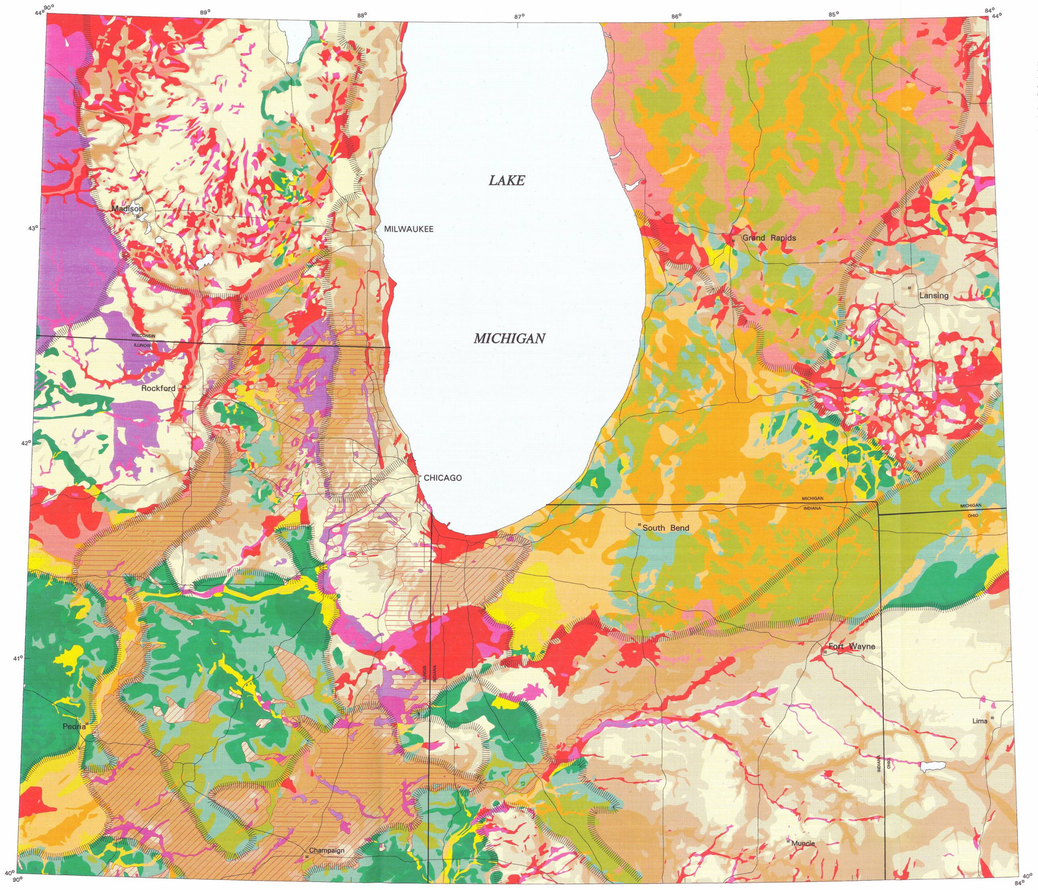
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
ILLINOIS STATE GEOLOGICAL SURVEY
U.S. ENVIRONMENTAL PROTECTION AGENCY

OPEN-FILE REPORT 92-694



Map compiled on U.S. Geological Survey, International Map of the World series base. Base information shown here is adapted from Defense Mapping Agency/U.S. Geological Survey, Digital Chart of the World. Lambert Conformal Conic Projection

SCALE 1:1 000 000

Warning:
This map provides an overview of aquifer contamination potential as interpreted from 1:1,000,000-scale geologic map information. It can be used as a screening or targeting tool to help identify regions in need of more detailed study, supported by more detailed map information. This map should NOT be the basis for evaluation of specific sites. For example, this map should NOT be used for point-source regulatory activities.

INTRODUCTION

Contamination of ground-water resources is a national concern. This concern focuses on both human health hazards that may arise when toxic and/or hazardous contaminants enter ground water which is subsequently extracted by public or private wells and consumed. It has, therefore, become a national priority not only to identify potential contaminant sources and routes of transport, but also to identify and evaluate certain water-bearing geologic units (aquifers) that are vulnerable to contamination (for example, see U.S. Environmental Protection Agency, 1984 and 1992; Fairchild, 1987).

Aquifers are comprised of either porous, unconsolidated deposits such as coarse-grained sand and gravel in glacial drift and coastal plain sediments, or high-permeability bedrock such as sandstones and fractured and jointed carbonate rocks. Aquifer protection is a critical issue for three reasons. First, by definition, aquifers can yield economically significant supplies of water (Freeze and Cherry, 1979). Second, because aquifers are permeable and permit relatively easy transmission of contaminants, they are vulnerable to contamination — particularly where located close to the surface. Third, once contaminated, aquifers are difficult to clean because of the generally slow rate of water movement (which is typically a few feet to a few hundred feet per year).

Ground water also occurs in confining units (aquitards), which are composed of relatively fine-grained materials (a surface layer of glacial till which confines or restricts the flow of water, for example). In many areas without shallow aquifers, large-diameter wells commonly tap the water table in a confining unit. However, because these deposits can yield ground water only at very low rates, such wells are generally shallow, large-diameter "dug" or bored wells for single households. Characterizing the contamination potential of ground water in confining units therefore requires assumptions and types of data different from those on this map.

This map shows estimates of relative contamination potential, based on sequences of geologic materials and their hydrogeologic properties, for a large part of the midcontinent region of the United States (fig. 1). Most of the source geologic map information is from Soller (in press a, b, c, d), which represents the thickness and character of Quaternary sediments in the glaciated part of the United States east of the Rocky Mountains. The part of that map used for this contamination potential map is shown in Soller (1991a). Map information was converted to digital format (Soller, 1991b), allowing the preparation of this map, produced using geographic information system (GIS) techniques.

The type, amount, and organization of data on the distribution, thickness, and character of earth materials is highly variable across the glaciated part of the continent. In areas where data are sparse, or detailed lithostratigraphic mapping is not available, precise information that can aid in predicting the potential for contamination of aquifers is limited. However, by compiling geologic information on a regional basis and utilizing geologic models, assumptions and concepts (such as those discussed below), some initial interpretations can be made; in the case of this map, it provides a regional interpretation that can serve as a screening tool for land-use and environmental planning. Obviously, additional information from more detailed studies, and from those studies which are unpublished or in progress, will add detail and insight not shown here.

Geologic sequences and the aquifers they contain were evaluated for potential for contamination from surface sources (for example, land application of agricultural chemicals), according to a model discussed in Soller and Berg (1992). This model is general in nature and its concepts are simple and straightforward. Most of the data required for the model are commonly available. For the one component for which data may not be widely available (presence of aquifers buried within the surficial deposits), the model uses a probabilistic approach where the data are absent. Therefore, although the level of detail for other components of geologic information may vary from place to place, the model can be used in other regions having different geologic settings. The usefulness of the map in any area will depend, of course, on the quality of source information.

The pattern of contamination potential map units depicted on this map are not simple because they are based on complex geology: 1) surficial geologic conditions reflect multiple depositional and (or) erosional events; 2) erosion due to glacial ice and interglacial streams has created a bedrock topography of high relief, which often very dissimilar to the present surface topography; and 3) bedrock topographic variations can result in abrupt changes in sediment character and thickness, as well as affect the position of buried aquifers. Four components are used to construct this map: texture of surface sediments, thickness of surficial deposits, hydraulic conductivity of the uppermost bedrock unit, and presence of aquifers buried within the surficial deposits. The complexity of map units results from the complex geologic processes mentioned above and the overlaying of the four component maps components.

This map is intended to show the complex geology and contamination potential in the region. It can be interpreted to a more generalized and simplified form, if desired, for presentation purposes. However, this simplification greatly reduces the information content. Decision-makers should recognize that geology can be complex and can result in highly variable aquifer contamination potentials. An oversimplified map may give the decision-maker the false impression that regulations or land-use restrictions can be highly generalized where the complexity of information argues for a more informed and detailed decision. Methods of generalizing and using this contamination potential map are discussed below.

This map was made to provide decision-makers, researchers, students, and others with a multi-state regional perspective of aquifer contamination potential. The map provides a common classification of geologic conditions and contamination potential to aid users in visualizing and interpreting the complex patterns of geology and contamination potential irrespective of state boundaries. Previous regional contamination potential maps have been confined to individual states, and have been based on different criteria (for example, Illinois: Berg and Kempton, 1984a, Wisconsin - Schmaltz and Skinner (1987), Minnesota - Porcher (1989), and Michigan - Lusch and others (1992)). The only comprehensive regional appraisal of contamination potential was done by Pettyjohn and others (1991); however, it had no integration of source information or commonality of map scale between states.

THE ROLE OF GEOLOGY IN GROUND-WATER ASSESSMENTS

Geologic maps depict the occurrence, distribution, and thickness of geologic materials. These materials dictate hydrogeologic properties that lead to interpretations of ground-water availability and contamination potential. Ground-water contamination may result from surface and near-surface activities such as the application of agricultural chemicals, leaching from municipal or hazardous waste landfills, and from septic systems, chemical spills, leakage from underground storage tanks, or surface spreading of wastes. Through these activities, contaminants are introduced into, transmitted through, and stored within, geologic materials. The properties of geologic materials not only affect the movement of contaminants and ground water, but also influence ground-water quality through filtration, sorption, cation-exchange, and other processes.

The actual potential for contamination of an aquifer depends, in part, on the properties of overlying and underlying geologic materials. Fine-grained geologic materials (a confining unit) tend to restrict movement of water and contaminants downward into aquifers, and reduce contaminant concentrations. In general, the thicker the fine-grained, low-permeability geologic materials between a potential contaminant source and an aquifer, the less likely is the aquifer to become contaminated (Berg and others, 1984a). Furthermore, low-permeability materials beneath an aquifer may restrict further downward migration of a contaminant if dissolved in water.

Because of the geologic controls on water movement and quality, data on the texture and three-dimensional framework of geologic materials is essential for appraising ground-water vulnerability to contamination. At the Illinois State Geological Survey (ISGS), comprehensive information on geologic materials in the depth to shallow aquifers (within 50 ft of land surface) and on hydrogeologic properties of materials between aquifers and the land surface (Berg and others, 1984a). Soil infiltration rates and presence of deep aquifers (defined as within 300 ft below land surface) are also used for contamination potential assessments (Keefer and Berg, 1990). Other studies, in Iowa (Kolpin and Burkart, 1989; Kolpin and Burkart b; Delaney, 1991), Indiana (U.S. Geological Survey (USGS) and Indiana University, 1992), and Michigan (Passero and others, 1989), support the use of geologic information as a primary component of a contamination potential assessment model.

DATA LIMITATIONS FOR MODELS

Evaluating an area for aquifer contamination potential is difficult, in part because of limitations of the geologic and hydrogeologic data. A contamination potential model is, by necessity, based on the types and quality of data available for the region of interest. In areas where the model was developed, the model may not be usable for other areas where that suite of data is unavailable or is of poor quality. Therefore, the selection of variables, or components, for which data are widely available is critical to a model that is intended for use in different areas or across a broad area. For aquifer contamination potential models, components are selected which have an influence on the rate at which contaminants move from the ground surface into the ground water, for which depth to the top of an aquifer and texture or permeability of surficial deposits are components that might be considered in such a model.

At a local scale (for example, at the scale of a farm), deterministic models requiring many quantitatively-defined variables have been developed (for example, see models reviewed in Ertel (1990)) to estimate pesticide and other patterns of contaminant migration as closely as possible. Unfortunately, these quantitative models have not been, and perhaps cannot be, applied to areas larger than farm-scale with notable success. In part, this is because the models require many variables that are not regionally available or feasible to collect because it is more difficult to precisely characterize the three-dimensional variability of geologic materials and ground-water flow regionally than locally.

Although valuable data on water and contaminant fate and transport are provided by site studies, a regional perspective is important to planners who recognize that geologic and hydrologic features are not constrained by site or political boundaries. This regional perspective, provided by information on regional maps, allows sites to be placed in context. This is a result of regional information, predictability of local conditions may be increased and, accordingly, confidence in site-specific geologic and hydrologic findings may be enhanced.

Models for regional assessment of aquifer vulnerability, such as the DRASTIC model of Aller and others (1987) cannot explain or predict ground-water contamination in the manner of a deterministic model. Accuracy of prediction is greatly reduced because only the broad, regional nature of the geologic and hydrologic framework can be characterized. Regional models use a limited number of generalized, qualitative variables, in contrast to the data requirements of a local deterministic model. Even so, high-quality data are usually not available for the entire area to be assessed.

THE MODEL USED IN THIS STUDY

This map was generated using a qualitative, regional model (Soller and Berg, 1992) intended to characterize the broad, regional nature of aquifer systems including aquitards. The contamination potential ranking procedure used on this map is slightly modified from that model. The model is an extension of ISGS contamination potential mapping techniques (Berg and others, 1984a), adapted for a more general and regional approach. The model uses only commonly available, regional three-dimensional geologic information. Limiting this model to basic, readily available information also allows the user from extensive data gatherers such as depth to the water table, which are required by certain contamination potential assessment models. Additionally, in this model the contamination potential map units retain the source (geologic) information, thereby allowing for reinterpretation of map units (or of the basic geologic information) for other purposes.

This model was developed by interpreting the geology for part of a texture-based, regional map of Quaternary surficial deposits (Soller, in press a, b, c, d, scale 1:1,000,000; Soller, 1992), supplemented by regional bedrock maps and cross sections. This geologic information was compiled in 1988. However, newer published information, where available, is not significantly different from Soller's information. The contamination potential map was produced from a preliminary, digital version of part of Soller's maps (Soller, 1991b).

The model assembles four categories of geologic information (components) for the discussion, below) into 26 map units according to a set of qualitative rules and assumptions. These map units are then ranked according to the contamination potential of aquifers or potential aquifers. **These rankings are not developed for any specific aquifer, and only a small relative significance may be implied by small differences in contamination potential.**

Model components

The model defines four components (table 1): 1) texture of surface sediments; 2) presence of aquifers buried within surficial deposits; 3) hydraulic conductivity of the uppermost bedrock unit; and 4) thickness of surficial deposits. The information for these components is shown in figure 2. Each component provides important information for evaluating the potential for ground-water contamination. Information not considered in this model (such as depth to the water table, organic carbon content of the near surface deposits, presence of fractures or other macropores, net rates of recharge, hydraulic gradients, micro-climate, and chemical and physical interaction between contaminants and the soil or geologic materials beneath the soil) also has a significant effect on ground-water quality. However, these data are generally unavailable at a regional scale, and can be generally and time-consuming to obtain.

Table 1. Description of model components and associated symbols used in the text and map explanation

Model component	Symbol
1 Texture of surface sediments	
coarse-grained, stratified sediment or organic-rich deposits	C
glacial till or fine-grained, stratified sediment	F
patchy glacial drift or exposed bedrock	R
2 Presence of aquifers buried within the surficial deposits	
known buried aquifer, depth unspecified	B
presence of buried aquifer	?
3 Hydraulic conductivity of the uppermost bedrock unit	
relatively low	L
relatively high	H
4 Thickness of surficial deposits (in feet)	
less than 50	1
50 to 100 ft	2
100 to 200 ft	3
greater than 200 ft	4

Component 1 -- Texture of surface sediments

Surface sediments are herein defined as those surficial deposits exposed at land surface. A more general term, surficial deposits, is used for unconsolidated deposits both at land surface and at depth. The distinction between surface and surficial is made because it is rare for a geologic map to show the entire thickness of the surficial deposits, detailed three-dimensional information on geologic materials is available for a limited number of areas, and models, components are selected which have an influence on the rate at which contaminants move from the ground surface into the ground water, depth to the top of an aquifer and texture or permeability of surficial deposits are components that might be considered in such a model.

Soils, which are developed in the upper part of surface sediments, are not considered as a separate component of this model. Soils are primarily differentiated and (or) mapped by texture, as mentioned above, other soils information, such as organic carbon content or macropore density is not readily available. Because the model considers texture of surface sediments, soils information would be somewhat redundant. Also, soil properties are commonly available at a scale of about 1:15,840 to less detailed than a 1:1,000,000-scale regional map, and compiling this information into a regional framework is time-consuming and tedious. Soil association maps are also undesirable for this model because they are highly generalized and in places not based on parent material considerations. Perhaps most significantly, the principal focus of the map is to classify contaminant hazard from surface sources, and soil properties significantly below the soil. Although surface sediments do not necessarily describe geologic conditions at depth, they more closely approximate those conditions than soils information.

On the map, surface sediments are primarily Pleistocene glacial deposits and Holocene alluvium and lacustrine deposits, with areas of patchy glacial drift and exposed bedrock. These surficial deposits were classified by Soller (in press a, b, c, d; Soller, 1992) according to their texture. Soller's map units are:

- till (unsorted and unstratified, ice-deposited material also described as diamicton)
- coarse-grained, stratified sediment (sorted and deposited by running water)
- fine-grained, stratified sediment (sorted and deposited in quiet water, for example, in a lake)
  - organic-rich deposits (peat, co-stratal marsh sediment)
- areas of patchy, discontinuous glacial drift of any texture with exposed bedrock
- areas of bedrock exposure.

For our model, the above map units are combined as follows based on similarity of potential aquifer hydraulic conductivities (table 2):

- coarse-grained, stratified sediment
- till, fine-grained, stratified sediment, and organic-rich deposits
- patchy glacial drift and exposed bedrock.

Physical properties of these units differ, and affect contamination potential. For example, the high permeability of coarse-grained deposits allows contaminants to move through them with the component judged most significant to aquifer contamination potential, the assumption of relative ease of movement in the vertical direction (fig. 3a). However, the assumption of relative ease of movement in the vertical direction (fig. 3a) is not true for the fine-grained till, and fine-grained, stratified sediment. Most clay deposits in a glacial drift are generally greater than 1x10-4* cm/sec. For the fine-grained till (till and fine-grained, stratified sediment), hydraulic conductivities are generally less than 1x10-4 cm/sec. Organic-rich deposits are included in the fine-grained unit despite the high-permeability of some organic deposits (peat, for example) because they tend to be thin, patchy units in areas of ground-water discharge, and are, therefore, most logically grouped for this application with the low hydraulic-conductivity, low-vulnerability deposits.

Component 2 -- Presence of aquifers buried within the surficial deposits

Aquifers can occur buried within surficial deposits. Such aquifers are common in the glaciated United States and can supply significant amounts of ground water. On a regional scale, information on the presence of buried glacial-drift aquifers is poorly documented because of difficulties in mapping subsurface glacial deposits. Our knowledge of buried aquifers is, in fact, a function of our knowledge of the subsurface. Because of the scarcity of regional subsurface information, Soller's maps depict where buried aquifers potentially exist. Areas where buried glacial-drift aquifers are absent or have not been mapped, because of the paucity of subsurface data, are not present, the known absence of aquifers could not be considered in this model.

Component 3 -- Hydraulic conductivity of the uppermost bedrock unit

Hydraulic conductivity and permeability were derived from State geologic maps or reports for Illinois (Willman and others, 1967), Indiana (Gray, 1982; Gray, 1987; Shaver and others, 1986), Michigan (Milstein, 1987), Ohio (Bownocker, 1920; Stout and others, 1943; Pavey, 1989), and Wisconsin (Mudrey, Brown, and Greenberg, 1982). For this map, the lithologic information on bedrock geologic maps was interpreted in terms of hydraulic conductivity (see table 2) in order to classify bedrock lithologies into relative permeability categories.

As stress relief fractures and fractured and (or) jointed carbonate rocks represent areas of relatively high permeabilities (hydraulic conductivities generally greater than 1x10-3 cm/sec), regional maps showing differences in unfractured and cemented carbonate rocks represent areas of low permeabilities (hydraulic conductivities generally less than 1x10-4 cm/sec). The hydraulic conductivity values are estimates based on regionally-mapped rock properties and lithologic descriptions. The actual hydraulic conductivity of bedrock in any given location, however, may vary significantly because of differences in depositional, diagenetic, or structural history.

Component 4 -- Thickness of surficial deposits

Aquifers at or near the land surface have the highest potential to be contaminated (Berg and others, 1984a). For example, at the scale of a regional map, aquifers at depth are less likely to be affected by land-surface activities than