Land-Use Decisions and Geology:
Getting Past "Out of Sight, Out of Mind"

Myrna M. Killey and Richard C. Berg

Geoscience Education Series 18   2004

Cover photo: Urban development in Champaign County. As communities expand, detailed geologic information is needed to make effective land-use decisions.

Illinois State Geological Survey

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Preface

To help respond to Illinois citizens' need for information, the Illinois State Geological Survey (ISGS) has produced a series of publications, of which this is the third. The first, *Illinois' Ice Age Legacy,* describes glacial processes and deposits and emphasizes their relationship to the soil, water, and minerals that sustain our daily lives and to some of the ways we use the land. The second, *Illinois Groundwater: A Vital Geologic Resource,* shows how geology relates to the accessibility and vulnerability of the state's groundwater supplies. These publications are useful sources of background information that provide a more complete understanding of the issues explored in this publication.

This third volume explains in a general way how scientists investigate geologic settings for their suitability for a variety of land uses, especially those that have the potential to cause environmental problems. This publication also explains how to use the findings from two important, fundamental scientific disciplines that frequently are overlooked when land-use decisions are made.

Acknowledgments

Many colleagues at the Illinois State Geological Survey contributed ideas and expertise to this publication. We especially acknowledge Keros Cartwright, whose years of experience working with the general public on groundwater and siting issues encouraged the production of this series of publications. We thank Jonathan H. Goodwin, David R. Larson, Ardith K. Hansel, Beverly L. Herzog, Richard C. Anderson, Emeritus of Augustana College, and LeAnn Benner for their thoughtful reviews; Robert Bauer for providing the liquefaction potential map and reviewing the earthquake text; and Barbara Stiff for her Geographic Information Systems mapping expertise and the revised cross section.

Thanks are given to Joel A. Steinfeldt and Cheryl K. Nimz for their editing contributions, Craig Gain for map scanning, and Michael W. Knapp for graphics and design. All photographs are by Joel M. Dexter unless otherwise noted.

Contents

Introduction

With 12 million inhabitants, Illinois ranks sixth among the 50 states in population and boasts the thirteenth-largest economy in the world, thanks to its strong industrial, commercial, and agricultural bases. However, these high rankings come at a cost. Illinois' large economy means that its citizens must solve many kinds of environmental problems.

According to the U.S. Environmental Protection Agency (EPA), Illinois has more than 3,400 landfills; more than 5,000 pits, ponds, and lagoons containing wastes; more than 40 active Superfund sites (sites federal agencies determine need cleanup or other corrective action); almost 400 hazardous waste sites; and nearly 24,000 hazardous waste handlers and generators. Illinois also has about 47,000 underground storage tanks, and about 60% of those, or roughly 28,000, are probably leaking, according to the Office of the State Fire Marshal and the EPA.

An economic and technological leader, Illinois also has led the way in developing logical, science-based approaches for siting major industrial and commercial facilities, choosing waste-handling facility sites, and evaluating land-use practices that may generate contaminants. However, there is an urgent need for even more unbiased earth science information to best determine which land-use practices are suitable for a site's geologic characteristics. Detailed geologic and hydrogeologic data also help determine the possible environmental consequences of land-use practices.

A region's geology and *hydrogeology* (italicized terms are defined in the glossary) are, for the most part, invisible underground—they are "out of sight, out of mind." Yet knowledge about these disciplines provides the crucial information needed to make effective land-use decisions and to ensure that wastes are handled and disposed of in the safest, most logical, and most cost-efficient manner. This volume focuses primarily on these topics with a view to protect groundwater resources.

This book

- presents the challenges for siting and disposing of various types and sources of contamination;
- describes the goals and advantages of safe siting;
- provides the geologic framework needed to understand siting issues;

- describes how to determine the contamination potential of facilities that generate or dispose of waste;
- discusses the effects of geologic hazards in land-use planning and siting issues;
- describes the research, mapping, and intepretation tools needed to answer questions about land use; and
- explains a step-by-step method used to determine how a given land use may affect a potential site and the surrounding area.

The authors hope this publication gives citizens and decision makers a greater understanding of how they can use geologic and hydrogeologic information to decide whether a site's characteristics will reduce or prevent groundwater contamination. This information is important for local, state, and federal agencies, educational institutions, private industry, and the general public so that they can make science-based decisions that will support economic development and infrastructure planning while protecting valuable resources such as groundwater, wetlands, and soils.

Challenge: Protecting the Environment

What kinds of human activities may harm the natural environment? Almost all of them. Here's why: humans use water and many other mineral and biological products every day, generating waste as a by-product. Because waste products may contain harmful substances that cannot be reused or recycled, society must take responsibility for their safe disposal. Certain land-use practices, such as over-applying sewage sludge, fertilizer, or pesticides to agricultural fields, also may harm the environment. Wise planning and the use of scientific information to make decisions can avoid or minimize the damage these practices may cause.

The first consideration is to lessen the amount of waste. Before decision makers resort to landfilling, more desirable practices should be considered, such as reducing consumer product packaging; reusing plastic bags, jars, and other packaging materials; recycling manufactured materials; and incinerating waste.

Despite attempts to minimize household waste, many millions of tons of waste still are buried, the safest disposal method available. From a geologist's point of view, "safest possible disposal" is the method that has the least potential to contaminate potable, or drinkable, groundwater resources.

Those three words, "safest possible disposal," represent a lofty goal. The problem lies in deciding how to achieve that goal. This publication can help support disposal decisions by offering a method that applies geologic and hydrogeologic principles to determine the vulnerability of groundwater to contamination by land-use practices or by facilities that generate waste. This information should increase the confidence of those involved in site selection that the proposed land use has no effect or has minimal effects on groundwater.

Contamination Considerations

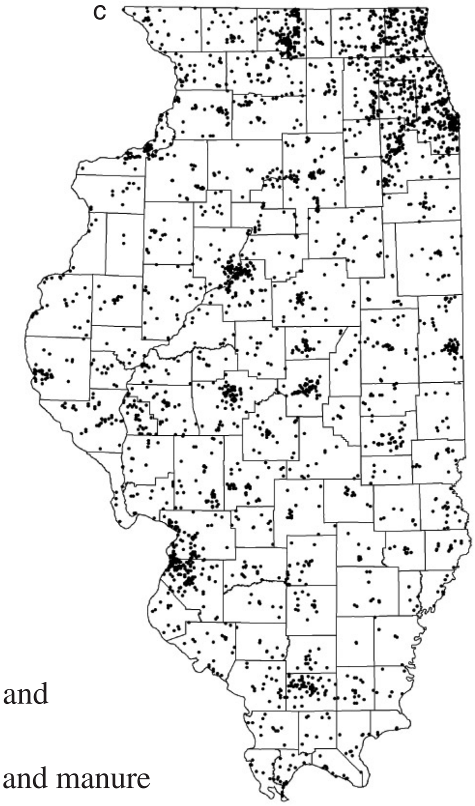
A variety of human activities can contaminate groundwater. Chief among these are disposal facilities for municipal, hazardous, and radioactive wastes (fig. 1) and industrial and commercial establishments that produce wastes such as cleaning solvents from manufacturing processes.

Figure 1 Landfills often contain hazardous substances. (a) Refuse is dumped at a landfill in central Illinois. (Photo by Michael W. Knapp.) (b) These barrels of hazardous waste were buried at a site in west-central Illinois. (Photo by Christopher J. Stohr.) (c) A map of Illinois landfill sites as of June 1, 1997.

a

b

c



Contamination also can result from

- underground tanks storing gasoline and other chemicals (fig. 2);
- septic systems;
- large animal-waste lagoons (fig. 3);
- chemical spills;
- chemicals over-applied on agricultural fields and lawns (fig. 4);
- sewage sludge, material from septic systems, and manure spread on fields as fertilizer; and
- road salt and other de-icers that run off paved surfaces.

Such land uses are referred to in this publication as “environmental hazards,” and contamination is considered to come from either point or non-point sources.

Figure 2 An exhumed tank is examined for leaks. Underground storage tanks usually contain gasoline or chemicals. (Photo by Anne Erdmann.)

Figure 3 Large animal confinement facilities, such as this hog farrowing and nursery operation in south-central Illinois, can generate considerable amounts of waste. The facility produces roughly 24,000 pigs each year. The waste produced is stored in the lagoon in the left portion of the image. Ponds and large-diameter bored and dug wells are the predominant sources of drinking water in the area.

Figure 4 A post-emergent herbicide is applied onto this field.

Point Sources of Contamination

Contaminants that are released at specific, easily identified sites are called point sources of contamination. Waste-disposal facilities, chemical spills, commercial or industrial accidents, leaking underground storage tanks, and waste lagoons at animal confinement facilities are point sources. Contaminants from these sources are among the most serious threats to groundwater quality, especially when contaminants enter an *aquifer*. Once the contamination source is identified, contaminant movement often can be predicted, and cleanup operations can begin, but such efforts can be quite costly, depending on the contaminant's type and quantity.

Case Study: Maps Protect Citizens from Contaminated Drinking Water

Winnebago County has the most vulnerable aquifers in Illinois. The county contains sand and gravel and porous bedrock close to the land surface and has heavy industry and a high population (278,418). Winnebago was the first (in 1984) Illinois county to obtain detailed, three-dimensional geologic information that revealed the depth and location of aquifers (fig. 5). The county has used that information for more than 20 years to identify areas where there was a high risk of contamination and take preventive measures to protect the health of its citizens.

The geologic information provided by the ISGS to Winnebago County Health Department officials identified high-risk areas where preventive measures and limited sampling resources could be focused. Health officials prevented citizens from drinking contaminated water found at eight “hot spots” of point source contamination. This ability to target higher risk areas allowed the county to use its financial resources more efficiently and to protect its citizens more effectively.

As noted in 2002 by J. Maichle Bacon, Director of the Winnebago County Health Department, detailed three-dimensional maps and derivative aquifer sensitivity maps, when used in combination with maps of industrial and residential development, “provided the framework needed to understand the environmental context for groundwater resource availability and protection issues. It would have been impossible to do this effectively without the detailed maps.” The map information consistently indicated areas that, when tested, were positive for contamination.

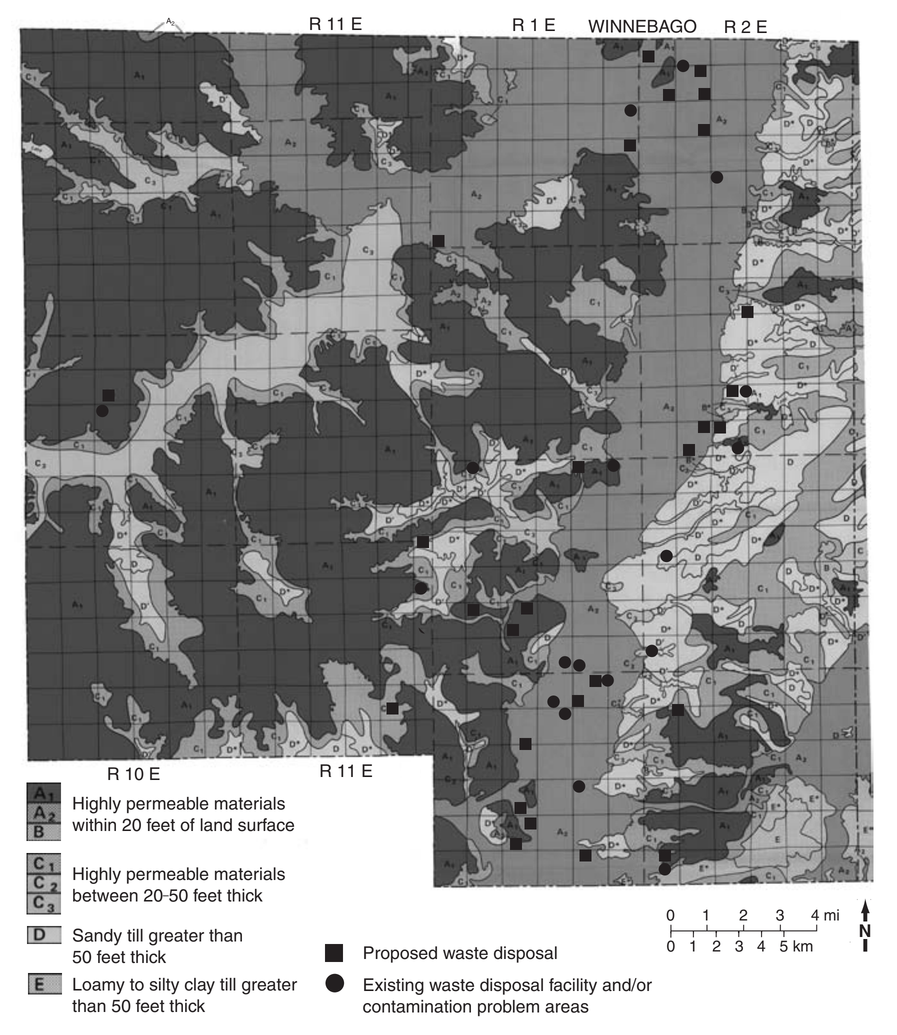


Figure 5 This portion of an aquifer sensitivity map of Winnebago County indicates where aquifers are within 20 feet of land surface. Black dots and squares indicate contamination problem areas.

Non-point Contamination Sources

Non-point sources of contamination are those that occur over wider geographic areas, such as agricultural fields, or a major highway, or anywhere contaminants enter the groundwater with relative uniformity and without any specific, easily identified entry point. Non-point sources include fertilizers and pesticides applied to agricultural fields and lawns; sewage sludge, septage, and manure spread on the land surface; and salt used to de-ice roads. It is very difficult to *remediate* groundwater or aquifers contaminated by non-point sources because contamination is widespread.

Often the only way to control non-point source contamination is to eliminate or substantially reduce the amount of contaminants applied to the land and hope that the groundwater ultimately "cleanses" itself. This solution is not the best, for several reasons. First, such natural cleansing may not be possible or, if possible, may require longer than a human lifetime. Prevention is easier, cheaper, and safer. Second, because non-point source contamination occurs over large areas, solutions may be technically complicated or impractical, may raise ethical questions, and may revolve around or require the passage of new environmental laws or other forms of government intervention. For example, if the presence of nitrates in groundwater is linked to agricultural practices, legislation may be required to control nitrate applications by farmers and others. However, watersheds, *ecosystems,* and people's livelihoods may be affected. If farmers were required to reduce their nitrate fertilizer applications, crop yields might be smaller, food supplies might be reduced, and farmers' personal incomes might drop substantially.

It is important to know that some potential groundwater contaminants can be applied to the land without causing harm as long as recommended procedures are followed and as long as the geologic and hydrogeologic conditions are such that they help protect groundwater resources. Unfortunately, some people and organizations, knowingly and unknowingly, use poor judgment when siting waste-disposal facilities or when applying agricultural chemicals and lawn fertilizers. A better-informed public should be able to use knowledge gained from this publication to insist on the safest possible sites for waste disposal and stress that land-use changes be compatible with geologic characteristics.

Case Study: Agricultural Contaminants in Water Wells

Pesticides and fertilizers are common non-point sources of contamination when over-applied to the 28 million acres of Illinois' farm fields and rural grasslands and 630,000 acres of residential lawns. In the early 1990s, the ISGS and Illinois Sate Water Survey designed a pilot study to investigate the occurrence of agricultural chemicals in rural, private water wells. Two hundred and forty water wells were sampled bimonthly for one year in five regions that differed in geologic setting and well type (fig. 6). The geologic setting was defined by the depth to the uppermost aquifer and was unique for each of four study areas in Mason, Kankakee, Livingston, and Piatt Counties. Effingham County was included to study how well type affected the occurrence of agricultural chemicals in wells.

One or more chemicals were detected in 55 (23%) of 240 wells. The occurrence of chemicals in wells varied between 0% in Piatt County to 46% in Effingham County. Well depth was an important predictor of the occurrence of chemicals in small-diameter wells in Mason, Kankakee, Livingston, and Piatt Counties. Chemicals occurred most in areas where the uppermost aquifer materials were within 20 feet of the land surface. The occurrence of chemicals fell to 8% when the depth to the uppermost aquifer materials was 20 to 50 feet and fell to 0% in Piatt County where aquifers are not present in the upper 50 feet.

The depth to the uppermost aquifer materials was not useful in predicting the occurrence of chemicals in the dug and bored wells of Effingham County because, in that area, thin, often discontinuous layers of sand (which are not aquifers) transmit water to the large-diameter wells. The largest factors affecting water quality are well construction and the surrounding land use.

Results for the limited areas covered by the pilot study suggest that there may be problems with nitrate and pesticide contamination in rural well water in Illinois and that a statewide evaluation of non-point source contaminants is warranted.

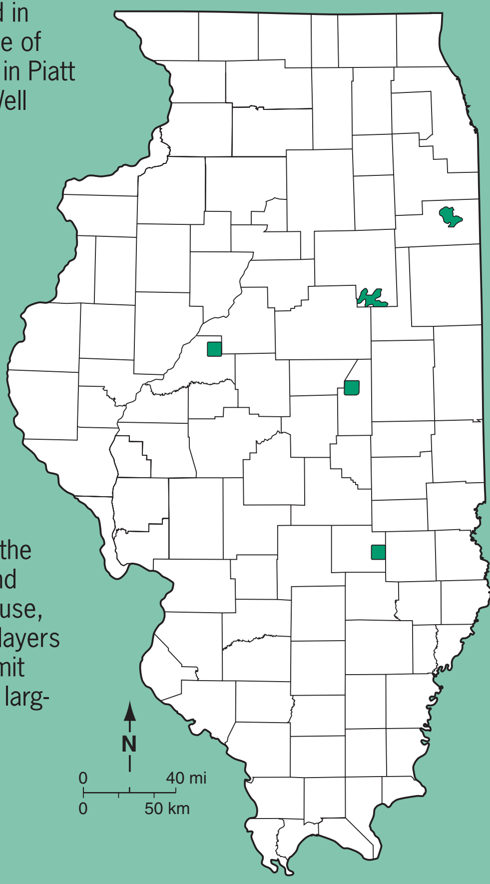


Figure 6 Green indicates the areas examined in a pilot study to investigate the occurrence of agricultural chemicals in rural, private water wells in Illinois.

Siting Goal

The goal of proper siting is to guide necessary waste-disposal activities and hazardous, yet economically viable, industrial ventures to regions where aquifers are less vulnerable and where populations are not at risk.

Approaches to Safer Siting

The best approach to preventing or minimizing groundwater contamination or other harm to the subsurface environment involves three main steps:

1. understanding the geology by mapping the length, breadth, and thickness of each geologic unit at the land surface (for example, from *outcrop*s) and below ground (for example, from drilling samples) and by delineating the distribution of the different earth materials;
2. understanding the hydrogeology by knowing where aquifers occur, how thick and geographically extensive they are, and how groundwater moves through geologic materials; and
3. applying this knowledge in a series of steps to create an understanding of a region's three-dimensional geology that allows for improved evaluation at specific sites.

Using this three-step procedure increases the probability that waste-disposal facilities will be sited in the safest possible settings and impose the least stress on the environment.

In the long run, proper siting of waste-disposal facilities and industrial activities that can generate wastes should lead to a lower likelihood of contamination. Better evaluation of the ability of geologic materials to withstand contamination threats should also reduce the possibility of contamination. Understanding information about geology and groundwater flow patterns can help environmental planners make informed decisions about environmental regulations. In regions where aquifers are especially sensitive to contamination, for example, where thick sand and gravel aquifers are at or near the land surface, stringent land-use restrictions must be imposed to protect groundwater quality. However, regions where aquifers are less sensitive may not need to be regulated as strictly.

Mapping Aids Long-term Planning

County and regional planners periodically develop land resource management guides for a given future time frame, such as 10 or 20 years. Planners must know about current land use, current and projected trends in converting land from one use to another, and the expected effects of population growth on land use to set realistic goals.

Geologic and hydrogeologic information is necessary to understand the environmental effects of the following types of land use:

- Municipal, industrial, and commercial land use includes plans, capital improvements, and potential or actual boundaries to population growth and water and mineral resource use. Potentially harmful land uses are included in this category. Also necessary are groundwater resources that are sufficient to meet the needs of municipalities and industrial and commercial entities.
- Residential land use (fig. 7) involves community expansion, development in floodplains and other environmentally sensitive areas, and adequate groundwater resources to support residential development.
- Infrastructure for residential, commercial, and industrial development requires high-quality, nearby sources of sand and gravel or bedrock to build highways, sidewalks, foundations, bridge abutments, and other structures.
- Agricultural and rural land use includes the need to understand soil types and the requirement for adequate water resources to sustain agriculture.
- Use and preservation of open space and environmental and natural resources call for an understanding of ecosystems. Earth materials, soils, and groundwater conditions are the foundation of all ecosystems.
- Transportation and utilities rely heavily on geology and hydrogeology; for example, bridge foundations for highways and railroads must take into account local geologic and hydrogeologic conditions, and energy utilities depend on fossil fuels such as coal, oil, and gas.
- Successful historic preservation must take into account soil foundation conditions and any geologic hazards such as the location of an historically significant site on or near unstable slopes, in a floodplain, or other hazards.

Figure 7 A subdivision in Champaign County. As communities grow, planners need detailed geologic information to ensure that groundwater resources are adequate to support residential development and that floodplains and other environmentally sensitive areas are avoided.

Background: The Geologic Framework

Geology, the study of earth materials, and hydrogeology, the study of water in relation to geology, provide the fundamental knowledge needed to determine whether land is suitable for waste disposal or other potentially harmful activities. The two sciences are inextricably linked because groundwater and the subsurface geologic materials are also linked. Groundwater movement through relatively uniform coarse-grained sediment is fairly predictable, but is less so when groundwater moves through fine-grained sediment that is fractured or cracked. To understand groundwater's behavior in the subsurface is to understand the nature and arrangement of the sediments and rocks both horizontally (the geographic area covered) and vertically (from the land surface to a selected depth or subsurface geologic unit). This multidimensional arrangement of sediments and rocks is referred to as an area's geologic framework and, in Illinois, consists of two major parts: the bedrock and the glacial deposits on top of the bedrock.

Bedrock

In Illinois, shallow bedrock (fig. 8) consists of sedimentary rocks, earth materials that have been cemented, compacted, or compressed into stone (lithified). Four dominant types of sedimentary rocks are found in the state:

- shale, a mix of lithified clay and silt that was deposited in ancient quiet-water seas;
- sandstone, lithified sand that was deposited along beaches or in river beds;
- limestone and dolomite, formed mostly from the limy muds that include shell fragments of algae, corals, clams, and snails and remains of other plants and animals that lived in the ancient, warm, tropical seas that repeatedly covered parts of what is now Illinois; and
- coal, plant remains altered and compressed into rock over geologic time.

Glacial and Post-Glacial Deposits

Nearly 90% of Illinois' bedrock is buried beneath glacial deposits laid down during the Pleistocene Epoch, known also as the Great Ice Age (fig. 9), as well as those laid down after the last glaciers retreated from the state. The deposits consist primarily of till, sand and gravel, silt, and clay.

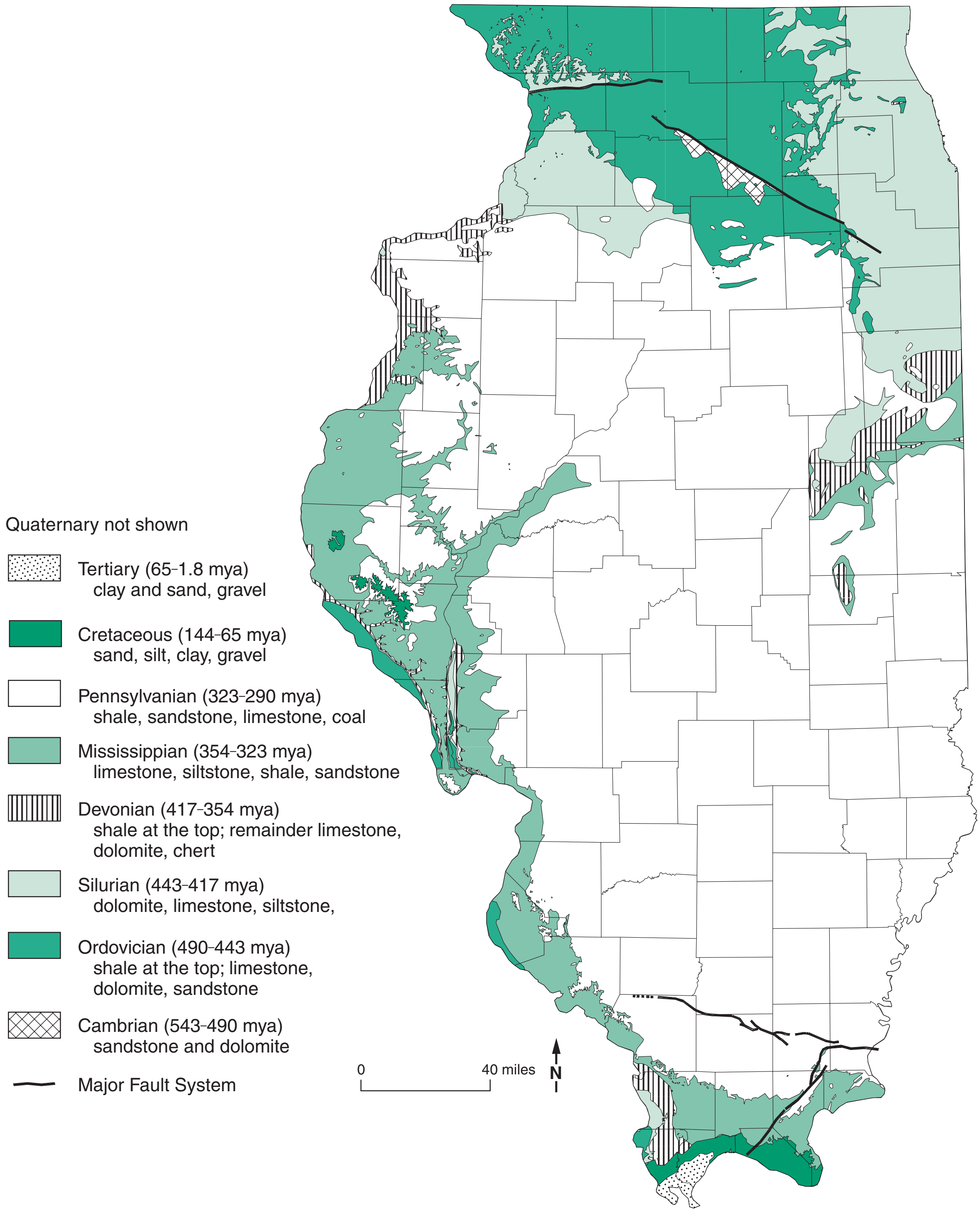


Figure 8 Types and ages of rocks that occur at the bedrock surface in Illinois; mya means million years ago.

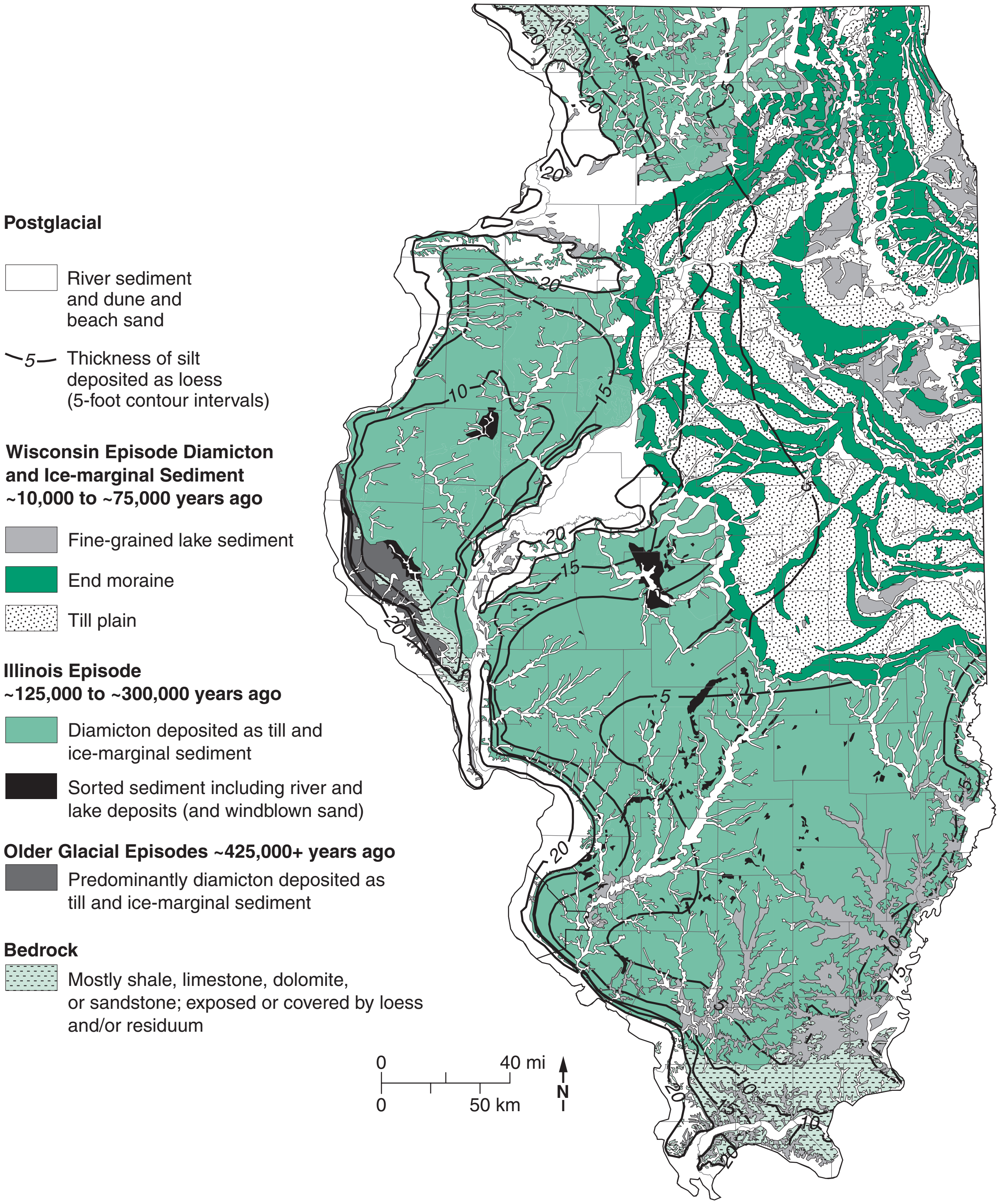


Figure 9 The cover of Ice Age sediments in Illinois at land surface as well as where bedrock occurs at or near the land surface.

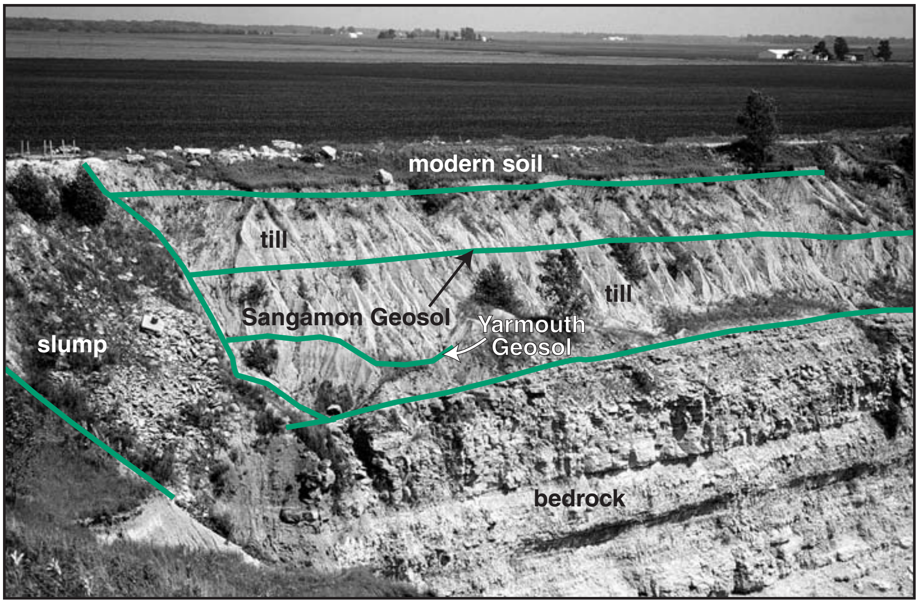


Figure 10 An exposure of Ice Age materials at a quarry in Douglas County. Arrows show the position of named old soils developed in tills.

Till, also called diamicton, is a mixture of clay, silt, sand, gravel, cobbles, and boulders. Till is the dominant glacial deposit in Illinois. Layers (called beds) of till were laid down by successive continental ice sheets that advanced into Illinois. Old soils (paleosols) that developed on the land surface between episodes of glaciation are preserved in many places (fig. 10).

Beds of *outwash,* composed of sand and gravel and deposited by meltwater streaming away from the glaciers, also commonly occur between and within beds of till. Thick deposits of buried sand and gravel are found in deep bedrock valleys throughout the state. Thin beds of silt and clay deposited in glacial lakes also occur between or within the tills and also may be found at the land surface (fig. 9).

A blanket of windblown silt, called loess, overlies the glacial deposits. Loess deposits are up to 100 feet thick on the uplands just east of the Mississippi and Illinois Rivers, but thin rapidly east of the river valleys (fig. 11). This loess layer is the parent material for many of Illinois' fertile soils. Altogether, the glacial deposits are more than 400 feet thick in places (fig. 12). Since the glaciers' retreat from Illinois about 10,000 years ago, geologic materials continue to be deposited, particularly silt and clay by rivers, peat and muck in depressions and low areas in the landscape, and various types of debris at the base of steep slopes (from slumping and landslides).

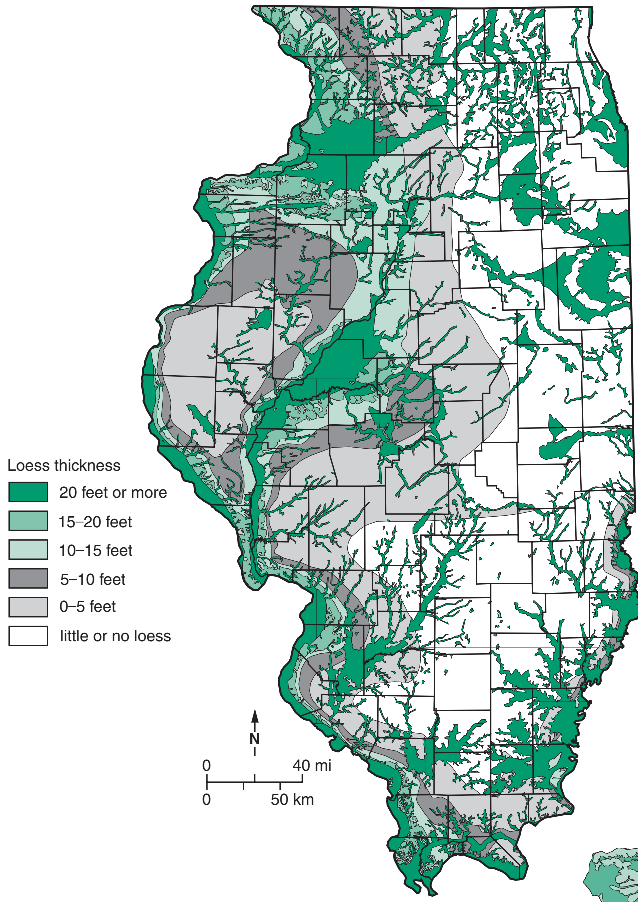


Figure 11 The loess blanketing Illinois is thickest immediately east of major river valleys and thins eastward with distance from the valley.

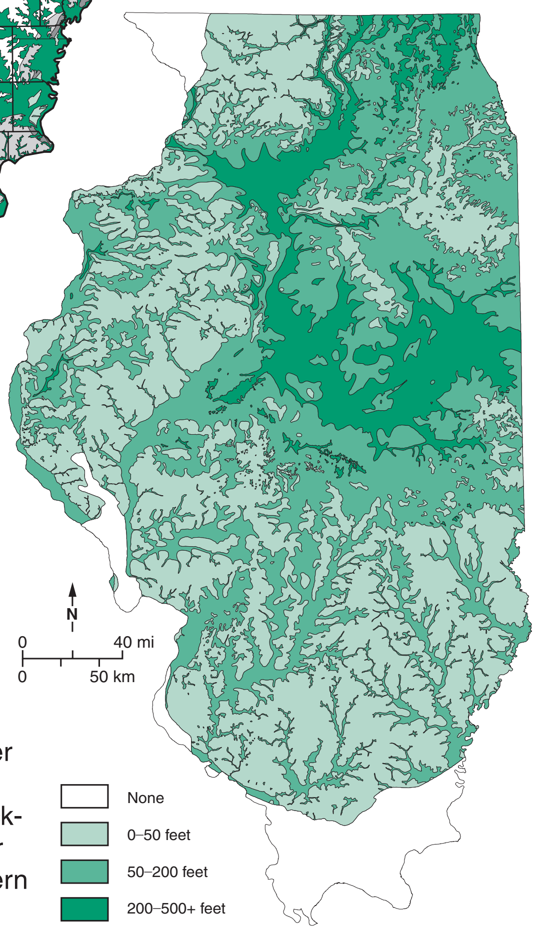


Figure 12 The thickness of the glacial sediments overlying bedrock: the darker the shade of green, the greater is the thickness of glacial sediments. The thickest deposits, up to 500 feet thick, occur in bedrock valleys in central and northern Illinois.

How Illinois' Variable Geology Affects Groundwater

Generally speaking, the bedrock and overlying sediments in Illinois were deposited in chronological layers, with the oldest lying beneath successively younger layers. When the details of the state's geology are closely examined, however, rock and glacial sediment layers are found to thicken and thin from one place to another or may be absent, and the rock layers have been warped into domes, basins, and other structures over geologic time (fig. 13). The rock beds are faulted in places so that the layers are offset vertically from one side of the fault to the other. Where faulting has occurred, adjacent rocks may be quite different on either side of the fault. Rock also tends to be fractured and crushed along fault zones.

In the same way, the thickness and character of glacial and postglacial sediments vary from place to place. Successive ice sheets advanced to different maximum distances in Illinois (fig. 9), and the ice carried ground-up rock debris made up of varying percentages of clay, silt, sand, and larger rocks. Each major advance and retreat left an ancient landscape similar to today's, replete with hills, valleys, rivers, and

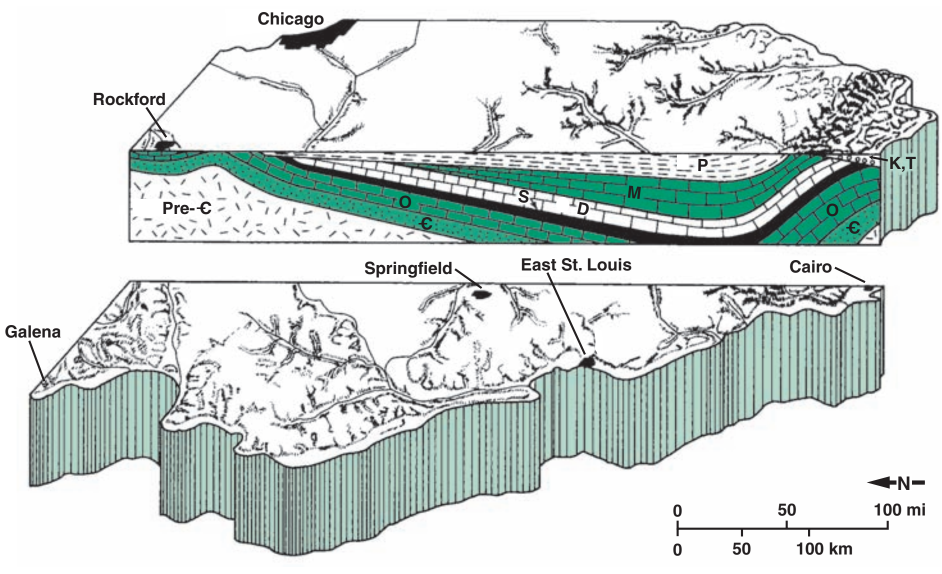


Figure 13 Generalized north-south cross section shows the structure of the Illinois Basin. To show detail, the thickness of the sedimentary rocks has been greatly exaggerated, and younger, unconsolidated surface deposits have been eliminated. The oldest rocks are Precambrian (pre-Є). These igneous rocks form a depression filled with layers of sedimentary rocks of various ages: Cambrian (Є), Ordovician (O), Silurian (S), Devonian (D), Mississippian (M), Pennsylvanian (P), Cretaceous (K), and Tertiary (T). The scale is approximate.

streams. Between glacial episodes, soil development, erosion, *deposition*, landslides, flooding, and other normal earth processes acted on these ancient landscapes, adding complexity to each surface. When the old landscapes were overridden by a succeeding ice advance, some of the complexities generated by the *interglacial* earth processes were preserved while other features were eroded away. For instance, remnants of sandy flood deposits along an ancient river were sometimes preserved but at times were replaced by other sediments deposited directly by the new glacial ice.

Meltwater flowed away from the front and sides of the glaciers, depositing sand and gravel in meltwater channels. Silt and clay were deposited in temporary lakes that formed in various places and at different times throughout the Ice Age. Although the general pattern of these deposits at the land surface can be seen fairly easily (fig. 9), the complexities associated with glacial and modern deposition and erosion make the details hard to understand. Interpretation is particularly difficult when the deposits occur in the subsurface and their physical and chemical characteristics and the vertical and lateral extent of the layers must be interpreted from drilling records, *cores*, outcrops, and samples (fig. 14).

Variations in the thickness and character of bedrock layers and beds of glacial sediment are encountered in many places and can affect groundwater availability and movement.

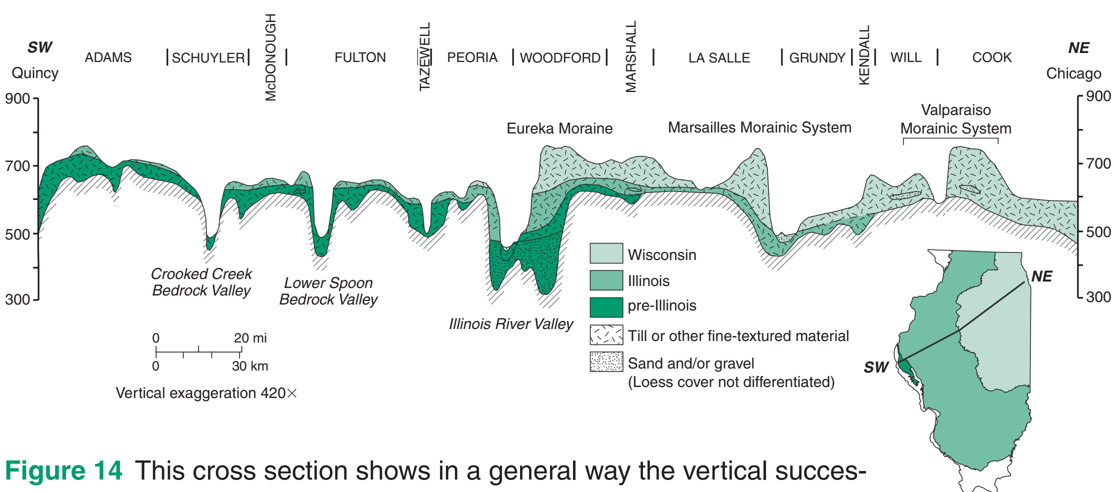


Figure 14 This cross section shows in a general way the vertical succession of deposits from the earliest episode of glaciation (pre-Illinois) to the last (Wisconsin Episode) in the subsurface along a line from Quincy on the west through Peoria to Chicago on the east. The small scale results in mapping generalizations across a broad expanse; cross sections on larger scales would illustrate more detail over shorter distances.

Facies changes A layer of one type of rock or glacial sediment may grade or blend into another type of rock, a feature known as a facies change (fig. 15). For example, a limestone may grade laterally or vertically into a shaley limestone, then a limy shale, and then a shale. A glacial sand and gravel layer may grade into a silty sand and then into a silt. Such variation means that groundwater yield from one area may be substantially different from that nearby. For example, groundwater yield is likely to be higher from sand and gravel or limestone than from silt or shale.

Discontinuities Features that formed during deposition, such as *bedding planes* and thin layers of particles of a different size from those above and below, commonly interrupt the continuity of bedrock layers and glacial and postglacial sediments (fig. 16). Where these thin beds are composed of sandy materials, groundwater flow is enhanced. However, when a layer of fine-grained, relatively impervious materials occurs within beds of coarser-grained sand and gravel, groundwater generally flows on top of the fine-grained beds, sometimes resulting in *perched aquifers.*

Other features Features that formed after deposition include faults (fig. 17), folds, *joints*, or *weathering* zones. All of these features can cause faster groundwater movement. However, predicting groundwater's movement through these features is often very difficult because their distribution may be irregular.

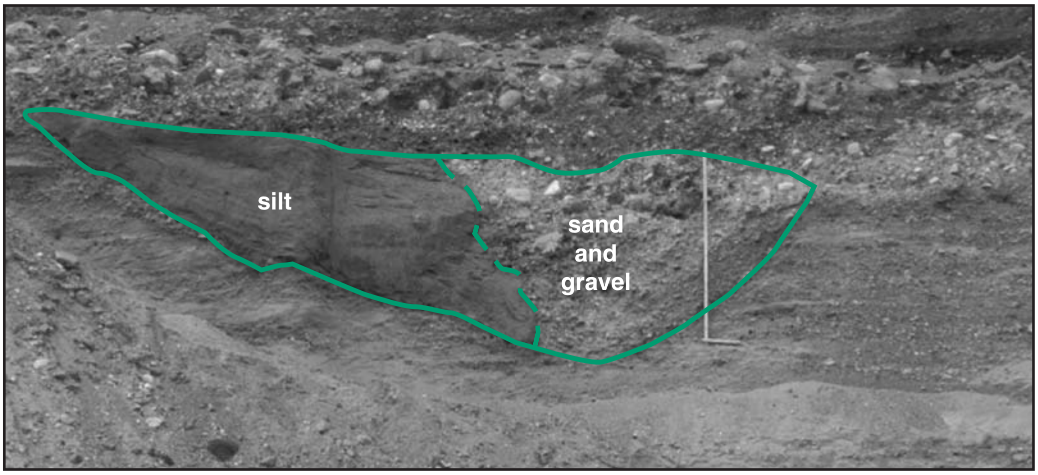


Figure 15 A sand- and gravel-filled stream channel cuts through sediments that illustrate the concept of facies change. The silt and sand and gravel are in a facies relationship. (Photo by Tim Kemmis.)

Figure 16 A pronounced dip of silty clay till, which acts as an *aquitard* slowing the flow of water through earth materials, is shown by the green line in this exposure of Ice Age sediments lying above bedrock. The dip is evidence of the abrupt change in geology that can occur in the subsurface.

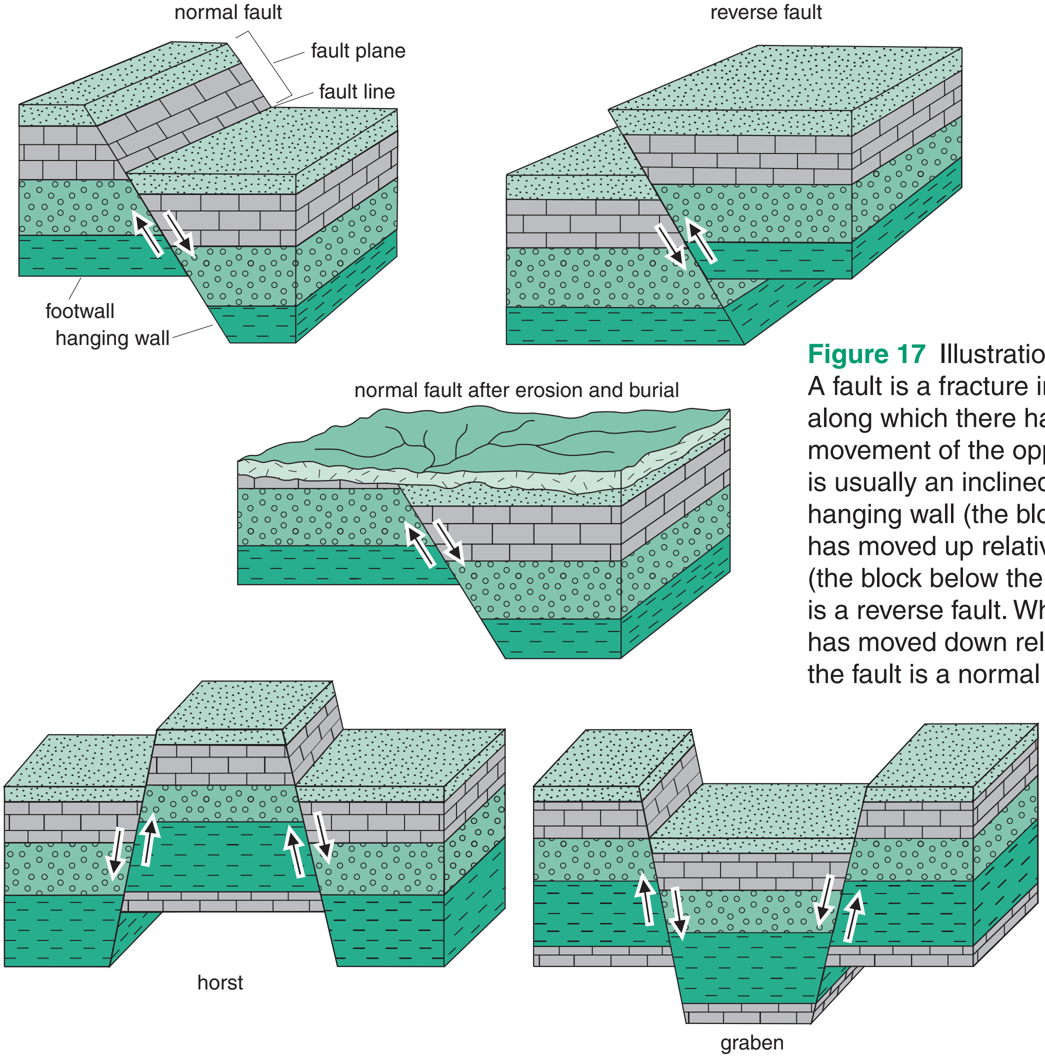


Figure 17 Illustrations of fault types. A fault is a fracture in the Earth's crust along which there has been relative movement of the opposing blocks. A fault is usually an inclined plane. When the hanging wall (the block above the plane) has moved up relative to the footwall (the block below the fracture), the fault is a reverse fault. When the hanging wall has moved down relative to the footwall, the fault is a normal fault.

These features, coupled with the variability of rock and glacial sediment types, can reduce water yield and affect the pathways by which contaminants travel to reach groundwater. For a more thorough discussion of groundwater issues, please refer to *Illinois Groundwater: A Vital Geologic Resource*.

Aquifers and Aquitards

Some types of bedrock and glacial deposits may readily transmit water through interconnected fractures or pore spaces and yield water to wells. Where saturated, these deposits are aquifers and make up the groundwater resource (fig. 18). Other deposits, such as silt and clay, may lack interconnected pore space or fractures or have only very small pores because they generally are composed of fine-grained materials. Known as aquitards, these deposits slow and may prevent the movement of water, or waste-contaminated liquids, called *leachate*. It is safest and most desirable to locate waste-disposal facilities in or above aquitards.

Sandstone and fractured limestone and dolomite generally make good aquifers. Shale, unfractured limestone and dolomite, and well-cemented

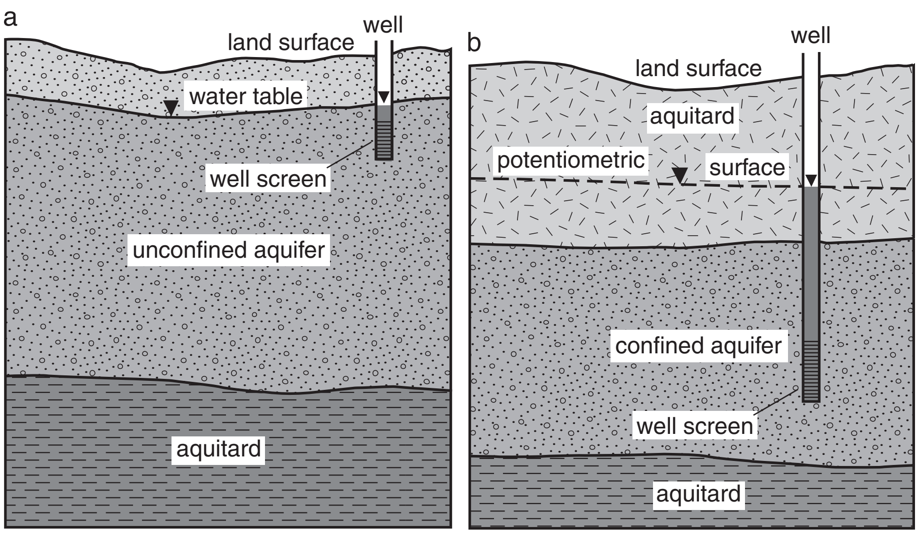


Figure 18 Examples are shown of two kinds of aquifers in Illinois: unconfined (a) and confined (b). An unconfined aquifer is one where the *water table* is the top of the aquifer. The water level in a well tapping an unconfined aquifer marks the water table. A confined aquifer has aquitards above and below it so that there is pressure on the groundwater in the aquifer. Because of the pressure, the water level in a well tapping a confined aquifer may rise above the top of the aquifer (artesian well).

sandstone make good aquitards. Outwash sand and gravel make the best aquifers, and till and clay make the best aquitards. Silt and loess also may be aquitards; however, water generally moves through these deposits faster than it moves through clay and till.

The variability of rock and sediment layers affects the thickness and continuity of aquifers and aquitards. Thicker aquifers can hold more groundwater, and uninterrupted aquifers have a greater likelihood of yielding large amounts of water. The most continuous glacial aquifers occur between deposits of major glacial advances. Thicker aquitards offer more protection to underlying aquifers. Discontinuous aquitards offer, at best, only spotty protection to a portion of an underlying aquifer, and the rest of the aquifer may be vulnerable to contamination.

Groundwater Movement

When considering whether a land use is appropriate for an area's geologic conditions, it is important to understand that groundwater moves slowly in the direction of decreasing *hydraulic head* (fig. 19). Hydraulic head is the amount of energy groundwater has at a given point underground. Height above sea level, weight of earth materials,

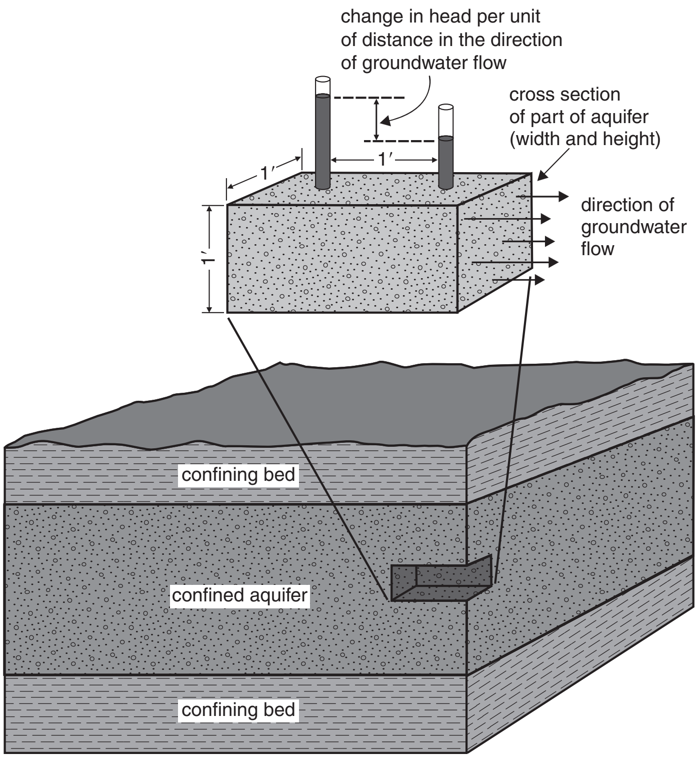


Figure 19 *Hydraulic conductivity* is the rate at which groundwater flows through earth materials. The rate is a function of the size and degree of interconnected pore space in the earth materials (Modified from Heath 1989.)

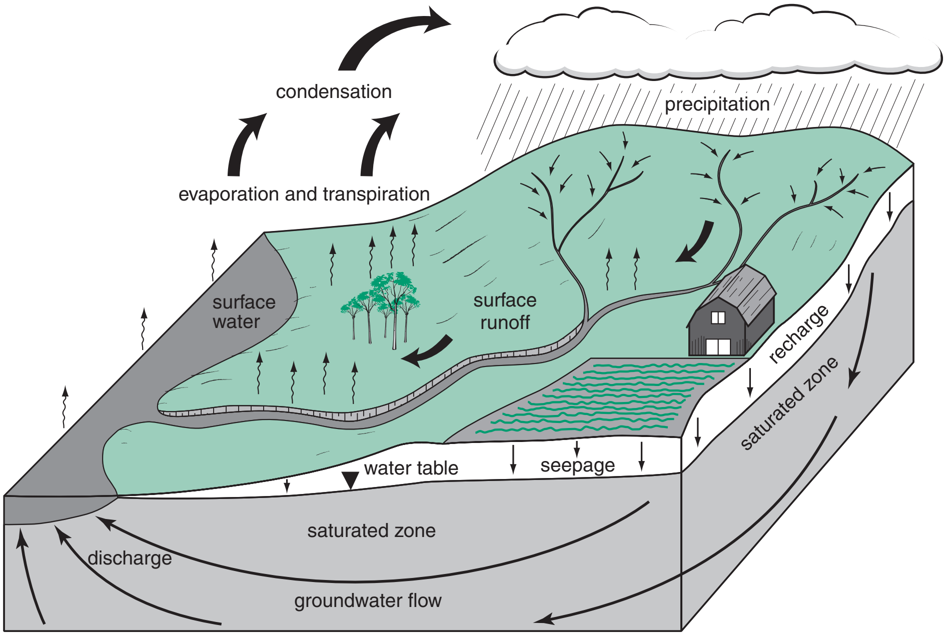


Figure 20 Arrows show the movement of water through a complete hydrologic cycle that includes precipitation, surface runoff into surface water, seepage into the ground, groundwater flow from *recharge* areas to zones of discharge, evaporation and transpiration, and condensation.

groundwater above that point, and groundwater movement all affect hydraulic head. Groundwater moves much more slowly than water in rivers and streams because of friction between the water and the walls of the small pore spaces in the sediment and rock. The amount of friction varies according to the type of sediment and rock and how the earth materials change laterally and vertically. Where the underground spaces are large, such as in the fractured *karst* areas of Illinois, groundwater can move as fast as surface water. The *hydraulic gradient* also affects how fast groundwater moves: water flows faster as the gradient steepens. For an unconfined aquifer, hydraulic gradients follow the slope of the water table, directing groundwater flow from upland areas toward lowland rivers and streams. Permanent streams are fed by groundwater flowing out at the ground surface in the stream bed.

Precipitation *percolating* into the ground replenishes, or recharges, groundwater (fig. 20). Precipitation recharges an aquifer easily and relatively quickly where the top of the sand and gravel, porous sandstone, fractured limestone or dolomite is exposed at the land surface. Deeper aquifers may take hundreds or thousands of years to recharge because groundwater may move very slowly through overlying fine-grained materials. Groundwater discharge to lakes, rivers, and streams is particularly related to the subsurface distribution of aquifers. Discharge is greatest where sand and gravel or bedrock aquifers lie within the upper 50 feet of land surface. See *Illinois Groundwater: A Vital Geologic Resource* for more information.

To protect groundwater supplies when making siting decisions, planners should seek sites with thick aquitards to retard the movement of contaminants into aquifers. Planners also should reduce the possibility of groundwater contamination by avoiding areas containing aquifers or by finding an area where aquifers are deep below ground.

Criteria: Making Land-Use Decisions

Ideally, land being considered for various uses requires geologic and hydrogeologic features that minimize the effect of planned activities on groundwater and surface water quality.

The geologic and hydrogeologic features of a region and a site must be mapped

1. to predict the area's vulnerability to groundwater contamination;
2. to determine the geologic suitability of areas for uses such as animal confinement facilities or the safe application of chemicals and fertilizers on agricultural land and residential lawns;
3. to locate and protect groundwater supplies;
4. to locate and plan for the future extraction of scarce mineral resources;
5. to plan the cleanup of contaminated industrial sites and other sites;
6. to establish the geologic criteria for selection of the safest possible sites for municipal, hazardous, and low-level radioactive waste disposal; and
7. to reduce uncertainty for land-use planning in general.

Mapping the distribution of the geologic materials at the land surface and subsurface allows interpretive maps to be made that show earth hazards and the risk of groundwater contamination. These maps then can be used to help evaluate how various land uses may affect the environment. Choosing which types of interpretive maps to develop is best accomplished by geologists and hydrogeologists working together with health officials and land-use planners, representatives of private industry, and citizens. Together these individuals can identify the specific needs of the community, county, or region.

Predictable Geology

To be predictable, the three-dimensional geology of an area must be relatively simple and understandable, which means that the character, thickness, and *areal distribution* of its components can be predicted using the available data. Predictable geology that identifies the occurrence and flow directions of groundwater increases the likelihood that the geologic and hydrogeologic features can be analyzed and understood.

Engineering Properties

By showing engineering properties, such as the density, *compaction*, *consolidation*, and optimum moisture content of earth materials, geologic maps can provide information about excavation conditions, guide the design and construction of foundations, and determine the suitability of geologic deposits for many different uses. Three-dimensional, detailed geologic mapping is needed to understand the engineering properties of the geologic units at or near an existing contamination site. Detailed mapping also is helpful at a site where contaminants may be used, generated, or contained. During mapping, the properties of geologic materials are tested, and the resulting data are compiled. Areas can be identified that are prone to shrinking and swelling soils, *liquefaction* from amplification of earthquake motions, landsliding, or other hazards.

Geologic Hazards

Areas should be avoided as disposal sites if they are susceptible to geologic hazards that might affect the site's long-term stability.

Earthquakes During an earthquake, loose, uncompacted, *unconsolidated* sediments, such as sand and gravel or lake silts, respond to seismic shaking more than do materials such as bedrock and *overconsolidated* tills. Unconsolidated sediments can significantly amplify the amount of earthquake vibration like a bowl of gelatin when shaken. If loose, unconsolidated sediments are saturated with water and the shaking is severe, the grains may lose contact with one another and the sediments become liquefied. Liquefied sediments lose their strength and cannot support the structures built on or in them. In these types of settings, the integrity of any constructed facility, particularly those that contain wastes or potentially hazardous materials, could be compromised unless the site has been modified to resist liquefaction. Figure 21 shows the areas of the central United States where liquefaction potential is high.

Landslides Overly steep stream banks, road cuts, or hillsides are unstable and prone to slide downhill (fig. 22). A common sight in a highway road cut is an overly steep slope that has been covered with rock as a way to slow landsliding. Landslides in Illinois often are caused by human disturbance of slopes (such as by construction) and may involve the bedrock, the overlying glacial deposits, or both. Water-saturated sediments tend to lose their coherence, or strength, causing slopes to fail. It is crucial to understand the geologic and hydrogeologic setting of a slope to determine its susceptibility to landsliding.

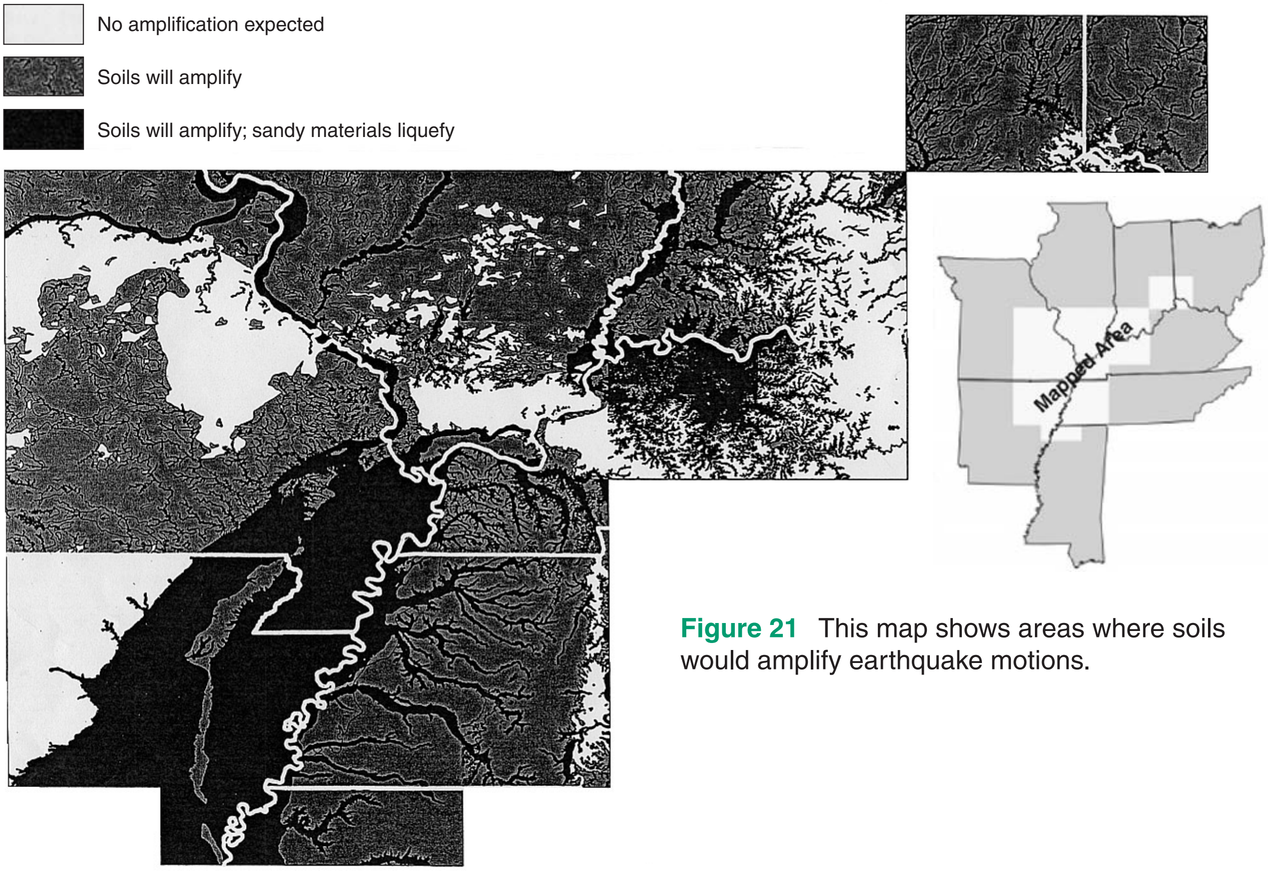


Figure 21 This map shows areas where soils would amplify earthquake motions.

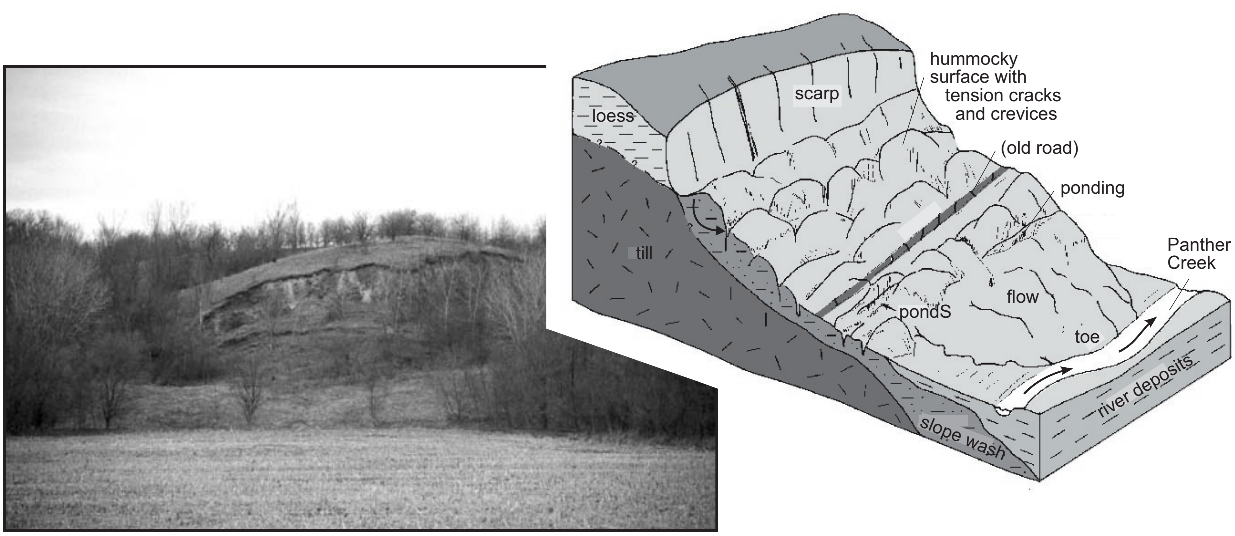


Figure 22 A road near Panther Creek in Cass County in central Illinois was destroyed by a landslide. Blocks of sediment moved down a slope creating large cracks in the surface. (Photo by Michael L. Barnhardt.)

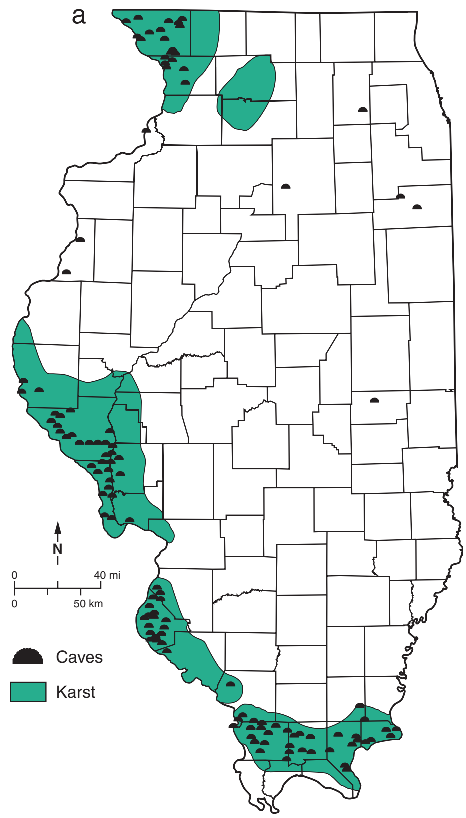
Flooding, erosion, and deposition Major river floods, such as ocurred in 1993 (fig. 23), inundate large areas of a river's floodplain, eroding sediment from some places and depositing it in others. Even during routine spring flooding, erosion and sediment deposition are common. Facilities where contaminants are used or contained should not be sited in areas subject to flooding, especially river floodplains, because floodwaters could damage containment structures or otherwise release wastes. Associated erosion and deposition could remove or bury the facility. Wetlands should be avoided because they may flood and their saturated soils are unstable.

Karst Karst refers to a type of terrain that is characterized by closed depressions or sinkholes, caves, and underground drainage networks (fig. 24a). Karst is produced by the dissolving action of water on limestone or dolomite. Water wells in karst areas are particularly susceptible to groundwater contamination because any contaminant dumped near or into a sinkhole quickly enters the groundwater. Unlike most areas, in karst, contaminants dissolved in surface water are not filtered slowly through a geologic unit such as a shale or a clayey till before reaching the groundwater. Instead, groundwater generally flows unimpeded through a network of subterranean streams in a karst area. *Infiltration* is very rapid, and the direction and rate of flow of groundwater are difficult to predict.

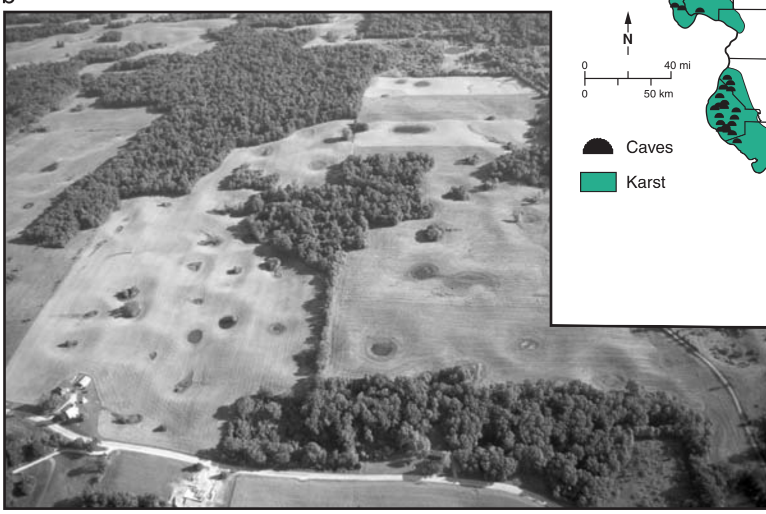
Figure 23 Flooding is common along Illinois rivers. It is essential that waste-generating land-use practices are sited outside flood-prone areas. These farm buildings in the Sny Levee District near Quincy in west-central Illinois were inundated during the Great Flood of 1993.

Figure 24 These potential karst areas in Illinois (a) have limestone or dolomite at or near the land surface. Photograph (b) and topographic map (c) show karst landscape in southwestern Illinois. Most closed circular features on this topographic map are sinkholes.

a



b



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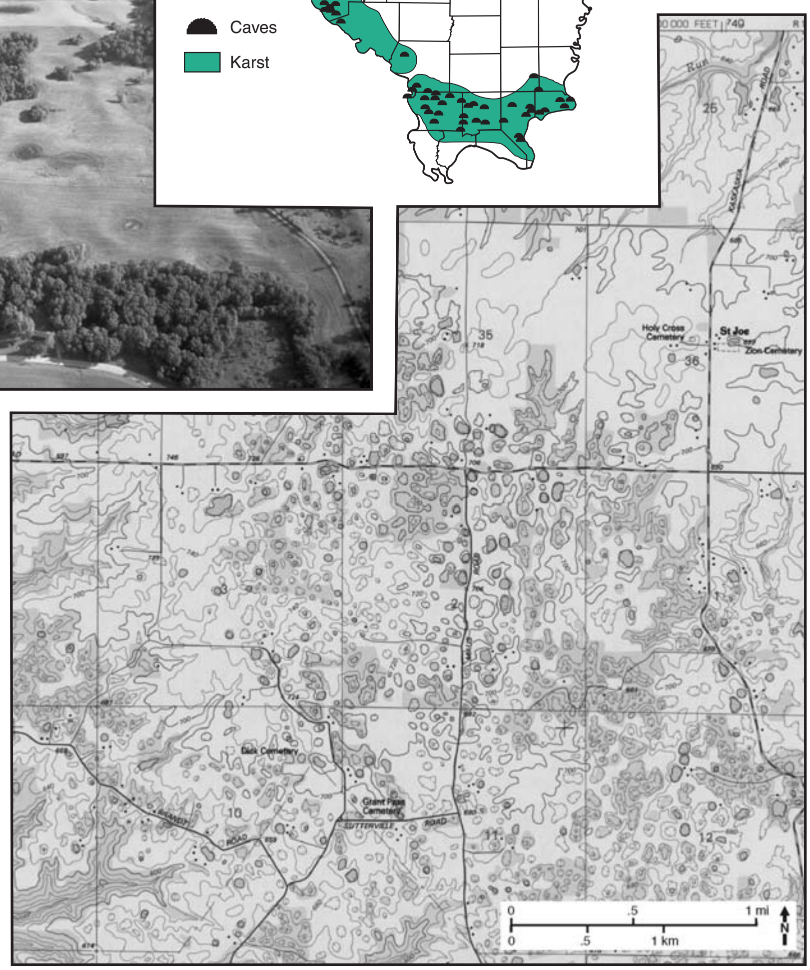


Most karst in Illinois occurs in rural areas (fig. 24b, c); however, limestone and dolomite rocks prone to karst development also are found near the St. Louis and Chicago metropolitan areas. It is not advisable to locate facilities where potential contaminants are used or contained in karst areas. Also, activities such as application of agricultural chemicals; spreading of sludge, septage, or manure; and operating large animal confinement facilities in karst areas can result in nitrates or coliform bacteria moving quickly into the groundwater and flowing into water wells.

Subsidence In Illinois, most land subsidence, or collapse, takes place over underground mines (fig. 25) or in active karst areas. Overlying earth materials, including bedrock and glacial deposits, may subside when a mine roof collapses. When the limestone or dolomite in a karst area dissolves, the overlying geologic materials ultimately collapse, creating a sinkhole (fig. 26). Both conditions may result in increased likelihood of groundwater contamination and property damage.

Swelling soils Some glacial deposits that contain certain types of clay minerals significantly expand when wet and shrink when dry. Cycles of shrinking and swelling cause cracks to open and close repeatedly, allowing them to fill with earth, leaves, twigs, and other debris. The gradual expansion of the soil's volume after repeated shrink-swell cycles can build enough pressure against foundations, buried walls, and other structures to cause severe cracking or failure of the structure (fig. 27). Shrinking and swelling soils eventually can damage waste containment structures, including earthen covers on landfills, rendering them incapable of safe containment.

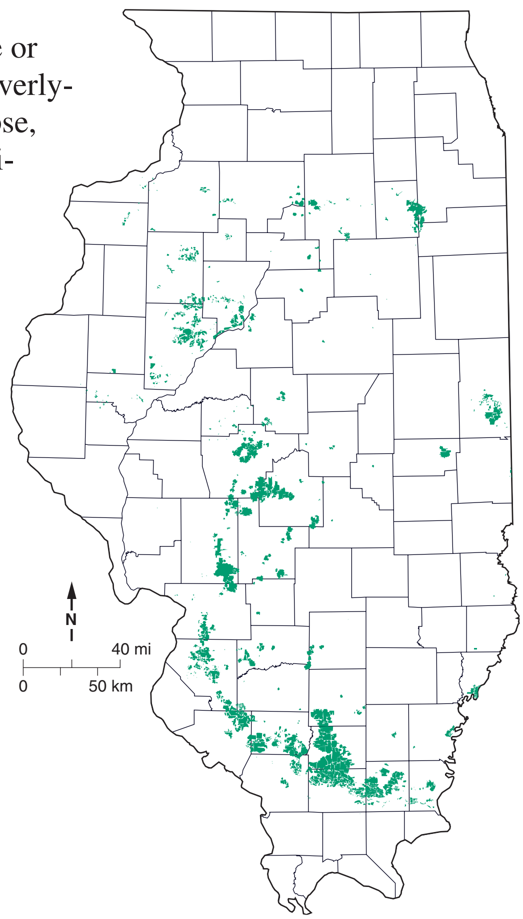


Figure 25 Areas of Illinois where underground coal mining has occurred.

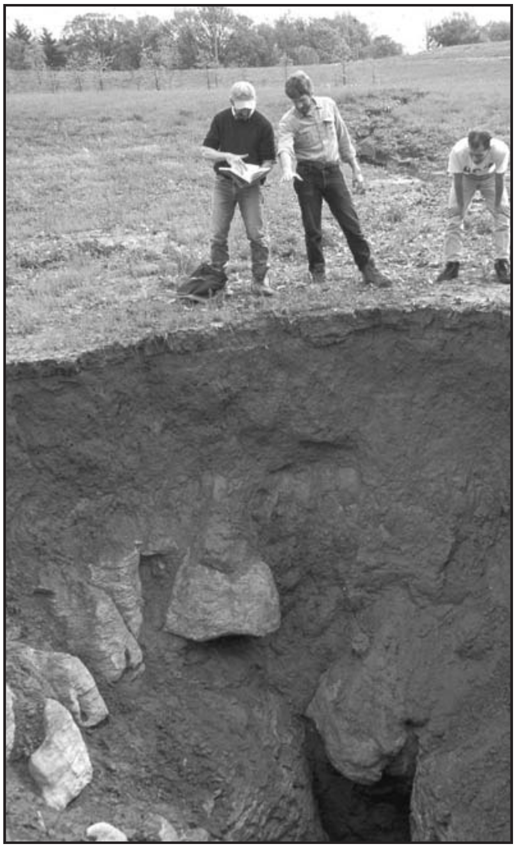


Figure 26 ISGS staff investigate a sinkhole in St. Claire County. The sinkhole was created when the underlying limestone or dolomite dissolved and the overlying geologic materials collapsed.

Figure 27 The wall of this building in Christian County was damaged by swelling soils. Note the inward bowing of the wall. (Photo by Bob Bauer.)

Identifying Mineral, Rock, and Petroleum Resources

It is important to identify valuable earth resources such as coal, sand and gravel, oil and gas, limestone, or dolomite during site evaluations, especially at the regional level of planning. The availability of resources within the region may affect the future economy of the area and must be considered during site selection.

Types of Waste

The type of waste to be generated or stored must be considered when picking a site for a waste-generating or waste-disposal facility or for evaluating other land-use activities.

Hazardous and low-level radioactive waste For hazardous and low-level radioactive waste disposal, the site geology must consist of predominantly fine-grained materials (such as shale or glacial till) to a depth of 300 feet in order to impede the flow of leaking fluids and to *attenuate* their pollutants. Sites above aquifers that are within 300 feet of the land surface should be avoided (fig. 28).

Municipal waste For municipal waste disposal, predominantly fine-grained materials should be present to a depth of at least 50 feet below the waste. If landfill trenches are to be 50 feet deep, there should be an additional 50 feet of fine-grained materials below the trench bottom to impede the flow of leaking substances.

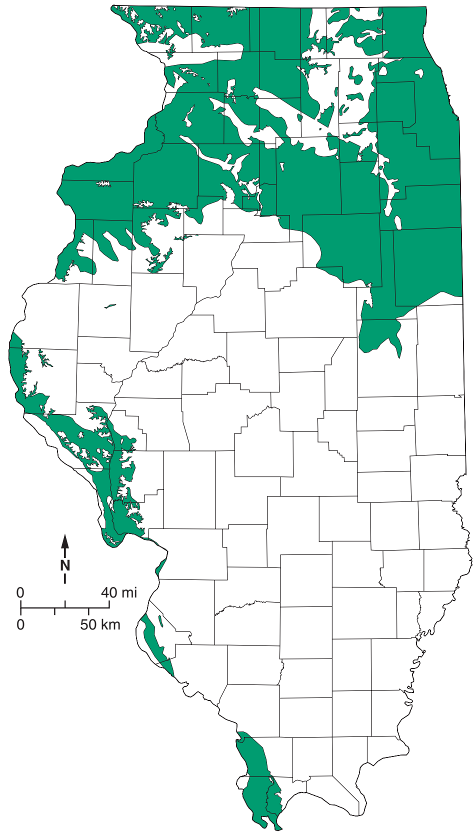


Figure 28 Major bedrock aquifers within 300 feet of land surface. Facilities that dispose of hazardous and radioactive wastes should not be sited in areas shown as shaded portions of the map.

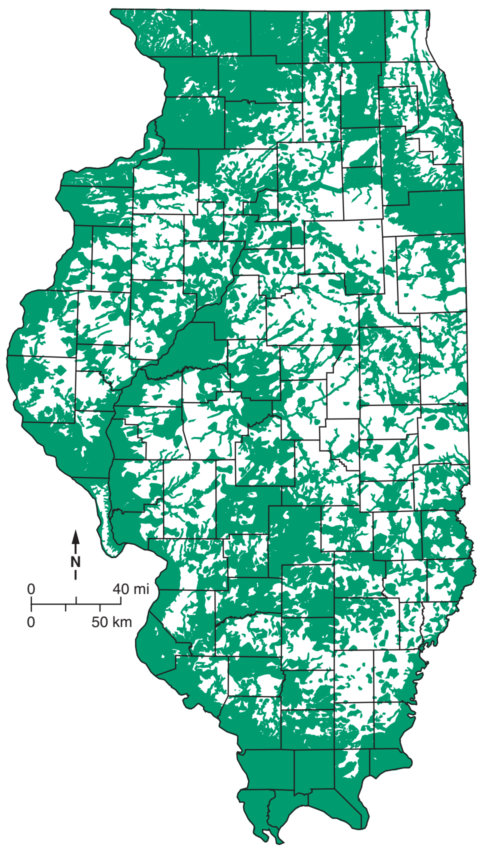


Figure 29 Shaded areas show aquifers within 50 feet of land surface.

Agricultural and residential by-products Aquifers should be more than 50 feet below the land surface for sites being considered for agricultural uses such as large animal confinement facilities (fig. 29) The application of chemicals and fertilizers should be done with an awareness of the underlying

Figure 30 A geologist examines a sinkhole in Monroe County. At the time, the sinkhole was used as a discharge for three septic systems. The effluent flowed directly into the owner's well. (Photo by Sam Panno.)

geology. Nitrate and pesticide contamination of wells in Illinois is much more common in geologic settings where aquifers are within 50 feet of land surface than where aquifers are deeper. Wells in aquifers within 20 feet of land surface are highly vulnerable. Septic effluent from large subdivisions with numerous private septic systems or from homes in karst areas also can cause problems (fig. 30).

These criteria, although not inclusive, illustrate the kinds of geologic conditions that must be known as fully as possible to site facilities successfully, to understand the problems that may arise in areas where waste is being generated, and to determine the best management options for handling contamination problems. These criteria underscore the importance of understanding geologic conditions, which is possible through detailed, three-dimensional mapping.

Case Study: Understanding Contaminant Movement

A hazardous waste disposal facility formerly located in southwestern Illinois provides an example of how valuable and necessary a detailed understanding of geologic materials can be. Mid-1970s facility designs considered standard engineering tests on the site's earth materials, laboratory tests of hydraulic conductivity in these materials, and the regulations governing such facilities. However, buried contaminants migrated from the trenches 100 to 1,000 times faster than predicted (fig. 31).

ISGS engineering geologists, stratigraphers, soil scientists, and chemists cooperated in a comprehensive study of the site to search for an explanation. Possible movement mechanisms included migration through previously unknown permeable zones, subsidence, chemical interactions between the buried waste and the geologic materials, and erosion.

To obtain first-hand information, drilling was conducted at numerous locations across the site, and samples were taken for detailed study of the glacial deposits and buried soils contained within them. At first, sand lenses within the surficial till at the site were thought to be the cause of the unexpectedly rapid travel times of the contaminants to perimeter monitoring wells. The sand lenses were suspected because fluids generally travel much faster through porous sand than through dense, clayey till. However, the sand lenses were not present everywhere.

Then, fractures in the till were suspected to be the main reason for the rapid contaminant migration, but the initial vertical drilling did not reveal the extent of these mostly vertical joints. However, boreholes drilled at an angle determined the orientation, frequency of occurrence, and degree of interconnection of the fractures more accurately. Field-measured hydraulic conductivity values that took into account interconnected fractures were 10 to 1,000 times greater than their 1970s laboratory-measured counterparts, largely accounting for the discrepancy between the predicted and actual migration rates. The study's results confirm the need to field test geologic materials and to conduct detailed regional, area, and site investigations to best predict a site's geologic and hydrogeologic character.

Figure 31 Scientists investigate hazardous waste barrels at a site in southwestern Illinois in the early 1980s. The landfill had faster-than-predicted pollutant migration. The information revealed by ISGS scientists studying the problem eventually resulted in the development of clay liners to create safer waste disposal facilities. (Photo by Christopher J. Stohr.)

Tools: Research, Maps, and Interpretation

The key to understanding the state's geologic and hydrogeologic framework lies in the work of geologists and hydrogeologists who map and describe bedrock and glacial deposits. Through detailed regional, area, and site studies, these scientists characterize the nature, occurrence, and extent of geologic materials and classify them. The information is compiled into large databases and used to make three-dimensional geologic maps and models that show the thickness and areal extent of the various types of rocks or sediments that are present. The maps, models, and data also provide a basis for understanding the occurrence of aquifers and the flow of groundwater into, through, and out of aquifers. Interpretations of these data also are the scientific basis for making wise decisions regarding the use of land and groundwater resources.

Fundamental Data Collection

Gathering fundamental data in the area to be mapped is the first step in constructing a detailed geologic map. The data that must be gathered include the identification and description of earth materials; their lithologic character; their length, width, and height at and below the ground; and their relationship to landforms. Data are collected from outcrops (exposures at ground surface) (fig. 32), water-well *logs,* and core samples from drilling. *Downhole geophysical logging* for every borehole and seismic reflection and *refraction* techniques help complete the picture.

Figure 32 Geologists examine an outcrop of Ice Age sediments at a quarry near Tuscola in Douglas County.

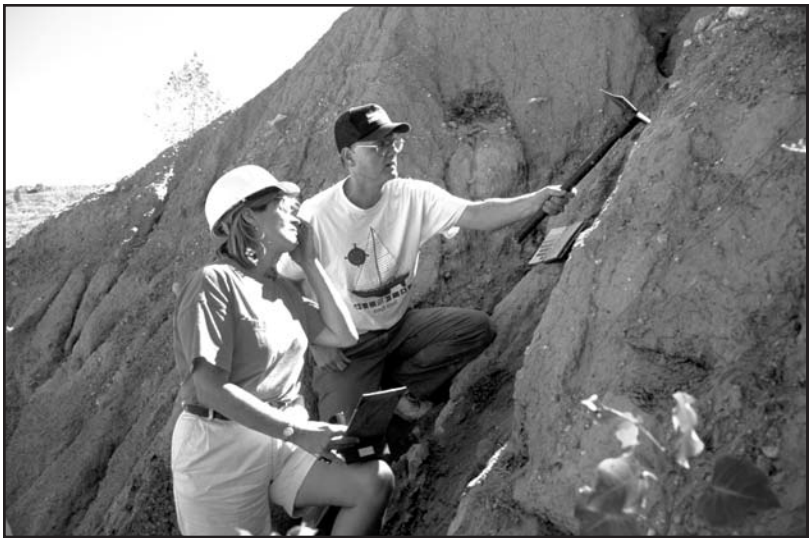


Figure 33 ISGS staff examine a core obtained by a drill rig near Kellerville in Adams County. Drill rigs are used to extract cores, sometimes to depths of several hundred feet, which are then described and analyzed by geologists. These data are basic to making three-dimensional geologic maps and cross sections.

Drilling and obtaining core samples (fig. 33) are the principal means of determining whether thick, fine-grained deposits or *permeable,* extensively weathered or fractured earth materials are present. There are several geophysical techniques that can be used to test the continuity of layers between test holes and detect differences in the subsurface geology from place to place. For example, using seismic testing, geophysicists measure differences in the velocity with which sound waves travel through different materials. These differences allow them to detect changes in the subsurface geology. The data provide information about the origin of the rocks and glacial and postglacial sediments, which helps scientists understand and predict how rocks and sediments may vary in character from one place to another.

Cross Sections and Three-dimensional Geologic Maps

Once geologists have collected data about the geologic materials and processes, they make maps that show the distribution of these deposits at the Earth's surface (fig. 9). Geologists also construct cross sections that show the vertical sequences of deposits—their depth and thickness—and how these sequences vary from place to place (fig. 14). Computer models provide three-dimensional views of the subsurface (fig. 34). These maps and models are interpretations of the continuity of the geologic units based on the collected data. These two- and three-dimensional depictions show the thicknesses of units and the elevations of major buried surfaces. For example, widespread sand and gravel aquifers can be differentiated from layers of till above and below them, and maps showing their distribution can be made.

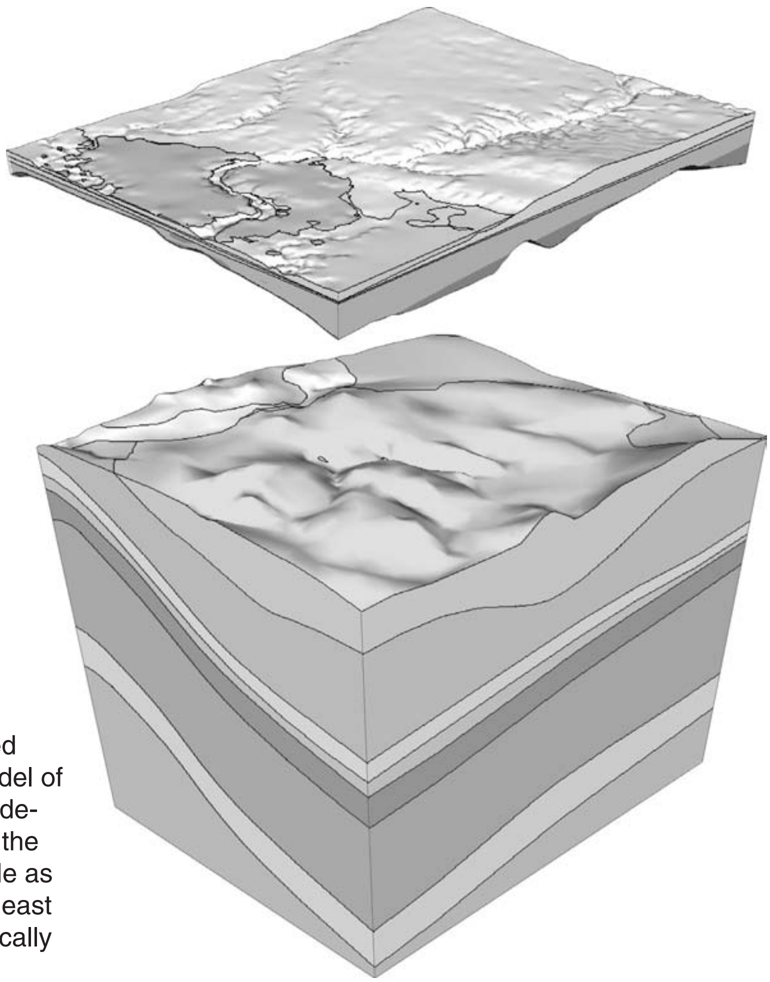


Figure 34 Generalized three-dimensional model of the Ice Age sediment deposits and bedrock of the Villa Grove Quadrangle as viewed from the southeast and exaggerated vertically 40 times.

Geologists use their scientific skills to predict the thicknesses and elevations of subsurface units between known points of reference (such as core samples). If adjacent reference points indicate that similar rocks with similar thicknesses are present at essentially the same elevation, then the geologists' job is easy. The contacts separating geologic units can be inferred, and rock layers can be correlated between those points. If adjacent reference points have quite different vertical successions of materials, geologists must infer a scenario to explain the discrepancy. The difference may be due to a fault that lies between the two points or because of the removal of layers by some other process. If the cross section or three-dimensional model is in a critical area of concern, more drilling may be needed to gather additional core samples and other data to use in the interpretation.

Cross sections and three-dimensional geologic models are used to indicate where a particular deposit begins to thin or thicken. If sufficient information is available, these depictions can predict in a general way where one or more layers in the succession may be absent. Even in areas where a drill hole or outcrop does not exist, a completed cross section or a three-dimensional block diagram can predict generally what might be found underground. Of course, the only way to find out the actual succession of subsurface earth materials is to drill a hole and obtain samples.

Hydrogeologic Interpretations

Good three-dimensional depiction of a region's geologic framework is one of the basic tools of hydrogeologists. Hydrogeologists combine information derived from geologic maps, cross sections, and hydraulic properties of materials with information on hydraulic head, hydraulic conductivity, *porosity*, and groundwater chemistry to determine the travel times and the flow patterns of groundwater through the units (vertical and horizontal hydraulic gradients). A groundwater flow model often is developed. A flow model helps hydrogeologists determine whether a given geologic material can provide sustainable groundwater yields to wells or promote or restrict groundwater flow rates. Such information is vital to understand and evaluate the potential effect of land uses in an area and site facilities. For more information on hydrogeologic principles and maps, refer to the glossary and *Illinois Groundwater: A Vital Geologic Resource*.

Methods: Evaluating Land Use

A logical approach to evaluate the potential for environmental consequences of land use is first to map the geology and hydrology on a regional scale. Regional information provides the background for more detailed investigations of successively smaller areas within the region. This step-by-step approach is most useful when selecting a geologically acceptable site for a land-use activity that may be a point source of contamination.

Similar procedures can be used to evaluate the potential effects of non-point source hazards. Regional and area investigations are most appropriate and useful for general screening. They can effectively determine which portions of the state or county have aquifers that are most vulnerable to contamination from septic system effluents or from agricultural chemicals. Area evaluations, followed by detailed site investigations, are most appropriate to determine the environmental consequences of hazards such as leaking underground storage tanks or chemical spills.

An understanding of scale is key to comprehending this step-by-step approach. A "region" or "regional scale" may refer to the entire state or to a single county, but generally refers to map scales of 1:500,000 to 1:100,000 (see sidebar on page 40). "Area" refers to land surrounding one or more candidate sites that are under consideration, for example, for waste disposal. Area studies generally are done at a mapping scale of 1:24,000 or larger. "Site" refers to a specific locale that may range in size from a few acres to one or two square miles. Individual sites generally are mapped at very large scales to show details of interpretations.

The step-by-step approach to finding geologically acceptable sites for a specific land use includes the following sequential investigations.

Step 1: Regional investigations Geologic and hydrogeologic studies identify the continuity of aquifers and aquitards over a broad region. Areas with promising characteristics are selected for more detailed investigations.

Step 2: Area investigations Geologic and hydrogeologic studies identify the continuity of aquifers and aquitards in the areas selected on the basis of regional investigations. Potential candidate sites are selected for more detailed evaluations.

Step 3: Site characterization Each candidate site's geologic and hydrogeologic characteristics are investigated and tested.

During each step, geologists and hydrogeologists interpret their data. Their interpretations become more specific and detailed with each successive step. Each *data point* (for example, an outcrop or drillhole log) yields information specific to that location. Site-specific data points must be close enough to one another to resolve uncertainties about the locations of critical boundaries between subsurface geologic units. Regardless of the mapping scale, geophysical methods can provide essential data where other sources of information are lacking, but interpretation of such information requires reference to regional geologic and hydrogeologic data that already are reasonably well known.

As an example of how scale affects interpretation, consider how data supporting the existence of possible aquifers are interpreted. Geologists and hydrogeologists show an aquifer's presence on a map only where data positively show that one or more aquifers exist. Consequently, regions or areas lacking adequate data may be mapped as being without aquifer materials when, in fact, such materials are present. This situation can be minimized by following the step-by-step approach because later evaluation steps either verify or disprove the succession and types of geologic materials indicated by earlier steps. The successive, more detailed evaluation and the acquisition of additional data from boreholes and outcrops also may indicate needed modifications to the interpretation of the succession and types of geologic materials.

Through this approach, information about geologic materials and groundwater occurence and movement can be integrated with the engineering principles involved in designing safe and effective waste-disposal facilities. As a general rule, a chosen site's geology and hydrogeology should be sufficient to compensate for flaws in the design of containment structures, and the design should be sufficient to compensate if the geologic and hydrogeologic setting does not perform as expected. In this way, public safety can be maximized even if a leak develops.

Now, let's look at the step-by-step methodology in more detail, realizing that data about the geology and hydrogeology are gathered and interpreted at each step, but at different levels of detail.

Map Scales

A map's scale generally is expressed as a ratio (for example, 1:24,000) that relates a distance on a map to the corresponding distance on the ground. General terms such as "statewide," "regional," or "detailed" are used to refer to map scales (fig. 35).

The ISGS commonly publishes its statewide maps at a scale of 1:500,000, which means that 1 inch on a map represents 500,000 inches on the ground, or nearly 8 miles.

Regional investigations generally use maps that vary from a scale of 1:500,000 to a scale of 1:100,000 (1 inch represents about 1.5 miles) for countywide maps. Mapping a site and its immediate vicinity, called area mapping, is at a much larger (more detailed) scale than regional or statewide mapping. Area mapping typically is done at the same scale as the quadrangle topographic maps, which is 1:24,000 (1 inch represents 2,000 feet).

The terms "small-scale" and "large-scale" generally are used to describe the level of detail. A 1:500,000 statewide map is smaller in scale than a 1:100,000 county map. Less detail can be shown on the smaller-scale statewide map because the map covers a bigger area.

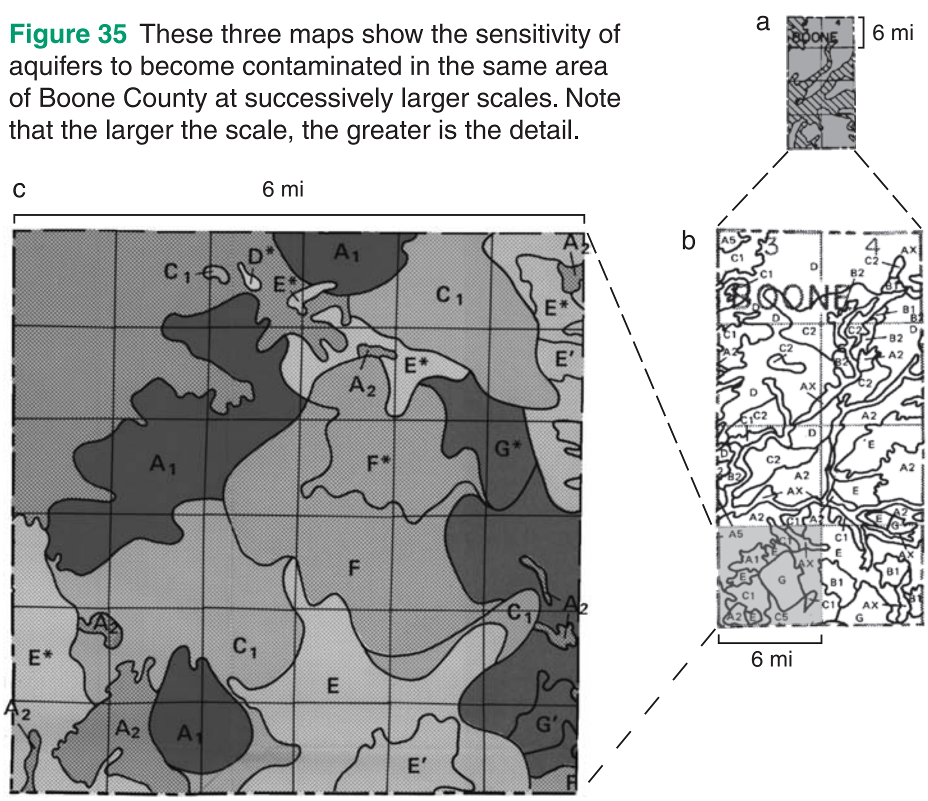
These concepts are illustrated by the maps of Boone County shown in figure 35. The small-scale map (a) shows generalized geologic units. Each small square represents the area of a township (6 miles on a side, or 36 square miles).

The mid-size map (b) shows Boone County map at a larger scale. The view of the shaded township in the southwest corner of Boone County is expanded in the large square on the left of the figure (c).

Notice how the features in the township are shown in greater detail as scale becomes larger.

Errors of interpretation can occur when maps are photographically enlarged. A line that is 1/16 inch wide on a map with a scale of 1:500,000 represents a strip almost half a mile wide on the ground! If a line that represents that much uncertainty is reproduced at a scale of 1:24,000, the line, which might represent contact between two geologic units, grows into a zone that is almost a mile and a half wide. Increasing a map's size may make it easier to read, but the accuracy is drastically reduced.

Figure 35 These three maps show the sensitivity of aquifers to become contaminated in the same area of Boone County at successively larger scales. Note that the larger the scale, the greater is the detail.



Regional Investigations

A regional investigation is particularly useful to determine the potential for groundwater contamination from non-point sources where effects may be widespread and may occur far from where contaminants were introduced.

The first step is investigation of the geologic and hydrogeologic characteristics of a wide region. This initial screening also serves to direct later, more detailed site studies toward regions where the known succession of geologic materials is most likely to contain a released contaminant and away from regions known to contain porous or fractured earth materials. Highly porous and fractured earth materials can provide pathways that allow contaminants to move rapidly toward potential groundwater resources or may themselves serve as such resources. Existing data generally are used for these regional investigations, which provide information on the regional geologic framework, hydrogeology and aquifer mapping, potential hazards, and mineral resources.

In the recommended approach, all subsequent investigations are guided by the findings of this initial regional evaluation. The regional study also is the step at which county or state decision makers and the public can begin to determine what may become a site-specific environmental problem. For example, if construction of a waste-disposal facility is under consideration and the results of a regional geologic investigation indicate a high probability of encountering aquifers at depth, questions should be asked about the viability of the site, and efforts should perhaps move elsewhere.

Geologic framework The regional geologic framework is established by reviewing all available information on the region's bedrock and sediments. Original data from existing water wells and other drillholes, descriptions of outcrops, and other records are interpreted to compile three-dimensional maps showing the lateral extent, thickness, and character of the region's rock and sediment layers. Particular attention is focused on the rocks and sediments that are or may be aquifers.

This review also provides information about how variable the character of the rocks and sediments may be in the region. The greater the regional variability, the more extensive the subsurface exploration must be to adequately evaluate the geological and hydrogeological setting at the area and site investigation levels.

Hydrogeology and aquifer mapping The regional investigation's main emphasis is to map the lateral extent and thickness of aquifers and other layers of highly permeable materials that can rapidly transmit contaminants (figs. 28 and 29). This focus includes determining the locations of regional recharge areas, variations in regional groundwater quality, and the present and probable future use of groundwater. As populations and cities grow, water may be withdrawn from presently unused aquifers, which could affect the predictability, rate, and direction of groundwater movement. Such changes might increase the risk that future users of groundwater will be exposed to contaminants.

Potential geologic hazards Regional investigations also help identify areas with potential geologic hazards such as karst, underground mining regions where subsidence could occur, and areas where seismic activity is most likely (figs. 21, 22, 23, 24, and 25). Karst and abandoned or active underground mines can affect regional groundwater flow by contributing to the rapid movement of contaminants in patterns that may be difficult to predict without detailed study. Unstable slopes can endanger facilities that are built either near the base of the slopes or on uplands adjacent to slopes. Layers of water-saturated, loose materials, which commonly occur in river floodplains, can be very susceptible to ground motions from seismic activity. These sediments can significantly amplify the ground motions that occur during an earthquake and may liquefy, allowing structures to tilt or topple over.

Identification of mineral resources The identification of resources such as coal, sand and gravel, oil and gas, and other minerals within a region is needed to reduce possible land-use conflicts between mineral resource developers, county and municipal planners, and potential waste generators. The presence and continued availability of these resources can affect the region's economic health and must be a consideration, especially in the final selection of a site for a waste-disposal facility or waste-generating business.

Associated issues It is important to understand how the information gained through a regional investigation can and cannot be used. Because regional assessments provide general information, regional-scale maps, models, and cross sections may not reveal geologic or hydrogeologic details that become obvious during more detailed studies of smaller areas or specific sites. Regional studies, however, do provide the information needed for initial models and assumptions about regional geologic and hydrogeologic conditions. Those models and assumptions can guide more localized, detailed investigations and be revised and refined as more precise data are gathered.

Applying Geology to the Siting Process: Lessons from Martinsville

In the late 1980s, Illinois and Kentucky complied with new federal laws regarding disposal of low-level radioactive waste by jointly agreeing to create a waste-disposal facility in Illinois for low-level radioactive waste, which includes radioactive hospital waste and clothing from nuclear power plants. Federal regulations required that the site be located in Illinois because the state's many nuclear power plant reactors generated considerably more low-level radioactive wastes than Kentucky.

To aid the search for a candidate site, the ISGS provided statewide screening maps for geologic hazards and groundwater considerations including the location of aquifers, mineral resources, and geologic variability (fig. 36). Because the location had to meet specific geologic and hydrogeologic criteria and be acceptable to nearby residents, only one site was considered seriously: an area one mile north of the city of Martinsville in Clark County in southeastern Illinois.

Regional Investigations

Regional investigations showed that the area met the specified criteria, particularly the absence of sand and gravel aquifers at and beneath the land surface (fig. 37).

Area Investigations and Site Characterization

When area investigations and site characterization began, two buried sand and gravel aquifers were discovered in a buried bedrock valley beneath the site, a potential "fatal flaw." At this point, state regulators and their consultants had two choices: (1) find another site, or (2) continue studying the area in the hope that the aquifers were not continuous and would not transmit released *radionuclides* to water wells. Because Martinsville was the only community willing to site a facility that federal law required to be operational within a few

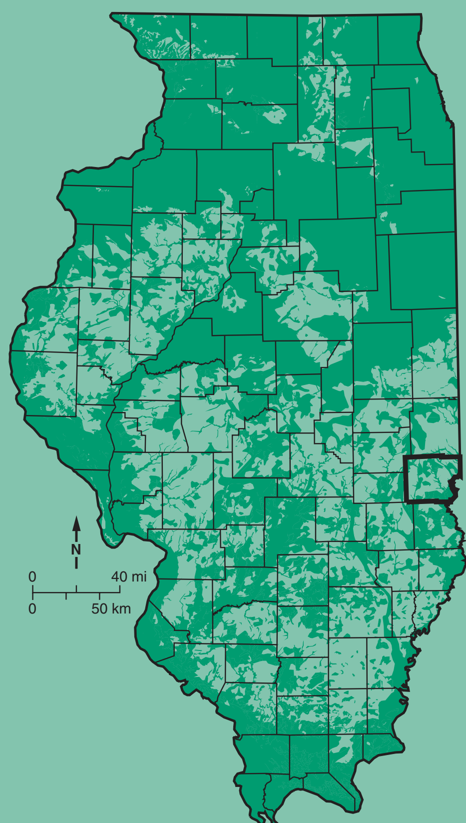


Figure 36 A statewide map that shows the distribution of aquifers and other highly permeable materials within 50 feet of the surface, major sand and gravel aquifers at any depth, and major bedrock aquifers within 300 feet of the surface.

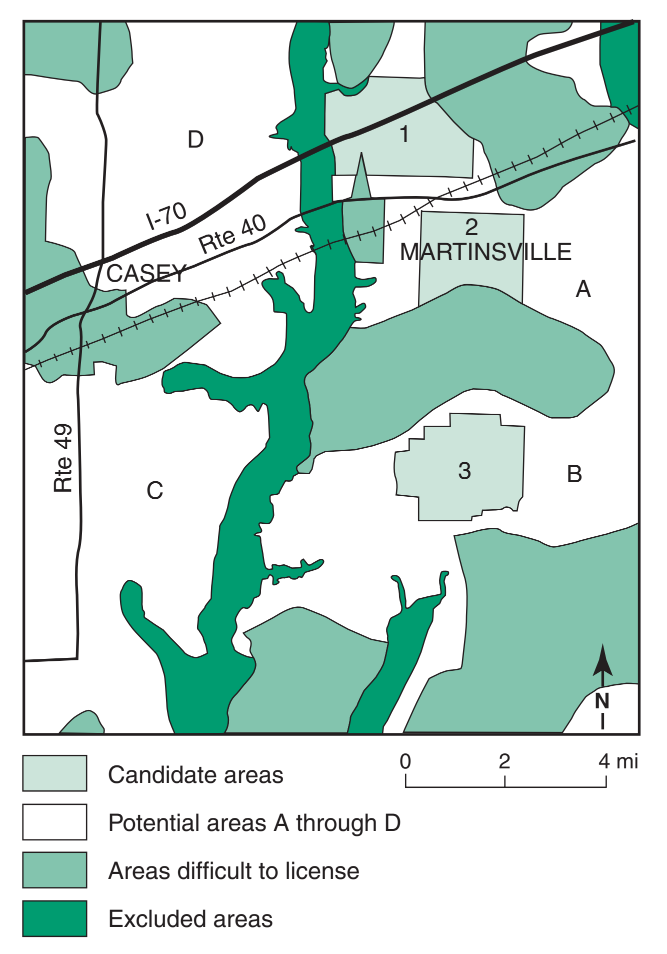


Figure 37 A regional map of the Martinsville area in Clark County showing candidate areas for a low-level radioactive waste disposal facility. The site was not chosen for a waste-disposal facility.

years, regulators decided to continue characterizing the area in the hope that the site could be proven safe.

Additional area investigations and site characterization, including geologic borings between the site and the city of Martinsville, were followed by construction of detailed cross sections (fig. 38) and groundwater flow modeling. The cross sections and flow models showed that the aquifers beneath the site had a direct connection to the sand and gravel aquifer used for the city's water supply. All of the information available then was compiled into reports that detailed the geology and hydrogeology of the site and its surrounding area. A siting commission evaluated the information and made a decision regarding the suitability of the site.

The siting commission scrutinized the safety of the site during 72 days of hearings, listening to hours of testimony from regulators, their consultants, and scientists from the ISGS and Illinois State Water Survey. A strong case was made that an engineered containment facility would

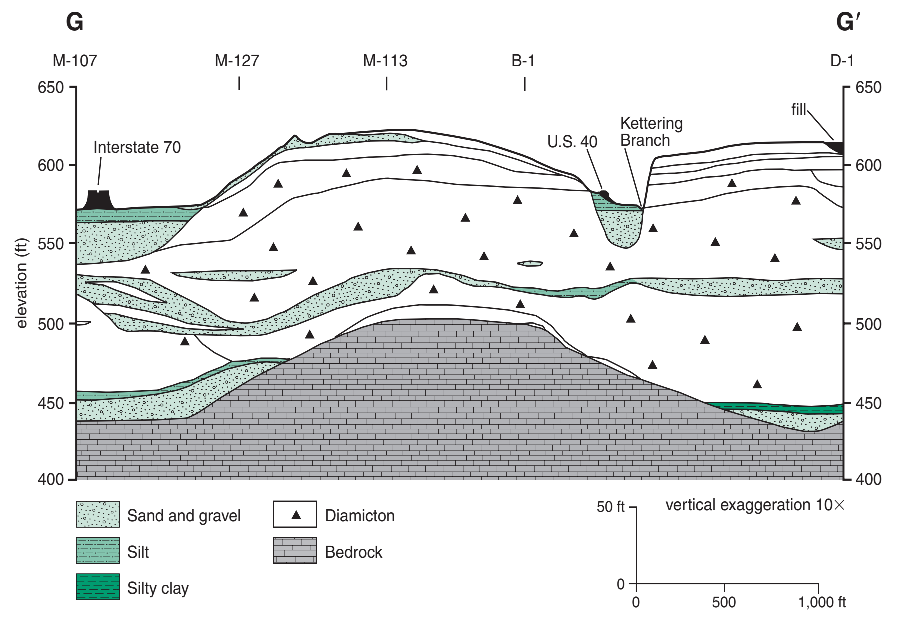


Figure 38 Cross sectional diagram through the Martinsville site that was chosen to be characterized for disposal of low-level radioactive wastes.

more than protect Martinsville residents from a radionuclide release. Even if wastes somehow got into the aquifer, potential for contamination of the municipal water supply was minimal. Nevertheless, the negatives far outweighed the positives for the decision makers, and the site was rejected in 1992. A total of $86 million was spent on regional and area investigations and site characterization, including about $100,000 per day to conduct the hearings.

Although the site was rejected, Martinsville illustrates the tiered siting approach and provides an excellent example of the value of detailed three-dimensional 1:24,000-scale geologic maps and models. Had this detailed information been available in the late 1980s, the buried sand and gravel aquifers at the site would have been known. The site could have been eliminated from consideration before any money had been spent.

To date, the urgency to locate low-level radioactive waste disposal sites in Illinois and elsewhere has lessened. Despite scientific explanations that low-level radioactive wastes pose a minimal threat, the connotation of “radioactive” still evokes very negative reactions from citizens. Low-level radioactive wastes continue to be shipped to out-of-state facilities at a high cost to Illinois or are stored at Illinois’ nuclear power plants or at other generator sites designed for short-term storage. Unfortunately, these Illinois storage sites are not necessarily the “best,” and many have a far more vulnerable geologic and hydrogeologic setting than Martinsville.

Area Investigations

Area investigations are used within regions that have been found to have geologically favorable conditions for a specific land use. Based on the regional findings, sites with geologically favorable characteristics can be selected as candidates for a specific land use. However, before the sites are characterized in detail, new data must be gathered and interpreted, such as water-well and engineering boring logs; sample studies from drilling; field investigations of outcrops; groundwater level and flow data to test the hydraulic properties of earth materials; and groundwater quality information. New holes may be drilled and cores collected and studied to verify the succession of geologic materials indicated by the regional evaluations.

By focusing on the relatively small geographic area surrounding an existing or potential land-use site, geologists may define the geological and hydrogeological conditions more accurately than was possible with the regional investigation. The area investigation is an essential step in fully understanding the potential connections between an existing site and its surroundings.

Decision makers and the public can also get involved at this stage (fig. 39) and should continue to ask questions pertaining to the geological characteristics of a site and the site's acceptability if contamination problems arise. For example, if a previously unknown aquifer is discovered, questions can be raised as to why the aquifer was not identified during the regional evaluation and whether it is worthwhile to continue to look for a site in this area, considering the apparent complexities of its geology and hydrogeology.

Figure 39 A geologist explains geologic concepts to citizens on a field trip to a sand and gravel pit near Lake Shelbyville west of Mattoon. It is important to share geologic information with concerned citizens when land-use activities are planned.

Geologists evaluating an area look at these factors:

- geology and hydrogeology,

including production of three-dimensional geologic maps and models;

- aquifer maps, an inventory of wells already drilled into the aquifers, data on groundwater withdrawals from the aquifers, and data on the elevations of water levels in the wells;
- topography, slope stability (fig. 22), and evidence of other geologic hazards such as fault zones, fracturing of geologic materials, or local karst development;
- strongly weathered materials such as buried soils (see *Illinois' Ice Age Legacy* for more information);
- engineering properties of the geologic units; and
- potential mineral resources.

Geology and hydrogeology An area-scale investigation provides a more accurate delineation of the succession of geologic materials, particularly the position and extent of small subsurface aquifers (fig. 40). An inventory of wells already drilled into these aquifers and measurements of the water levels in them at several times during the year help identify the groundwater flow patterns around specific sites. Pumping wells at designated rates for a set length of time, along with other measurements of aquifer characteristics, allow the sustainable maximum water yield from each aquifer to be determined and show the pumping's effect on flow patterns. A proposed site for a waste-disposal facility should be located as far from active wells as possible to maximize the distance

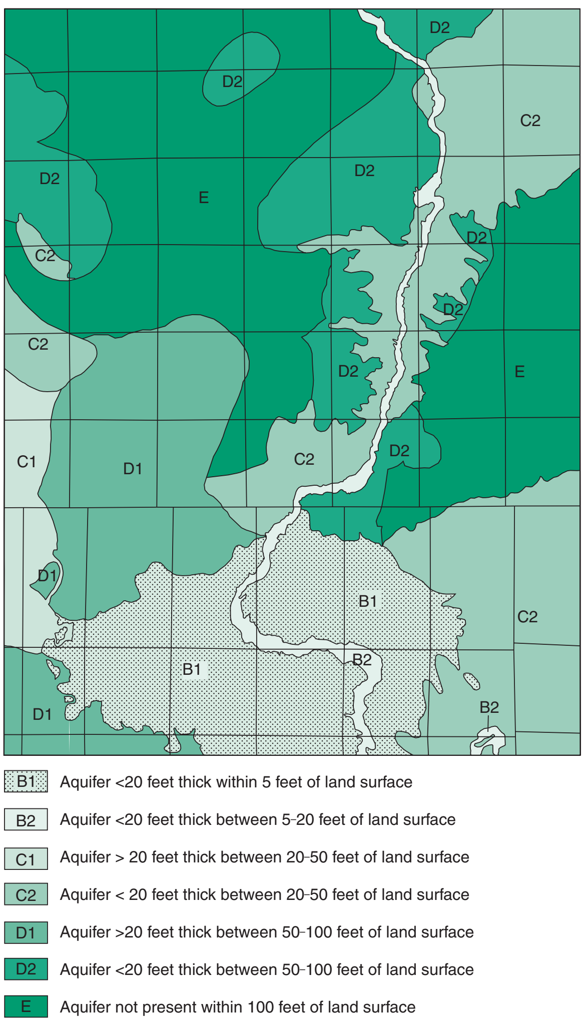


Figure 40 General aquifer sensitivity map of the Villa Grove Quadrangle showing local aquifers.

for attenuation of a contaminant in an aquifer and to increase the time available to implement mitigation measures before a contaminant enters active wells.

Area topography and geologic hazards Close examination of an area's topography (fig. 41) and geology can reveal slope stability and erosion potential on or near sites. When selecting a site for any facility, it is essential to avoid areas where erosion recently has occurred and is likely to continue, such as at the top or the foot of unstable or potentially unstable slopes. Relatively flat terrain is best. Evidence of other potential geologic hazards is reviewed and interpreted, including the location of underground mined-out areas, fault zones that might reactivate during seismic activity, and fractured geologic materials or local karst features that could provide pathways for rapid migration of contaminants into the groundwater system.

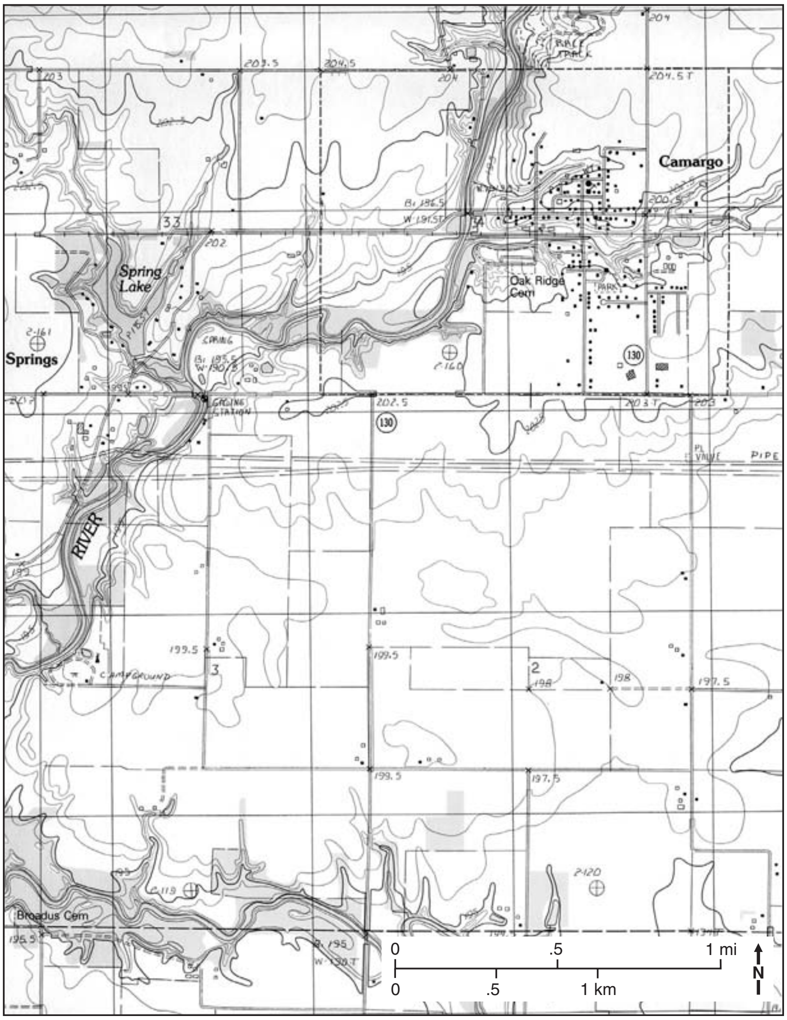


Figure 41 A portion of a topographic map of the Villa Grove Quadrangle.

Strongly weathered materials Differences between the engineering and chemical properties of weathered and fresh earth materials should be considered when the geologic data for the area study are compiled. Highly weathered materials tend to be fractured and more permeable, which increases the number of pathways for a contaminant to reach the groundwater system and decreases the amount of material available to attenuate a contaminant. It is especially important to determine the position and extent of weathered zones in the subsurface.

Engineering properties of geologic units Engineering tests and data about the geologic units may identify areas that are prone to collapse, shrinking and swelling of soils, liquefaction, or other hazards. Initial tests also help guide foundation designs and help determine the suitability of local geologic materials as a source of cover material.

Potential mineral resources Detailed geologic mapping in the area of a proposed land-use site or an existing contamination site allows for more detailed identification of mineral resources. Once identified, more study can lead to detailed information on the availability, quality, and quantity of resources and the economic feasibility of extraction (fig. 42). The presence of valuable resources may significantly affect the development of a proposed waste-disposal site.

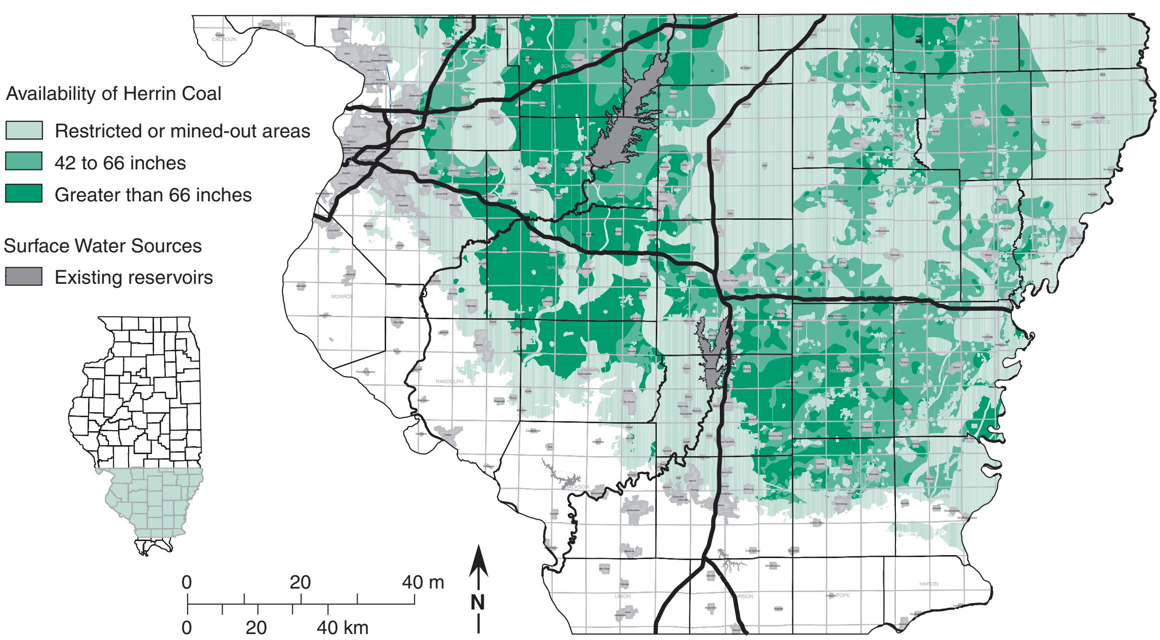


Figure 42 A generalized version of a map showing the availability of the Herrin Coal and information about water resources and infrastructure in southern Illinois.

Site Characterization

Site characterization provides the data needed for a detailed understanding of the site's geology and hydrogeology. This step assumes that all regional and area studies are complete and that selected sites meet the criteria for geologic compatibility with the proposed land use. Much new data are gathered during this step to test how well the geology at the site matches the predictions from the regional and area investigations. The information helps scientists predict how the site might perform under various environmental and human-induced conditions.

During characterization, the site is subjected to intensive field (fig. 32) and laboratory investigations to test the geologic and hydrogeologic interpretations made from the regional and area investigations. This testing is particularly important when selecting geologically acceptable sites for potentially harmful land-use activities for several reasons:

1. Aquifers could be present that did not show up during the regional and area investigations.
2. The engineering characteristics of the site's earth materials must be suitable for long-term waste containment with minimal leakage.
3. The site must be free of potential geologic hazards.
4. Potential mineral resources that were not detected previously may be identified.

Decision makers and the public must be assured that the candidate site is the best available usable site, as determined by a methodical evaluation process that includes sufficient scientific testing to discover adverse site characteristics, such as an unknown aquifer. The geologic characteristics of a viable site should minimize problems for current and future generations. Predicting the lateral and vertical extent of contamination at an existing site requires a thorough site characterization program.

Specific objectives of site characterization In addition to providing a detailed understanding of the geology, site characterization also evaluates the geographic area that might be affected by contamination, determines the degree and extent of potential contamination into various geologic materials, and predicts the rate and direction of any contaminant migration off the site.

Selecting a suitable site for a hazardous or low-level radioactive waste disposal facility adds specific objectives to site characterization. Investigations must provide the information needed to determine the ability of the site's geology to isolate waste from the surrounding environment if contaminants leak from their holding areas. (The facility itself, of course, must be designed, engineered, and constructed to include all precautions against such an emission.) The site characterization must also provide information that is specific enough to allow for the results of processes such as wind and water erosion over the next several hundred years and to estimate the potential of such processes to compromise the site's integrity. It is necessary to look forward in this way because present-day environments or land uses probably will not persist over the time period that the waste must be contained. The site characteristics also must account for the potential for inadvertent intrusions into the facility from future natural resource exploration or construction work.

Mapping the site's geology If the site is being considered for a waste-disposal facility, its geology and hydrogeology must be suitable to accept waste. A detailed and accurate three-dimensional geologic map is the first and most essential tool in characterizing the site. "Detailed and accurate" means that all geologic features must be explored in detail so that their three-dimensional characteristics are well understood. For example, if initial studies indicate that sand and gravel bodies within a buried bedrock valley are not continuous, additional tests should be conducted to show whether they are connected to each other or to some underlying or overlying, more continuous sand and gravel body. Geologic materials should be understood to a depth sufficient to reveal the presence and continuity of any thick, uninterrupted sequences of fine-grained geologic materials that could restrict downward groundwater movement and protect an aquifer from contamination. Such information also is important for those evaluating the extent of site contamination and cleanup methods.

A three-dimensional, detailed geologic map also would show the continuity of permeable materials, zones of fractured rock or sediments, intensely weathered zones, or other conditions that indicate the serious contamination potential or unsuitability of a site. The site's geology must be understood well enough to predict or to estimate the depth, thickness, *lithology*, and character of each geologic unit at any given point within the site. As the variability of the site's earth materials increases, the chances of successfully predicting geologic conditions decreases.

Site hydrogeology Measurements of water levels, analyses of water samples from monitoring wells, and pump tests provide information about local groundwater flow patterns and groundwater quality. The groundwater model developed from these and other data sources is

Three-dimensional Mapping Aids Land-Use Planning

The Illinois State Geological Survey applies the knowledge obtained by three-dimensional geologic mapping to help communities construct buildings and transportation corridors, install utilities, safely dispose of wastes, develop and manage water and mineral resources, and plan the most efficient and beneficial use of the land. Three-dimensional geologic studies of specific areas have been published for Kane, DeWitt, Boone, Winnebago, McHenry, and Rock Island Counties and portions of Douglas, Lawrence, Lake, Marshall, Peoria, and Putnam Counties.

Mapping Illinois

In 1996, in response to the need for accurate, objective geologic information, the ISGS began its Illinois Geologic Mapping Program, called IGMaP. The program's goal is to map the geology of Illinois in three dimensions and in detail from land surface to bedrock. Currently almost 95% of the state's land area has yet to be mapped at the 1:24,000 scale (one inch on the map represents 24,000 inches—2,000 feet—on the ground). This detailed scale is needed to show the complexity and variability of earth materials clearly enough to enable people to make regional and area land-use decisions.

Critical land-use decisions are being made daily, especially in rapidly expanding urban areas, and often without sufficient geologic information. Reliable geologic maps and interpretative map products that show engineering properties, geologic hazards, and the sensitivity to contamination of geologic units are urgently needed. Such maps are essential to help planners make decisions that optimize environmental protection and resource extraction.

To meet this information need in a timely way, the ISGS has developed a standardized approach to three-dimensional mapping that combines proven techniques such as

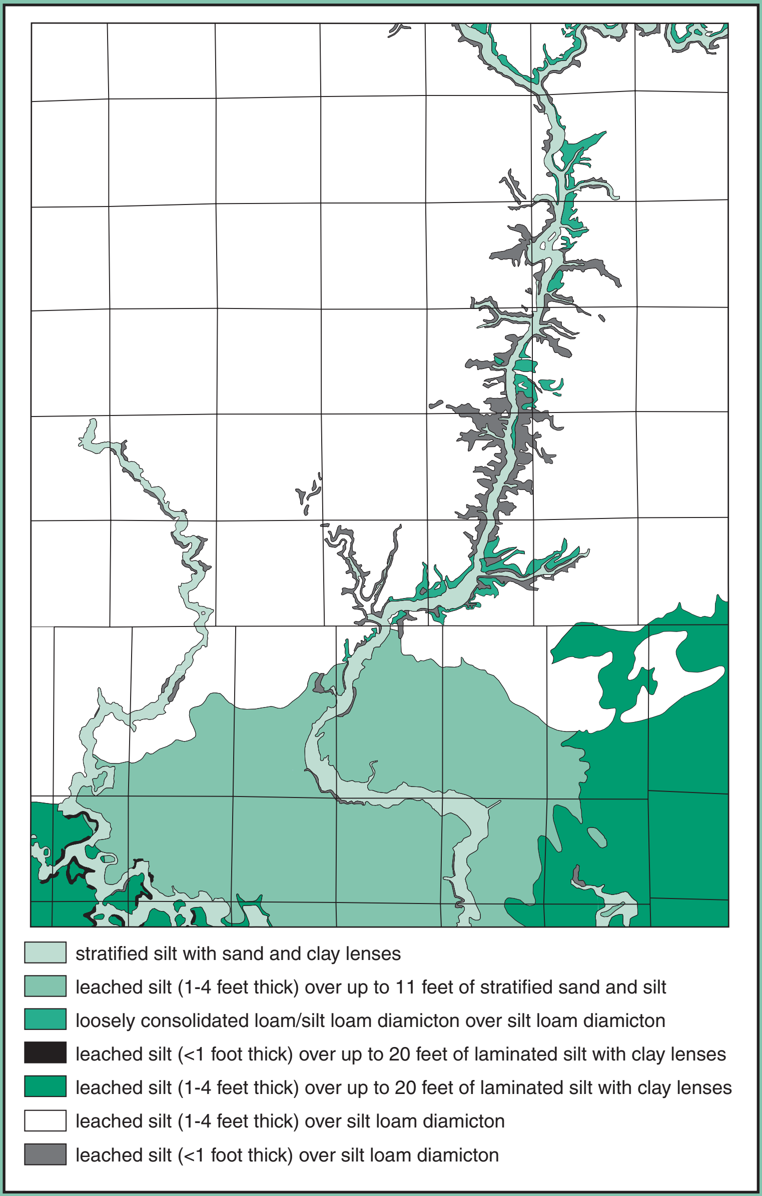


Figure 43 Map of surficial glacial materials for the Villa Grove Quadrangle.

drilling with the use of the latest technological tools, including seismic refraction, applied geophysics, Geographic Information Systems, and Global Positioning Systems. Data gathered by these methods and others are verified and entered into digital databases used to make three-dimensional models and basic and interpretative maps (for example, figs. 43 and 44). The number and types of maps produced for each quadrangle depend on its geologic materials and resources.

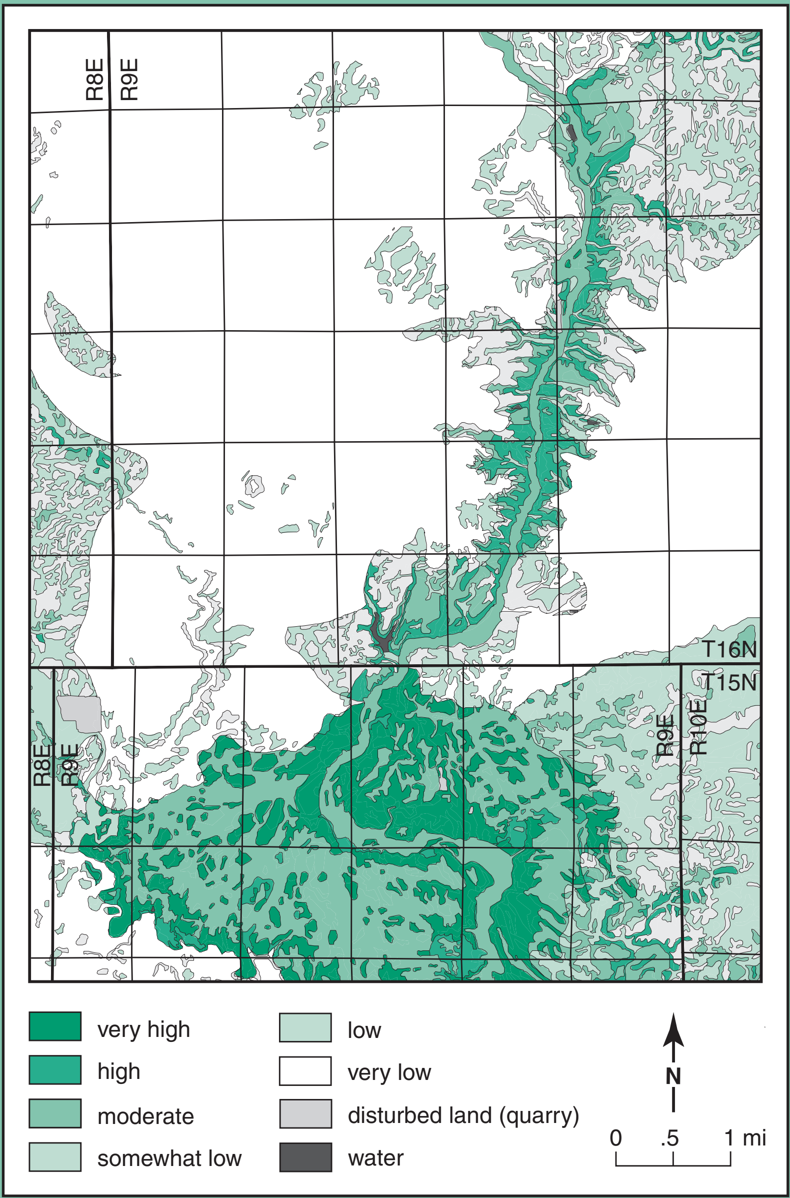


Figure 44 This map shows the potential for nitrate to leach into aquifers in the Villa Grove Quadrangle.

Mapping the Region Together

In addition to the IGMaP program, in 1997, the Illinois, Indiana, Michigan, and Ohio state geological surveys and the U.S. Geological Survey formed the Central Great Lakes Geologic Mapping Coalition to map the glacial deposits in the four states in a complementary, cooperative way. The Coalition has begun to develop regional databases of comprehensive geologic information and to create updatable, detailed, three-dimensional geologic maps and map products.

The Coalition program increases the cost effectiveness of 1:24,000-scale mapping, sets mapping and materials description standards, and serves as a model of state and federal cooperation. The program's primary goal is to use detailed geologic mapping in high-priority areas to provide information that can be used to solve significant societal problems pertaining to the environment, hazards, and resources. The information can also be used to help people evaluate the sustainable development of resources and to understand hazards and other environmental issues.

Both the IGMaP and Coalition programs allow the ISGS to provide critical geologic information that can be used for siting, land use, and other types of area investigations.

used to predict the directions and volumes of groundwater flow and to permit conclusions to be drawn about the effects on local wells of either an existing or a potential contamination problem from a waste-disposal operation. This modeling can only be accomplished after the three-dimensional geologic and hydrogeologic conditions are well understood and clearly conveyed to the site engineers and informed citizens.

It is important that geological and hydrogeological studies be conducted together. These properties are interdependent and equally important for successful site characterization. For example, similar water levels or similar groundwater quality in several wells may suggest that they all extract water from the same aquifer. This information may confirm that shown in the three-dimensional geologic map of the site or may indicate that the map should be modified. In the same way, different water levels or different chemical compositions of groundwater may suggest that the water is not coming from the same aquifer.

Conclusions

Following a step-by-step approach in which regional, area, and site-specific investigations are conducted is especially useful to find suitable sites for businesses that generate wastes and for waste-disposal facilities. It provides a method for evaluating land areas for potential and existing contamination.

The step-by-step approach helps determine existing or potential contamination problems and aids the process of investigating and interpreting a site's geology and hydrogeology. The approach

- increases confidence in the interpretation of the site's geology and hydrogeology by drawing upon the findings and interpretations of previous, more general investigations to improve the understanding and predictability of a site's geologic materials;
- allows a more accurate extrapolation of a specific site's geology and hydrogeology to the larger area and surrounding region;
- improves the understanding and predictability of the long-term performance of a site;
- saves money because the regional and area evaluations can eliminate geologically unsuitable sites from further consideration. Projects can be halted prior to the final site characterization, preventing the locating of a poor site and the need for potential cleanup.

When siting a new facility, areas with the following characteristics offer the greatest groundwater protection:

- thickest successions of earth materials with high clay content,
- greatest possible depth to the water table,
- groundwater flow patterns that can be understood in detail,
- greatest vertical and horizontal distances from an aquifer,
- farthest distance possible from potential flooding regions,
- least fractured and faulted earth materials,
- no karst features,
- least potential for disruption by geologic hazards,

- least seismically active areas,
- no recoverable mineral resources, and
- highest bearing capacities for facility foundations.

Political, social, and economic concerns also play an important role in land-use decisions. However, those societal factors must be integrated with a full understanding of the geology and hydrogeology gained through studies at successively more detailed scales. Without such a foundation, the selection of a site comes down to little more than random chance. Using the results of careful scientific investigations for such decisions can ensure that the effects of waste disposal or other adverse land uses are dealt with in the safest, most logical, and most cost-efficient manner possible.

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Glossary

The following definitions are adapted from a variety of sources. The *Glossary of Geology*, published by the American Geological Institute, was especially useful.

aquifer A body of saturated rock or sediment that yields useful quantities of groundwater to wells or springs.

aquitard A body of rock or sediment of low permeability that can confine groundwater and transmit it slowly from one aquifer to another.

areal distribution Refers to the geographic area over which a rock or sediment unit occurs, either buried or exposed at land surface.

attenuate To reduce or lessen the concentration of a substance.

bedding plane The surface of a bed of rock or sediment that visibly separates each successive layer of rock or sediment from its overlying or underlying layer.

compaction The reduction in volume or thickness of a body of sediment in response to the increasing weight of overlying material. The process reduces pore space between sediment grains and packs the grains closer together.

consolidation The process of forming rock out of soft or loose sediments.

core A cylindrical sample of a subsurface formation taken by a hollow sampling device and brought to the surface for geologic examination and analysis.

data point An item of factual information derived from calculations, measurements, or research.

deposition The accumulation of loose rock material by processes such as the settling of sediments or the accumulation of organic materials from the bodies of dead animals and plants.

downhole geophysical logging The process of lowering sondes into a test hole or well to measure and continuously record some physical property of the adjacent rock or sediment, such as electrical resistivity, natural gamma radiation, or the diameter of the test hole.

ecosystem An ecological unit made up of a community of organisms and the non-living elements in the community's environment.

hydraulic conductivity The capacity of earth materials to transmit groundwater stated in terms of the volume of groundwater that will move in a unit of time (one second, one minute, one day, etc.) through a unit cross sectional area (one square foot, one square meter, one square centimeter) under a unit hydraulic gradient. Hydraulic conductivity is commonly expressed in gallons (the volume of groundwater) per day (the unit of time) per square foot (the cross sectional area) under a hydraulic gradient or a vertical drop of one foot over a distance of one foot

hydraulic gradient The change in hydraulic head with a change in distance in a given direction. For an unconfined aquifer, this is the slope of the water table. Hydraulic gradient has horizontal and vertical components.

hydraulic head The term used to describe the total amount of energy groundwater has at a given point in an aquifer or groundwater flow system. It is the sum of the height of the point above sea level (elevation head), the weight of the earth materials and groundwater overlying the point (pressure head), and the movement of the water (velocity head).

hydrogeology The science that deals with the geologic aspects of subsurface water.

infiltration The flow of a fluid into solid matter through pores or small openings.

interglacial The time interval between two glacial episodes.

joint A fracture in a bed of rock or sediment with no displacement of the bed on either side of the fracture.

karst A type of landscape that is formed as water dissolves underlying limestone and other rocks. Karst topography is characterized by closed depressions or sinkholes, caves, and underground drainage systems.

leachate Water that has trickled through contaminants or waste materials and then contains some of those substances in solution.

liquefaction The process by which loosely packed sediments behave like a fluid instead of a solid. The process can be triggered by shaking during an earthquake.

lithology, lithologic The physical character of rocks, including mineralogical composition, grain size, color, and structure.

log A record describing the earth materials obtained in a well bore.

outcrop Part of a glacial deposit or bedrock that is exposed and visible at the earth's surface.

outwash Earth materials (usually sand and gravel) washed out from a glacier by meltwater streams.

overconsolidated A term used by engineers to refer to the dense property of till, a glacial sediment. The compression of till by glacial ice caused consolidation and de-watering so that till behaves similarly to rock when subjected to certain standard types of engineering tests.

perched aquifer An aquifer separated from a more extensive aquifer below by an unsaturated zone or aquitard.

percolating Seeping through a porous material.

permeable The capacity of a porous rock, sediment, or soil to transmit a fluid through interconnected pore spaces, cracks, or other openings.

porosity The amount of void space, such as cracks or pores, in a rock or sediment.

radionuclides A radioactive kind of nuclide, an atom characterized by the number of neutrons and protons in its nucleus.

recharge The replenishment of groundwater by infiltration of precipitation or surface water through the soil.

refraction The change of direction of a seismic wave passing from one medium into another of different density, which changes its speed.

remediate, remediation Actions taken to correct. The actions taken to remediate groundwater include containing or removing the contaminant, managing the source of or exposure to the contaminant, or treating the water before using it.

unconsolidated Sediment that has not been compacted, consolidated, or changed into coherent and solid rock.

water table The level below which the soil, sediment, or bedrock is saturated with groundwater.

weathering The process of physical disintegration and chemical decomposition by which earth and rock materials are changed in color, texture, composition, firmness, or form upon exposure to the atmosphere.

The Geoscience Outreach Program of the Illinois State Geological Survey uses many channels to inform the public about the geology and mineral resources of the state and the results of the Survey's research projects. The Survey distributes nontechnical publications, offers sets of rock and mineral specimens to Illinois schools and educational groups, presents lectures and exhibits, responds to inquiries, conducts workshops for teachers, and leads field trips. The program's full-day field trips, each given in widely separated areas of the state, offer teachers, students, and the public the opportunity to learn about the geologic processes that shaped the land and formed the rocks and glacial deposits.

The outreach program is specifically designed to assist in the teaching of earth sciences and to help citizens understand how the research programs of the Illinois State Geological Survey protect the environment and strengthen the economy of Illinois.

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