

Illinois Groundwater: A Vital Geologic Resource

Myrna M. Killey and David R. Larson



Cover photo: A boy plays in the spray of water generated by special playground equipment at Hessel Park in Champaign. Groundwater supplies many aquatic recreational facilities in Illinois.



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Illinois Groundwater: A Vital Geologic Resource

Myrna M. Killey and David R. Larson

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Preface

This publication is designed to inform Illinois citizens, lawmakers, teachers, planners, municipal and county government officials, and others about groundwater, a resource vital to Illinois.

To help respond to Illinois citizens' need for unbiased earth science information, the Illinois State Geological Survey has undertaken the production of a series of three books, of which this is the second. The first volume, *Illinois' Ice Age Legacy*, describes glacial processes and deposits and emphasizes their relationship to the soil, water, and minerals of Illinois that sustain our daily lives. This second volume explains the importance of groundwater to Illinois citizens and how this vital resource can be better understood and protected. The third volume, *Land-Use Decisions and Geology: Getting Past "Out of Sight, Out of Mind,"* brings together geology and hydrogeology to explain the crucial role these disciplines play in making effective land-use decisions that protect Illinois' groundwater resources.

The authors hope this publication provides readers with a better understanding of the groundwater resources of Illinois and the importance of using those resources wisely to protect them for future generations.

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 book; Ross Brower, who made excellent suggestions concerning subject matter and provided references on wells and the history of groundwater use; Beverly Herzog, who provided references and helpful suggestions; and ISGS reviewers Linda Roderick, Robert Vaiden, and Jon Goodwin. Dennis R. Kolata helped find suitable illustrations.

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Introduction



Figure 1 Playing in the spray of playground equipment at Hessel Park in Champaign is one of many delights made possible by the use of groundwater.

Water is vital to the lives and activities of Illinois citizens, and, fortunately, Illinois is a water-rich state. In most years, enough precipitation falls to keep lakes and reservoirs full and rivers and streams flowing. During years when precipitation is reduced, however, water levels fall in lakes, reservoirs, rivers, and some streams. Smaller lakes, reservoirs, and streams may temporarily go dry.

These surface water sources are valuable as a water supply and for recreational purposes. Because of its visibility, surface water can be observed, understood, and monitored.

But what about *groundwater*? (Italicized terms are defined in the glossary.) It is as valuable as surface water, perhaps more so because groundwater is not affected by short-term changes in precipitation. Groundwater supplies the drinking water for about one third of the state's total population and 90 percent of its rural population. Groundwater supplies much of the state's industry and agriculture, including water used for cooling and irrigation. In all, Illinois uses more than one billion gallons of groundwater every day.

We humans are liquid beings. In fact, about 60 percent of the human body is water: in our blood (82 percent), lungs (90 percent), and brains (70 percent).

We fill our days with tasks that use water or objects manufactured with water, much of it taken from groundwater supplies. We are immersed in a world groundwater makes possible (fig. 1) from the time we lift our heads each morning (from bedding made from cotton irrigated in

the field, cleaned, processed, spun into threads, and woven into fabrics, all using water) to the glass of water we drink at bedtime.

We brush our teeth with water, shower and bathe in it, and flush our waste away with it. Water is in the orange juice we drink at breakfast and the radiator of the vehicle that takes us to our jobs, where water surrounds us in our workplaces. We cook our meals, care for our lawns, and wash our dishes and cars with it. We “wet our whistles” with designer bottles of it. For the most part, we take groundwater for granted.

Although we must have water to live, the amount of groundwater available for drinking, bathing, manufacturing, and irrigation is finite. Groundwater resources should be used wisely and should be protected because once contaminated, groundwater is difficult to *remediate*. Our very dependence on this vital resource makes understanding groundwater all the more compelling.

Because groundwater is hidden from view below the land surface, its presence and behavior may seem mysterious. But groundwater flow obeys basic physical laws and principles as part of Earth’s hydrologic cycle, and understanding that cycle is necessary to understand groundwater.

The Hydrologic Cycle

The vast and complex circulation of water between the Earth and the atmosphere is called the hydrologic cycle (fig. 2). The cycle works this way: precipitation falls from the atmosphere onto the land or into rivers, streams, lakes, and oceans. Most of this water returns directly to the atmosphere by evaporation, the process by which water is changed into vapor. Water also returns to the atmosphere by transpiration, the water taken up by the plants from the soil through their roots and released through their leaves as water vapor. Some precipitation flows across the land to streams and rivers as surface runoff. The remainder *percolates* downward through the ground to the *saturated zone* where all available openings in the earth materials are filled with water. This downward movement, called *recharge*, is the primary source of groundwater.

Groundwater flows under the influence of pressure and gravity and eventually discharges at the land surface as springs (fig. 3) or as seepage into streams, rivers, lakes, or wetlands. Once on the surface, the water can evaporate. When water vapor cools, it condenses into clouds from which precipitation falls to the earth, completing the cycle.

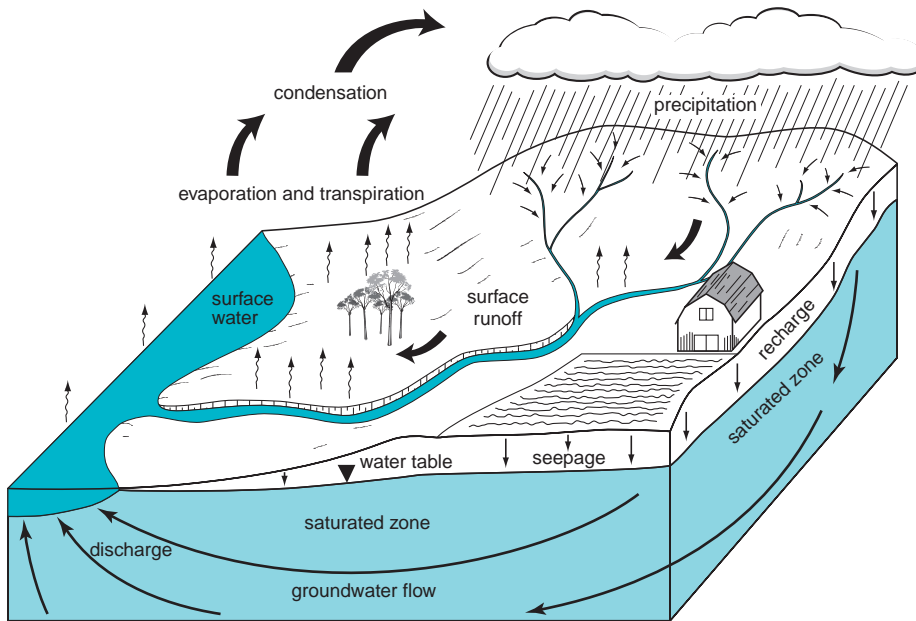


Figure 2 Arrows show the movement of water through a complete hydrologic cycle that includes precipitation, surface runoff into surface water, seepage into the ground, groundwater flow from recharge to discharge, evaporation and transpiration, and condensation. The triangle indicates the top of the water table.



Figure 3 Groundwater seeps from a spring in Forest Glen Preserve in Vermilion County.

Although water constantly moves through the hydrologic cycle, the amount of water in each part of the cycle remains about the same (fig. 4). About 97 percent is found in the oceans as salt water. The other 3 percent is fresh water, most of which is frozen in the polar ice caps and mountain glaciers. Groundwater makes up about 22 percent of the fresh water in the hydrologic cycle and, more importantly, makes up about 97 percent of the fresh water that is not frozen in ice caps or glaciers. There is far more groundwater than the fresh water found at the Earth's surface.

A Close Look At Groundwater

As water seeps into the ground, it moves through a zone just below the land surface where the empty spaces, or pores, between soil and rock particles contain both water and air (fig. 5). Because air fills part of these pores, this zone is called the *unsaturated zone* or the zone of aeration. Water molecules in this zone tend to adhere to the surfaces of soil or rock particles and are not free to move toward a well.

Below the unsaturated zone is the saturated zone where the pore spaces in the earth materials and the fractures and fissures in rocks generally are completely filled with water (fig. 5). The *water table* marks the top of the saturated zone. The surface tension at the water molecule boundaries and the attraction between water molecules and soil particles draws water from the saturated zone into small pores within the unsaturated zone to form the *capillary fringe*. The amount of water in the capillary fringe typically is greater than in the rest of the unsaturated zone.

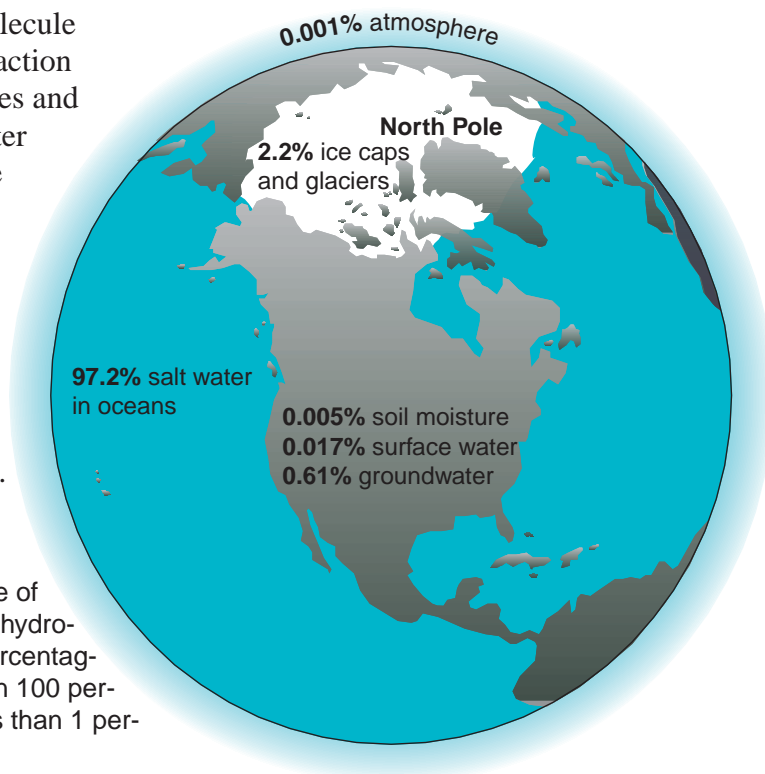


Figure 4 The percentage of water in each part of the hydrologic cycle worldwide. Percentages total slightly more than 100 percent because values less than 1 percent were rounded.

The capillary fringe in fine-grained sediments (such as silts and clays) is typically thicker than that in coarse-grained sediments (like sand and gravel) because the pores are smaller. *Capillary forces* prevent water in the capillary fringe from moving freely to a well, which is why a water well needs to be constructed so that its screen extends below the water table.

The water table does not form a level surface but mirrors in a subdued way the shape of the land surface (fig. 6). Where the water table intersects the land surface, groundwater may appear as springs or may flow into rivers, streams, lakes, and wetlands. If the water level in rivers, streams, lakes, or wetlands is higher than the water table, surface water moves into the subsurface and becomes groundwater. If the water level in the same bodies of water is lower, groundwater flows into the surface water. This groundwater

discharge maintains the flow of rivers and streams during dry periods, a common situation in Illinois.

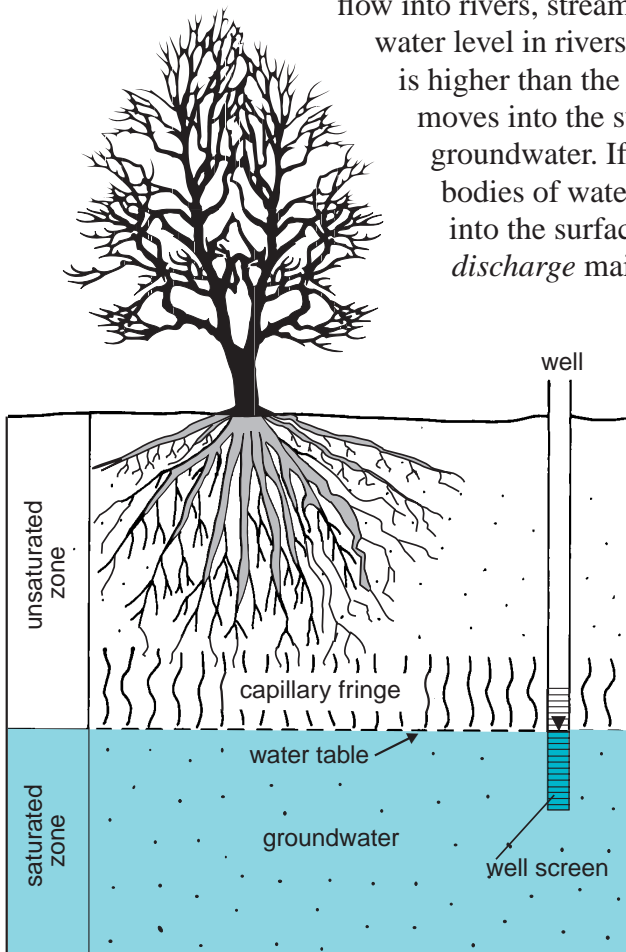


Figure 5 The connection between the unsaturated and saturated zones, showing the capillary fringe and water table. The triangle indicates water level in the well and the top of the water table.

The water table rises or falls as groundwater, most of which comes from precipitation, is gained or lost. During dry conditions, rainfall does not replenish the water in the saturated zone, and the water table slowly drops. When rain is abundant, the water table gradually rises, until low areas of the landscape fill with water. This ponding occurs because the water table has intercepted the land surface and because groundwater discharges into lower areas.

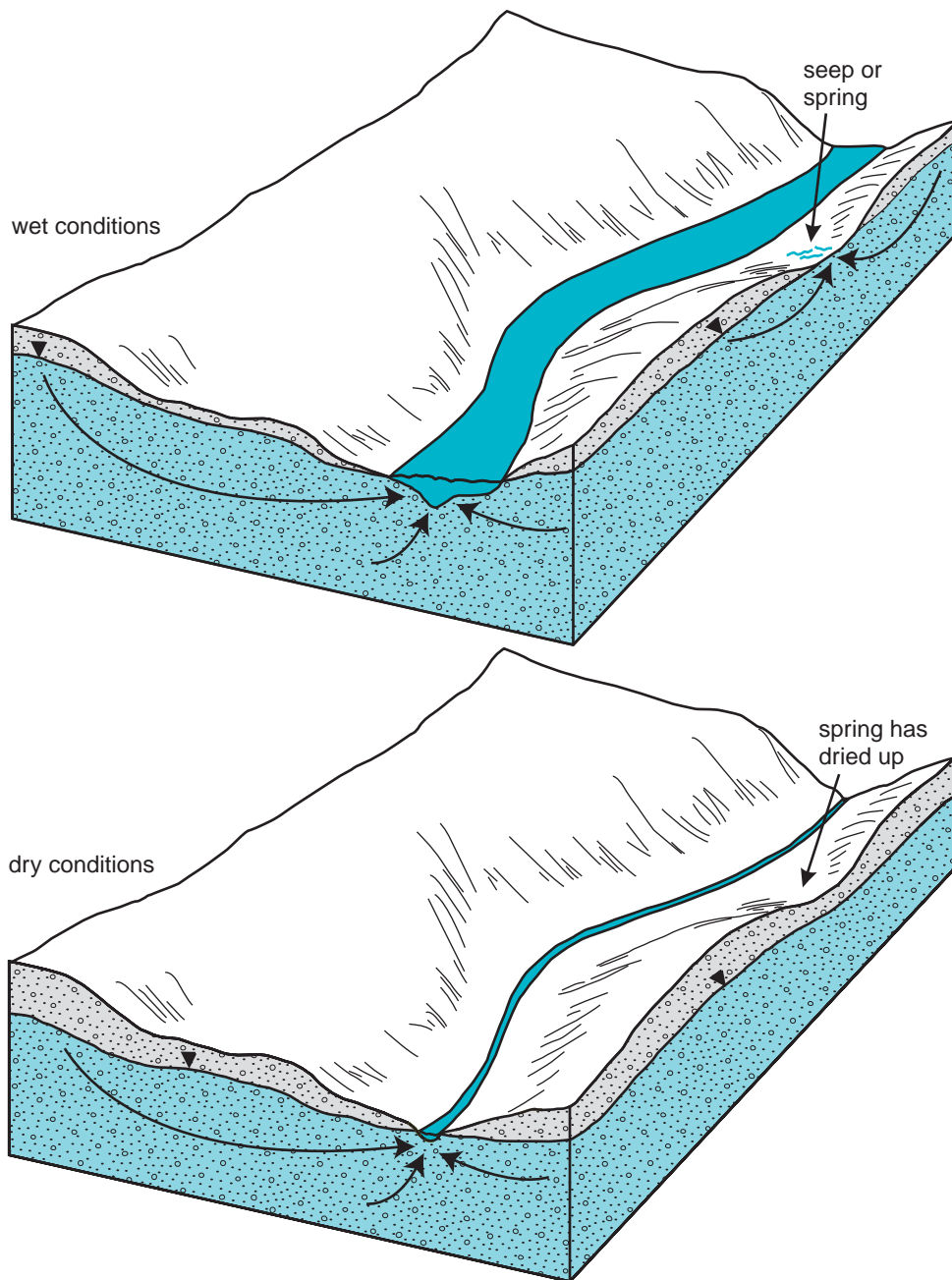


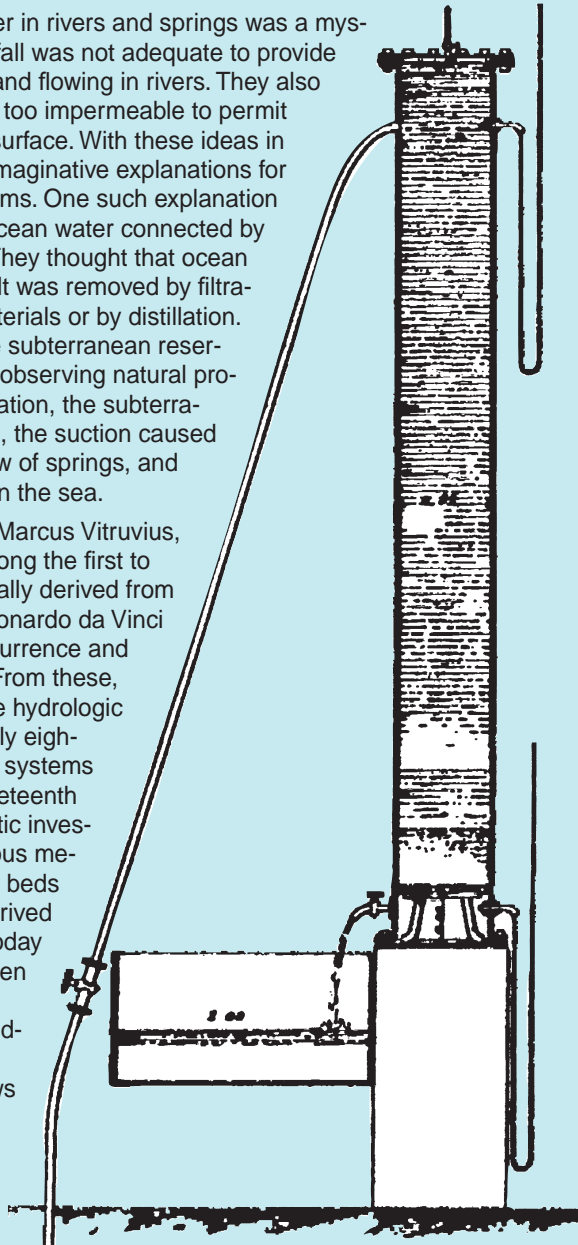
Figure 6 The water table reflects the surface topography. In both wet and dry conditions, the water table generally is higher beneath high areas of the land surface and lower beneath low areas. Arrows show the direction of groundwater movement toward the spring and the stream. Triangles indicate the top of the water table.

How the Concept of Groundwater Developed

For many centuries, the source of the water in rivers and springs was a mystery. Ancient observers reasoned that rainfall was not adequate to provide the amount of water issuing from springs and flowing in rivers. They also thought the ground was, for the most part, too impermeable to permit rainwater to seep very far below the land surface. With these ideas in mind, the ancients developed some very imaginative explanations for the origin of the water in springs and streams. One such explanation involved vast subterranean reservoirs of ocean water connected by conduits to surface springs and streams. They thought that ocean water became fresh water because the salt was removed by filtration as the water moved through earth materials or by distillation. Ideas for how the water was lifted from the subterranean reservoirs and through the conduits came from observing natural processes such as vaporization and condensation, the subterranean pressure in rocks evident from caves, the suction caused by the wind, the vacuum formed by the flow of springs, and the pressure caused by wind and waves on the sea.

Influential Roman architect and engineer, Marcus Vitruvius, who lived in the first century B.C., was among the first to state the theory that groundwater is generally derived from precipitation infiltrating into the ground. Leonardo da Vinci collected accurate observations of the occurrence and behavior of water in his own countryside. From these, he helped develop an understanding of the hydrologic cycle. During the late seventeenth and early eighteenth centuries, the principles of *artesian* systems were first developed in Italy. In the mid-nineteenth century, Henry Darcy did the first systematic investigation of water movement through a porous medium. Based on his experiments with sand beds that were used to filter water (fig. 7), he derived the basic equation for groundwater flow. Today we understand that water circulates between the Earth and its atmosphere in the hydrologic cycle. We also understand that groundwater is part of that cycle and flows in the subsurface according to basic physical laws and principles.

Figure 7 In the mid-nineteenth century, Henry Darcy drew this diagram of an apparatus designed to determine how water flows through sand. Water was pumped up the tubing on the left to the top of the apparatus and percolated downward through sand layers (horizontal lines) before flowing out of the faucet at the bottom. The U-shaped tubes on the right measured the *head* at two points in the column of sand.



In Illinois, where rainfall is usually plentiful, the water table generally is within a few feet of the land surface. The shape of the surface, called its topography, and the type of sediments, however, may substantially affect the depth to the water table. For example, water moves very slowly through fine-grained sediments, and the water table generally is high where such sediments are at or near the land surface. In contrast, where thick deposits of sand or a mixture of sand and gravel exists at the land surface, the water table may be deeper. The greater depth is possible because water can move more quickly through coarse-grained sediments and does not have time to build up in the subsurface.

Water can move through nearly all geologic materials, but it does so at vastly different flow rates, which depend on the type of material. Groundwater moves readily through coarse-grained geologic materials, such as sandstone or sand and gravel, because their pore spaces are interconnected. These types of materials, when saturated, yield useful quantities of groundwater to wells or springs and are called *aquifers*. Groundwater does not readily move through fine-grained geologic materials such as shale, silts, and clays because their pore spaces are poorly connected. These types of materials are called *aquitards*.

The complex nature of Illinois earth materials makes it very challenging to predict where groundwater is, how much there is in any particular area, how fast the water is traveling, and which direction it moves. The nature and arrangement of underground earth materials are major factors affecting the availability, quantity, and quality of groundwater.

Groundwater contains dissolved minerals and other substances, most of which occur naturally. Some substances also may be present because of human activities, such as elevated concentrations of nitrate or pesticides applied to the soil. Some substances in the atmosphere are carried back to the soil by precipitation. The water then gains more dissolved mineral matter as it moves through the unsaturated zone to the saturated zone. Most dissolved materials in groundwater, however, come from the earth materials of the saturated zone as the water slowly moves from recharge to discharge areas.

The composition and solubility of the sediments and the length of time groundwater is in contact with them affects the type and concentration of dissolved minerals in groundwater. Temperature, pressure, and acidity of the groundwater also affect how fast minerals dissolve and how much is in the groundwater. In general, the concentration of dissolved minerals increases the longer and more deeply groundwater moves through the subsurface. This relationship explains why groundwater

found in deep bedrock aquifers in central and southern Illinois generally is too saline to be used for drinking water.

Groundwater quality depends not only on the amount of dissolved minerals and other chemical substances it contains, but also on physical characteristics such as temperature, color, odor, and turbidity and biological characteristics such as the presence of bacteria, viruses, or other microbes. Groundwater quality typically is evaluated in terms of how the water will be used. Drinking water standards, which are the most strict, specify quality requirements for groundwater to be used for human consumption. Sometimes less stringent standards pertain to industrial or agricultural uses.

Geology And Groundwater

Understanding the geologic framework of groundwater is essential to comprehend where groundwater occurs and how it behaves in the subsurface. Once that framework is understood, especially the variation in geologic conditions from place to place, individuals can more easily grasp why groundwater is readily available in some areas of Illinois but is difficult to obtain in others.

Geologic Framework

The geologic framework of Illinois consists of two major parts: (1) bedrock and (2) the glacial deposits that overlie the bedrock throughout most of the state. Their water-yielding characteristics are described because groundwater supplies come from aquifers in these formations.

Bedrock Geology

In Illinois and much of the Midwest, bedrock refers to the solid rock (fig. 8) that underlies the sediment deposited during the Great Ice Age, which lasted from about 1.8 million years ago to about 13,500 years ago. The evidence from thousands of test holes and water wells drilled into bedrock reveals that many layers of *sedimentary rocks* lie below the Ice Age deposits. Some of the deepest holes show that these rocks lie above older *igneous* crystalline rocks, mainly granite. These basement rocks are found more than 2,000 feet below the land surface in Illinois, but extend to great depths in the Earth's crust. For this reason, and because they yield no *potable* water, these rocks are not discussed further.

The overlying sedimentary rocks are about 2,000 to nearly 14,000 feet thick and range in age from about 543 million to about 290 million years. The sedimentary rocks mainly consist of layers of shale, sandstone, limestone, coal, and dolomite (fig. 9) stacked one above the other. These rocks formed from sediments deposited in or on land near ancient seas whose margins fluctuated across what is now the midcontinent of North America, including Illinois. Over time, the sediments were gradually lithified, or converted into rock, as they were compressed and cemented together. After the seas retreated from the midcontinent for the last time near the end of the Pennsylvanian Period, which ended about 290 million years ago, the land surface was subjected to erosion.

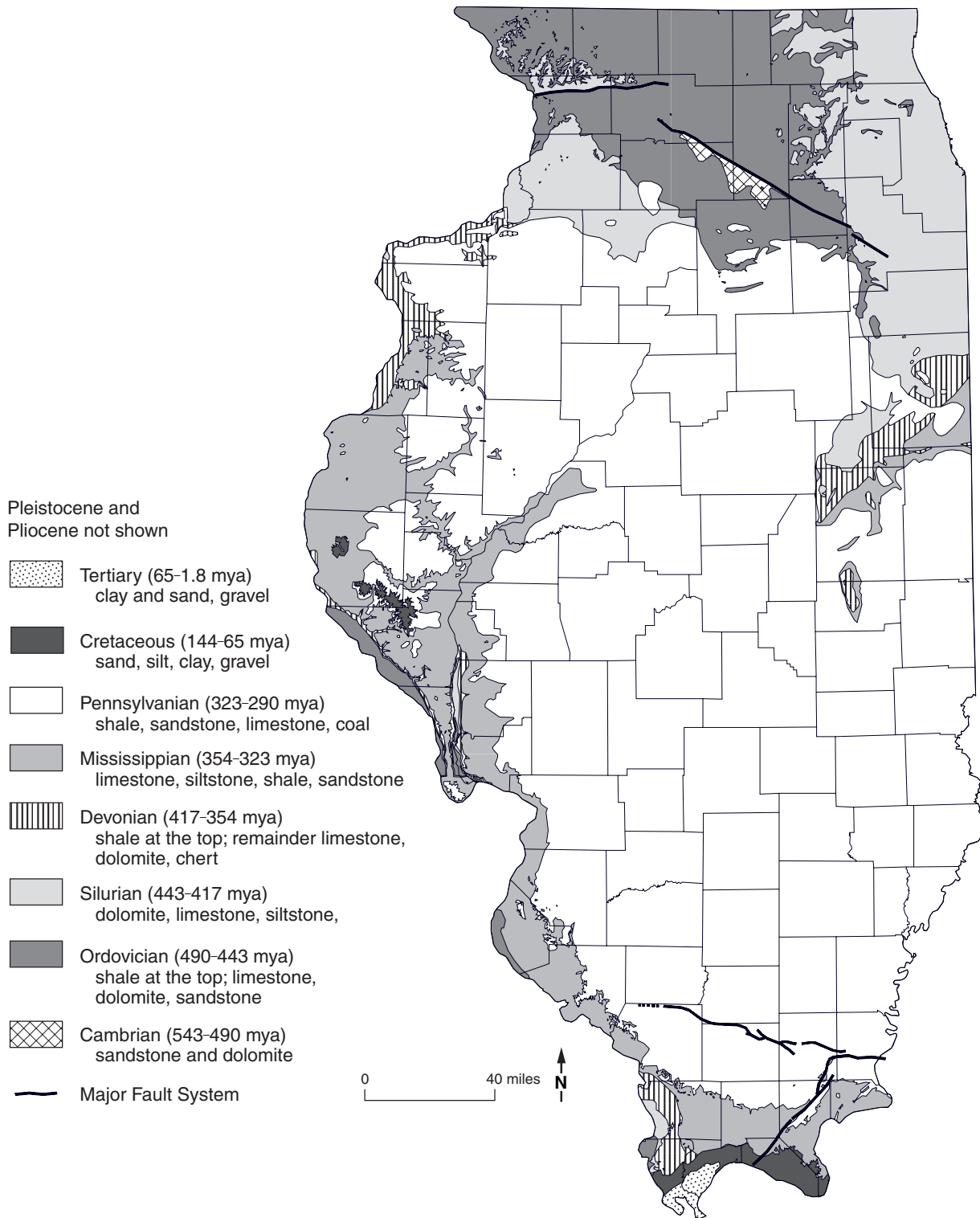


Figure 8 The age and distribution of bedrock units that occur at the bedrock surface in Illinois; mya means million years ago.

Era	Period or System and Thickness	Epoch	Age (years ago)	General Types of Rocks	Aquifer and Nonaquifer Characteristics	
CENOZOIC "Recent Life"	Quaternary 0-500 ft	Holocene	10,000	Alluvium in river valleys		
		Pleistocene Glacial Age		Glacial till, glacial outwash, gravel, sand, silt, lake deposits of clay and silt, loess and sand dunes; covers nearly all of state except north-west corner and southern tip	Outwash, gravel, sand are aquifers; till, lake clays and silts, and loess are not aquifers	
	Tertiary 0-500 ft	Pliocene	1.8 mya 5.3 mya 33.7 mya	Chert gravel, present in southern and western Illinois	May be locally significant aquifers	
		Eocene		Mostly micaceous sand with some silt and clay; present only in southern Illinois		
MESOZOIC "Middle Life"	Cretaceous 0-300 ft	Paleocene	54.8 mya	Mostly clay, little sand; present only in southern Illinois	Not an aquifer	
			65 mya	Mostly sand, some thin beds of clay, and, locally, gravel; present in southern and western Illinois	May be locally significant aquifers	
PALEOZOIC "Ancient Life"	Pennsylvanian 0-3,000 ft ("Coal Measures")		144 mya 290 mya	Largely shale and sandstone with beds of coal, limestone, and clay	Sandstone, fractured limestone are aquifers; shale, coal, clay, and massive limestones are not aquifers	
		Mississippian 0-3,500 ft	323 mya	Black and gray shale at base; middle zone of thick limestone that grades to siltstone chert, and shale; upper zone of interbedded sandstone, shale, and limestone	Sandstone and fractured/creviced limestone are aquifers; shale, siltstone, and massive limestone are not aquifers	
	Devonian 0-1,500 ft		354 mya	Mostly limestone, minor sandstones, and shales; largely chert and cherty limestone in southern Illinois; black shale at top	Fractured limestone and sandstone are aquifers; shale and massive limestone are not aquifers	
		Silurian 0-1,000 ft	417 mya	Principally dolomite and limestone	Fractured/creviced dolomite and limestone are aquifers; massive dolomite and limestone are not aquifers	
	Ordovician		443 mya	Largely dolomite and limestone but contains sandstone, shale, and siltstone formations	Fractured/creviced dolomite and limestone are aquifers; shale and siltstone are not aquifers	
		Cambrian 1,500-3,000 ft	490 mya	Chiefly sandstones with some dolomite and shale; exposed only in small areas in north-central Illinois	Sandstone and fractured/creviced dolomite are aquifers; shale is not an aquifer	
	Precambrian		543 mya	Igneous and metamorphic rocks; known in Illinois only from deep wells	Not an aquifer	

Figure 9 Geologic column showing the age, general rock types, order of occurrence, and prevalent aquifer and nonaquifer characteristics in Illinois. Age dates are from the Geological Society of America 1999 Geologic Time Scale. (Modified from *Guide to the Geologic Map of Illinois*, 1961.)

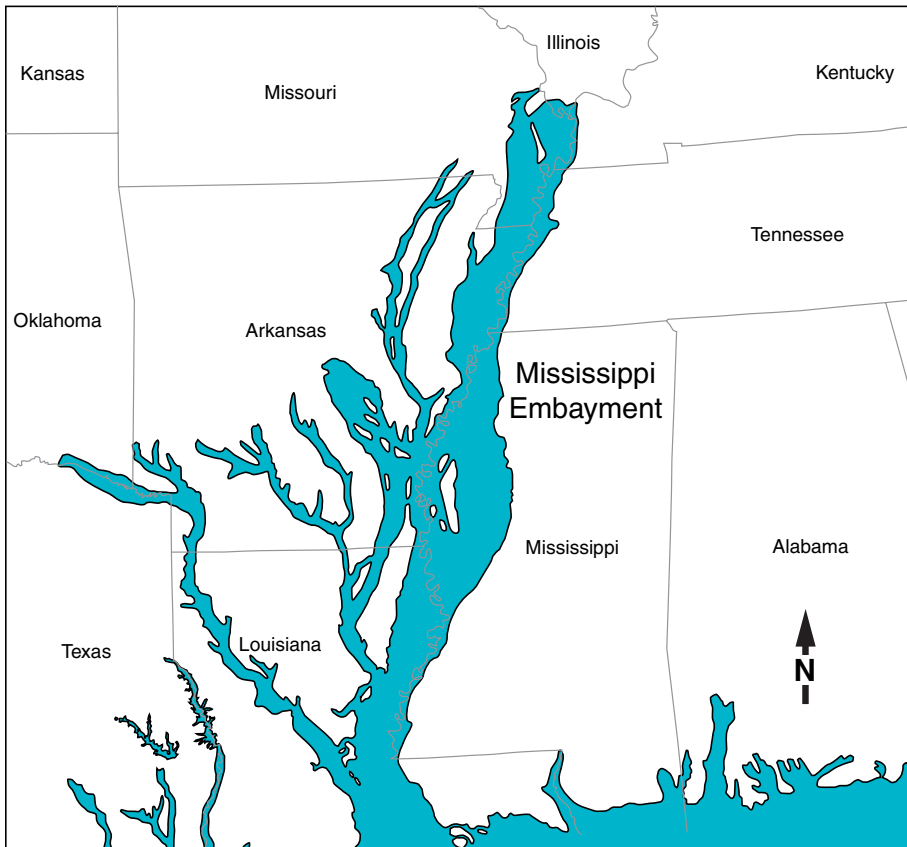


Figure 10 Sediment consisting mostly of sand with lesser amounts of gravel, silt, clay, and organic matter was deposited in southernmost Illinois when the Mississippi Embayment extended northward from 99 to about 65 million years ago.

Much later, from 99 to about 65 million years ago, a shallow sea extended northward from what is now the Gulf of Mexico to the southernmost tip of Illinois (fig. 10). Sand and lesser amounts of gravel, silt, clay, and organic matter were deposited in a delta at the mouth of a major river that flowed into the *embayment* from the east. In western Illinois during this time, sand and clayey sand with gravel, silt, and clay were deposited as beach and nearshore sediments in the shallow sea. The distribution, age, and types of rocks at the bedrock surface are illustrated in figure 8.

In many areas of Illinois, the layers of sandstone, shale, limestone, dolomite, and coal were warped and tilted through geologic time to form several major structures in the bedrock. The largest of these structures, an oblong depression called the Illinois Basin, is located in the

southern two-thirds of the state (figs. 11 and 12). At the deepest part of the basin in south-central Illinois, the sedimentary rocks are nearly 14,000 feet thick. Another major structure is the long, narrow, arch-like La Salle *Anticlinorium*, a complex upfold in the rocks that trends northwest to southeast in the eastern half of Illinois.

Major bedrock structures affect the position of bedrock aquifers. Along the narrow upfold of the La Salle Anticlinorium, for example, bedrock aquifers are found close to the land surface and are locally important sources of potable groundwater. These same bedrock aquifers are found far underground in the deeper parts of the Illinois Basin, and the groundwater within them has very high concentrations of dissolved minerals, making the water unfit for drinking.

Some bedrock structures are quite complex locally and include faults, or fractures, in the rock, along which movement took place far back in the Paleozoic Era, 543 to 290 million years ago. These structures also can affect the movement of groundwater because faults are rarely single, clean breaks. Instead they generally are relatively narrow zones of highly broken rock through which groundwater travels more easily than through the adjoining unfractured rock. Faulting also may move a water-yielding rock, such as sandstone, into a position next to a rock layer, such as shale, that does not easily transmit groundwater, altering the groundwater flow. Also, stress within bedrock may cause the development of crevices and fractures that

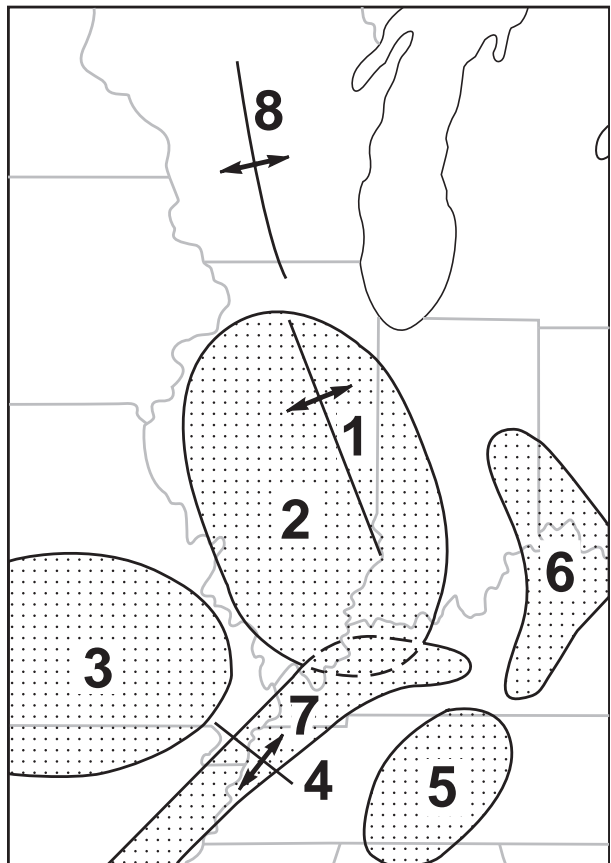


Figure 11 Location of some major bedrock structures in the Illinois region: (1) La Salle Anticlinorium, (2) Illinois Basin, (3) Ozark Dome, (4) Pascola Arch, (5) Nashville Dome, (6) Cincinnati Arch, (7) Rough Creek Graben-Reelfoot Rift, and (8) Wisconsin Arch.

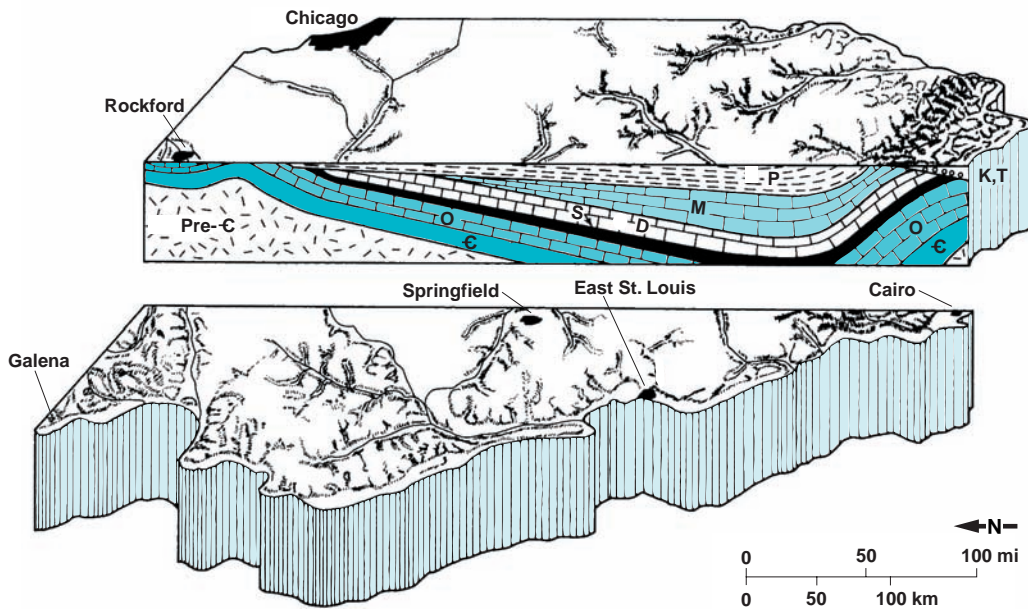


Figure 12 Generalized north-south cross section shows the structure of the Illinois Basin. To show detail, the thickness of the sedimentary rocks has been greatly exaggerated, and younger, unconsolidated surface deposits have been eliminated. The oldest rocks are Precambrian (pre-C). These igneous rocks form a depression filled with layers of sedimentary rocks of various ages: Cambrian (C), Ordovician (O), Silurian (S), Devonian (D), Mississippian (M), Pennsylvanian (P), Cretaceous (K), and Tertiary (T). The scale is approximate.

may be water-filled and provide local sources of groundwater. In some limestones and dolomites, portions of the rock have dissolved along such fractures and crevices, creating openings of various sizes that are now filled with water.

Bedrock Surface

The bedrock surface of Illinois has features such as broad river valleys and adjacent uplands and hills (fig. 13). These bedrock features were filled in or smoothed by the glacial processes and glacial deposits that shaped most of the present-day landscape (fig. 14). Two major buried bedrock valleys join in central Illinois—the Mahomet Bedrock Valley from the east and the Middle Illinois Bedrock Valley from the north. The Mahomet Bedrock Valley extends east to west in a large arc across the central part of Illinois from the Indiana border to the Illinois River valley. The Middle Illinois Bedrock Valley follows the present-day Illinois River valley northward where it joins the Princeton Bedrock Valley along the course of the Ancient Mississippi River. Other major

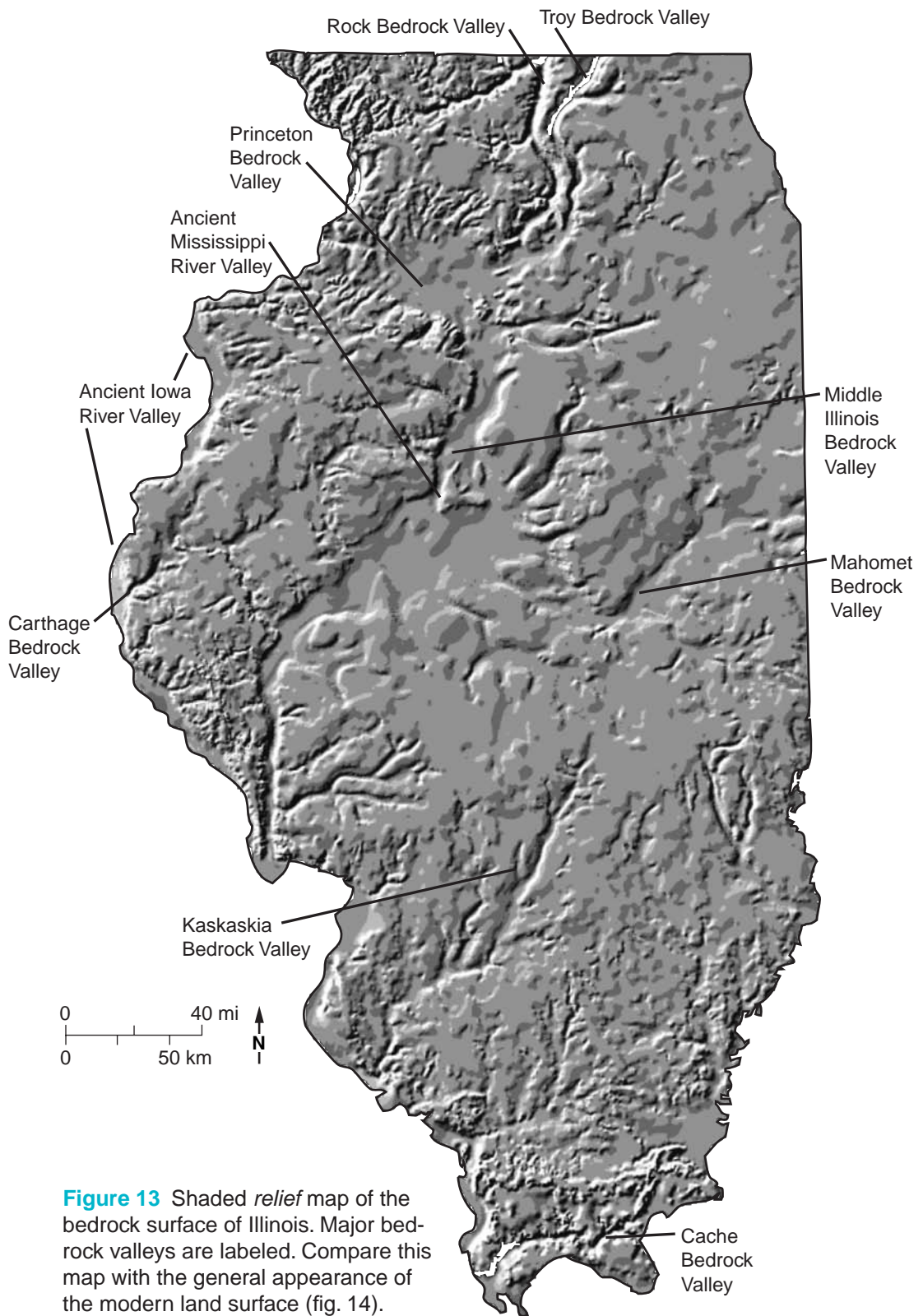


Figure 13 Shaded *relief* map of the bedrock surface of Illinois. Major bedrock valleys are labeled. Compare this map with the general appearance of the modern land surface (fig. 14).

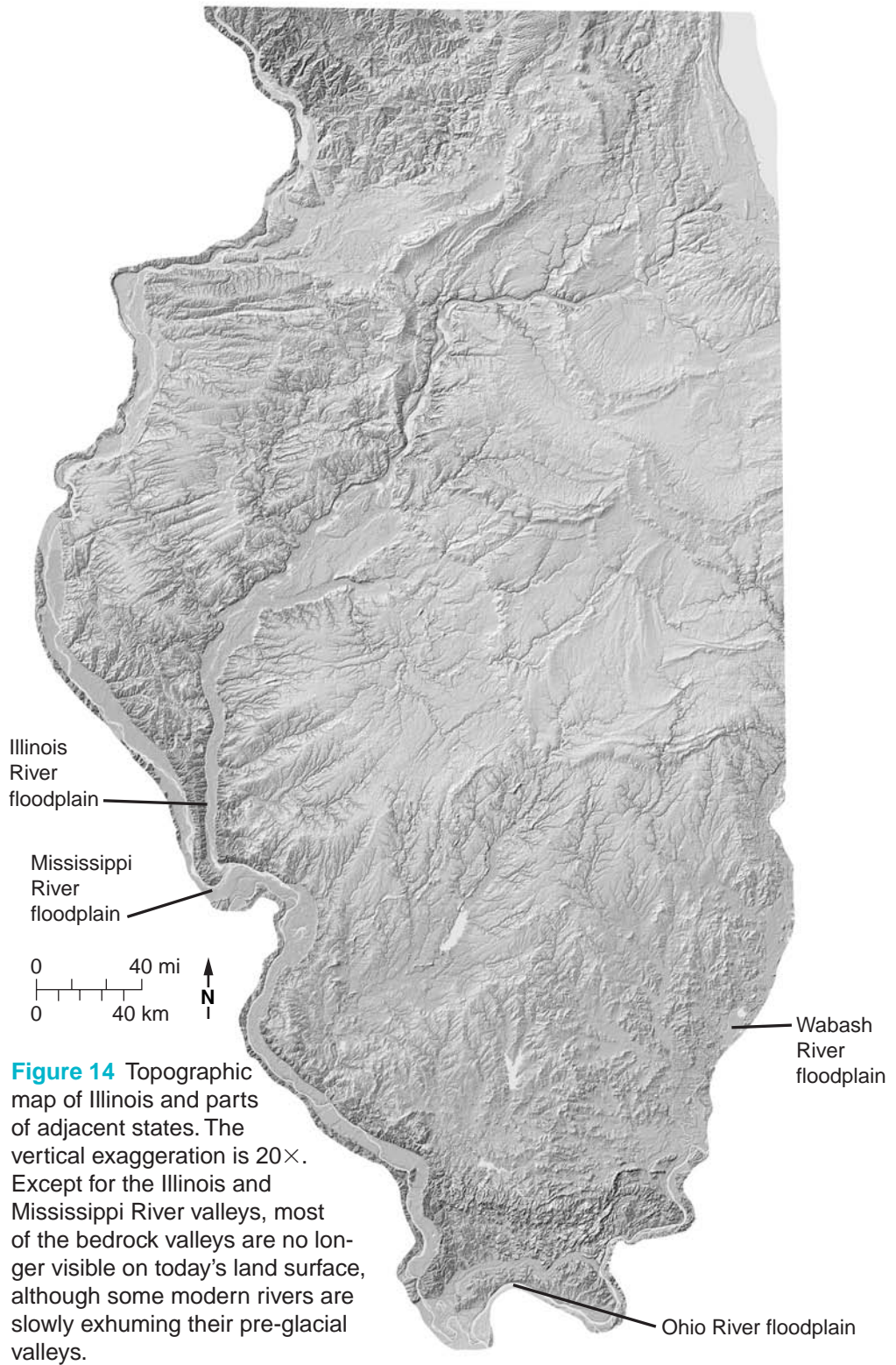


Figure 14 Topographic map of Illinois and parts of adjacent states. The vertical exaggeration is 20 \times . Except for the Illinois and Mississippi River valleys, most of the bedrock valleys are no longer visible on today's land surface, although some modern rivers are slowly exhuming their pre-glacial valleys.

bedrock valleys include the Rock and Troy in northern Illinois, the Carthage in western Illinois, the Kaskaskia in southwestern Illinois, and the Cache in southern Illinois. Sand and gravel deposits found in these bedrock valleys are major sources of groundwater, as explained in the following sections.

Glacial Geology

The Great Ice Age in Illinois lasted from about 1.8 million years to approximately 13,500 years ago. During this time, immense sheets of ice, called glaciers, advanced from arctic regions in Canada into the central states, including Illinois. As the glaciers spread southward, they picked up and carried massive amounts of sediment and rock. When the glaciers retreated, they left behind the relatively flat landscape seen today in most parts of Illinois (fig. 14). They also left widespread deposits of sediment and rock debris that completely filled most of the bedrock valleys in the state. The modern landscape looks much different from the older, buried bedrock surface (compare figs. 13 and 14). A comprehensive look at the Great Ice Age in Illinois is presented in *Illinois' Ice Age Legacy*.

Layers of unlithified glacial sediment (fig. 15), which geologists call *glacial drift*, blanket approximately 90 percent of Illinois. In the deepest parts of the bedrock valleys, the glacial drift is more than 400 feet thick. Over most of the state, however, the thickness probably averages about 100 feet. The glacial sediment consists of several different types, each deposited in a particular way by processes related to glaciation. The nature and distribution of these sediments are important factors affecting where aquifers occur and how much groundwater is found at any particular location across much of the state.

Layers of ground-up rock debris that were deposited directly out of the melting ice are present across broad expanses of Illinois. This debris, called till, consists of relatively compact, dense mixtures of different sizes of rock particles, mainly clay, silt, and sand with some pebbles, cobbles, and boulders (fig. 16).

Other kinds of Ice Age sediments were deposited by water or wind. Major valleys in the bedrock surface carried immense volumes of meltwater from the earliest Illinois glaciers. Sediments deposited by this flowing water (outwash; fig. 17) included coarse-grained sand and gravel as well as fine-grained silt and clay. Outwash filled most of the lower parts of many of these bedrock valleys. Most of the silts and clays were deposited on the bottoms of lakes that formed during that

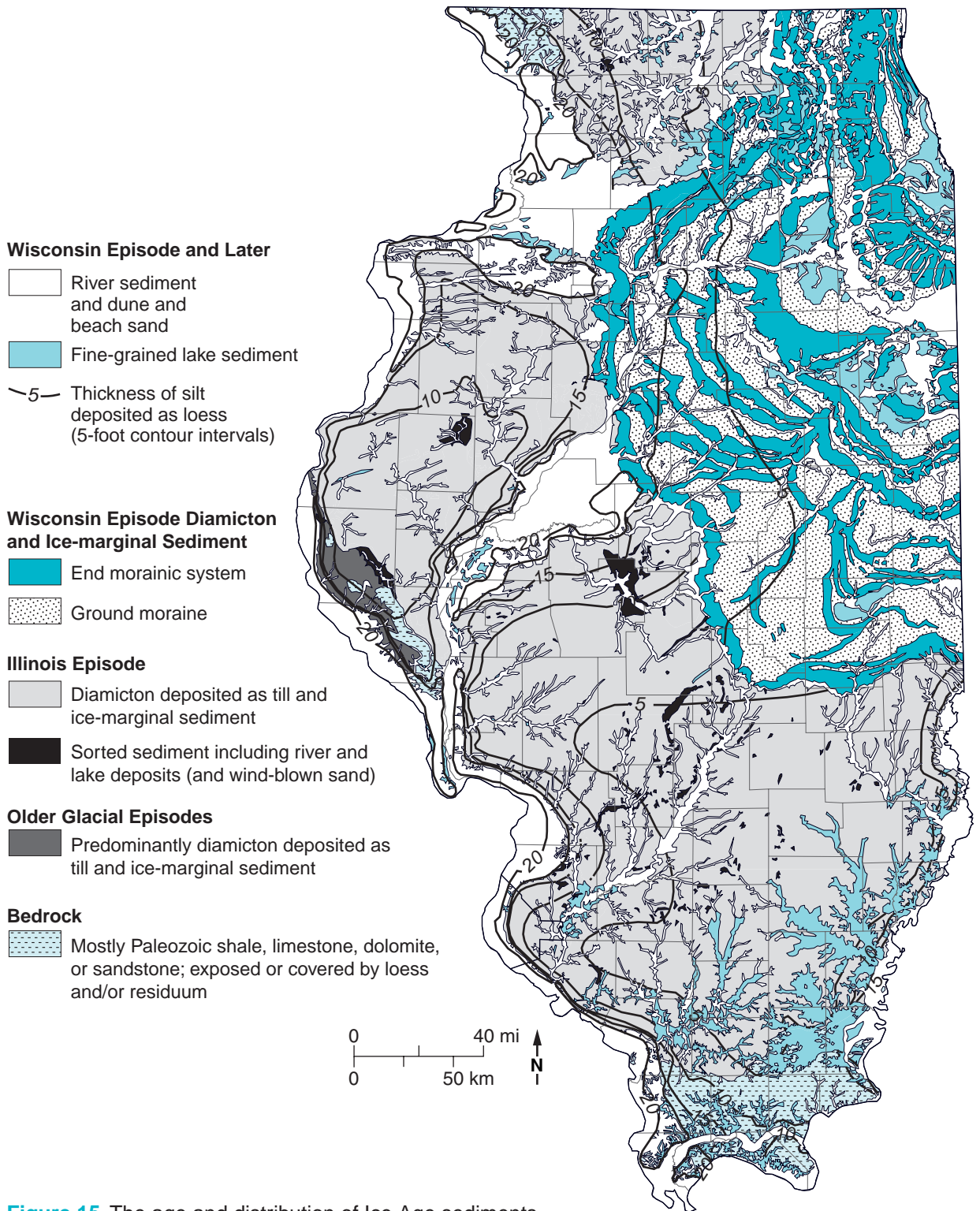


Figure 15 The age and distribution of Ice Age sediments across Illinois.



Figure 16 An exposure of glacial till near Chicago illustrates the variety of grain sizes packed tightly together that is typical of this type of sediment. (Photograph by Ardith K. Hansel.)

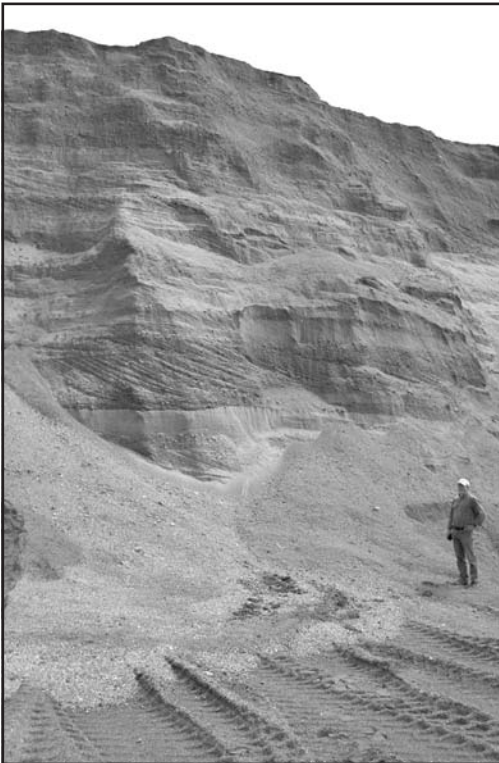


Figure 17 Layers of outwash revealed in the wall of a sand and gravel quarry near Lacon in Marshall County, Illinois. (Photograph by Timothy J. Kemmis.)



Figure 18 ISGS geologist measures a deposit of windblown silt called loess revealed in the Mississippi River valley southwest of Columbia in Monroe County, Illinois.

time period and in major river valleys. The silt and clay provided the source material for wind-deposited dust.

Most of Illinois is blanketed by this dust (figs. 15 and 18), called loess, in which many of the state's most productive soils were formed. Loess thickness ranges from several tens of feet in some areas along bluffs close to the source valleys of the Mississippi and Illinois Rivers to less than a foot in the northeastern corner of the state.

How Illinois Geology Relates to Groundwater

Geologists use outcrops—the bedrock or sediment deposits exposed at the land surface—and drilling records of wells and test holes to gather general information about the three-dimensional configuration and regional distribution of rock types and glacial deposits. Outcrops and drilling records also provide information about the depth to bedrock and where the rocks are folded and faulted. Although local variations occur in the characteristics of bedrock and glacial sediments, geologists use distinctive layers within them to *correlate* the bundles of bedrock or glacial sediments from one area to another. These correlations help considerably in predicting the occurrence, extent, and thickness of water-yielding units both in bedrock (fig. 19) and glacial deposits (fig. 20).

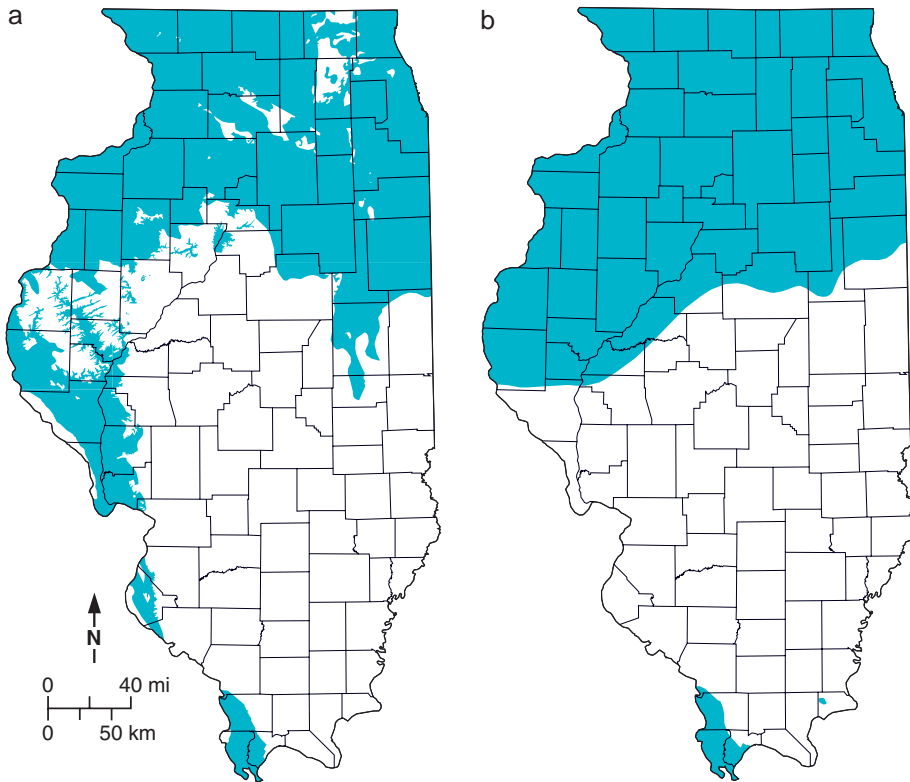


Figure 19 Major bedrock aquifers (a) at depths within 500 feet of land surface and (b) at depths greater than 500 feet below land surface.

Groundwater flows rather easily through certain types of rocks, such as sandstone and fractured limestone, and through certain types of glacial sediments, such as sand and gravel outwash deposits. Knowing where these rocks and sediments occur is fundamental to locating, using, and protecting groundwater resources. In contrast, fine-grained geologic materials, such as shale and glacial till, generally are barriers to groundwater movement. Determining the three-dimensional distribution of geologic materials that either yield water or act as barriers to its movement helps us understand the extent of groundwater resources. This knowledge helps us place waste disposal facilities, such as landfills, in locations that have the least potential to contaminate groundwater, and in so doing, protect groundwater supplies. This understanding also helps us evaluate the effects of other land-use activities that may harm groundwater quality, activities such as applying fertilizers and pesticides to crops, golf courses, or lawns. *Land-Use Decisions and Geology: Getting Past “Out of Sight, Out of Mind”* discusses geology and land-use issues.

Illinois rocks and sediments consist of grains of different shapes and sizes, and scientists determine which materials will hold and yield water by measuring their *hydraulic conductivity*. Saturated rocks and sediments with high conductivity form aquifers, and those with low hydraulic conductivity form aquitards.

In general terms, hydraulic conductivity is how much groundwater can move through the interconnected pores of earth materials over a set area, time, and pressure (fig. 21).

1. The area commonly used to measure hydraulic conductivity is one square foot oriented at right angles to the direction of groundwater flow.

2. The unit of time is usually one day.

3. Pressure is measured as *hydraulic head*, which is the amount of energy groundwater has at a given point underground. Hydraulic head depends on that point's height above sea level, the weight of the earth materials and groundwater above that point, and the movement of groundwater.

Hydraulic gradient is the change in hydraulic head—the groundwater's energy—over a set distance in the direction of groundwater flow. A unit of hydraulic gradient is a one-foot vertical decline in hydraulic head over a horizontal distance of one foot.

Hydraulic conductivity is commonly expressed as gallons per day per square foot. It is important to remember that if a rock or sediment has a hydraulic conductivity of 100 feet per day it does not mean the water will move that distance in 24 hours. It means that 100 cubic feet of water can move through a cross section area of one square foot in one day under a unit hydraulic gradient. Table 1 lists the hydraulic conductivities of various aquifer and aquitard materials.

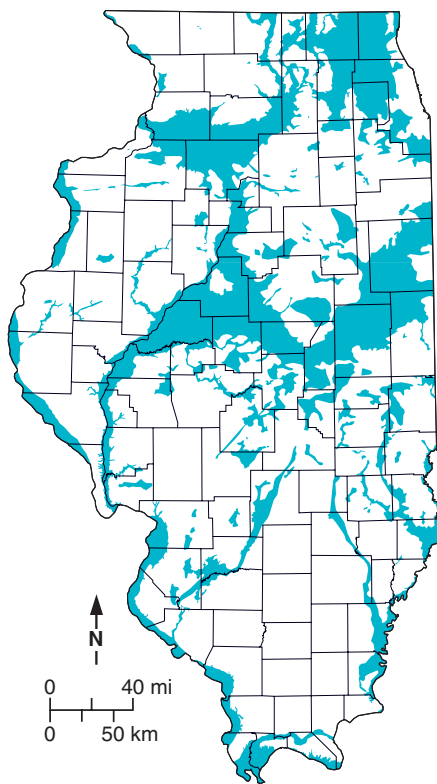


Figure 20 Major sand and gravel aquifers.

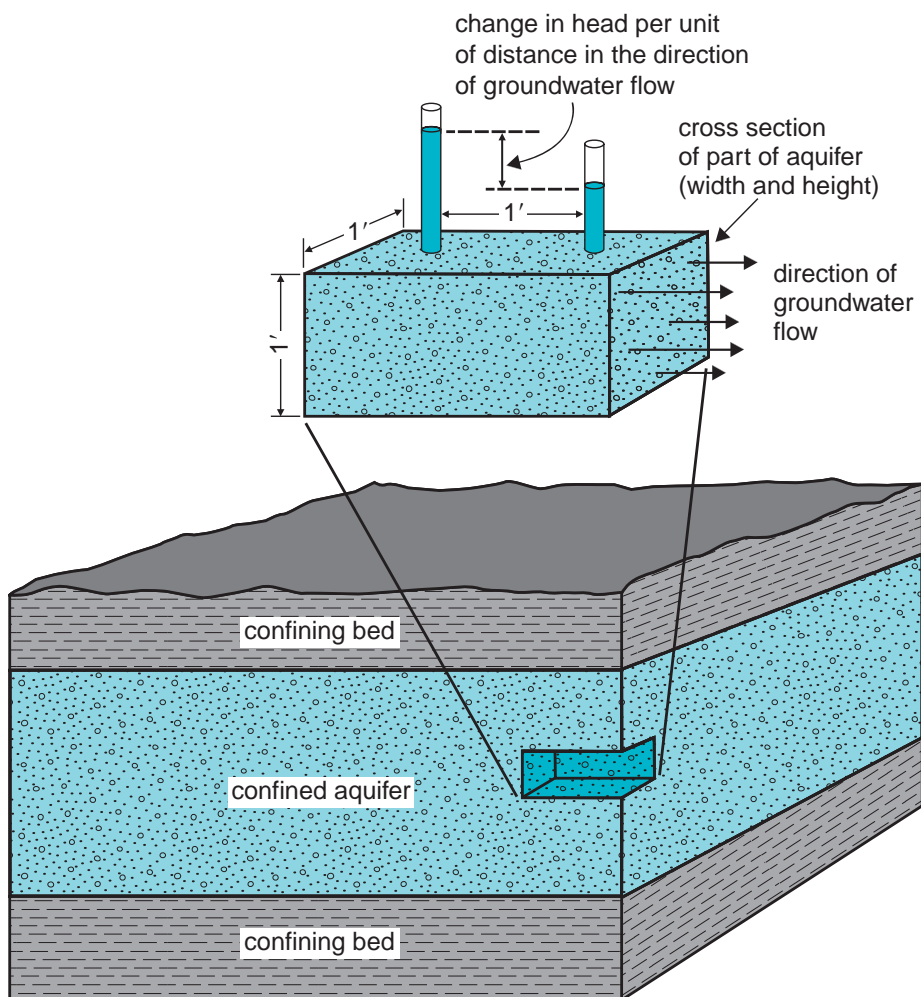


Figure 21 Hydraulic conductivity is the volume of groundwater that will move in a unit of time under a unit hydraulic gradient through a unit cross section area oriented at right angles to the direction of groundwater flow. A unit hydraulic gradient is a one-foot vertical decline in hydraulic head over a horizontal distance of one foot. (Modified from Heath 1989.)

Typical Aquifer Materials

Sandstone Sandstone typically is made up of well-rounded sand grains that are fairly uniform in size (fig 22a). Because the spaces between the grains (*porosity*) of this type of sandstone are mostly interconnected, the *permeability* of a typical sandstone is relatively high. Not all sandstone is like this. In some sandstone, the sand grains are cemented together by mineral matter, reducing pore space and permeability. Some sandstone is so thoroughly cemented that groundwater moves only through fractures in the rock rather than through the spaces

Table 1 Equivalent times for the range of hydraulic conductivity of various geologic materials.

Geologic Material	Equivalent Time ^A	Hydraulic Conductivity (gpd/ft ²) ^B
Gravel	0.1 second to 84 seconds	10 ⁶ to 10 ³
Sand	8 seconds to 1 day	10 ⁴ to 1
Fractured limestone and dolomite	8 seconds to 10 days	10 ⁴ to 10 ⁻¹
Sandstone	14 minutes to 2.7 years	10 ² to 10 ⁻³
Loess	2.4 hours to 2.7 years	10 to 10 ⁻³
Silt	10 days to 100 years	10 ⁻¹ to 10 ⁻²
Till	10 days to 2,740 years	10 ⁻¹ to 10 ⁻⁶
Clay	100 days to 2,740 years	10 ⁻² to 10 ⁻⁶
Shale	2.7 years to 27,400 years	10 ⁻³ to 10 ⁻⁷

^A The time it takes for a gallon of water to flow through one square foot of the geologic material under a unit hydraulic gradient.

^B Expressed using scientific notation, a way to communicate very large or small numbers using a numeral multiplied by a power of 10. For example, the number 0.000000123 is expressed as 1.23×10^{-7} (the decimal point moves seven positions to the left of 1.23). gpd/ft² means gallons per day per square foot.

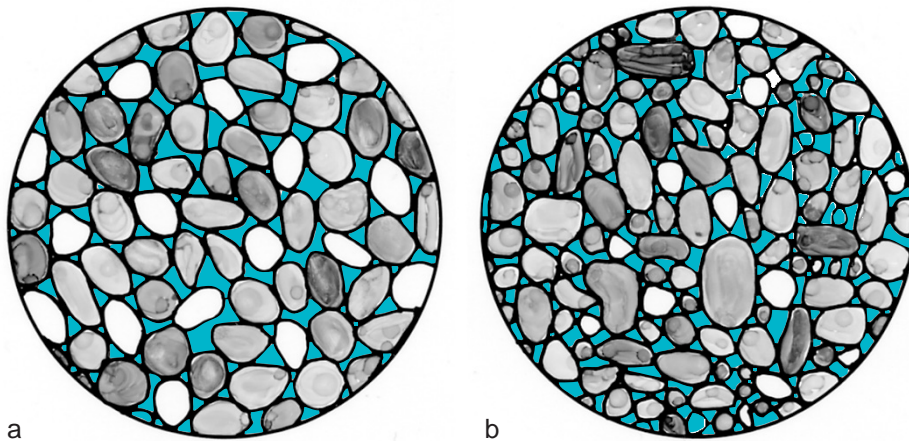


Figure 22 (a) Rounded grains of roughly equal size and shape result in higher porosity and permeability than (b) grains of varying dimensions and degrees of angularity, which allow finer sediment to fill some of the spaces between the larger grains.

between grains. Other sandstone consists of mixtures of very fine to very coarse grains. The grains may be angular instead of rounded, and the sandstone may be “muddy” or “dirty,” containing silt or clay in the pore spaces. These conditions reduce pore space and decrease their interconnectedness (fig. 22b), which, in turn, reduces their capacity to transmit water. The amount of cementing mineral matter and the roundness or angularity of the grains affect the hydraulic conductivity of sandstone.

Limestone and dolomite Originating on the ocean floor as limy muds or sands and seashell fragments, limestone and dolomite are relatively dense and may lack large interconnected pores. Many limestones and dolomites, however, contain numerous interconnected cracks, crevices, and solution channels. If a well reaches such openings and those openings are filled with groundwater, an adequate supply of water may be obtained. Because these openings and fractures usually are underground, their presence and extent at any specific location are not readily predictable. Generally, fractured and creviced limestones and dolomites are productive aquifers. These rocks form aquitards, however, where they do not have fractures, cracks, and crevices (fig. 23). Where these rocks contain fossils, some porosity may exist if the remains have been dissolved out of the rock. However, the degree of interconnectedness resulting from such dissolution of fossils is not likely to be very high.

Glacial outwash deposits Glacial outwash deposits consist of sand, gravel, or a combination of the two. Outwash deposits store and readily transmit groundwater because their porosity and hydraulic conductivity typically are high. The equivalent times for these materials show why they form aquifers. Thick deposits of sand and gravel covering large areas are the most productive aquifers in Illinois.

Typical Aquitard Materials

Shale Shale is made up of platy grains—tiny, flat particles of clay stacked tightly together in parallel layers with tiny pore spaces between the particles (fig. 24). Although shale may have relatively

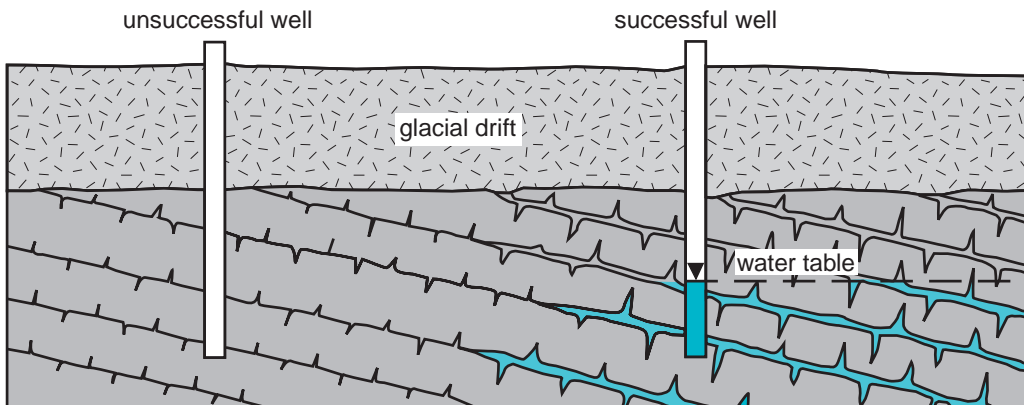


Figure 23 A well that intersects open crevices and cracks in limestone below the water table may yield usable quantities of water.

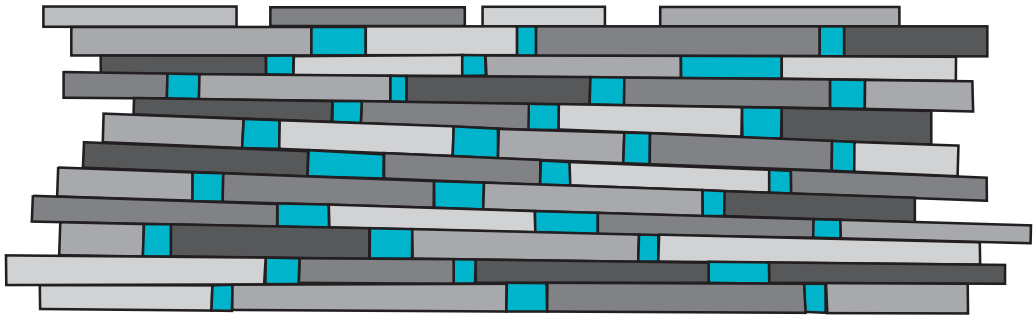


Figure 24 A stack of platy grains illustrates high porosity but low permeability because of the poor interconnection of pore spaces (shown in blue).

high porosity, the arrangement of the clay particles greatly reduces the interconnections between the pores. Because shale has low hydraulic conductivity, groundwater moves through shale extremely slowly. Clays and silts within glacial sediments also act as aquitards because of their low hydraulic conductivity. Hydraulic conductivity may be greater if the shale, clay, or silt is weathered or fractured.

Till Although till is a relatively compact, dense mixture of all grain sizes, clay and silt constitute the major portion of the mixture. Till can be as much of a barrier to groundwater movement in glacial deposits as shale is in bedrock. Weathered till, till with fractures, and very silty or sandy till allow some movement of groundwater because of increased hydraulic conductivity.

Loess Loess is a fine-grained sediment, so groundwater moves through it rather slowly. As loess gradually weathers into soils, openings develop, and water may move through weathered loess somewhat more readily than through the unweathered material.

Coal Coal is formed from altered and compacted plant remains that were buried and lithified long ago in coastal swamps. Compared with most other sedimentary rocks in the state, Illinois coal beds are so thin that they typically are of no great significance in terms of being either aquifers or aquitards. In parts of southern Illinois, however, fractured coal is the only source of small supplies of water in some localities.

Types of Aquifers

Although most people realize that an aquifer is an underground source of water, they may not know that aquifers are designated as unconfined or confined.

Unconfined Aquifers

In a deposit of very permeable earth materials that has a water table which is free to rise and fall (unrestricted) and does not intersect an aquitard, the groundwater is described as being unconfined. Consequently, this type of aquifer is called an *unconfined aquifer* (fig. 25a) or a water table aquifer because the water table delineates the top of an unconfined aquifer. The permeable earth materials above the water table are not saturated but can become so if the water table rises. As a result, the thickness of an unconfined aquifer changes with the rise and fall of the water table. The *static water level* in a well completed in an unconfined aquifer is very close to that of the water table adjacent to the well, indicating that the pressure on the groundwater is about equal to atmospheric pressure (fig. 25a). Unconfined aquifers in Illinois typically occur at relatively shallow depths.

Confined Aquifers

Where a deposit of very permeable, completely saturated earth materials has aquitards above and below it, the groundwater is described as being confined. This type of aquifer is called a *confined aquifer* or artesian aquifer (fig. 25b). Examples of confined aquifers are sand and gravel sandwiched by two layers of till, or a sandstone formation with

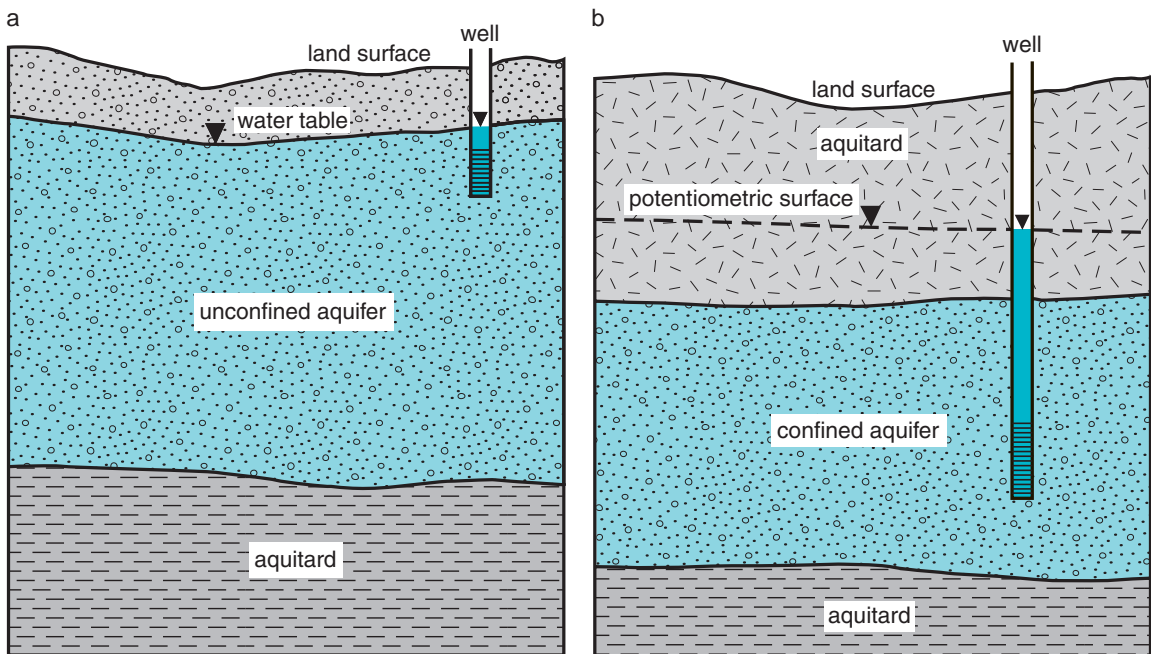
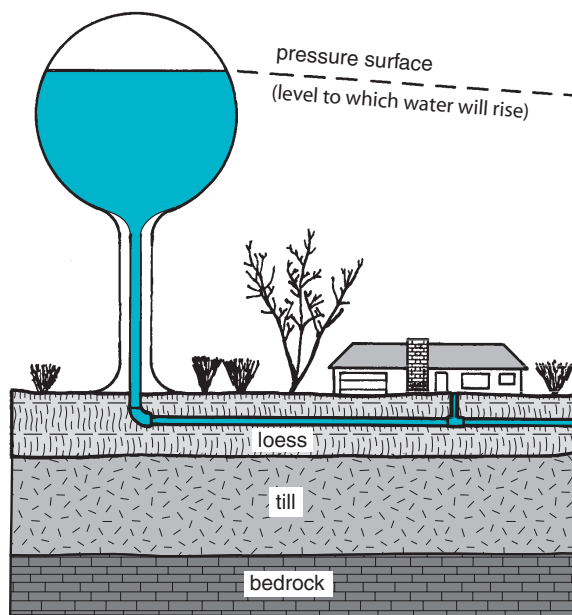


Figure 25 Illustration of (a) an unconfined aquifer and (b) a confined aquifer. The triangles indicate the water level in the well, the water table, and the potentiometric surface.

Figure 26 A city water tank provides a good analogy for the pressure on the groundwater in a confined aquifer. An invisible pressure surface—similar to the potentiometric surface of the aquifer—covers a broad circle of land around the water tank. The pressure of the water elevated in the tank causes water to flow freely from water faucets within the area of the circle.



shale above and below it. The sand and gravel or the sandstone are the aquifers; the relatively impermeable till or shale are the aquitards, or *confining units*.

Because the groundwater in the aquifer is confined, the *hydrostatic pressure* on the groundwater is greater than the atmospheric pressure. This pressure, also called *artesian pressure*, is generally due to the weight of water and earth materials overlying the aquifer. As a result, the static water level in a well completed in a confined aquifer rises above the top of the aquifer to a level where it is balanced by atmospheric pressure. This static water level marks the *potentiometric surface* of the aquifer (fig. 25; see also the sidebar on page 30). A well completed in a confined aquifer is called an artesian well. If the pressure on the groundwater is great enough, water will flow from the well without the use of a pump. This type of well is called a flowing artesian well. A common misconception is that water from a flowing artesian well is of excellent quality, but the term “artesian” implies nothing about groundwater quality.

The pressure on groundwater in a confined aquifer is similar to the pressure on water in a water distribution system fed by a city water tower. The tower elevates water to a level above the buildings it serves. The water in the supply pipes below is under pressure and will flow freely when the faucets are turned on (fig. 26).

The Complexity of a Hydrogeologic Setting

The hydrogeologic setting of an area can be quite complicated. For example, in figure 27, the bedrock serves as an aquitard. The lower and middle aquifers are separated by an aquitard, another aquitard is sandwiched between the middle and upper aquifers, and an aquitard covers part of the upper aquifer.

The water levels in the three wells indicate the potentiometric surfaces of the aquifers. For instance, the water level in well A indicates the potentiometric surface of the lower aquifer. Even though the well casing penetrates the middle and upper aquifers, the well is sealed off from those aquifers.

Note that to the right of well A the potentiometric surface of the lower aquifer is above the top of the middle aquifer. To the left of well B, the water table is the top of the upper aquifer. The water level in well C marks the potentiometric surface of the middle aquifer.

The potentiometric surfaces in each aquifer show where the aquifers are confined and where they are not. For instance, the potentiometric surfaces of the lower and middle aquifers indicate that they are confined aquifers, and the potentiometric surface of the upper aquifer to the right of well B shows that this part of the aquifer is confined. But the potentiometric surface of the upper aquifer to the left of well B extends beyond the aquitard, indicating that this part of the aquifer is unconfined.

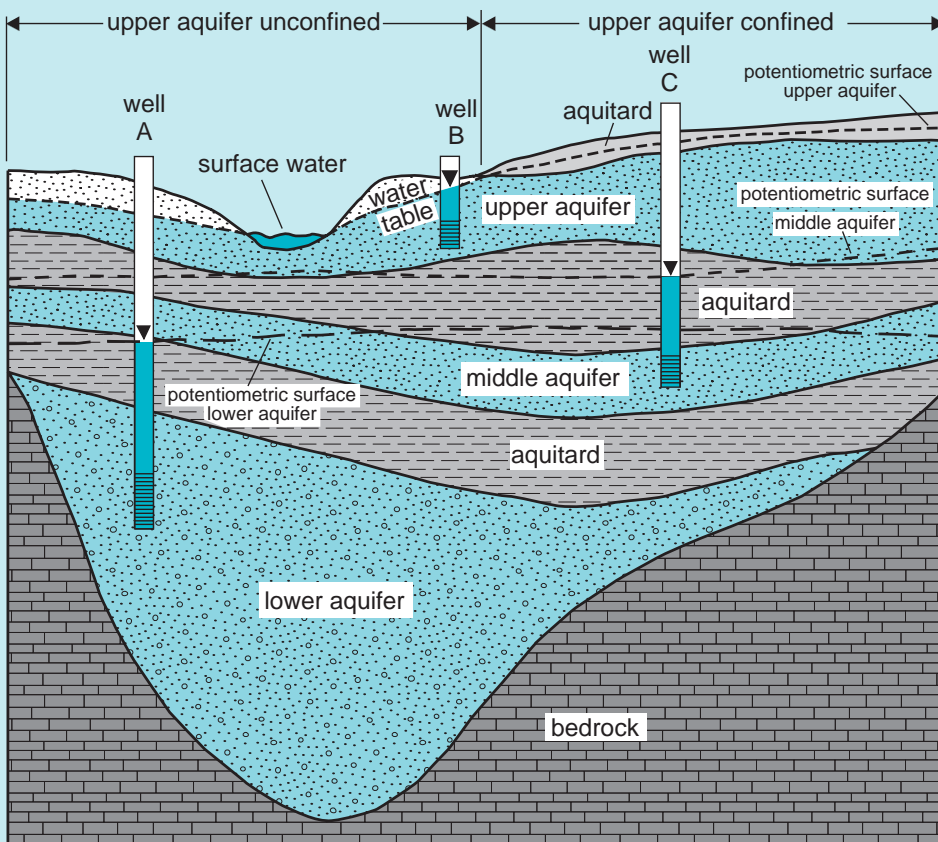


Figure 27 Confined and unconfined aquifers, their potentiometric surfaces, and water levels in wells of three different depths.

Groundwater's Natural Movement

Groundwater does not stay in one place. It moves slowly in the direction of decreasing hydraulic head, such as in the direction of the downward slope of the water table in an unconfined aquifer (fig. 28).

Groundwater travels through the sediments and rocks along flow paths of various lengths and depths (fig. 29).

Local flow paths are relatively short and shallow, so the amount of time groundwater spends in the subsurface is measured in days or weeks. The length of time groundwater resides underground in regional flow paths is measured in centuries or millennia. At the end of the flow paths, groundwater emerges at the land surface as discharge to rivers, streams, lakes, springs, and wetlands.

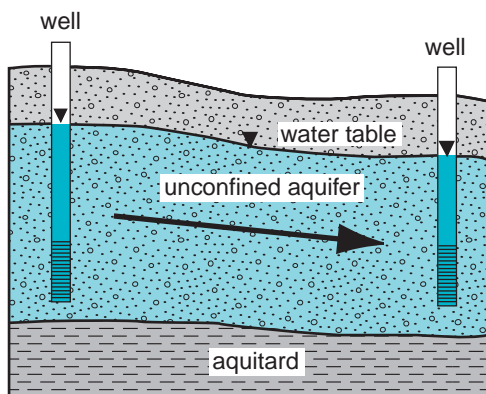


Figure 28 Groundwater moves slowly in the direction of decreasing hydraulic head, such as the downward-slope direction of the water table in an unconfined aquifer.

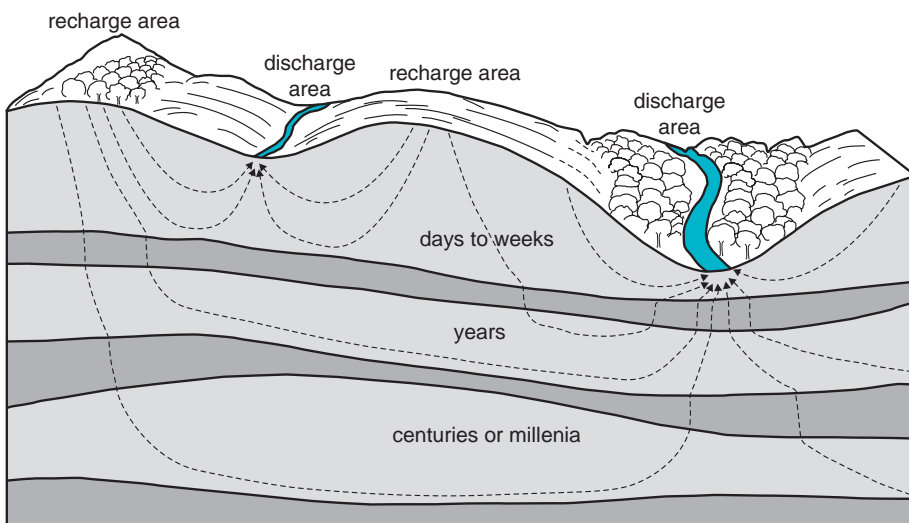


Figure 29 A region's groundwater flow system consists of its entire hydrogeologic setting. Water enters the groundwater flow system over the entire recharge area and moves through the system to discharge areas. The time it takes for groundwater to move through the groundwater flow system varies from days in the shallow flow system adjacent to the discharge area to thousands of years in the deepest flow system. (Modified from Heath 1989.)

A Refined Understanding of Groundwater Concepts

It is important to understand the difference between permeability and hydraulic conductivity. Permeability is the capacity of a sediment or rock to transmit any fluid through its interconnected pore spaces. Hydraulic conductivity is the capacity of a sediment or rock to transmit groundwater only.

A third term, transmissivity, refers to the total amount of groundwater that can be transmitted through the different types and thicknesses of all of the materials that make up an aquifer (fig. 30).

Figure 31 illustrates a few more groundwater concepts. Head is a general term that refers to the pressure exerted on a fluid. Hydraulic head, or *total head*, is the energy of groundwater at a given point in an aquifer. Three components make up hydraulic head: (1) *elevation head*, which is the height above sea level of the point in the aquifer at which head is being measured; (2) *pressure head*, which is produced by the weight of the earth materials and groundwater overlying the point; and (3) *velocity head*, which is the rate of movement of water in the aquifer. Because groundwater typically moves very slowly, velocity head is usually negligible.

The static water level in a well represents the hydraulic head in the interval of the aquifer to which the well is open. The potentiometric surface associated with an aquifer is represented by the static water levels of tightly cased wells completed in that aquifer. For an unconfined aquifer, the water table is the potentiometric surface of the aquifer. *Head loss* is a decrease in hydraulic head over distance. An example of head loss is the difference between static water levels in two wells at separate locations but open to the same aquifer. Hydraulic gradient is the change in head with a change in distance, either horizontally (fig. 31) or vertically (fig. 32). A vertical hydraulic gradient can be either upward (fig. 32a) or downward (fig. 32b), depending upon the direction of head loss.

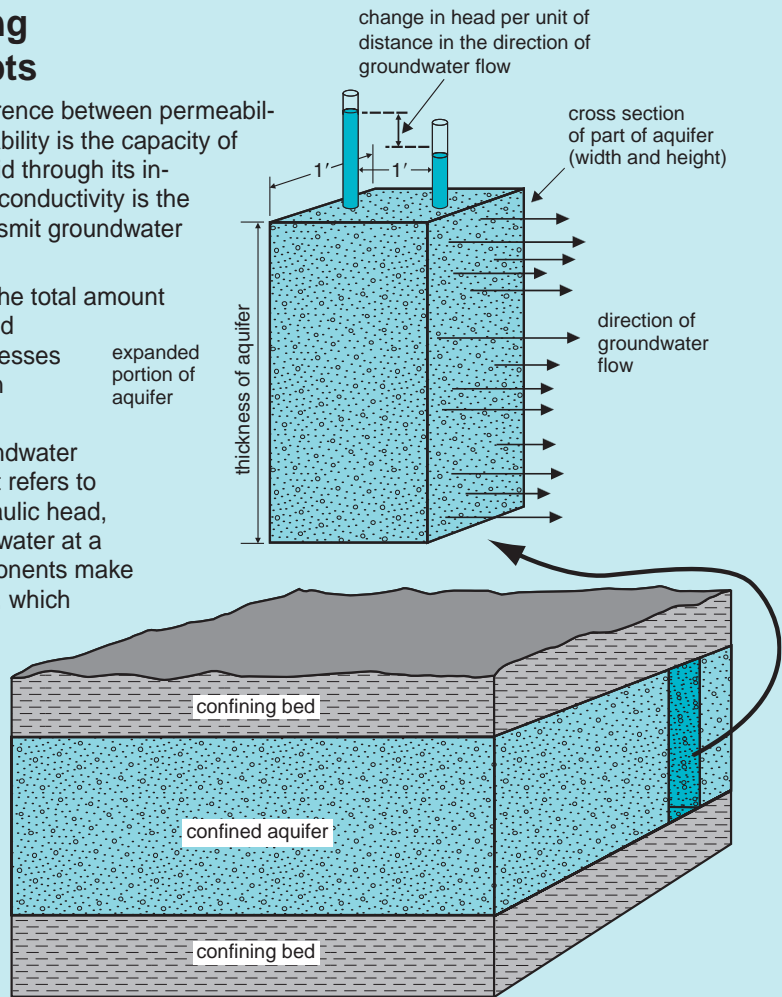


Figure 30 Transmissivity is the capacity of an aquifer to transmit groundwater. Transmissivity equals the hydraulic conductivity of each type of earth material present in the aquifer multiplied by the thickness of that type of earth material. (Modified from Heath 1989.)

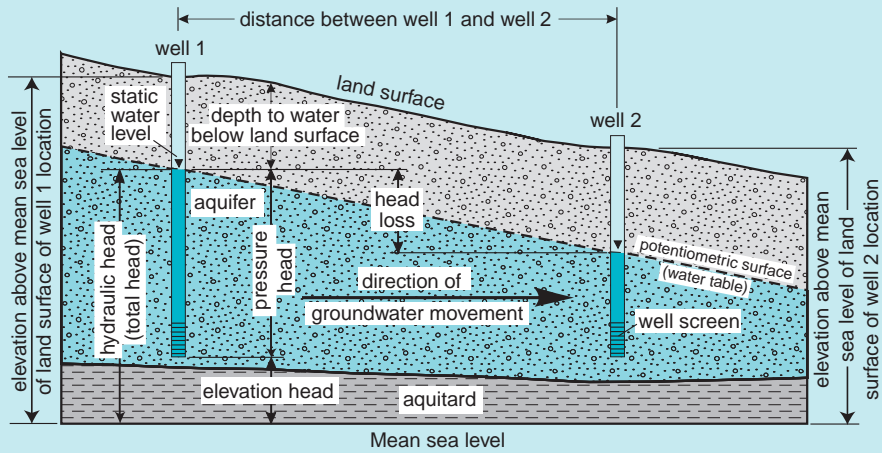


Figure 31 This sketch of an unconfined aquifer shows groundwater movement in the direction of decreasing hydraulic (or total) head. Horizontal hydraulic gradient is the change in head over a horizontal distance, such as the amount of head loss between wells 1 and 2.

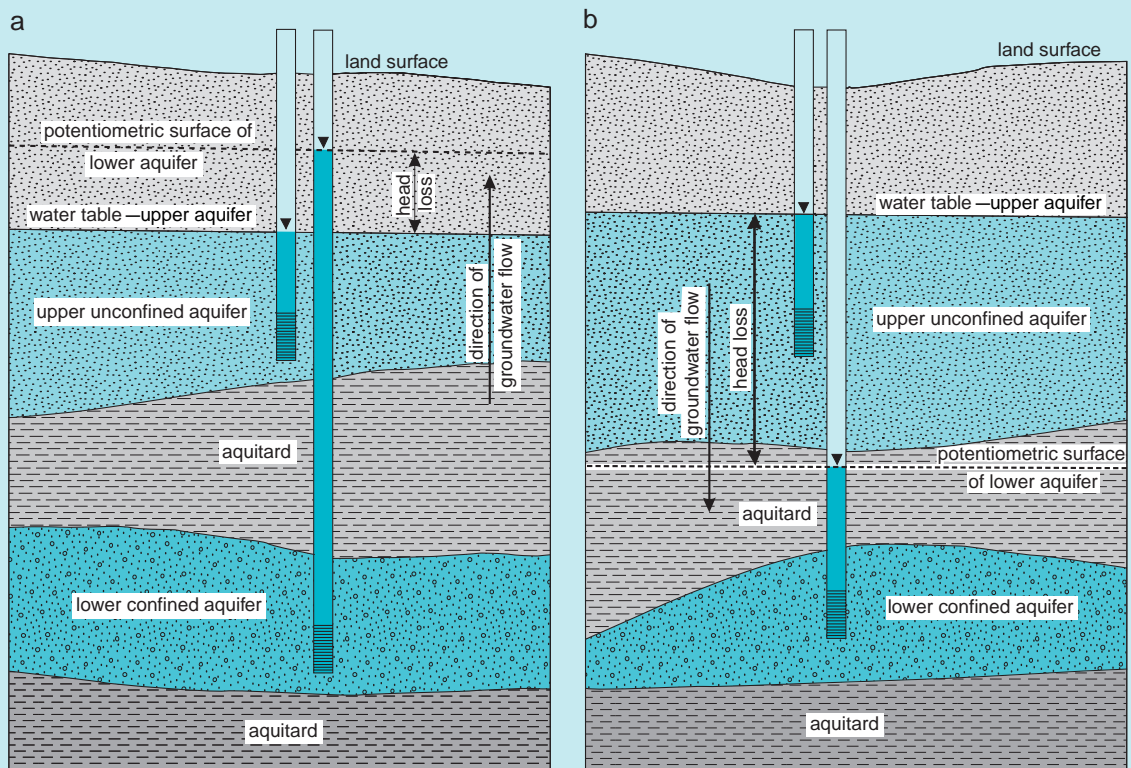


Figure 32 This sketch of an unconfined aquifer illustrates vertical hydraulic gradient, the change in head over a vertical distance at a given location. A vertical hydraulic gradient can be upward (a) or downward (b), depending on the direction of head loss.

Unlike surface water flowing in rivers or streams, groundwater moves very slowly because of friction between the water and the walls of the pore spaces or other small spaces in the sediment and rock. How much friction there is varies both laterally and vertically according to the type of sediment or rock. Groundwater flows rapidly where subsurface spaces are large, such as in the karst region of southern Illinois. Karst refers to a type of terrain characterized by *sinkholes*, caves, and underground drainage networks 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.

Recharge and Discharge

The portion of precipitation that reaches the zone of saturation replenishes groundwater in areas where the vertical hydraulic gradient is downward. These areas are called groundwater recharge areas, and water that flows into an aquifer is called aquifer recharge. Understanding groundwater and aquifer recharge and recharge areas is essential to using groundwater resources wisely and protecting those resources from contamination. Several factors influence where and how much recharge occurs:

1. **Precipitation** The timing, intensity, and duration of precipitation affect the amount of water available for recharge.
2. **Topography** Recharge generally occurs where the land surface is high. Groundwater generally flows toward topographic lows in the direction of a decreasing hydraulic gradient.
3. **Hydraulic properties** Earth materials with high hydraulic conductivity near the land surface allow rapid recharge from precipitation. The water moves quickly through such materials to the zone of saturation. Where earth materials of low hydraulic conductivity are at land surface, recharge is correspondingly slow.
4. **Unsaturated zone moisture content** When the amount of water in the unsaturated zone is high, recharge may occur more swiftly because the water has less distance to travel to reach the water table.

In groundwater discharge areas, an upward vertical hydraulic gradient provides the force for groundwater to overcome gravity (fig. 32a). Where the water table intersects the land surface, groundwater discharges to the land surface as springs or into rivers, streams, lakes, or wetlands.

Interactions

Because groundwater and surface water are both part of the hydrologic cycle, they should be thought of as an integrated resource. Groundwater discharge to rivers and streams contributes to their water flow. This discharge, which keeps these surface-water bodies flowing during the dry times of the year, is called *base flow*.

Springs are places where the water table intersects the land surface and groundwater flows from relatively distinct openings. Figure 33 illustrates the general settings of springs in Illinois. Springs form where the water table intersects depressions in the land surface (fig. 33a). They also appear where an aquitard inhibits the downward movement of groundwater, forcing the water to flow laterally until it intersects the land surface (fig. 33b). Springs may develop in sinkholes where the water table intersects the land surface (fig. 33c), such as in the karst areas of southwestern Illinois.

Wetlands are areas where surface water or groundwater is sufficient to provide for wet conditions in low areas of the landscape for at least part of a year (fig. 34). The wet conditions cause waterlogged (hydric) soils and support plants and animals that thrive in wet habitats. Wetlands that are saturated or that have open water during the summer typically are groundwater discharge areas, and the water table is at or near the land surface.

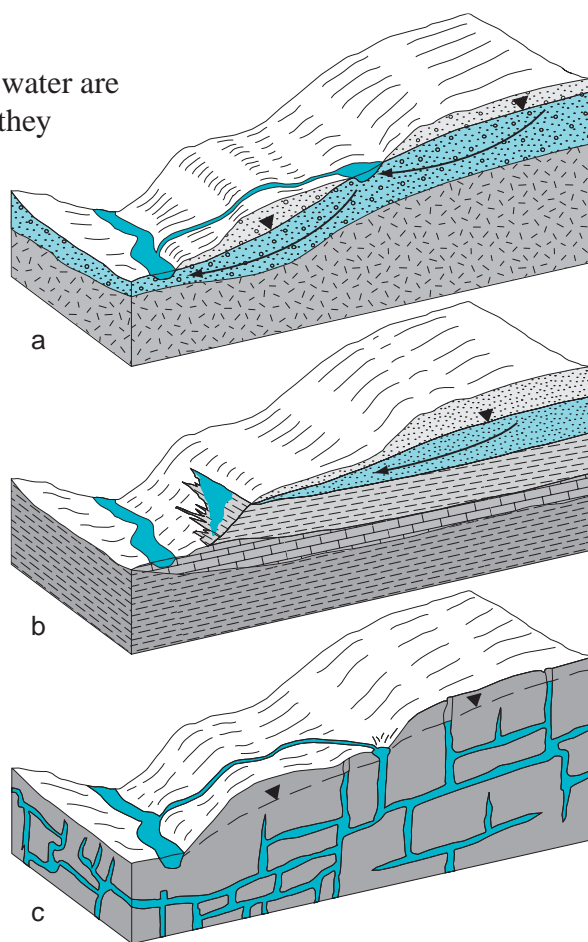


Figure 33 Springs form where the water table intersects the land surface. In Illinois this can be (a) in depressions in the land surface, (b) on the side of a valley where groundwater moves laterally along the top of a layer of relatively impermeable rock or sediment, or (c) in sinkholes.



Figure 34 A wetland in the Paul Douglas Forest Preserve in Cook County in northeastern Illinois. A wetland is an area where the water table is at or near the land surface for at least part of the year, where wet soils are prevalent, and where plants that thrive in wet habitats typically are found. (Photograph by David R. Larson.)

Groundwater Flow between Bedrock and Glacial Deposits

In Illinois, groundwater flows between bedrock and the glacial deposits overlying it. Understanding this movement is critical to understanding groundwater availability and groundwater protection issues. The direction of flow depends on the prevailing vertical hydraulic gradient. How easily groundwater moves between the two depends on the hydraulic characteristics of the bedrock and the glacial deposits that overlie it. Groundwater may flow relatively freely between the two where both have high hydraulic conductivity, such as where sands and gravels overlie limestone that has fractures or crevices. Groundwater flow may be restricted between the two in areas where a large difference in hydraulic conductivity exists.

How Much Water?

The amount of groundwater available for use as a water supply depends on a number of attributes. These attributes need to be understood in order to manage a groundwater resource wisely and to determine its long-term sustainability. Fundamental knowledge is needed to under-

stand the thickness, extent, hydraulic conductivity, and storage capacity of the aquifer; the volume and rate of recharge to and discharge from the aquifer; and the speed water can flow through the aquifer. Information also is needed about the thickness, extent, and distribution of aquitards.

Common Misconceptions

Common misconceptions about the nature of groundwater in Illinois are that groundwater exists in underground rivers and lakes, that it originates to the north of Illinois and flows southward, and that groundwater can be found by water witching.

Underground rivers and lakes Groundwater generally does not occur as underground rivers and lakes, even though those are popular terms used to describe the nature of the rocks, sediments, and physical conditions below the ground. The subsurface streams that do exist in Illinois are found only in specific geologic settings.

The rivers that carved the valleys in the bedrock surface of Illinois are now gone, and the valleys the rivers once flowed through are buried by glacial sediment. Because these bedrock valleys served as outlet channels for meltwater flowing from the glaciers, much of the glacial sediment in them is outwash. The outwash deposits are saturated and are excellent sources of water for those fortunate enough to be located over or near one of these valleys. Although the bedrock valleys do not contain underground rivers, they do contain aquifers. In the same way, there are no underground lakes, just groundwater in aquifers of various dimensions.

If massive water-filled cavities existed underground in Illinois, the rocks and sediments overlying those cavities would collapse or subside because of the lack of support when that water was pumped out. But vast areas of Illinois do not subside, and water well drillers do not find huge underground cavities—good indicators that underground rivers and lakes do not exist.

Small underground streams in limestone caves and subterranean mines are the only exceptions. The caves are so small compared with the thickness of the limestones and the vastness of the overlying landscape that they rarely collapse. Over long periods of time, however, dissolution of the limestone may enlarge a shallow cave, reducing support for the overlying rocks and soil. Without sufficient support, collapse occurs and a sinkhole forms. Karst areas contain a large number of sinkholes (fig. 35), and sinkholes often form small circular ponds.



Figure 35 Sinkholes dot the karst terrain of Monroe County in southern Illinois.

Northern origins A second misconception is that groundwater originates to the north and flows southward in subsurface rivers. It may be tempting to think of groundwater in Illinois as flowing in underground streams from as far north as Canada. Perhaps the number of larger rivers in Illinois that flow in a generally north-to-south direction brings this idea to mind, or perhaps the overall north-to-south orientation of features left behind by the Ice Age glaciers that advanced out of Canada into Illinois invites such speculation. Whatever its origins, this idea is not true.

Using information from extensive drilling of deep holes throughout Illinois and north of it, geologists have mapped the distribution of rocks and sediments to great depths. They learned that the rocks in the region differ from one another and that their continuity is interrupted by bedrock structures such as basins, domes, and faults. Studies show that groundwater moves along paths of different lengths (fig. 29), all of which are affected by the occurrence and distribution of rocks and sediments. Structures in the bedrock can alter, interrupt, or otherwise modify the longest flow patterns. Also, studies have shown that groundwater chemistry varies according to the nature of rocks and sediments that contain the water, that the chemistry of groundwater in Illinois is different from that in the regions north of Illinois, and that groundwater chemistry varies even from one aquifer to another in

Illinois. This variability shows that the aquifers are not continuous enough to allow groundwater to flow into Illinois from the north.

Water witching or dowsing The enduring tradition of water witching or dowsing suggests groundwater can be located by using a forked stick or other device (such as a wire coat hanger or rod, keys, pliers, or a pendulum) that appears to react to the water when a water witch, also called a diviner or dowser, walks across a buried “vein.” A successful water well that is drilled at a site selected by water witching reinforces the belief that this method “finds” water and that groundwater occurs in subsurface “veins.” Also, water witching focuses on finding a specific spot to drill a well. The adequacy of the supply, its long-term availability and quality, and the possible effects on nearby wells typically are not considered. A scientific method is more successful.

Managing Illinois’ groundwater resources for future generations requires mapping aquifers. Geologists use existing records or may conduct test drilling to find out about the types and layers of subsurface earth materials. The existing records of water wells, engineering tests, oil and gas wells, coal tests, and other test borings contain drillers’ logs that show the depths and types of sediment and rock encountered during drilling. The records may have information about depth to water. Geologists use these records to identify aquifers and aquitards within the glacial sediments or bedrock, correlate the sediment and rock types in an area in order to map the character and distribution of aquifers and aquitards, and characterize groundwater flow patterns by drawing potentiometric surface maps. Geologists then can answer questions about groundwater availability, well depths, pumping rates, effects on nearby wells, and groundwater contamination.

Groundwater Supply and Wells

Developing a Supply

The key to developing a site-specific groundwater supply is to determine whether any of the layers of rock or sediment present are aquifers that could furnish the amount of water needed on a long-term basis. Information must be gathered and analyzed about the presence and depths of aquifers and aquitards, the potential depth of the water level if a new well is drilled (which determines pump size and cost), the thickness, continuity, hydraulic properties, and condition of the aquifers and aquitards, and whether those formations are confined or unconfined. It then is possible to determine available groundwater amounts, calculate a pumping rate to provide a sustained yield from the well, and estimate the possible effects a new well may have on nearby wells.

A well is the most common means for developing a groundwater supply, whether the well is a low-capacity well for a house or a high-capacity well for a city, industry, or irrigation. Because groundwater is hidden from view, it is difficult to determine whether the water supply

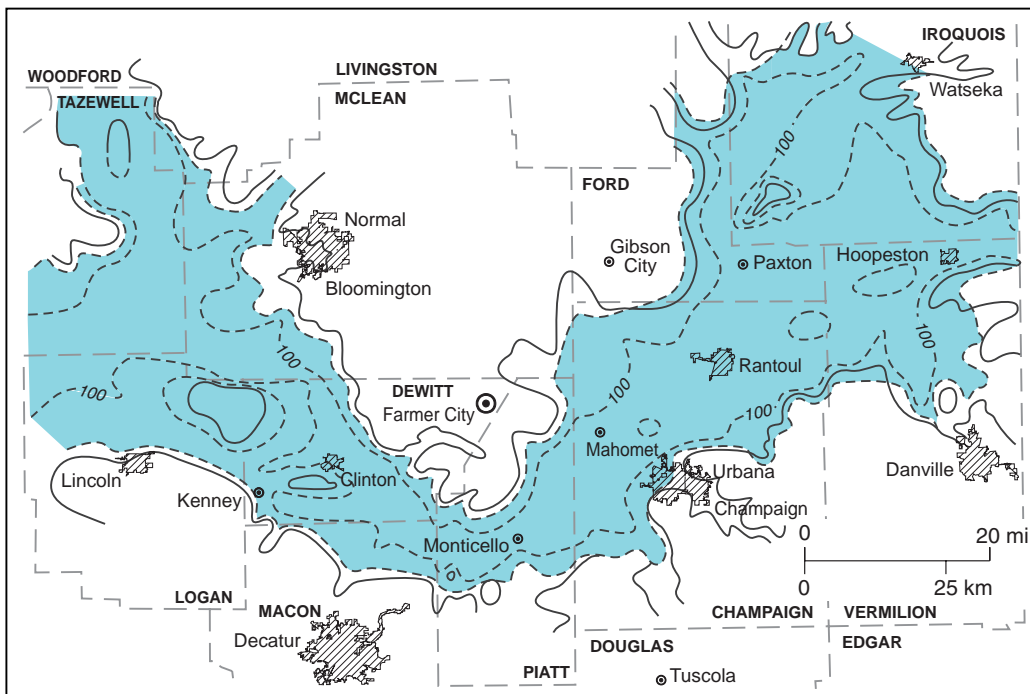


Figure 36 An example of a hydrogeologic map showing the thickness of the Mahomet aquifer located in central Illinois. Contours are in feet.

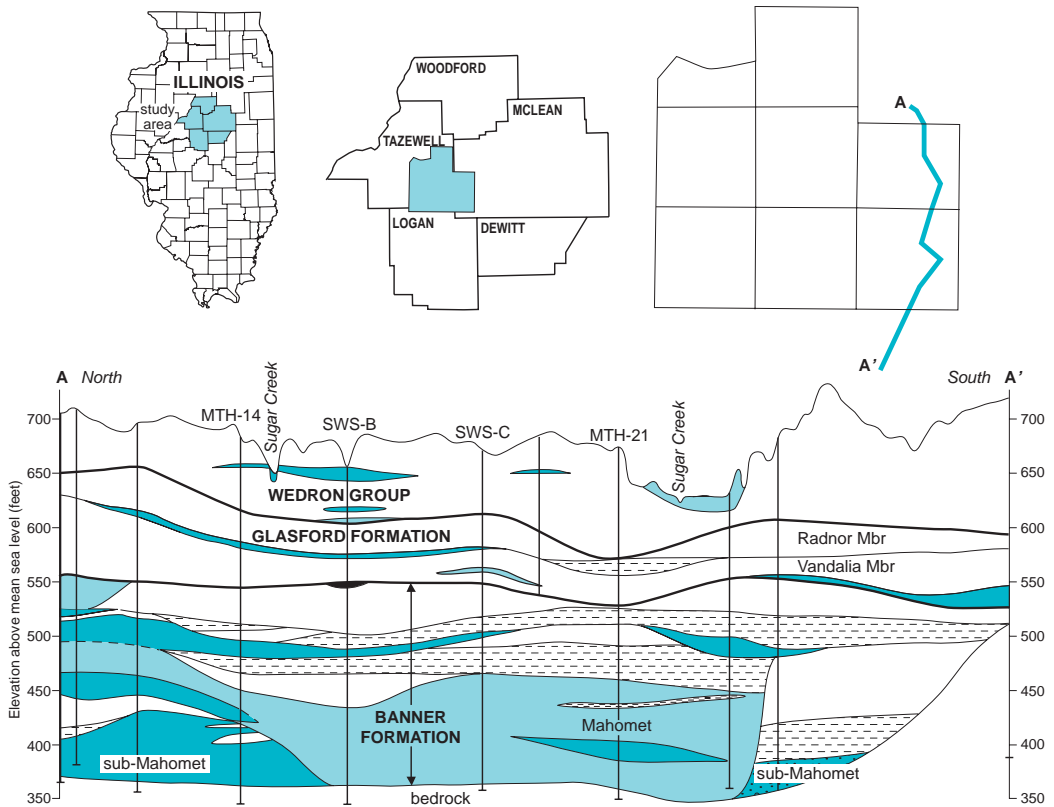


Figure 37 An example of a hydrogeologic cross section across southwestern McLean County in central Illinois showing the aquifers (blue) from the land surface to bedrock.

can be obtained at a particular location. Analyzing information about the subsurface hydrogeology of the location can increase the likelihood of drilling a successful well. The Illinois State Geological Survey has on file reports, maps, and records of water wells, engineering borings, and borings for coal, oil and gas drilled throughout the state. These are an excellent source of hydrogeological information, especially drillers' logs.

For a proposed domestic well, existing information may be adequate to determine the likely depth of any aquifer and the likelihood of obtaining an adequate supply. A proposed high-capacity well, or a well field of several such wells, requires a more detailed hydrogeologic analysis of the location and surrounding area, including an inventory of existing wells. Such an analysis generally includes developing hydrogeologic maps (fig. 36) and cross sections (fig. 37) based on existing information. The maps show features such as the distribution, thickness, or hydraulic properties of aquifers and aquitards across the area, or



Figure 38 ISGS scientists and drillers collect samples of earth materials during test drilling in the University of Illinois' Robert Allerton Park near Monticello. Test drilling is the only way to find out directly what lies below the land surface at a specific location.

the configuration of the potentiometric surface of an aquifer. Cross sections show a vertical slice through the hydrogeologic units from land surface to a selected depth. The complexity of the hydrogeology determines the number of maps and cross sections that are developed. Analysis of the maps, cross sections, and other available information may indicate that some of the information needs to be verified or that more information is required before the long-term sustained yield of the proposed well and the effects of pumping on nearby wells can be determined. Test drilling and geophysical methods are used to verify existing information or gather new information.

Test Drilling

Test drilling is the only way to find out directly what lies below the land surface at a specific location (fig. 38). The subsurface earth materials encountered are examined, and their type and characteristics are described. Samples may be collected for further evaluation. Drilling also reveals the sequence of layers of earth materials and the thickness, continuity, and variability of each layer. The information obtained from a test hole applies only to a small area adjacent to the test hole. A single test hole is usually all that is needed for a new domestic well.

If little information is available for a particular area or if the proposed development of a groundwater supply is extensive (such as installing one or more high-capacity wells), additional test holes are required to provide an understanding of the thickness, extent, physical characteristics, and hydraulic properties of aquifers in the area.

Geophysical Methods

Geophysical methods provide information about certain properties of an area's earth materials, including how easily sound waves or electrical currents pass through the materials or how much natural background radiation comes from each type of material. Geophysical surveys are conducted on the land surface within an area of interest. *Downhole geophysical logging* is conducted in wells and test holes.

Geophysical surveys allow information about the subsurface geology of an area to be collected fairly quickly. Seismic surveys and electrical earth resistivity (EER) surveys are especially helpful in groundwater investigations. During seismic refraction and reflection surveys, seismic energy is created by hitting the ground with a sledgehammer or by setting off a small charge of dynamite (fig. 39). The energy radiates in all directions into the subsurface and travels at different rates through different types of earth materials. For example, the energy travels faster through till and bedrock than it does through sand and gravel. Some of the energy is *refracted* or reflected by a surface between two earth materials with contrasting seismic velocities, such as the bedrock surface, and returned to the land surface. The time it takes for the seismic energy to travel from the energy source to the underground

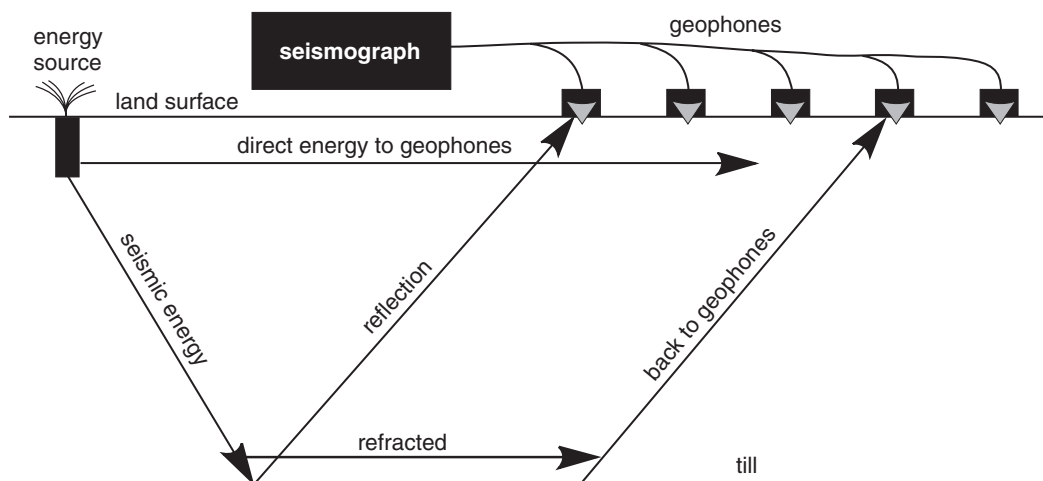


Figure 39 Schematic drawing of the seismic survey method.



Figure 40 ISGS geologist records information obtained by a sonde as part of a downhole geophysical logging project near Benton, Illinois.

surface and back to the land surface is measured with a series of *geophones* (fig. 39) placed on or in the ground in a line starting at the energy source. The geophones detect seismic energy and change it into electrical energy that can be sent to a recording device. The recorded information is used to calculate the depth of the surfaces, such as the depth to bedrock.

During EER surveys, a weak electrical current is introduced into the subsurface, and the resistance to the current is measured. Because of differences in electrical resistance, an EER survey helps determine the depth and extent of sand and gravel layers, which have higher resistance than glacial till. The results from these two types of geophysical surveys done before test drilling are useful in helping hydrogeologists select the locations for test drilling. The results from surveys performed after test drilling help confirm the information obtained from the test holes and assist hydrogeologists in applying the information across the area of investigation.

Downhole geophysical logging involves lowering devices called *sondes* into a test hole or well in order to measure various properties of the adjacent earth materials (fig. 40). Downhole logging may provide a more detailed record of how the properties vary with depth. The depths at which the changes occur than can be obtained using most

conventional drilling techniques. Descriptions of earth materials, recorded as the test hole is drilled, can be enhanced by downhole geophysical logging. Details about test holes spaced throughout an area are used to help interpret variations in physical properties of the earth materials across the area.

Two Well Types

After an aquifer is found that can yield enough water to supply requirements, a well is constructed (fig. 41) according to the specifications given in the *Illinois Water Well Construction Code* published by the Illinois Department of Public Health. The code is available online (www.idph.state.il.us/).

Drilled wells (fig. 42) and large-diameter bored wells are the two types approved by the *Illinois Water Well Construction Code*. The diameter of drilled wells depends in part on the amount of water needed. Domestic wells usually are 4 to 6 inches in diameter. High-capacity wells used for municipal, industrial, or irrigation supplies may be 30 inches or more in diameter. A well completed in a glacial drift aquifer (sand or sand and gravel) typically has a casing and screen (fig. 41). The casing, which is usually plastic or steel pipe, keeps the surrounding earth materials from collapsing into the well. The well screen keeps the sand and gravel of the aquifer out of the well. Water flows into the well through holes in the well screen. For bedrock aquifers, the well casing is typically set a short distance into the bedrock to keep unstable, overlying sediments from collapsing into the well. A well casing and screen usually are not put into the borehole in the bedrock because the surrounding rock is generally solid and will not collapse.

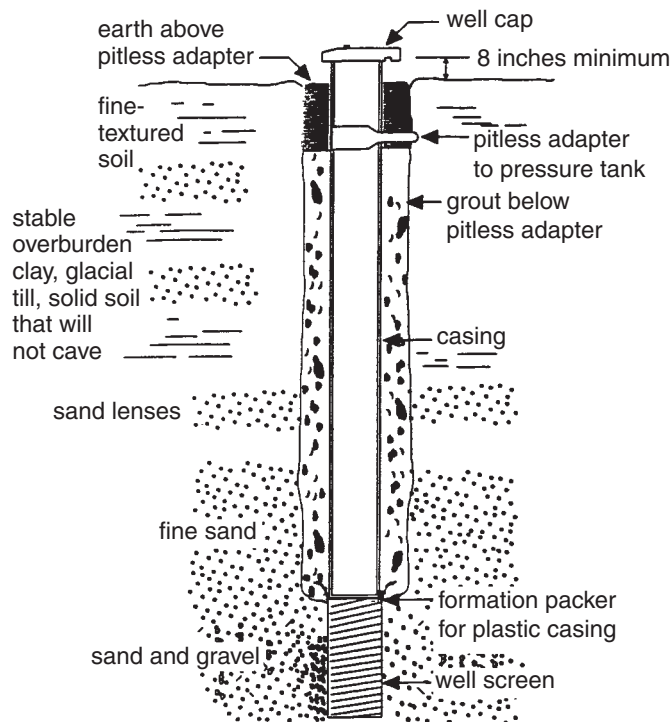


Figure 41 Illinois Department of Public Health guidelines for a well completed in a glacial drift aquifer. (Modified from the *Illinois Water Well Construction Code*.)



Figure 42 Workers drill a small-diameter water well in Champaign, Illinois.

Large-diameter, bored wells typically have diameters of 2 to 4 feet. These wells generally are shallow and used for domestic supplies. The large-diameter borehole is lined with precast concrete tile or other approved casing material. The well can be constructed with a buried concrete slab (fig. 43a) or without one (fig. 43b). This type of well is essentially an underground storage tank for water and is commonly used in areas where fine-grained materials are prevalent. Groundwater slowly seeps into the well from thin seams of saturated sand or fractures in the adjacent fine-grained material. Water may be pumped until the volume stored in the well is exhausted. Water can be pumped again only after groundwater seepage has replenished the well. A large-diameter well works satisfactorily as long as the demand for water doesn't exceed well storage capacity or the rate groundwater flows into the well.

After a well has been properly constructed and developed, it is tested to see how much water it will produce and how efficiently it does so. Well yield, measured in gallons per minute, and the decline in the water level in the well from the static water level (*drawdown*),

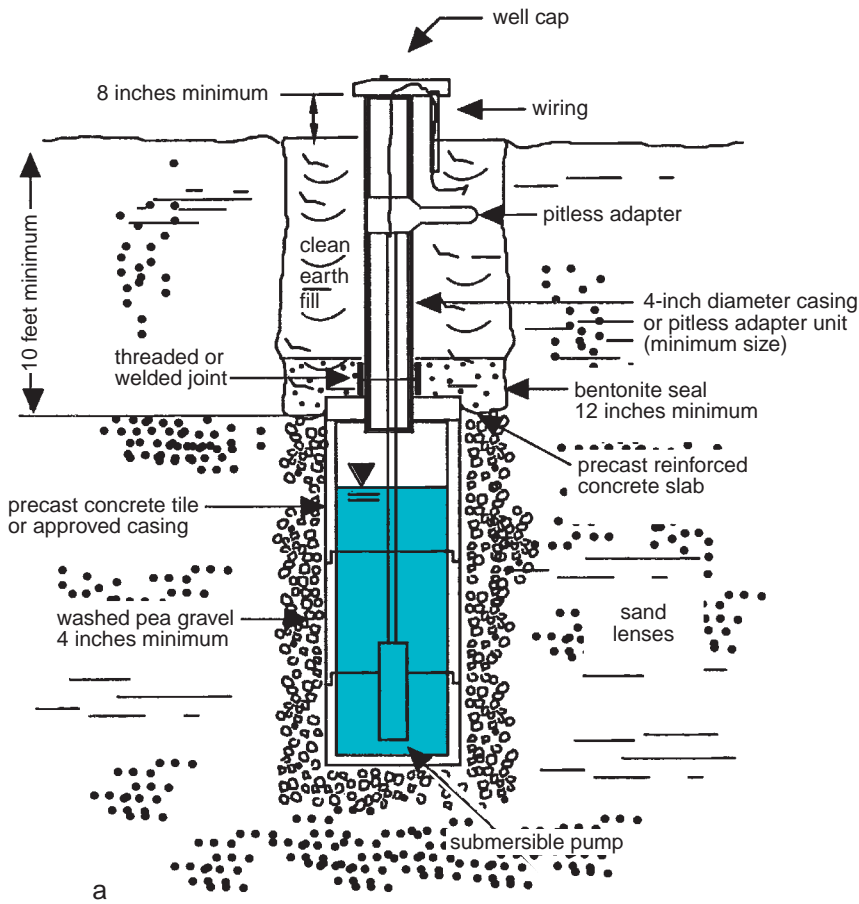
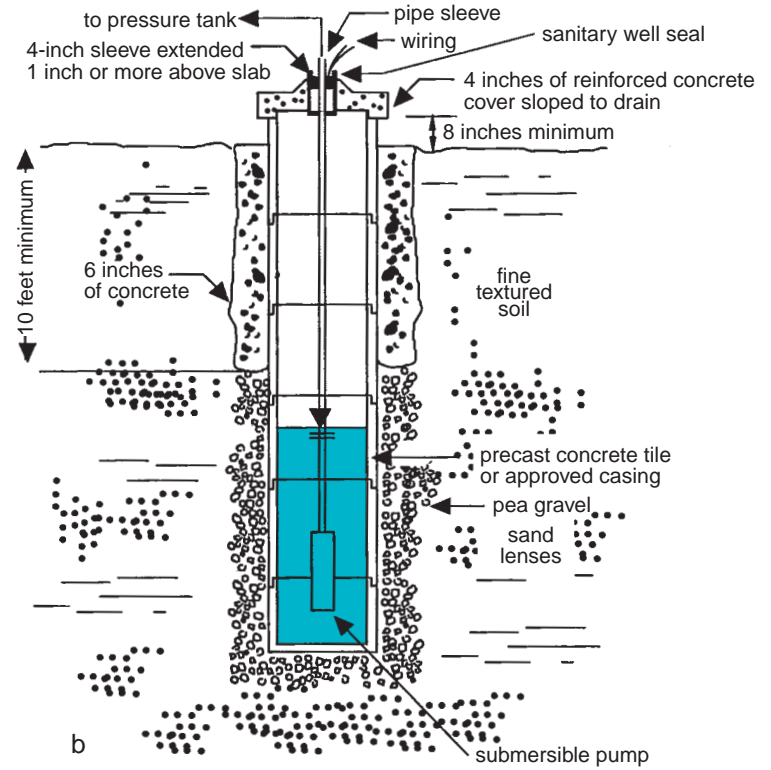


Figure 43 (a) Large-diameter, bored well constructed with a buried concrete slab. (b) Large-diameter, bored well constructed without a buried slab. The large-diameter casing extends above the land surface. (Modified from Illinois Department of Public Health's *Illinois Water Well Construction Code*.)



measured in feet, are carefully recorded. *Specific capacity*, a measure of the well's performance, is obtained by dividing the well yield by the drawdown (fig. 44). Because specific capacity generally decreases with time as the drawdown increases, the number of hours the well was pumped before the drawdown was measured should be reported. Several factors may affect the specific capacity of a well, notably well efficiency and aquifer productivity. Well efficiency, which relates to the amount of water the well yields compared with the amount of drawdown, affects how much energy it takes to pump water from the well. Well efficiency is maximized by designing and constructing a well so that it yields the desired amount of water with the least amount of drawdown.

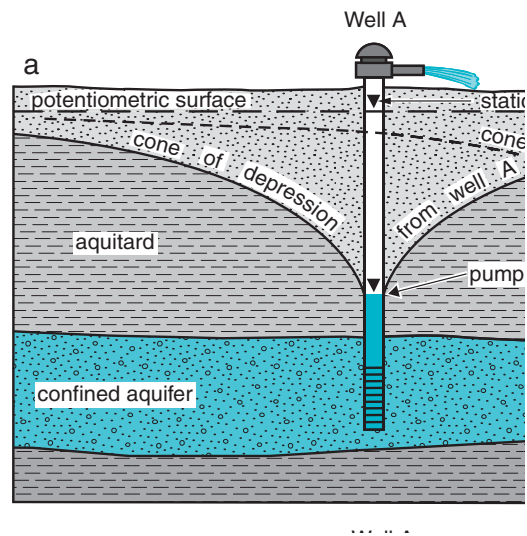


Figure 44 Specific capacity is a measure of a well's performance. It is calculated by dividing the well yield by the drawdown.

Groundwater Movement to a Well

When water is pumped from a well, the water level in the well lowers relative to the potentiometric surface of the surrounding aquifer. This difference in head creates the hydraulic gradient toward the well that causes groundwater to flow from the aquifer into the well. As pumping continues, a *cone of depression* in the potentiometric surface of the aquifer develops around the well and extends some distance from it (figure 45a). The shape and extent of the cone of depression depend on the rate and duration of pumping, whether the aquifer is unconfined or confined, and the hydraulic properties of the aquifer. If the cone of depression from one pumping well intersects that of another pumping well, drawdown in both wells is increased. This phenomenon is called well interference. If wells are located too closely together, well interference can add significantly to the drawdown in all of the wells (fig. 45b).

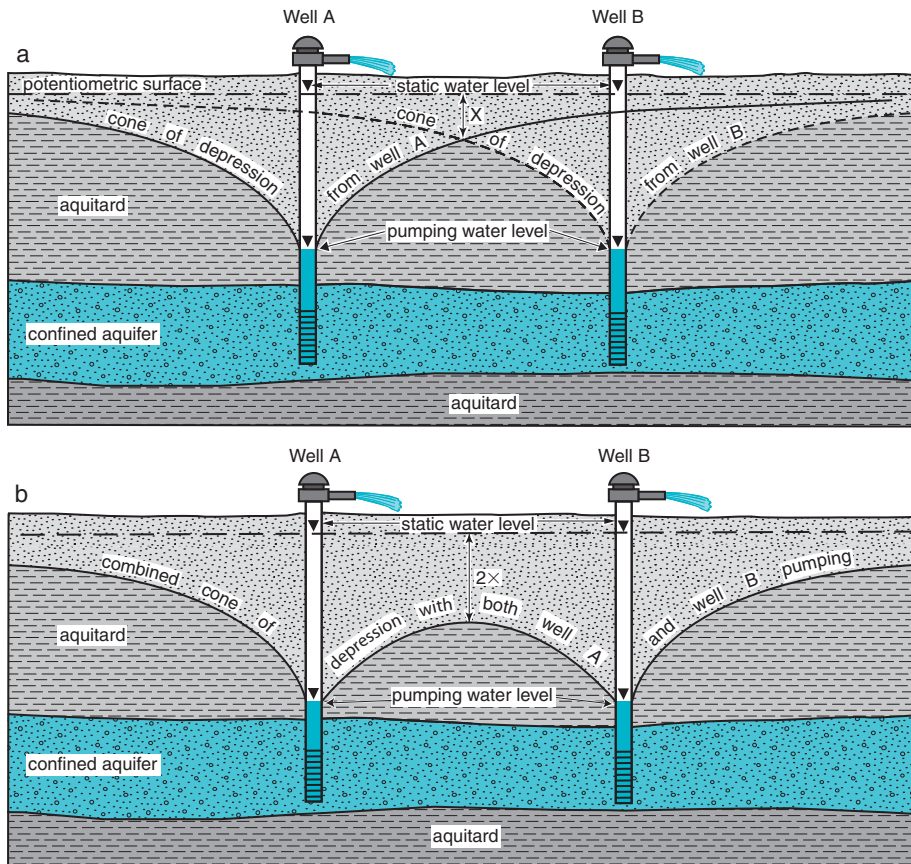


Figure 45 A cone of depression (a) develops around a pumped well. Well interference is the intersection of the cone of depression of a pumped well with that of another pumped well, increasing the drawdown in both wells and changing the shape and extent of the cone of depression (b).

Groundwater Quality

The suitability of groundwater for various uses is determined mostly by its chemical properties, such as the kind and amount of dissolved minerals present, and its biological properties, such as the presence of harmful bacteria or pathogens. To a lesser extent, suitability is determined by the water's physical properties, such as temperature, turbidity, and odor. Criteria for acceptable water quality depend on use. For example, groundwater quality parameters important in domestic use are *hardness* and the concentrations of calcium, magnesium, sodium, iron, manganese, sulfate, chloride, fluoride, and nitrate. The presence or absence of pesticides and other agricultural and industrial chemicals is an important indicator of groundwater contamination from sources at or near the land surface. Nitrate and arsenic may cause health problems, so the maximum allowable levels for drinking water have been

set at 10 milligrams of nitrate-nitrogen per liter and 10 micrograms of arsenic per liter.

After a well has been installed and properly developed, a sample of the groundwater is collected and analyzed to determine its quality (fig. 46). The results of this analysis help to establish the suitability of the water for its intended use, to identify problems that may arise, and to suggest treatment options.

The Illinois Department of Public Health requires minimum lateral distances between a well and contamination sources in order to minimize the possibility of well contamination. The department requires that a water sample from the well be tested for *coliform bacteria* to show that the well and the water meet sanitary standards. A well must be disinfected if coliforms are found. Periodic testing for coliforms ensures that the water will continue to be safe to drink. If a recurrence is found, additional investigation into the sources of the bacteria is warranted.

Analysis of the water sample also shows if a water softener is needed to reduce hardness or if the water might stain plumbing fixtures or laundry because of iron and manganese. The water sample should be analyzed for pesticides or other man-made chemicals if their presence is suspected.

Publications available from the Illinois Department of Public Health and the Office of Extension and Outreach at the University of Illinois are excellent sources of information about Illinois groundwater quality and protection. For communities using groundwater, the Illinois Environmental Protection Agency administers a wellhead protection program to help communities minimize the contamination potential of their wells.



Figure 46 ISGS geochemist tests water flowing from a yard hydrant on a farm in Logan County. The water is pumped from a well that supplies water to the farm.

Well Maintenance

Wells require upkeep. Problems with wells usually show up as a decline in well yield or a change in water quality. One of the main causes for declining yield is bacteria or algae clogging the well screen or adjacent aquifer. Screen openings may be widened by corrosion, which allows sediment to enter and plug the well. Mineral matter may be deposited across the screen openings (fig. 47), or fine-grained sediment may be drawn next to the well screen because the well is overpumped and the water flows through the screen too fast. Bacteria, algae, and other organisms can affect water quality by imparting off-flavors or odors to the water or by generating hydrogen sulfide gas.

Well yield can be maintained by disinfection, chlorination, or the use of other chemicals to remove bacterial and algal growths or dissolve encrusting mineral matter on well screens. Pumping a well at its designed rate means groundwater will enter the well slowly enough that fine-grained sediment is unlikely to move into the well and mineral matter is not likely to be deposited on the screen.

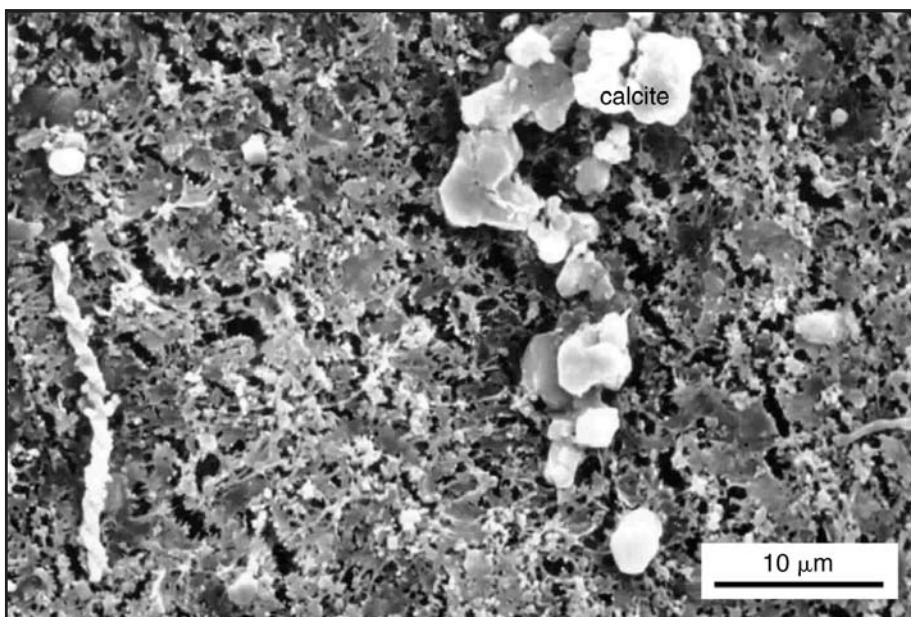


Figure 47 A scanning electron microscopic image of calcite crystals that grew on the screen of a high-capacity production well in the Mahomet aquifer. Bacteria and calcite deposits growing on the screen reduced the productivity of the well. (Image by Samuel V. Panno.)

Abandoned Wells

An abandoned water well is one that is no longer used to supply water or is in such a state of disrepair that it has the potential for transmitting contaminants into the groundwater or otherwise threatens the public health or safety. Abandoned wells are found throughout Illinois in rural, suburban, and urban settings as well as in industrial and commercial areas. Water wells are abandoned for a variety of reasons. Old windmills dot the rural landscape, showing where farmsteads once may have stood and where an abandoned well may be located (fig. 48). In growing suburban areas, new distribution systems supply water formerly obtained from individual wells that now may be abandoned and forgotten.

Abandoned large-diameter wells and cisterns threaten public safety because humans and animals can fall into them. Abandoned wells are a source of groundwater contamination because they provide pathways for surface water and contamination to move directly into aquifers. Any substance that can be dissolved, mixed, or carried in water can pollute groundwater through an abandoned well. Such wells offer tempting but illegal and totally unacceptable places to dispose of liquid and solid wastes.

The *Illinois Water Well Construction Code* requires abandoned wells to be sealed. If a well that supplies potable water is found to have been contaminated by an abandoned well, the owner of the abandoned well is responsible for providing a safe and sufficient supply of water to the owner of the contaminated well. Further information about abandoned wells and requirements to seal them properly can be obtained from the Illinois Department of Public Health. The code is available online (www.idph.state.il.us/).



Figure 48 The sun sets behind a windmill in Coles County. Commonly used to pump well water, such old, inactive windmills often mark the location of abandoned wells.

Conclusion

Clearly, Illinois citizens need to understand groundwater, a resource that is vital to them and the state's economic and environmental well-being. Illinois' groundwater resources, although plentiful, are finite and are not distributed uniformly across the state. Groundwater must be integrated into water resource planning in order to be wisely managed as future demand for water increases.

Because more land-use decisions that affect water resources are being made each year, managing the state's groundwater for long-term sustainability and protecting it from various polluting activities become ever more important. Everyone—especially those involved in industry, commerce, government, and education—must become more aware of how critical groundwater is to Illinois to ensure that informed decisions are made to manage and protect this resource.

Information Sources

Information about Illinois groundwater resources and protection can be obtained from several sources:

Illinois State Geological Survey
615 East Peabody Drive
Champaign, IL 61820-6964
217/333-4747
<http://www.isgs.uiuc.edu>

Illinois Department of Agriculture
P.O. Box 19281
State Fairgrounds
Springfield, IL 62794-9281
217/782-2172
800/273-4763 (toll free in Illinois)
<http://www.agr.state.il.us/>

Illinois Department of
Natural Resources
One Natural Resources Way
Springfield, IL 62702-1271
217/782-6302
<http://dnr.state.il.us/>

Office of Water Resources
Illinois Department of Natural Resources
3215 Executive Park Drive
Springfield, IL 61703
217/782-0690
http://dnr.state.il.us/owr/OWR_index.htm

Illinois Department of Public Health
535 West Jefferson Street
Springfield, IL 62761
217/782-4977
<http://www.idph.state.il.us/>

Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820
217/244-5459
<http://www.sws.uiuc.edu/>

Illinois Water Well Sealing Coalition
<http://dnr.state.il.us/orep/inrin/eq/well/trial.htm>

College of Agricultural, Consumer,
and Environmental Sciences
University of Illinois Extension
214 Mumford Hall
1301 West Gregory Drive
Urbana, IL 61801
217/333-5900
<http://www.extension.uiuc.edu>

Illinois Association of Groundwater
Professionals
P.O. Box 5378
River Forest, IL 60305
708/386-1566 or 800/990-2209
<http://www.iagp.org/>

For More Information

These publications provide general information related to groundwater, groundwater protection, and the geology of groundwater resources of Illinois.

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- Groundwater—A Primer for Pennsylvanians, undated: University Park, Pennsylvania, Pennsylvania State Cooperative Extension, 12 p.
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- Heath, R.C., 1989, *Basic Ground-Water Hydrology*: Denver, Colorado, U.S. Geological Survey, Water-Supply Paper 2220, 84 p.
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Glossary

The following definitions are adapted from a variety of sources, including the American Geological Institute's *Glossary of Geology*; the Ohio Environmental Protection Agency's *Groundwater*; U.S. Geological Survey poster *Groundwater: The Hidden Resource*; and U.S. Geological Survey *Water-Supply Paper 2220, Basic Ground-Water Hydrology*.

- anticlinorium** A composite structure of bedrock arches of regional extent.
- aquifer** A body of saturated rock or sediment that yields useful quantities of groundwater to wells or springs. See also *confined aquifer* and *unconfined aquifer*.
- aquitard** A body of saturated rock or sediment of low permeability that slows water transmission to or from an aquifer.
- artesian** An adjective referring to the hydrostatic pressure on groundwater in a confined aquifer.
- artesian pressure** See *hydrostatic pressure*.
- base flow** The portion of the flow in streams or rivers that comes from groundwater discharge and that keeps them flowing during dry periods.
- capillary force** The upward attraction of water molecules in the capillary fringe from surface tension at the edges of the water molecules and between water molecules and soil particles.
- capillary fringe** The lowest part of the unsaturated zone immediately above the water table where water is drawn upward by capillary force.
- coliform bacteria** A family of organisms whose presence in groundwater indicates fecal contamination.
- cone of depression** A cone-shaped depression in the water table (unconfined aquifer) or the potentiometric surface (confined aquifer) created by pumping water from a well.
- confined aquifer** An aquifer bounded by aquitards above and below it.
- confining unit** See *aquitard*.
- correlate** To tie together similar types of geologic structures or formations in separate locations on the basis of physical characteristics and stratigraphic position.

- discharge** Groundwater movement between aquifers; or from an aquifer to the land surface through wells, springs, or seeps; or into lakes, streams, and wetlands.
- 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.
- drawdown** A lowering of the water table (in an unconfined aquifer) or the potentiometric surface (in a confined aquifer) caused by pumping groundwater from wells.
- elevation head** A measure of the hydrostatic pressure above some reference point, usually sea level.
- embayment** Formation of a bay; a bay.
- geophone** A device placed on or in the ground that detects seismic energy and changes it into electrical energy that can be sent to a recording device.
- glacial drift** A general term for all rock material carried and deposited by glaciers or glacial meltwater.
- groundwater** Water found in the earth below the water table.
- hardness (water)** A property of water, caused mainly by calcium and magnesium ions, to form an insoluble residue or scum when used with soap.
- head (hydraulic head, total head)** The elevation to which water rises as a result of pressure.
- head loss** The decrease in hydraulic head between two points.
- hydraulic conductivity** The rate of water flow volume 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 (see *head*) with a change in distance in the direction of groundwater flow. For an unconfined aquifer, this is the slope of the water table. Hydraulic gradient has horizontal and vertical components.
- hydraulic head** See *head*.
- hydrostatic pressure** The pressure exerted by the water at any given point in a body of water at rest. The hydrostatic pressure, also called

artesian pressure, of groundwater is generally due to the weight of overlying water and earth materials.

igneous rock When molten rock (magma) cools and crystallizes.

percolate, percolation The slow movement of water into and through soil, sediment, or rock.

permeability, permeable The capacity or property of a rock, sediment, or soil to transmit fluid.

porosity The volume of empty space in a rock or sediment, such as cracks, pores, or other types of voids, in relation to the total volume.

potable Suitable for drinking.

potentiometric surface A surface represented by the level to which water will rise in tightly cased wells. The water table is the potentiometric surface for an unconfined aquifer.

pressure head The height of a column of liquid supported by pressure at a point in the liquid.

recharge The addition of water to the saturated zone.

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

relief The general unevenness of Earth's surface. The vertical difference in elevation between hilltops and valleys of a given region. An area showing little variation in elevation has low relief.

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

saturated zone The zone below the land surface where all openings in the soil, sediment, or rock are filled with water.

sedimentary rock A rock formed by the accumulation and lithification of sediment.

sinkhole A general term for a closed depression in a karst region that is formed by near-surface limestone completely dissolving away or the collapse of the limestone into underlying caves.

sonde A device lowered down a test hole or well by a cable in order to acquire a well log, a reading of the physical properties of the adjacent rock or earth materials.

- specific capacity** The yield of a well per unit of drawdown, commonly expressed in gallons per minute per foot of drawdown.
- static water level** The water level in a well that has not been pumped recently. The level at which pressure on the groundwater is the same as atmospheric pressure.
- total head** See *head*.
- unconfined aquifer** An aquifer that rests on top of an aquitard but that is not bounded on top by a confining layer. The water table indicates the top of the aquifer.
- unsaturated zone** The zone immediately below the land surface where pore spaces or fractures contain both air and water; also called the zone of aeration or the vadose zone.
- velocity head** Groundwater head resulting from water movement.
- water table** The level below which the soil, sediment, or bedrock is saturated with groundwater; the top of the saturated zone.

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.

Illinois State Geological Survey
615 East Peabody Drive
Champaign, Illinois 61820-6964
(217) 333-4747
<http://www.isgs.uiuc.edu>

Equal opportunity to participate in programs of the Illinois Department of Natural Resources (IDNR) and those funded by the U.S. Fish and Wildlife Service and other agencies is available to all individuals regardless of race, sex, national origin, disability, age, religion, or other non-merit factors. If you believe you have been discriminated against, contact the funding source's civil rights office and/or the Equal Employment Opportunity Officer, IDNR, One Natural Resources Way, Springfield, Illinois 62702-1271; 217/785-0067; TTY 217/782-9175.

This information may be provided in an alternative format if required. Contact the IDNR Clearinghouse at 217/782-7498.