of the wheat acreage in the state, but application rates are much lower, approximately 70 to 90 pounds per acre. Less than 10 percent of the soybean acreage receives nitrogen and, where applied, rates are usually less than 20 pounds per acre.

Hydrogeologic Principles

Groundwater is defined in the Illinois Groundwater Protection Act as "underground water that occurs within the saturated zone and geologic materials where the fluid pressure in the pore space is equal to or greater than atmospheric pressure." In the zone of saturation, groundwater is stored in openings ranging from tiny pores between particles of silt and clay, to larger pores in sand and gravel, to large crevices in dolomite and limestone. This definition of groundwater is independent of the character of earth materials, and is therefore not related to the availability of water to wells.

The source of groundwater in Illinois is precipitation that infiltrates the soil and percolates downward to the groundwater system. About 10 percent of the precipitation enters the groundwater system (Berg et al. 1984b). Recharge, the replenishment of groundwater, depends upon soil moisture conditions, soil permeability and water retention capacity, type and distribution of vegetation, precipitation duration and intensity, and location within the groundwater flow system. Regionally, the interrelationship of surface soils, underlying geologic materials, and configuration of the landscape determine the rate and amount of recharge, and the direction of shallow groundwater flow. (In agricultural areas, tile drainage systems may considerably alter natural drainage and recharge characteristics.) Recharge does not occur at specific points or even in small local areas; some recharge occurs in all unpaved areas except the discharge areas themselves. In Illinois, as in most humid areas, streams that flow for all or most of the year are groundwater discharge areas. Water will infiltrate to the water table over the entire interstream area. Some of this water will move back upward in response to evapotranspiration.

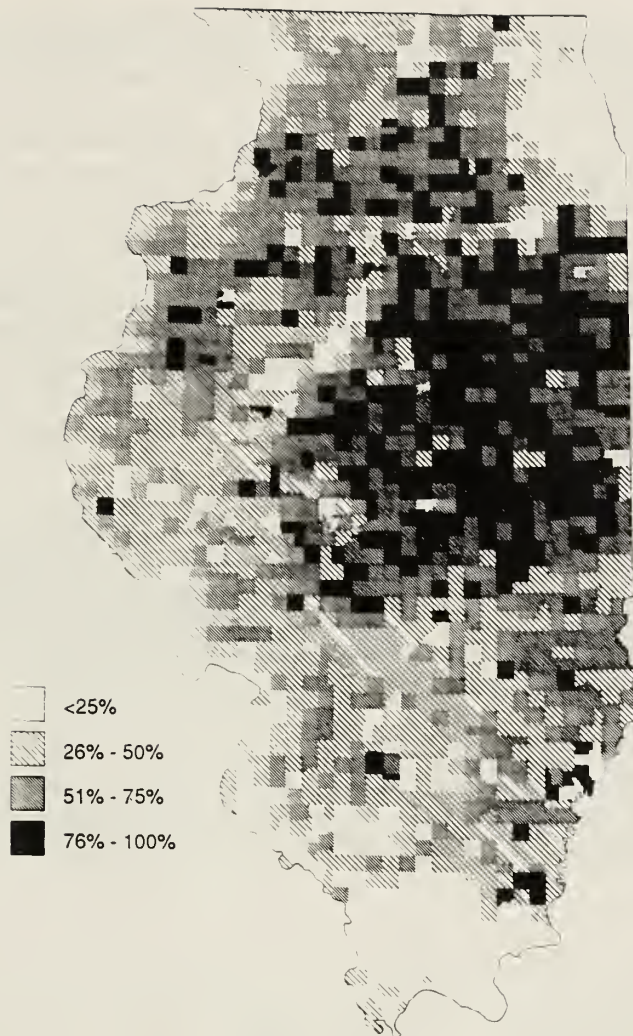


Figure 1 Illinois townships: percentage of total land planted to corn and soybeans in 1978 (IDOA 1979).

The remainder will continue to move downward into the saturated zone. Some of this water will discharge into nearby streams; the remainder will move deeper and become part of the regional groundwater flow system.

The rate of groundwater movement is directly related to the permeability of geologic materials and the hydraulic gradient; relatively rapid infiltration and groundwater movement will occur in areas directly underlain by permeable bedrock or sand and gravel. Conversely, surface runoff may be greater and groundwater movement generally slower in areas directly underlain by silty or clayey materials, which have a considerably lower permeability. Thus, over a given period of time, these areas provide considerably less recharge to aquifers than do areas composed of sand and gravel or permeable bedrock at or near land surface.

The water table is the surface at which pore-water pressure is atmospheric. Below that surface almost all pores are filled with water. Above the water table, water is held by tension forces and will not flow freely to a well or spring. The water table in humid areas such as Illinois roughly parallels the surface topography, rising under the uplands and intersecting the ground surface at perennial streams, lakes, swamps, and springs. At these points of intersection, groundwater is discharged to surface water bodies (fig. 2).

The water table occurs at shallow depths in most surficial materials found in Illinois. However, these materials may not yield enough water to a small-diameter drilled well for domestic or farm use. An adequate supply of water will be available only if the well encounters material with sufficiently high hydraulic conductivity. A large excavation below the water table, such as a large-diameter bored well, will slowly fill with water even in clayey materials that have very low hydraulic conductivity. This type of well can supply domestic or farm needs because water is stored for periods of heavy water use.

The Groundwater Protection Act defines an aquifer as "saturated (with groundwater) soils and geologic materials which are sufficiently permeable to readily yield economically useful quantities of water to wells, springs, or streams under ordinary hydraulic gradients." Earth materials that produce sufficient water to supply a well for a single residence might not yield enough to serve as an aquifer for a municipal well. (In this report, the term aquifer refers to earth materials capable of yielding sufficient water from a single, small-diameter well to supply at least several residences.)

Aquifer distribution varies across Illinois, from areas such as Mason County where the aquifer occurs within a few feet of the ground surface, to areas such as Champaign County where aquifers lie more than 100 feet below the surface and are protected by overlying materials of low permeability. In large parts of western and southern Illinois, where aquifers are not present or the groundwater in the aquifers is naturally of poor quality, homeowners rely primarily on cisterns or large-diameter dug or bored wells (fig. 3).

Environmental Fate of Agricultural Chemicals

The processes affecting the fate of pesticides include plant uptake, volatilization to the atmosphere, chemical or microbial degradation, adsorption by the soil, and transport by water (leaching and runoff). Processes affecting the fate of nitrogen fertilizers include plant uptake,

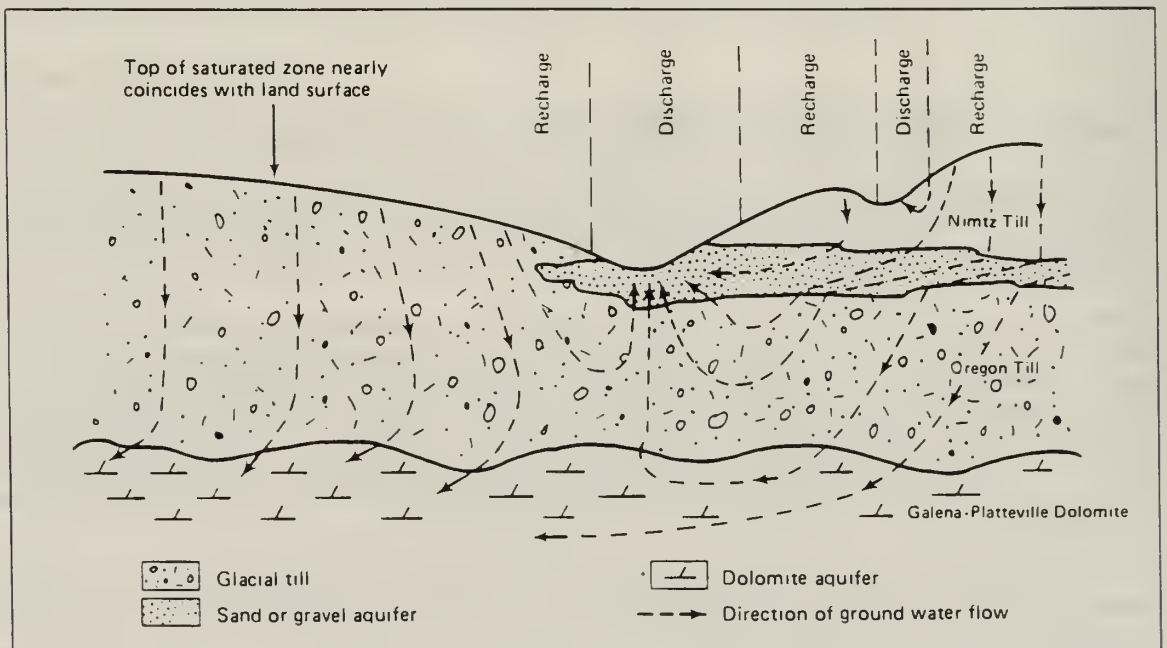


Figure 2 Details of groundwater flow systems (modified from Hughes et al. 1971).

nitrification, immobilization, denitrification, volatilization, and leaching. The amount of a chemical that is stored, transformed, or transported will be controlled by (1) the amount and properties of the chemical, (2) climatic factors, (3) soil properties, and (4) hydrogeologic conditions.

■ Chemical Properties

The potential of a pesticide to leach into groundwater depends to a large extent upon the chemical characteristics of the pesticide, especially soil adsorption potential (the tendency of a pesticide to be attached, by chemical or physical bonds, to the surface of soil particles) and half-life in soil (the time required for a pesticide in soil to be degraded to one-half of its original concentration) (Gustafson 1989). The formulation in which nitrogen is applied may affect its initial reactions with the soil (e.g., sorption of ammonium forms), but over a longer period formulation probably has little effect on leaching losses of nitrate.

■ Climatic Factors

Temperature, precipitation, wind, and relative humidity influence the fate of chemicals applied at the surface. Recharge, the amount of water available to move dissolved chemicals through the unsaturated zone to the water table, depends upon a large number of factors, including climate, soil properties, and agronomic management. The intensity and distribution of rainfall and the extent of evapotranspiration (a function of temperature, wind, relative humidity, and soil and crop characteristics) influence both the amount of water available for percolation through the crop root zone and the leaching of dissolved chemicals. In Illinois, average total precipitation varies from 32 inches in the north to 46 inches in the south. Higher potential evapotranspiration rates in the south result in higher potential soil-water deficits during the growing season (Bowman and Collins 1987). However, even if the soil is not saturated, intense rainfall shortly



Figure 3 Areas of Illinois where more than 50 percent of the private wells are large-diameter dug or bored wells (NWWA 1986).

after application may result in rapid movement of dissolved pesticides below the crop root zone through macropores (e.g., root channels or cracks) (Helling et al. 1988, Priebe and Blackmer 1989). This phenomenon is more important in the spring and early summer when pesticide concentrations are highest.

■ Soil Properties

Two soil properties most directly affect leaching of pesticides: (1) organic carbon content, which largely determines the adsorption of pesticides; and (2) hydraulic conductivity, the rate at which water moves through earth materials. For example, pesticides are more likely to leach in sandy soils with high hydraulic conductivities and low organic carbon content than in fine-grained soils with low hydraulic conductivities and high organic carbon content. Nitrate is highly water soluble and does not adsorb onto organic matter or clay particles. Under certain conditions, however, nitrate may undergo denitrification and subsequent volatilization to the atmosphere. The rate of nitrate movement is controlled by redox conditions in the soil and the rate at which water moves through the soil. Consequently, leaching of nitrogen is also most likely to occur in sandy soils because of their high rate of nitrification and relatively high hydraulic conductivities.

■ Hydrogeologic Factors

The vulnerability of aquifers to agricultural chemical contamination is a function of soil properties and hydrogeologic conditions. An increasing body of evidence on the significance of preferential movement of pesticides through macropores in soils suggests that predictions of potential pesticide leaching based solely on the attenuation properties of the soil matrix may be misleading. In addition, soils with a high leaching potential may occur in areas where aquifers are deeply buried and not vulnerable. For example, soils formed in windblown sands occur on uplands throughout Illinois. These coarse-textured soils with a low attenuation capacity for agricultural chemicals may overlie thick sequences of fine-grained glacial materials. Aquifers beneath these fine-grained materials are unlikely to be contaminated as a result of normal use of agricultural chemicals.

The thickness and character of the geologic materials between the base of the soil and the top of the underlying aquifer greatly affect the potential for contamination of the aquifer. Once contaminants such as pesticides or nitrates reach the water table, their rate of movement to an aquifer depends upon the hydraulic gradient and conductivity, effective porosity, and attenuating capacity of the materials overlying the aquifer. In general, the rate of movement of a contaminant is controlled by the average linear velocity of the groundwater. However, dispersion causes some contaminant molecules to move faster and others to move slower than the groundwater. These processes can also cause the contaminant to spread in directions transverse to the groundwater flow path (Freeze and Cherry 1979). The net effect of these processes is dilution, a reduction of the concentration of the dissolved contaminant in the groundwater system.

Dissolved pesticides within the groundwater system may be subject to chemical and microbial degradation and adsorption by saturated materials. As a result, the movement of the pesticide is slowed and the amount of pesticide in solution is reduced. The adsorbed compound may desorb and re-enter the groundwater if the adsorption reaction is reversible and the concentration of the contaminant in solution decreases because of dispersion, dilution, and/or the cessation of contaminant input.

In contrast to the number of processes affecting the fate of pesticides, dilution is apparently the only significant process affecting the fate of nitrates in deeper aquifers. Although it is clear that denitrification occurs in soils and relatively shallow groundwater, the role of denitrification in removing nitrates from groundwater in deeper aquifers is uncertain. Conflicting results from investigations of denitrification suggest that the process may be occurring in some aquifers and not others (Keeney 1986). Denitrification is a biologically mediated reaction; the appropriate

microbes and an organic substrate (necessary as an energy source) must be present. The environmental conditions required for denitrification may not exist in deeper aquifers. Even if all the necessary conditions are present to facilitate denitrification, a large influx of nitrate can overwhelm the capacity of the system to attenuate the nitrate (Hallberg 1986).

ESTIMATING THE POTENTIAL FOR AQUIFER CONTAMINATION BY AGRICULTURAL CHEMICALS

A number of methods have been developed for estimating the potential for movement of agricultural chemicals away from the point of application. Simulation models such as PRZM (Carsel et al. 1985), LEACHMP (Wagenet and Huston 1986), and RUSTIC (Dean et al. 1989) provide numerical or analytical solutions to mathematical equations describing the processes affecting pesticide transport in the root, vadose, or saturated zones. These models, developed for research and regulatory/management purposes, require extensive data inputs on pesticide and soil properties, crop growth, site hydrology, and meteorological conditions. Statistical models have also been used to relate the occurrence of pesticides in water supply wells to soil, hydrologic, land use, and other factors (Steichen et al. 1988; Chen and Druliner 1987; Kolpin and Burkart 1989).

Since 1980, state and federal agencies in Iowa have documented the extent of groundwater contamination by agricultural chemicals in their state. The studies summarized by Kelley et al. (1986) indicated a much higher percentage of wells withdrawing water from aquifers within 50 feet of the land surface had detectable levels of pesticides than wells finished in deeper aquifers. Kolpin and Burkart (1989) reported that the thickness of unconsolidated material overlying an aquifer was the most statistically significant indicator of pesticide occurrence in wells withdrawing water from shallow aquifers in Iowa. Holden and Graham (1990) reported a strong association between the occurrence of agrichemicals in rural domestic wells and the type of aquifer (unconfined, intermediate, or confined) from which a well withdraws water. Similar results were reported in Minnesota (Klaseus et al. 1988), where pesticides were most commonly found in karst areas and in shallow sand and gravel aquifers.

Perhaps the most widely used method of estimating contamination has been the agricultural version of DRASTIC (Aller et al. 1985). This method provides relative rankings of contamination potential based on weighted scores for seven soil and hydrologic variables. DRASTIC rankings were used as one variable in stratifying the total population of wells to be sampled by the USEPA (1990) in the National Pesticide Survey (NPS) and by Monsanto Agricultural Company (Holden and Graham 1990) in the National Alachlor Well Water Survey (NAWWS). Results from the NPS and NAWWS indicate that the DRASTIC rankings developed for those surveys were not reliable predictors of the occurrence of agricultural chemicals in private wells or in public water supplies. Balu and Paulsen (1991) reviewed nationwide monitoring data for atrazine and concluded that "DRASTIC should not be used as an indicator for potential atrazine transport to groundwater."

The failure of DRASTIC as a predictive tool in these studies may be due to (1) problems inherent to the method (i.e., inclusion of inappropriate factors such as topography or exclusion of important factors such as soil organic carbon content), (2) inappropriate weighing of the various factors in the model, or (3) inaccurate information on or mapping of the DRASTIC factors. Perhaps, a more important reason is that the sampled population in most monitoring studies (groundwater from private and public water supply wells) is not appropriate for verifying a method that evaluates the groundwater pollution potential of hydrogeologic settings. In general, DRASTIC and other models developed to predict contamination over large areas (including the method described in this report) predict the pollution potential of the uppermost aquifer. Water supply wells may withdraw water from deeper aquifers that have a lower contamination potential. Many private wells withdraw shallow groundwater from near-surface

materials with low permeability that are highly vulnerable to contamination but are not considered aquifers in the predictive models.

Relationship between Aquifer Vulnerability and Well Vulnerability

The vulnerability of groundwater in a well to contamination from surficial nonpoint sources of contamination, such as pesticides or nitrates, is a function of all of the processes and factors affecting contaminant movement through earth materials and the properties of the well itself. Well-specific factors affecting the potential for well-water contamination include (1) adequacy of surface seal, (2) depth of screened interval, and (3) position in the groundwater flow-path in relation to potential sources of contamination.

Figure 4 depicts several types of private water supply wells commonly found in Illinois. The geologic settings depicted in figure 4a and c are typical of areas shown on figure 6 as having aquifer materials within 20 feet of land surface. The geologic settings in figure 4b and d are typical of areas with no aquifers within 50 feet of land surface.

Sand point wells (fig. 4a) are probably most vulnerable to contamination because of their shallow depth (typically less than 40 feet) and because they are used in areas where highly permeable sand and gravel aquifers occur at shallow depths. Large-diameter dug or bored wells (fig. 4b) are also particularly vulnerable to contamination from sources near the well because of their design and generally shallow depth. The source of water for these wells is

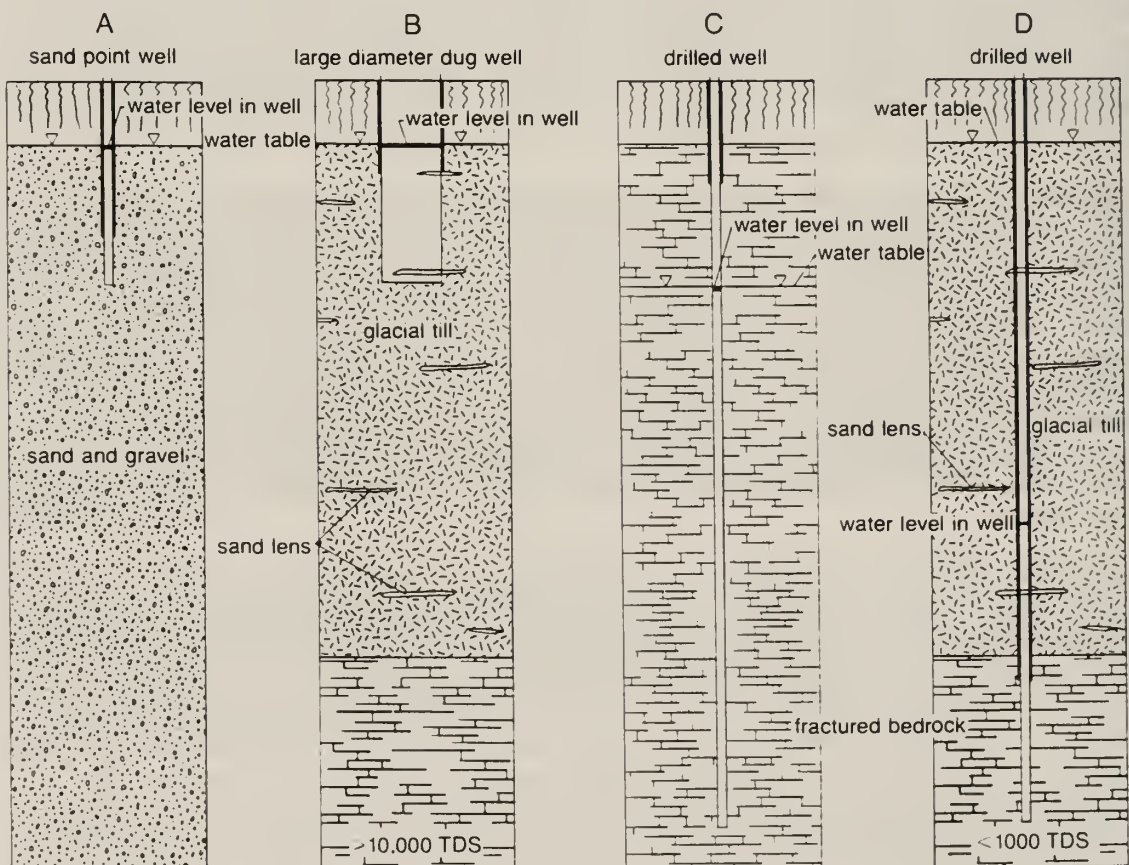


Figure 4 Common well types in Illinois and typical geologic setting.

generally thin sand layers or joints and fractures within bedrock or fine-grained glacial materials, and only a limited area around a well will contribute water to these wells. This type of well is used as a source of groundwater for domestic use in large areas of Illinois (fig. 3). (There are approximately 100,000 large-diameter wells in Illinois, approximately 20 percent of the total number of wells in the state; NWWA 1986.) These wells are most common in areas where water quality in deep aquifers is poor or aquifers are not present.

Deep drilled wells often are not considered vulnerable to contamination from nonpoint sources. However, the depth to the aquifer and the depth of the open or screened interval should also be evaluated. A deep well that is only cased into the upper few feet of a fractured bedrock aquifer may withdraw shallow groundwater, which is vulnerable to contamination (fig. 4c). A deep well that is cased through a thick sequence of fine-grained glacial materials and withdraws water from the same bedrock aquifer (fig. 4d), probably would not be as vulnerable to contamination.

Mapping the Potential for Agricultural Chemical Contamination of Aquifers

Interpretive maps that display the relative vulnerability of aquifers to contamination are developed on the basis of our knowledge of (1) the distribution of earth materials (soil and/or geologic maps) and (2) the effect of the hydrologic system (climate, soils, and geology) on the movement of contaminants to resource groundwater (contaminant transport model).

Geologic mapping has been used in Illinois since the early 1960s to identify areas where aquifers are vulnerable to contamination from landfills and other waste disposal practices. Berg et al. (1984a) mapped the statewide potential for contamination of shallow aquifers by surface and near-surface waste disposal activities. Ratings were made by comparing capacities of 18 generalized sequences of geologic materials to transmit contaminants. Highly permeable materials (sands, gravels, fractured carbonate rocks, and sandstones) generally allow rapid migration of contaminants. Materials of relatively low permeability (loess, glacial till, shales, cemented sandstone, and unfractured carbonate rocks) generally restrict contaminant migration. The thickness of the fine-grained materials controls the susceptibility of the underlying aquifers to contamination. As the thickness of these fine-grained materials increases, the potential increases for the attenuation of a contaminant (due to dilution, degradation, or adsorption) before it reaches an underlying aquifer (fig. 5).

Our evaluation, based on the system developed by Berg et al. (1984a), provides relative ratings of the potential for aquifer contamination based on the hydraulic conductivity and thickness of geologic materials overlying the uppermost aquifer. The ratings do not consider properties of specific pesticides or soils, or climatic factors for which appropriate statewide data are not available. The General Soil Map of Illinois was published at a scale of 1:500,000 (Fehrenbacher et al. 1984). However, the individual soil series that comprise the soil associations shown on that map differ in several important properties, such as organic carbon content and permeability, which affect the potential for leaching of agricultural chemicals. Consequently, the soil association map is not suitable for evaluating leaching potential on a statewide scale.

■ Mapping Conventions

The geologic information used to map the potential for contamination of aquifers by agricultural chemicals was compiled from the Stack-Unit Map of Illinois (Berg and Kempton 1988). The mapped units depict the distribution of geologic deposits vertically from the surface to a depth of 50 feet, as well as horizontally over a specified area. The minimum thickness of continuous mapped units is 5 feet, except where a unit less than 5 feet was mapped over at least 0.4 square miles (Berg and Kempton 1988). Where a unit is mapped as laterally discontinuous within the specified area, the unit is frequently less than 5 feet thick.

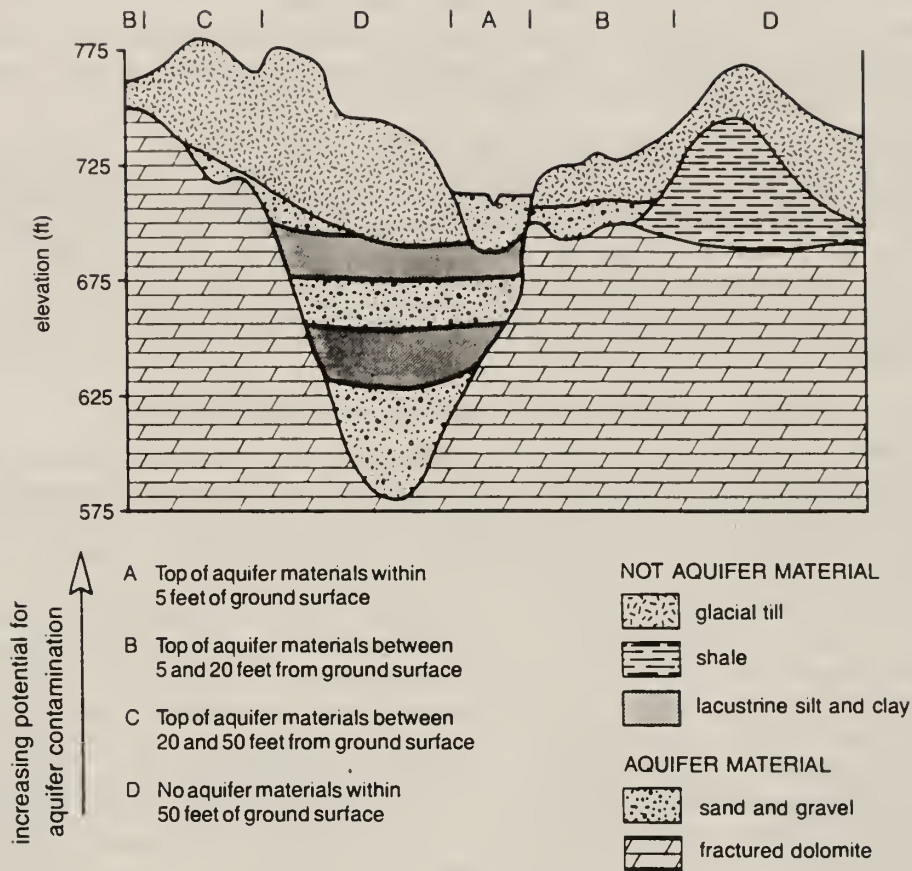


Figure 5 Geologic sequences with ratings for potential for contamination from agricultural chemicals.

The stack-unit map was published at a scale of 1:250,000 (1 inch = approximately 4 miles) and updated versions are available on the computerized geographic information system (GIS) at the Illinois State Geological Survey. Generally, the mapping is assumed to be 75 percent accurate, that is, at 75 out of 100 sites, the sequence of materials is as designated on the map (Berg et al. 1984a). The availability of subsurface data varies across the state. Consequently, the accuracy of the map will also vary. In areas such as Mason County, the map is probably 95 percent accurate. In areas with complex geology and limited data, map accuracy may be only 50 percent (Berg, personal communication). The maps are most accurate in describing geologic conditions within the upper 20 feet.

The 18 sequences of Berg et al. (1984a) were combined into four groups on the basis of relative potential for contamination of shallow aquifers from agricultural chemicals. Except as noted below, these four groups were differentiated by the distance from the land surface to the top of the first continuous deposit of aquifer materials: (1) within 5 feet of land surface, (2) between 5 and 20 feet of land surface, (3) between 20 and 50 feet of land surface, and (4) greater than 50 feet from land surface.

For this study, the distinction between aquifer materials and aquifers is that aquifer materials have the hydrogeologic characteristics to be classified as aquifers, but the materials may not be saturated. Aquifers, by the definition used in the Illinois Groundwater Protection Act, are saturated. In Illinois, the water table generally occurs within 20 feet from ground surface. Below

Table 1 Estimated hydraulic conductivity of typical geologic materials in Illinois (source: Berg et al. 1984a).

Geologic material	Hydraulic conductivity (cm/sec)
Clean sand and gravel	1×10^{-3}
Fine sand and silty sand	1×10^{-5} to 1×10^{-3}
Silt (loess, colluvium)	1×10^{-6} to 1×10^{-4}
Gravelly till containing less than 10% clay	1×10^{-7} to 1×10^{-5}
Till containing less than 25% clay	1×10^{-8} to 1×10^{-6}
Clayey tills, greater than 25% clay	1×10^{-9} to 1×10^{-7}
Sandstone	$> 1 \times 10^{-4}$
Cemented fine sandstone	1×10^{-7} to 1×10^{-4}
Fractured rock	$> 1 \times 10^{-4}$
Shale	1×10^{-11} to 1×10^{-7}
Dense limestone/dolomite (unfractured)	1×10^{-11} to 1×10^{-8}

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this depth, aquifer materials are generally saturated and capable of yielding water to a well. In areas mapped as having aquifer materials within 5 feet of the surface (about 17 percent of the land area in rural Illinois), the materials may not be saturated. Areas underlain by these materials were interpreted to have a potential for contamination equivalent to areas having aquifers within 5 feet of land surface, since these highly permeable materials would not significantly restrict movement of agricultural chemicals to the underlying saturated, permeable materials (aquifers).

Sand and gravel greater than 5 feet thick, sandstone greater than 10 feet thick, and fractured carbonates greater than 20 feet thick are considered to be aquifer materials. Loess, glacial till, shale, and nonfractured carbonate rocks have relatively low hydraulic conductivities (table 1) and generally will not provide a sufficient volume of water to a drilled well and are not considered aquifer materials for this study. Discontinuous sand and gravel deposits were not mapped as aquifers. As identified in the stack-unit map, these units are frequently less than 5 feet thick and always laterally discontinuous within the mapped area. For this study, continuous, surficial sand and gravel deposits less than 20 feet thick overlying fine-grained (non-aquifer) materials are also not considered to be aquifers. Because of seasonal fluctuations in the depth of the water table, these near-surface deposits are probably not reliable sources of water to wells.

Another modification to the interpretations by Berg et al. (1984a) used in our evaluation involved alluvial deposits, which are found in the floodplains and channels of streams and rivers. Berg et al. (1984a) mapped alluvium in a separate potential for contamination group because it was impossible to map the often abrupt lithologic changes common to alluvial deposits. Analysis of stack-unit map data indicates that about 12 percent of the land surface of Illinois is covered by alluvial deposits (McKenna et al. 1989b). In most stream and small river valleys in Illinois, alluvial deposits are laterally continuous but usually are less than 20 feet thick. In major river valleys, deposits may exceed 50 feet in thickness (Willman and Frye 1970). In Illinois, alluvium generally consists of fine-grained materials eroded from the loess- and diamicton-covered uplands. Where upland deposits are coarse-textured, however, floodplain deposits also tend to be coarse-textured. For this reason, alluvium was considered to have the same general lithology as the first continuous deposit below it. For example, an area with less than 20 feet of alluvium overlying thick glacial diamicton or shale was mapped as an area of continuous fine-grained deposits (no aquifer materials within 50 feet). An area with continuous alluvium overlying a thick deposit of sand and gravel would be treated as an area of continuous sand and gravel at land surface.

■ Potential for Agricultural Chemical Contamination of Aquifers in Illinois

The four contamination potential map units shown in figure 6 indicate the relative potential for agricultural chemical contamination of the uppermost aquifer. No quantitative difference between any of the units is implied.

Highest potential Shallow aquifers are most vulnerable where the top of the aquifer materials lies within 5 feet of ground surface. These areas, about 15 percent of rural Illinois, typically consist of thin loess or bedrock residuum over jointed limestone or dolomite or porous sandstone; or less than 5 feet of loess or silty lacustrine materials over thick deposits of sand and gravel. Principal areas with this potential are north-central, northwestern, and extreme southern Illinois and areas adjacent to the Mississippi, Illinois, Ohio, and Wabash Rivers.

Second level Aquifers are also vulnerable where the top of the aquifer materials lies between 5 and 20 feet of ground surface. These areas, about 13 percent of rural Illinois, have continuous deposits of relatively fine-grained materials, such as loess, till, or lacustrine deposits, overlying highly permeable aquifer materials. Principal areas with this potential are northern, southern, and extreme western Illinois.

Third level Areas where continuous aquifer materials lie between 20 and 50 feet from ground surface rank next in vulnerability. These areas, about 11 percent of rural Illinois, have at least 20 feet of fine-grained materials overlying highly permeable deposits. Although these sequences of earth materials occur throughout Illinois, they are concentrated mainly in the western, south-central, and southern parts of the state.

Lowest potential Areas with no continuous aquifer materials within 50 feet of ground surface are least vulnerable to contamination. These areas, more than 60 percent of rural Illinois, are underlain by at least 50 feet of fine-grained glacial deposits or low-permeability bedrock. Every county in Illinois contains sequences of earth materials like these, but the greatest areal coverage occurs in northeastern and central Illinois.

■ Use of the Map

The scale and accuracy of the map showing the potential for aquifer contamination by agricultural chemicals are appropriate for use in targeting educational and technical assistance programs and for designing regional groundwater monitoring programs, but they are not adequate for regulating the use of agricultural chemicals on specific fields. The relative ratings of aquifer vulnerability presented in this report should not be used to evaluate the vulnerability of specific wells.

These maps should not be used to predict the vulnerability of karst aquifers to contamination from agricultural chemicals. Karst aquifers develop in carbonate rocks such as limestone, dolomite, and gypsum. They are formed through the dissolution of significant portions of the rock material. Where these aquifers are near the land surface, this dissolution is commonly expressed as underground caves, sinkholes, and "lost rivers." Bretz (1961) identified regions in Illinois that exhibit karst features. The direct run-in of water from farm fields to sinkholes or other surface or near-surface karst features would suggest karst areas have a high vulnerability to contamination of groundwater from agricultural chemicals. Results from karst area studies in Iowa demonstrate, however, that the evaluation of aquifer vulnerability for these areas is not possible using regional information (Rowden and Libra 1990). They found that the relationship between direct surface to water run-in into sinkholes and the more diffuse flow through the overlying soil and rock materials was complex and spatially variable. Accordingly, the vulnerability of shallow bedrock aquifers in karst areas must be evaluated locally. The scale and the detail of these aquifer vulnerability maps are insufficient for the evaluation of the influences of karst features on agricultural chemical transport to groundwater. Recently, however, the Illinois State Geological Survey began a 2-year study to generate detailed maps of the karst

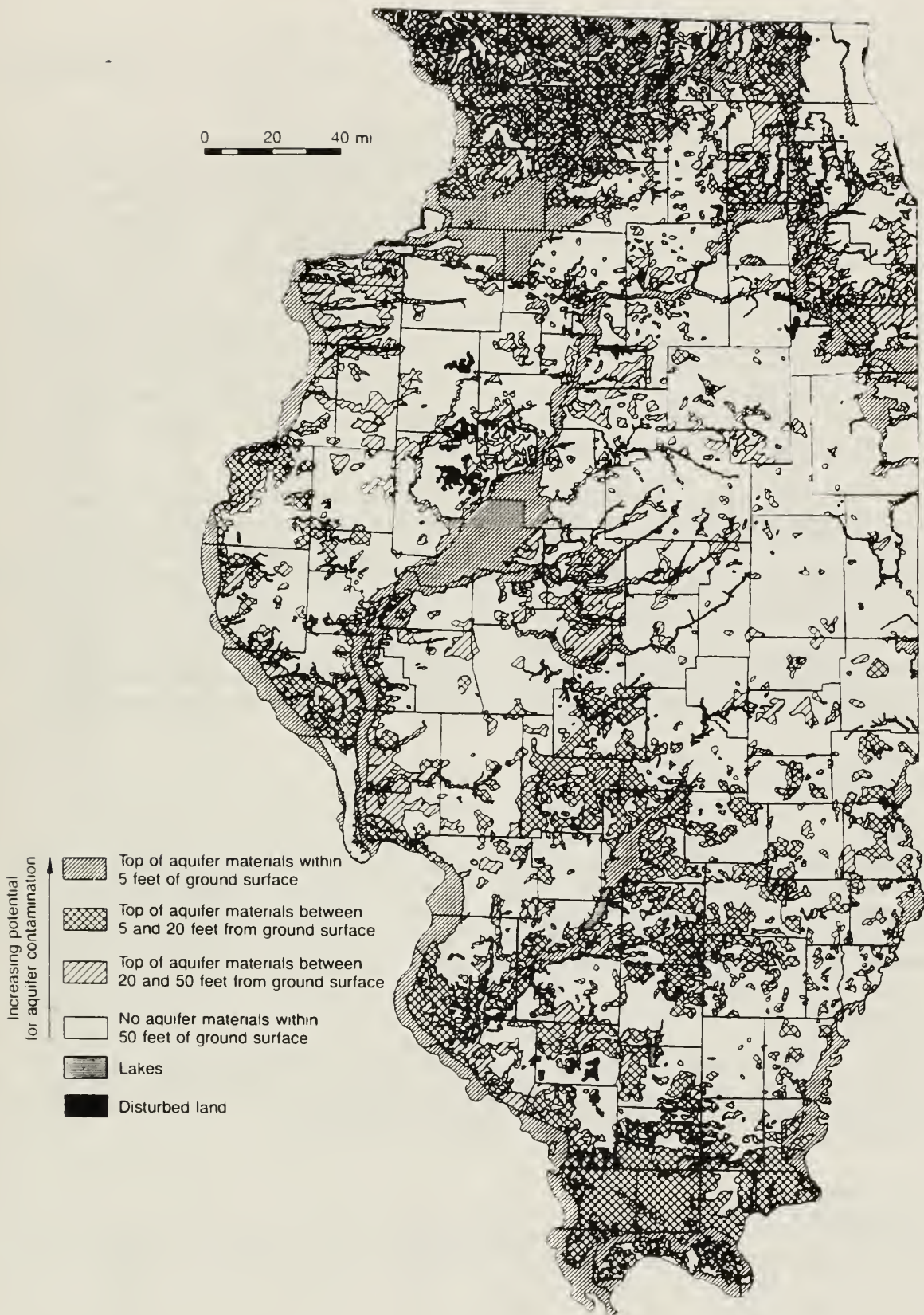


Figure 6 Potential for agricultural chemical contamination of aquifers in Illinois.

areas of Illinois and to begin evaluating the vulnerability of these shallow karst aquifers to contamination from agricultural chemicals. The results from this study should be available after July 1994.

Overlaying additional map features on any of the county maps accompanying this report may result in apparent distortion or registration problems between the maps. Berg and Kempton (1988) used a U.S. Geological Survey 1:500,000-scale map of Illinois as the base map for their stack-unit map. Use of overlays projected from different base maps is not recommended. Additional features can be accurately shown on the county maps by registering the overlay map(s) with specific county features, such as distance from the southwest corner of the county.

Several large lakes and reservoirs were not shown on the original base map (e.g., Clinton Lake in De Witt County and backwater lakes along the Illinois and Mississippi Rivers). The stack-unit map was compiled from some pre-1984 map sources (see Berg and Kempton 1988, Berg et al. 1984a); so the delineation of surface water bodies or disturbed land areas will reflect these source data. Areas designated as disturbed land include land disturbed by surface mining, land fill along the Lake Michigan shore, and large pits and quarries.

The largest scale of geologic mapping (1:250,000) presently available for most of the state is not suitable for use in making farm-level decisions. Aquifer vulnerability mapping at a scale of 1:24,000 (1 inch = about 2,000 feet) or larger would be appropriate for these uses. A much higher degree of accuracy in mapping and characterization of soil properties is available in county soil survey reports prepared by the USDA Soil Conservation Service in cooperation with the Illinois Agricultural Experiment Station. These reports include detailed soil maps at a scale of 1:15,840 (1 inch = 1320 feet) and data on the bulk density, clay content, organic carbon content, and permeability for the various horizons of each of the soils mapped. The Soil Conservation Service in Illinois has developed a pesticide-soil interaction rating to estimate the potential for leaching for all soils mapped in the state.

SUMMARY

Statewide geologic mapping of Illinois has been used to identify regions with aquifers vulnerable to contamination by agricultural chemicals. Areas with intensive corn and soybean production and aquifer materials within 50 feet of ground surface are most vulnerable to contamination. This interpretation is based on our present understanding of pesticide persistence and rates of groundwater movement coupled with the results of studies in Iowa and Minnesota. In approximately 40 percent of rural Illinois, aquifers lie within 50 feet of ground surface. These shallow aquifers occur throughout Illinois but are most common in the northern and southern parts of the state and along the major river valleys. In about 60 percent of rural Illinois, the aquifers are more than 50 feet deep and apparently protected from pesticide contamination by the attenuation capacity of soils and thick sequences of fine-grained materials. Pesticide use, largely for corn and soybean production, is heaviest in areas of the state where aquifers are generally least vulnerable to contamination.

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