Iowa's Groundwater Basics

Iowa Department of Natural Resources

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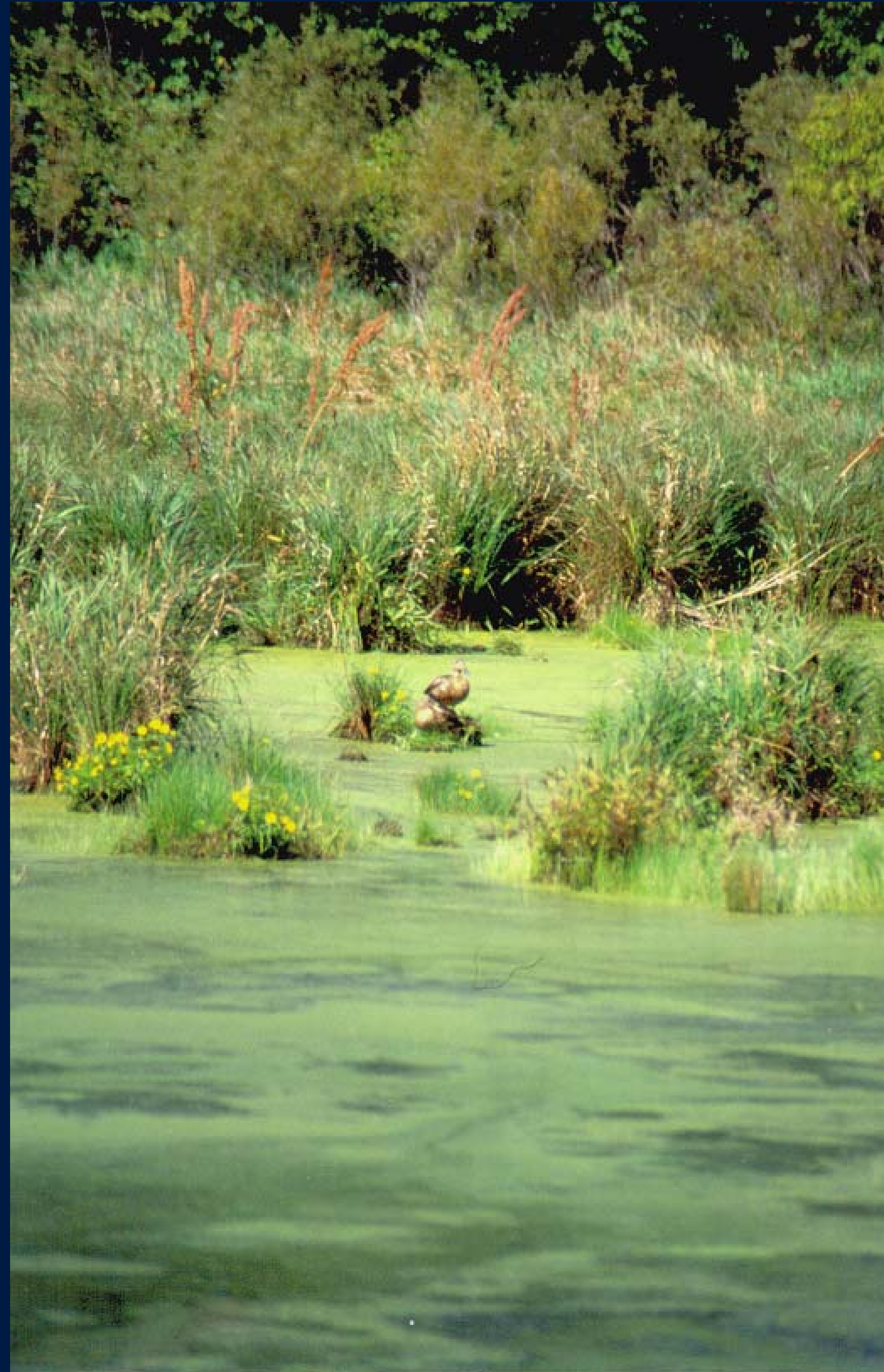
A geological guide to the occurrence, use, & vulnerability of Iowa's aquifers.



IOWA'S GROUNDWATER BASICS

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This guide summarizes our present understanding of Iowa's groundwaters. The information is derived from and is an acknowledgement of many years of data collection from cooperating drillers throughout Iowa as well as years of analysis and interpretation by geologists and hydrologists of the Iowa Geological Survey and U.S. Geological Survey, Iowa District Office.

The need for a publication to promote public awareness, understanding, and protection of Iowa's groundwater resources has existed for many years. Michael Burkart, originally with the U.S. Geological Survey, assisted with the earliest draft outline. Iowa Geological Survey geologists Edward Nealson, Robert Rowden, and Lynette Seigley worked on beginning drafts. Keith Schilling and Michael Gannon provided helpful discussions on technical and organizational aspects. Co-authors Janice Boekhoff, Mary Howes, Robert Libra, and Paul VanDorpe met periodically as the publication took shape and produced drafts of several current chapters and many of the maps and tables. Brian Witzke compiled and interpreted the three new stratigraphic cross-sections of Iowa that appear in this book. Mary Howes was instrumental in preparing ArcView maps for publication. Deanna Thomann colorized digital images of previously hand-drawn illustrations. Patricia Lohmann's clean design and graphics do an excellent job of presenting our material to the reader.

The publication benefited from outside reviews by Donald Koch, State Geologist (retired); James Caldwell of the U.S. Geological Survey; Thomas Glanville of Iowa State University; Diane Joslyn of Aquadrill, Inc.; Ubbo Agena and Marie Leat of the Iowa Department of Natural Resources (IDNR), Nonpoint Source Program, and Michael Murphy and Randall Clark with the IDNR Legal Services; and Michael Burkart of the National Soil Tilth Laboratory. Valuable internal reviews were provided by Greg Ludvigson, Janice Boekhoff, Calvin Wolter, Patricia Lohmann, and Michael Gannon, members of the Iowa Geological Survey Editorial Committee, as well as the co-authors. Proof-reading assistance was provided by Donald Koch, Lynette Seigley, and Jill VanDorpe.

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Front cover photo:
The groundwater table in Iowa, usually hidden from view, forms the surface of Iowa's wetlands, lakes, and streams. Wetlands replenish groundwater supplies, improve water quality through filtration, provide storage to reduce flood risks, and furnish habitat for nesting waterfowl. (Cerro Gordo County)

Back cover photo:
A valuable means of protecting water quality in Iowa is to buffer surface waters with permanent vegetation. This early spring burn, at dusk, is designed to encourage a restored section of prairie. (Story County)

Photos by Clay Smith.

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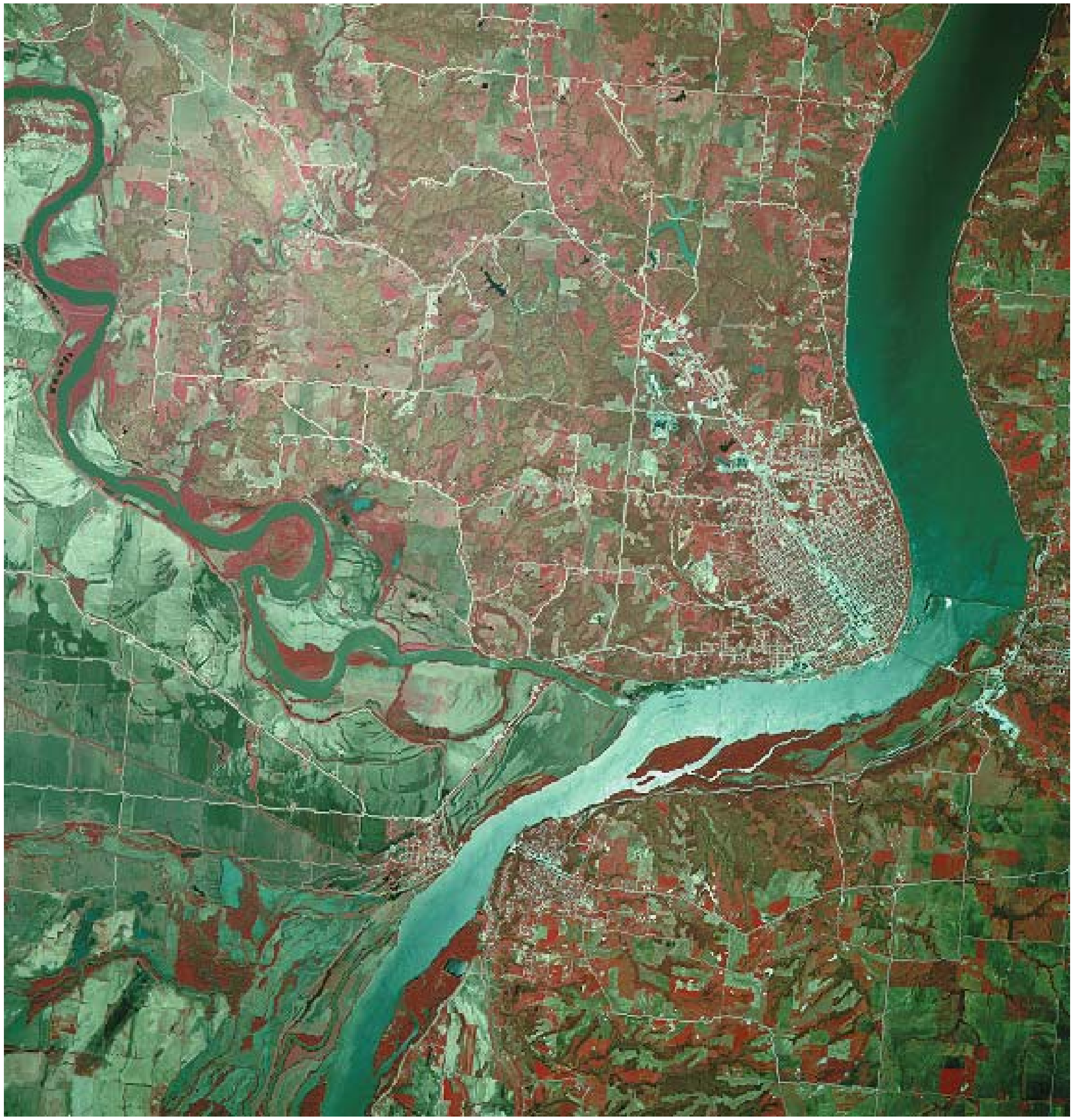


The Mississippi River (right) is joined by the meandering Des Moines River (left) at the southeastern tip of Iowa, near Keokuk. The state's rivers are fed not only by runoff from the land surface but also by groundwater discharge to their channels. The interactions between surface water and groundwater play a major role in the quality of water supplies in Iowa as well as those downstream. (May 10, 1978 color-infrared photo; altitude 40,000 ft.)

PREFACE

"At this stage in the . . . history of Iowa when a larger number of water works are being built than ever before, . . . there is need of specific and authoritative information as to the aqueous treasures of the rocks."

– William Harmon Norton
Artesian Wells of Iowa, 1897

The fate of any farmstead or community in Iowa is tied to an adequate supply of fresh water. The most frequent questions asked of the Iowa Geological Survey are about groundwater – that vital, but hidden, natural resource that supplies 80 percent of Iowans with their drinking water. As important as groundwater is to our state, most people are unaware of the underground conditions that supply water to wells and, in turn, affect its vulnerability to contamination. ***Iowa's Groundwater Basics*** takes a statewide, in-depth look at Iowa's groundwater resources – where they occur; how they behave; where they are vulnerable; and how they are used. The intent is to provide basic information about the occurrence of groundwater in Iowa and to describe the various geologic settings that affect both its availability and its vulnerability. Understanding this information is in the best interests of Iowans; it is essential to groundwater protection and management efforts in general, and to implementation of the State's Source Water Protection program in particular.

Consider that throughout Iowa all human activity is supported by geological substrates – layers of the Earth's surface composed of land and its accompanying water resources. Our past and present agricultural, urban, and commercial uses of this land carry far-reaching consequences for both resources. Because these human, earth, and water interactions will be with us far into the future, and the number of people affected by them continues to increase, there is particular need for a broadened public understanding of the geological basics of Iowa's groundwater resources.

Successful land and water management is based upon reliable information and the support of a well-informed public. We hope to supply this needed information to Iowa citizens, lawmakers, educators, engineers, and drillers, as well as to those municipal, county, state, and federal agencies that handle groundwater contamination issues, source water and wellhead protection efforts, and various natural resource management projects. This guide is designed to provide a framework for understanding groundwater availability and protection issues throughout the state. It also can serve as a bridge to connect a general audience with the more detailed information available in technical publications. Finally, it can awaken interest among Iowans to the dynamic hydrologic aspects of their surrounding landscapes, watersheds, and wetland habitats.

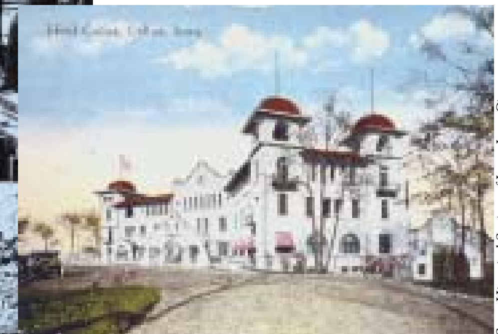
Iowa's Groundwater Basics is a general treatment of groundwater in Iowa and does not address the numerous local variations that can occur. Readers are directed to "References and Information Sources" at the end of this publication or to the Iowa Geological Survey for more site-specific information.

INTRODUCTION to GROUNDWATER

"Delicious water, clear, cool, refreshing, wells out from the hillsides in generous volume at all the water-bearing horizons, and each spring-fed rivulet rushes off, sometimes with clamorous haste, to add its tribute to the axial stream."

– Samuel Calvin
Geology of Allamakee County, 1895

Calvin Collection, University of Iowa



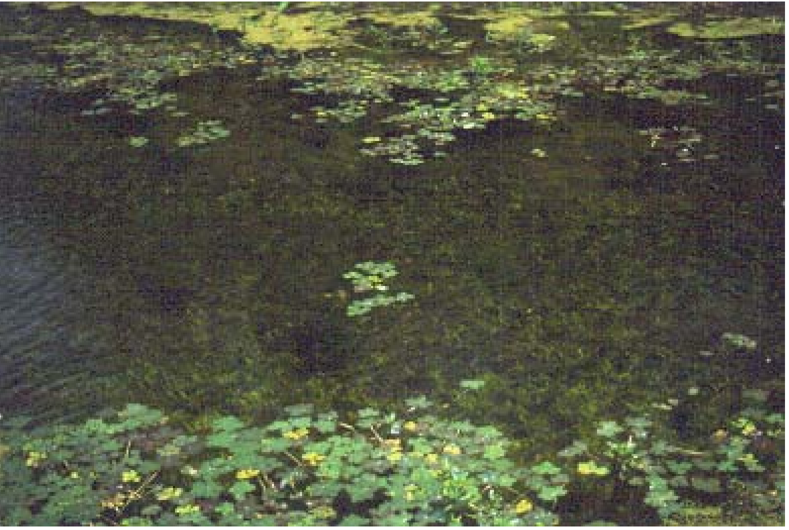
State Historical Society of Iowa, Iowa City

(Left) "Jumbo" flowed out of control for months after well drilling in Belle Plaine. (Above) Mineralized well water attracted visitors to the ornate Hotel Colfax, a once-popular health resort.

Water sources have always been a precious commodity for human life. So it's not surprising that one of the oldest words in the English language refers to water, especially where it flows from the ground. The word "well" originally meant a spring, a fountain, or surging water. Only later did it evolve to mean a pit or hole sunk into the earth to reach a supply of water – groundwater. The word "source" means to spring forth or to rise, and the word "resource" refers to a new or reserve source of supply. These linguistic roots of the phrase "groundwater resources" emphasize the long-standing need to find water supplies within the earth.

On occasion, Iowans encounter groundwater in places that rouse their curiosity about its origin and extent. For example, hillside seeps and perennial wet spots, notorious hazards for farm equipment, are often reported on hillslopes across southern Iowa. Elsewhere, *springs** flow vigorously from recessed crevices in the limestone bedrock of northeastern Iowa. Small waterlogged mounds of black peat, known as *fens,* are host to unusual plants and insects at scattered sites across northern Iowa. Newspaper accounts from 1886 reported an unexpected gush of water known as "Jumbo" during *well* drilling in Benton County (photo above). The Jasper County town of Colfax was a popular health resort in the 1880s, as the mineral waters from its wells were presumed to have therapeutic effects (photo above). And, no matter how dry the summer, most of Iowa's rivers continue to flow. The natural phenomenon behind all of these conditions is groundwater. Each example offers a glimpse of the vast, largely unseen world of water that occupies the seemingly solid earth beneath our feet. The purpose of this publication is to explore that realm as it is understood here in Iowa.

* Italicized words are defined in the Glossary.



Clay Smith

Groundwater feeds Iowa's surface lakes and streams, entering through the sides and bottom of stream beds. (Wilson Island State Park, Harrison County)

Consider that thousands of years ago, water in its solid form inched southward as massive glaciers that brought the raw materials for much of Iowa's present landscape. In turn, the melting of those glaciers laid the courses of most rivers draining the land today. Even the state's deeper bedrock strata, often seen as picturesque ledge and bluff outcroppings, began as sediment settling out of seawater on ancient sea floors, along coastlines, or in stream channels millions of years ago.

These past geological processes thus produced the earth materials that contain Iowa's present surface water and groundwater resources. The geologic deposits determine where groundwater occurs, how fast it moves, whether it can be tapped by wells, and where it will return to the land surface. These deposits also affect the natural quality of today's groundwater supplies, as well as their vulnerability to contamination from human activity.

As noted, some water resources, such as rivers, lakes, and springs, are easily seen on the land surface (photos above, far right). Their underground counterpart – groundwater – is less visible in our surroundings; yet 80 percent of all Iowans depend on groundwater for their household water supplies. Though this resource is essential to life and well-being, most people are unfamiliar with how groundwater occurs, or how local and regional geological conditions affect the abundance and quality of groundwater in wells. Nor are most people aware of the basic hydrologic connections between groundwater, surface water, *watersheds,* and biological habitats.

Below ground, as well as above, water is an ever-present geologic force as well as a vital natural resource. And because water in our environment is forever interconnected as part of the broader hydrologic cycle, human activities that affect water quality in one part of the system can carry through to affect other parts of the system. Historically, our groundwater was considered a safe, pure source of drinking water; whereas today, movement of contaminants into the groundwater realm is a focus of many of Iowa's environmental protection and natural resource issues.

Michael Bounk

Lynn Betts

Water tables are especially shallow in north-central Iowa. Following heavy rainfall or removal of drainage tiles, wetlands return quickly to low sags on the landscape. (Palo Alto County)

Art Bettis

Springs occur where groundwater flow emerges at the land surface. Dunning Spring, near Decorah in Winneshiek County, tumbles from a crevice in the limestone bluff on the north side of the Upper Iowa River valley.

(Photo left) Groundwater can infiltrate crevices in limestone and dolomite, eventually enlarging them to form subterranean cavern systems such as Cold Water Cave in Winneshiek County.

Roger Hill

The water in this Hamilton County wetland accumulates from groundwater seepage as well as from rainfall and snowmelt. A legacy of melting glacial ice, such wetlands function today as valuable habitat for native plant and animal species and natural filters for water resources. (Bjorkboda Marsh)

GROUNDWATER BASICS
OCCURRENCE, MOVEMENT, and QUALITY

"Les fontaines publiques de la ville de Dijon," by Henry Darcy, 1856.

> – The birth of the science of groundwater hydrology is traced to this report on the public water supply for Dijon, France, by a French hydraulic engineer. Today, "Darcy's Law" is used to compute the quantity of water flowing through an aquifer.


Clay Smith

Replenishment of Iowa's groundwater supplies begins with precipitation to the land surface.

Water may be the most recycled substance in nature. Though the Earth's water supply changes through time and space, the total amount remains basically the same. This water is always on the move, circulating through our environment in a process known as the *hydrologic cycle* and kept in motion by solar energy and gravity. Clouds condense and rain falls to the ground (photo, right), where it may be taken up by plant roots, flow as runoff across the land surface to feed creeks and streams, or slowly soak deeper into the earth to become *groundwater*. Water returns to the atmosphere as vapor, primarily by evaporation from lakes and streams and by *transpiration* from plants. Groundwater is a hidden, but fundamental part of this enduring hydrologic cycle (diagram, p.6).

As water from rain or snowmelt soaks into the ground beyond our sight, it becomes more difficult to study. It no longer has the discrete form of streams or lakes we are familiar with on the land surface. Instead, water disperses and spreads through the earth materials that now form its container. From the land surface on down, groundwater must be understood in terms of these geologic materials in which it occurs. This water within Iowa's seemingly solid ground fills small pores between grains of sediment or openings along fractures and crevices through more compact rock materials. In this subterranean environment, gravity, pressure, and the interconnectedness of pore spaces and fracture openings affect everything about the occurrence and movement of groundwater, including our use of this resource.

Rainfall or snowmelt infiltrating the soil, beyond the grasp of plant roots, eventually reaches the *water table*. This is the place below the Earth's surface where the ground, regardless of its composition, is saturated with water. The process of *infiltration* is called *recharge*. This replenishment of groundwater supplies often occurs over fairly level upland areas, particularly those with porous soils. The gathered groundwater produces a rise in the water table beneath this recharge area, causing an incline along the water table and movement of groundwater in a down-gradient direction. So, like the rest of the hydrologic cycle, groundwater is in continual motion, slowly moving within the earth away from areas of higher pressure or *hydraulic head* to areas of lower pressure.

Sooner or later, some of this groundwater makes its way back to the land surface at lower elevations, discharging to rivers, lakes, and *wetlands.* Such *discharge* also occurs at higher elevations if less *permeable* geologic strata should impede downward infiltration. Groundwater then travels laterally and, if intersected by a valley, can produce hillside springs and seeps. Springs are places where groundwater flows to the land surface with a noticeable current. This discharge can occur in a spectacular fashion from rock fractures or cave openings, especially in the spring or following periods of heavy rainfall (photo, p.3). Seeps are more diffuse in nature, forming wet soggy places, often at similar positions on different hillslopes. Groundwater-fed wetlands are larger seepage areas where the water table lies above the land surface during part of most years. Once groundwater discharges to the land, it follows the surface-water paths of the hydrologic cycle, flowing downslope to other water bodies, to evaporate and eventually fall again as rain or snow.

When thinking about a stream's watershed, it is important to include these underground hydrologic pathways as functioning parts of the more familiar surface-drainage system. Water movement in the underground portion of a watershed is determined by the *permeability* and thickness of its underlying geologic materials. These

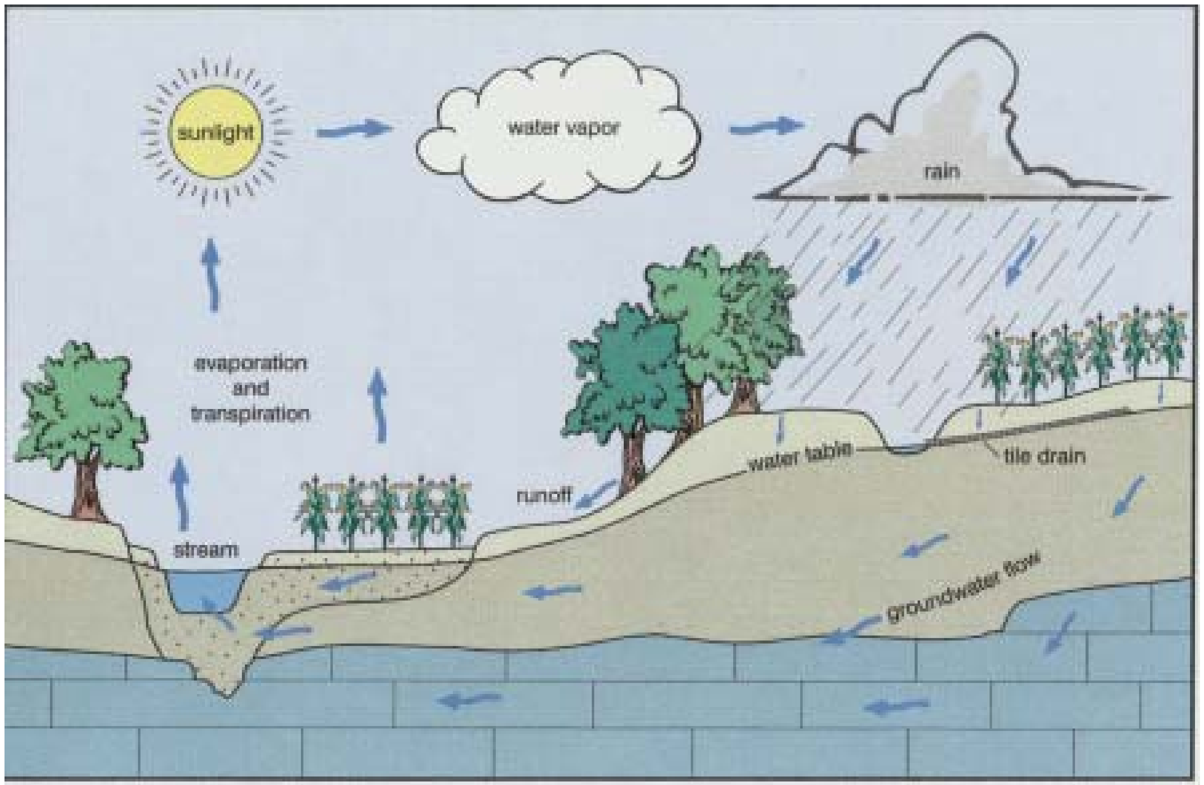
Photographic Services, University of Iowa

Water vapor in the air, snowmelt from the land, and stream flow are readily visible parts of the Earth's enduring hydrologic cycle. (Johnson County)

materials will affect the depth to and speed with which water infiltrates and later returns to the land surface.

As mentioned, groundwater moves through interconnected openings within earth materials. In granular materials such as silt, sand, or gravel, these openings occur between grains. In solid rock, on the other hand, these openings occur more often as vertical fractures, or as thin horizontal partings between rock layers, or in some cases as cavernous zones that have been dissolved by circulating groundwater. The amount of this open space in any earth material, its *porosity*, determines how much groundwater the soil or rock can store. The size of these openings and, in particular, how

The Hydrologic Cycle in Iowa



well connected they are, determine how easily different earth materials will transmit groundwater. This property is referred to as the material's permeability (also called its *hydraulic conductivity*). The rate of groundwater flow at any location also depends on a driving force. This energy is supplied by gravity acting on the slope of the water table or on the incline of water-bearing strata. In materials of very low permeability, groundwater may move less than a few inches per year, while in highly permeable materials flow may be measured in feet per minute.

Geologic deposits that are capable of storing and transmitting groundwater are called *aquifers*. The word "aquifer" comes from two Latin words, **aqua** (water) and **ferre** (to bring). Aquifers fall into two categories, unconfined and confined. *Unconfined aquifers* lie relatively near the land surface and include the water table. Below the water table, in the *saturated zone*, all pores, fractures, and openings are filled with groundwater. Above the water table, in the *unsaturated zone*, pore spaces contain a mix of air and water. A close-up view of the water table would reveal its *capillary fringe*, a thin zone irregularly saturated with water pulled by surface tension above the water table along tiny vertical openings (diagram, p.8).

Occasionally conditions exist where a layer of low-permeability material lies above the water table and within a sequence of permeable materials. Here, downward percolating water may accumulate on the low-permeability deposit, forming a *perched water table,* sometimes well above the true water table.

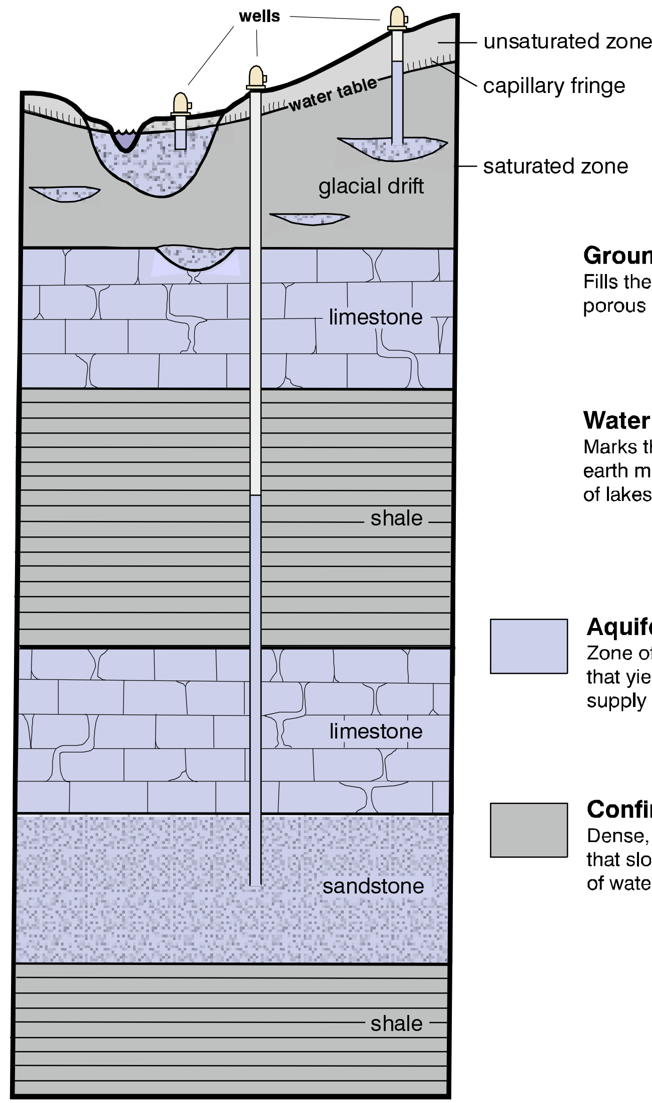
In Iowa, the position of the water table in the ground closely follows the contours of the land surface (diagram, left; p.10). Typically it lies just below the ground in low places, and lies deeper beneath uplands and hilltops. Groundwater moves in the direction of the water table's slope, from higher elevations on the landscape to lower elevations, and always from areas of higher hydraulic head to lower hydraulic head.

Confined aquifers, on the other hand, are capped by impermeable strata called *aquitards*, or confining beds composed of geologic materials that allow little or no water movement (diagrams, p. 8, 10). These aquitards are an important part of the groundwater system, as they affect water levels, water quality, and well yields by restricting both water flow and mixing between aquifers. The groundwater in a confined aquifer is under *artesian* pressure – a result of the seal provided by the overlying aquitard, the aquifer's incline away from its recharge area, and the weight of the water. Water levels in wells that tap a confined aquifer will rise above the top of the aquifer because of this pressure. Artesian wells are common among wells drilled into the southwesterly inclined bedrock throughout much of Iowa. The term "artesian" is derived from **Artesium,** the Latin for Artois, an ancient province of northern France where a bored well has flowed steadily since 1126 A.D.

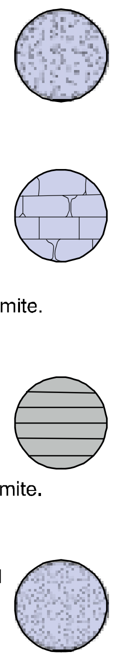
Today the term artesian applies both to wells whose waters overflow and to those whose waters fall short of the land surface, as well as to those *hydrogeological* conditions that sustain them. If a sufficient head of artesian pressure exists, the water level will rise above the land surface and the well becomes a flowing artesian well (diagram, p.45). Most of the time, however, groundwater rises only part way to the land surface in an artesian well. This elevation defines the aquifer's *potentiometric* (or pressure) *surface* at that location. Groundwater flow in a confined aquifer tends to move down the gradient of this pressure surface. In places, a confined aquifer may not be capped by an aquitard and thus is locally unconfined. Such areas are important because they form the most readily recharged parts of an aquifer.

The course of groundwater from a recharge area to a discharge area can be a short trip or a never-ending journey. This time-of-travel depends on the porosity and permeability of aquifer materials and on the strength of the driving force. Its course also is determined by the type of flow system in which the groundwater occurs. The most actively circulating groundwater is contained in shallow local-flow systems that lead from hilltops to nearby small perennial streams (diagram, p.10). The groundwater in such systems is

Groundwater Basics



Porosity and Permeability



Water is stored and moves easily between grains in sand and gravel.

Water is stored and moves along fractures, solution channels, and bedding planes in limestone and dolomite.

Water is stored, but does not move easily in shale and dense, unfractured limestone and dolomite.

Water is stored and moves in fine-to-coarse grained sandstone.

Groundwater
Fills the spaces in porous earth materials.

Water Table
Marks the top of water-saturated earth materials; forms the surface of lakes and streams.

Aquifer
Zone of porous earth material that yields enough water to supply wells and springs.

Confining Layer
Dense, compact earth material that slows the easy passage of water.

typically in an unconfined aquifer setting and flow distance from recharge to discharge area usually is measured in thousands of feet to just a few miles. This groundwater is often in residence for periods of only months to a few years and is an important contributor to stream flow.

For example, if you have ever wondered why some streams continue to flow during dry periods, or during the winter when there is no rainfall, the answer lies in the fact that, at those times, virtually all the water is being supplied by groundwater. The portion of a stream's flow that is maintained by this groundwater discharge is known as *baseflow*. It is a reminder that land surface watersheds have an important underground component. In fact, baseflow in Iowa's streams generally accounts for more water during the year than that resulting from runoff following rainfall or snowmelt.

In contrast to local flow systems, other water remains in the ground for many years. This groundwater moves more deeply as part of a regional flow system, following flow paths that can stretch hundreds of miles (diagram, p.10). Groundwater in these regional systems is typically in a confined aquifer setting. It flows deeply beneath smaller streams and rivers, and may be in residence for centuries to tens of thousands of years before it finally finds its way back to the earth's surface at some low area or is pumped from the ground via a deep well. The age of groundwater pumped from some of Iowa's deep aquifers is dated by radiocarbon isotopes as being over 10,000 years old. For much shallower aquifers with shorter flow paths, tritium, an unstable isotope of hydrogen, is an accurate indicator of groundwater recharge that occurred after 1953, when testing of nuclear weapons significantly increased the amount of tritium in the atmosphere.

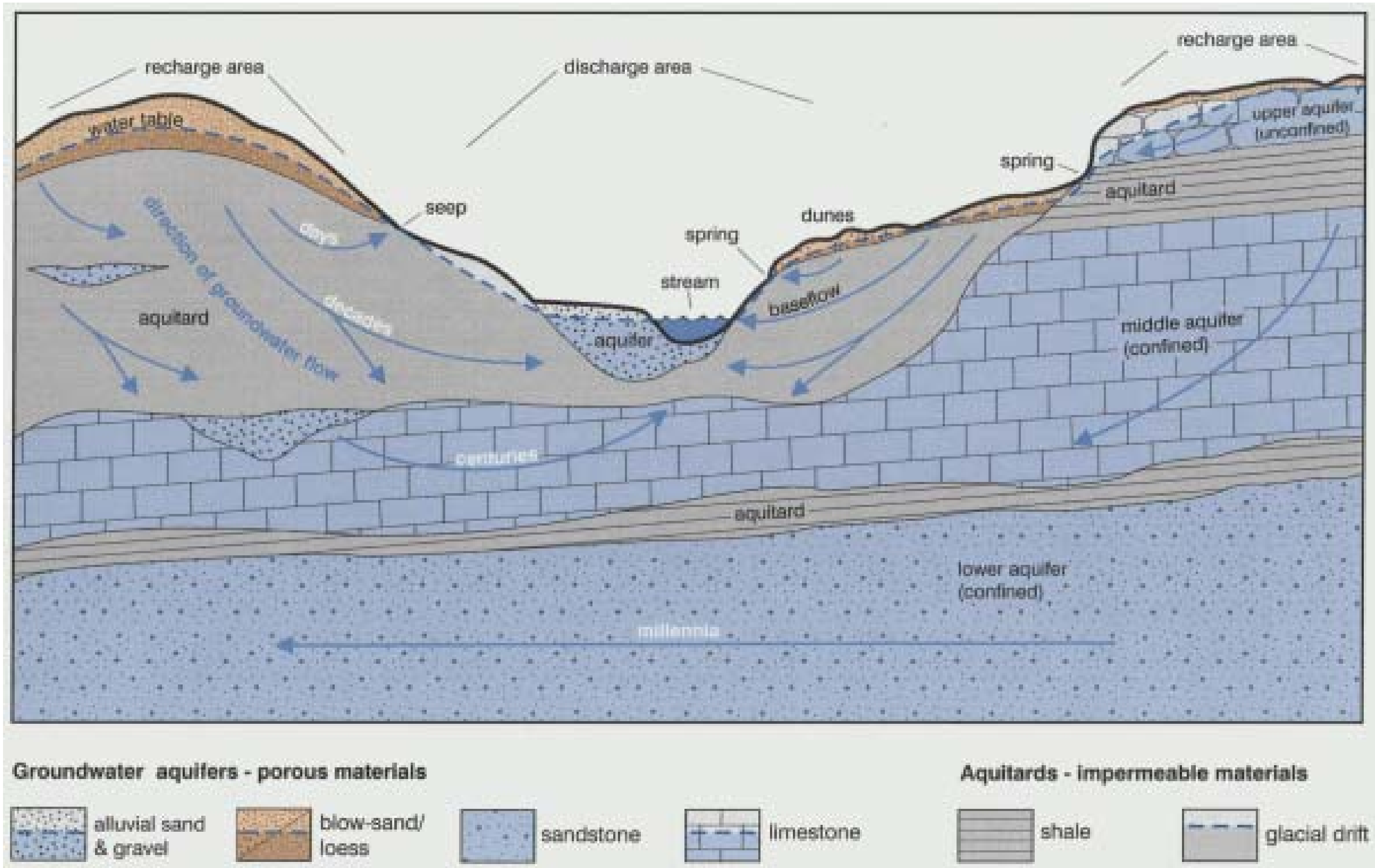
Rick Langel

Groundwater emerges from horizontal bedding planes in limestone and freezes on contact with winter air in this Clayton County quarry.

Ray Anderson

Groundwater infiltrating vertical fractures in Iowa's bedrock seeps into subfreezing air near a limestone mine entrance, creating cave-like stalactites and stalagmites of ice (Black Hawk County).

Groundwater Flow Paths beneath Iowa



The volume of groundwater stored in aquifers changes through time. Storage volumes rise during periods when recharge to an aquifer exceeds discharge, and fall when discharge exceeds recharge. There is a seasonal trend in this recharge-discharge relationship. In Iowa, recharge usually exceeds discharge during the spring when melting snow and rains generate abundant infiltration to the water table, causing groundwater levels to rise. During the summer, warmer conditions and growing vegetation result in significant evaporation and transpiration of water. This tends to limit recharge, and water levels generally decline, especially in unconfined aquifers. In autumn, cooler conditions return and plant uptake essentially stops, allowing recharge to occur again. Finally, winter brings snow falling on frozen soils, which often brings recharge to a halt. Even though seasonal variations occur, there is still a natural long-term balance between the volumes of water entering and leaving an aquifer. Because of this, groundwater levels and the amount of groundwater stored in an aquifer often fluctuate within fairly narrow ranges. Major withdrawal of groundwater from wells can alter this balance and cause local or regional declines in water levels and in the volume of stored groundwater. Extended periods of drought may do the same.

Aquifers that are near the surface, with no significant overlying confining bed, are readily recharged. Water from rain or melting snow may reach such shallow aquifers within hours to days. This rapid replenishment of near-surface aquifers is a "good-news, bad-news" situation, as the quickly infiltrating water can readily bring along contaminants from the surface. Where thicker confining beds are present, longer periods are needed for recharge to occur, and contaminant delivery is less significant.

As groundwater moves through the earth, it is in contact with the rocks and minerals that comprise aquifers. Typically, groundwater dissolves some of the more soluble minerals in an aquifer, adding to the water's *total dissolved solids*. The state's older groundwaters have had longer to do this, so they tend to have higher concentrations of various dissolved solids. Carbonate minerals are the most commonly soluble and contribute dissolved calcium, magnesium, and bicarbonate to groundwater. Sulfur-bearing minerals such as gypsum and pyrite, while less common, add sulfate. Other minerals or buried organic matter can add even more dissolved or gaseous constituents such as iron, manganese, arsenic, hydrogen sulfide, ammonia, methane, or radioactive compounds. In the end, groundwater is a natural stew of contributions from contact with various rock layers through time. These naturally occurring constituents can affect the taste of water, its use for particular purposes, and human health if used for drinking or cooking.

A final note about groundwater quality concerns temperature. The Earth's temperature, and that of groundwater too, depends on depth. Aside from places with volcanoes, geysers, and hot springs, the temperature of groundwater within a hundred feet of the land surface is about the same as a region's mean annual air temperature. In Iowa, this ranges from about 48 degrees Fahrenheit (F) in northern Iowa to about 52 degrees F in southern Iowa. But the deeper the well, the warmer the water, and here in the Midwest, that's about a degree for every hundred feet. This rate of increase is known as the *geothermal gradient*. Groundwater temperature is important for industrial users as well as for geothermal heating and cooling.

FINDING GROUNDWATER in IOWA
ITS GEOLOGIC PATTERNS

" . . . and some rin up hill and down dale,
knapping the chucky stanes to pieces wi' hammers,
like sae mony road makers run daft – they say it is to see
how the warld was made!"

– Sir Walter Scott
St. Ronan's Well, 1824

Clay Smith

Several of Iowa's underlying bedrock aquifers are seen at the land surface as spectacular bluffs in northeast Iowa. (Galena Group dolomite, Turkey River Mounds State Preserve, Clayton County)

In thinking about groundwater, it is helpful to visualize the ground beneath Iowa as a package of layered earth materials thousands of feet in depth and miles in breadth. These strata contain the state's groundwater, though the resource itself is not evenly distributed through them. Whether you can find enough water to supply a well at a particular location depends on the composition of these materials and how they are arranged beneath the land surface. This arrangement is not haphazard, but falls into a series of predictable geologic sequences across the state. These different sequences determine the depth of a groundwater supply, the quality of its water, and the amount that can be pumped from a well. In some places, more than one source of groundwater is available.

Quite simply, Iowa's groundwater aquifers are found in layers of water-bearing bedrock, or in porous glacial materials, or along modern or buried river valley sediments. It is important to put to rest any myths that depict groundwater as a vast underground river or lake fed by water from Canada. The subtle character of Iowa's terrain tends to keep its subsurface geology something of a mystery. However, over 100 years of collecting thousands of records from Iowa's well drillers and other sources continues to produce an increasingly refined picture of the state's geologic strata and the groundwater resources they contain (table, p.14-15).

To begin with, Iowa's groundwater resources are broadly categorized as being either *surficial* aquifers or *bedrock* aquifers. Historically, Iowa's ancient native people and early European explorers and pioneers drank from pristine streams, lakes, and springs. As settlement expanded westward, shallow aquifers were tapped to supply water for new homesteads. These surficial aquifers occur in the relatively loose granular sediments that lie between the land surface and deeper solid bedrock.

The granular materials and the state's low-relief landscapes result from a long history of contact with glaciers. From this glacial heritage came the basic materials composing Iowa's surficial aquifers and aquitards. These include *alluvium* (water-deposited sand and gravel), *loess* (wind-deposited silt), and *glacial till* (pebbly or sandy clay deposited by ice) – materials often loosely referred to as "soil" or "dirt." Their thickness across the state varies considerably, from none in parts of northeast Iowa where bedrock outcrops at the land surface (photo, left), to over 600 feet in west-central Iowa. Except for alluvium, these glacial-age materials tend to be fine-textured and have moderate-to-low permeability. Throughout Iowa, the water table within these materials occurs at fairly shallow depths, typically 3 to 30 feet below ground, and generally following the slope of the land's surface. Beneath more highly permeable materials, especially along the state's numerous river floodplains, the water table is at a more consistent depth, averaging about 6 feet.

Bedrock aquifers, on the other hand, lie beneath the state's surficial materials and consist of solid rock layers such as limestone, dolomite, and sandstone. This sedimentary bedrock foundation originated in tropical marine environments that submerged Iowa in the distant geologic past. The bedrock aquifers are further defined by less permeable strata, such as shale, that separate and isolate individual aquifers.

Together, Iowa's surficial and bedrock aquifers absorb and store trillions of gallons of water in their pores and fractures. Wells tap this water for use in drinking, cooking, cleansing, recreation, industry, and irrigation. Though finding enough water is essential, its quality for human consumption is vital. Some of the state's aquifers occur in geologic settings that are especially vulnerable to contamination as a consequence of human activity on the land surface. For example, agricultural fertilizers and pesticides, industrial wastes, and waste-storage facilities may release bacteria, nitrates, pesticides, gasoline, or hazardous metals that can seep into porous earth materials containing groundwater aquifers. Where aquifers are separated from the land surface by fifty feet or more of dense glacial till or impermeable shale bedrock, contamination is less likely to occur. This protection may be either a temporary benefit resulting from slower travel time of contaminated waters, or a more lasting result of natural attenuation of contaminants by chemical interaction with clay or organic matter. It depends on the contaminant.

As noted earlier, even if an aquifer is covered by a protective layer of impermeable clay or shale, groundwater still may have naturally occurring quality problems that limit its use for drinking. Dissolved minerals become part of groundwater as it lies in contact with its host bedrock over long periods of time. Problems with highly mineralized groundwater generally increase with depth below the ground and with distance away from the aquifer's recharge area.

As with most earth resources, groundwater often is taken for granted until drought, flood, broken pumps and water mains, or contamination problems suddenly remind us of its importance.

Iowa's Geologic Strata: Their Aquifers and Confining Layers

Stratigraphic units		Hydrogeologic units	Dominant geologic materials	Hydrologic conditions	Major areas of use
Quaternary	Holocene	Alluvium	sand, gravel, silt, clay	local to regional aquifers	statewide
	Pleistocene	Glacial drift	pebbly clay, silt, sand & gravel	local sand & gravel aquifers	statewide
		Buried valley	sand & gravel	local to regional aquifers	statewide
Tertiary		"salt & pepper" sands	sand & silt	local to regional aquifers	western
Cretaceous	Niobrara Formation (Fm.) Carlile Shale Greenhorn Fm. Graneros Shale	Cretaceous confining units	shale, limestone	confining beds; aquitard	
	Dakota Fm.	Dakota aquifer	sandstone	regional aquifer	western
Jurassic	Fort Dodge Fm.	Jurassic confining unit	gypsum	aquitard	Webster Co.
Pennsylvanian	Virgilian Series Missourian Series	Pennsylvanian confining units	limestone, shale	confining beds; aquitard	
	Marmaton Group Cherokee Group Caseyville Fm.		shale, siltstone, limestone sandstone, coal	confining beds; aquitard local sandstone aquifers	 central, southern
Mississippian	Pella Fm. St. Louis Fm.	Mississippian aquifer	limestone, sandstone, shale		southeast south-central
	Warsaw Fm. Keokuk Fm. Burlington Fm.		dolomite, shale, limestone, chert	local aquitard regional aquifer	central
	Gilmore City Fm. Maynes Creek Fm.		dolomite, limestone, chert		north-central
	Prospect Hill Fm.	Mississippian confining units	siltstone, shale	aquitard	

Devonian	Upper Devonian shale formations (Maple Mill)	Devonian confining units	shale, siltstone, dolomite	confining beds; aquitard	
	Lime Creek Fm.		shale, dolomite, limestone	confining beds; aquitard	
				local aquifers	north-central
	Cedar Valley Group	Devonian aquifer	dolomite, limestone, chert	regional aquifer	eastern north-central
	Wapsipinicon Group		limestone, dol., shale, gypsum	local aquitard	eastern
Silurian	Gower, Scotch Grove Hopkinton, Blanding, Tete des Morts, Mosalem formations	Silurian aquifer	dolomite, chert, limestone	regional aquifer	eastern
Ordovician	Maquoketa Fm.	Ordovician confining units	shale, dolomite, chert	confining beds; aquitard	
				local aquifer in northeast	northeast
	Galena Group		dolomite, limestone, chert	confining beds; aquitard	
				local aquifer in northeast	northeast
	Decorah, Platteville, Glenwood formations		shale, limestone, sandstone	confining beds; aquitard	
	St. Peter Sandstone	Cambrian - Ordovician aquifer ("Jordan aquifer")	sandstone	regional aquifer	statewide
	Prairie du Chien Group		dolomite, sandstone, chert	regional aquifer	
Cambrian	Jordan Sandstone		sandstone		
	St. Lawrence Fm.		dolomite		
	Lone Rock Fm.	Cambrian confining units	shale, siltstone, sandstone	confining beds; aquitard	
	Wonewoc Fm. Eau Claire Fm. Mt. Simon Sandstone	Dresbach aquifer	sandstone, shale, dolomite	regional aquifer	east-central northeast
Proterozoic	undifferentiated		igneous & metamorphic rocks; sandstone, shale	unknown	

Gary Hightshoe, Iowa State University

Floodplains are underlain by porous sand and gravel deposits that yield valuable groundwater supplies. These shallow alluvial aquifers are vulnerable to contamination from the land surface. (Iowa River meander loops, Iowa County)

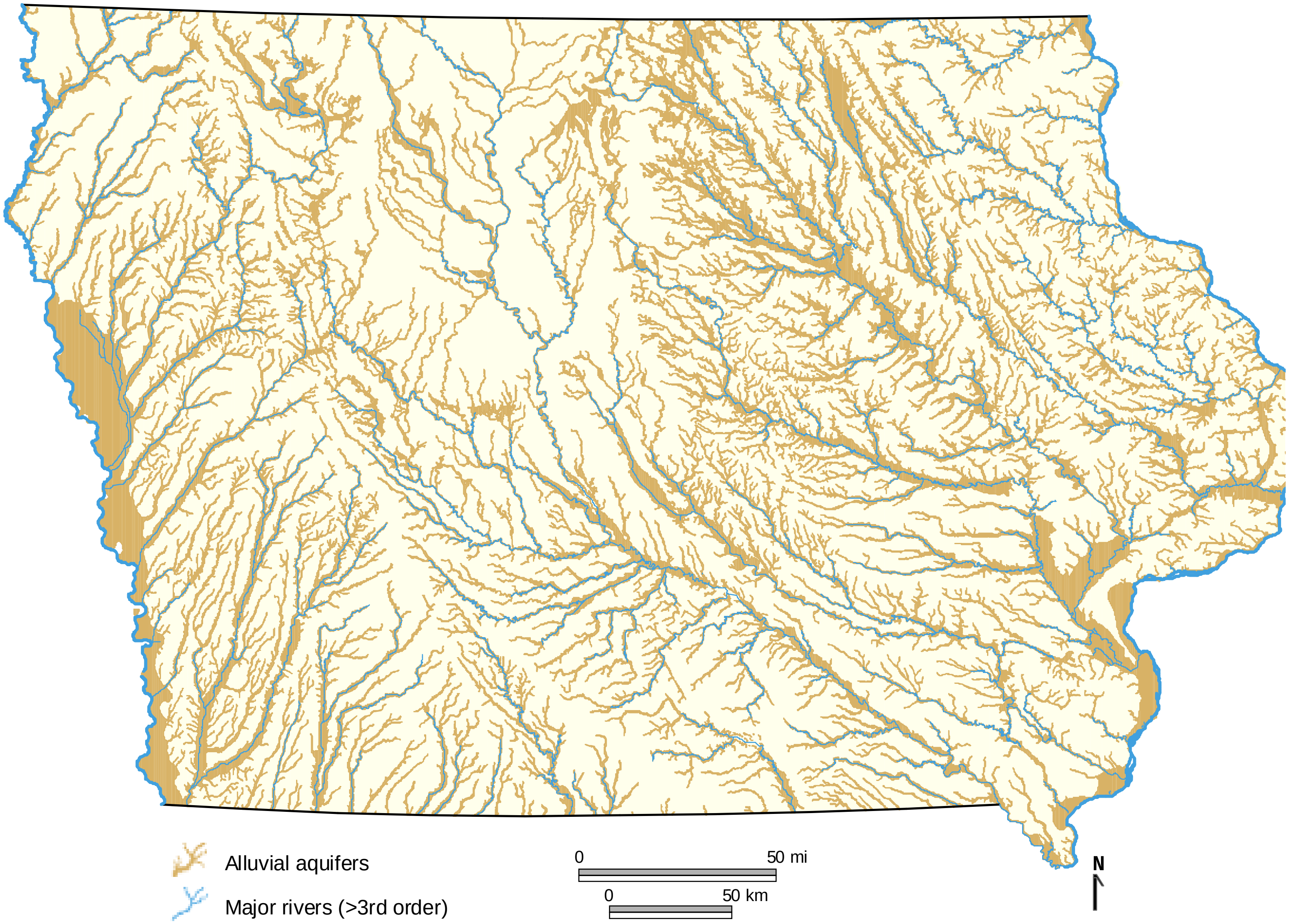
SURFICIAL AQUIFERS (Quaternary age)

Alluvial aquifers

River valleys are one of Iowa's major landscape features. Along and beneath these valleys are shallow sand and gravel deposits containing *alluvial aquifers*. The alluvium itself was deposited during a river's past history. Such sediment may be as young as a sand bar from last year's flood or as old as a deep 10,000-year-old gravel deposit left by the last glacier's meltwater flow. Alluvial aquifers are important sources of moderate-to-large water supplies across the state, but their lateral extent is restricted to river valley corridors. The distribution of Iowa's alluvial aquifers is shown on the map to the right.

Alluvial materials can change abruptly in grain size both vertically and horizontally. This reflects rapid shifts in velocity and direction of a stream's flow during its history. Some alluvial deposits are dominated by fine-grained silts and clays, which reduce an aquifer's potential by restricting the ability of water to move through in response to pumping. In contrast, when alluvial materials are coarse, thick, and extensive, a productive and dependable source of groundwater can be expected. The advantages of alluvial aquifers are their abundant yields and shallow well depths, typically less than 100 feet deep. By the same token, their shallow depths and high

Alluvial Aquifers of Iowa



porosity make them particularly vulnerable to seasonal variations in precipitation, and thus subject to drought and fluctuating water table conditions. Their depth and porosity also leave these aquifers open to direct infiltration from the land surface, which increases their susceptibility to contamination problems.

Generally speaking, alluvial aquifers contain the least mineralized groundwater in Iowa (typically less than 500 milligrams per liter [mg/L] of dissolved solids) because the water has been in the ground for the shortest period. Quality can vary, however, since it also depends upon aquifer thickness, depth of wells, the character of an underlying aquifer or aquiclude, and the source of the groundwater (local precipitation, induced infiltration from a nearby river, or longer-term storage within the aquifer). Since sand and gravels usually are connected hydraulically with an adjoining river, these deposits also reflect the river's natural recharge and quality characteristics.

Significant alluvial aquifers occur along the broad Missouri and Big Sioux river valleys in western Iowa and along the Mississippi River corridor in eastern Iowa. These aquifers are also present along Iowa's larger interior streams (photo, p.16). The coarser, more permeable deposits in all these valleys result from sorting and depositing of outwash material transported during glacial meltwater flooding. Today, sand and gravel resources are frequently developed from these river valley deposits. Alluvial materials range from 50 to 160 feet thick along the Mississippi and Missouri rivers, and they store enormous quantities of groundwater. Thinner, narrower alluvial aquifers along major interior rivers may be from 30 to 70 feet thick. In isolated places, the alluvium may be thicker where modern river valleys coincide with older, deeper buried valleys cut into the underlying bedrock surface. Characteristically, alluvial deposits are thicker, coarser, and more productive in a downstream direction. Such deposits also tend to thin out near the valley sides and grade into finer grained, less productive sediments.

Groundwater and surface water interactions are closely tied in alluvial settings. As mentioned earlier, alluvial aquifers are unconfined; that is, they have no overlying impermeable layer to seal them under pressure, leaving the aquifer's water surface free to fluctuate up and down. The familiar backwater lakes seen along river *floodplains* are actually low places where the water table (groundwater surface) intersects the land surface. Lake Odessa at Mark Twain National Wildlife Area in Louisa County, Otter Creek Marsh State Wildlife Refuge in Tama County, Blue Lake at Lewis and Clark State Park in Monona County, and DeSoto Bend National Wildlife Refuge in Harrison County are good examples of these "windows" to the water table. These oxbow lakes fill low areas scoured by earlier cut-off meanders of the river channel.

A rising river level will cause a simultaneous rise in the water table of an adjacent alluvial aquifer, sometimes to visible heights in nearby fields. Similarly, a falling river stage will produce a falling water table, and shallow lakes may disappear. The subsurface gradient of the water table slopes toward the river during falling river levels and away during rising river levels. The continuous contribution of groundwater to streams, known as baseflow, keeps them flowing even after long periods without rainfall.

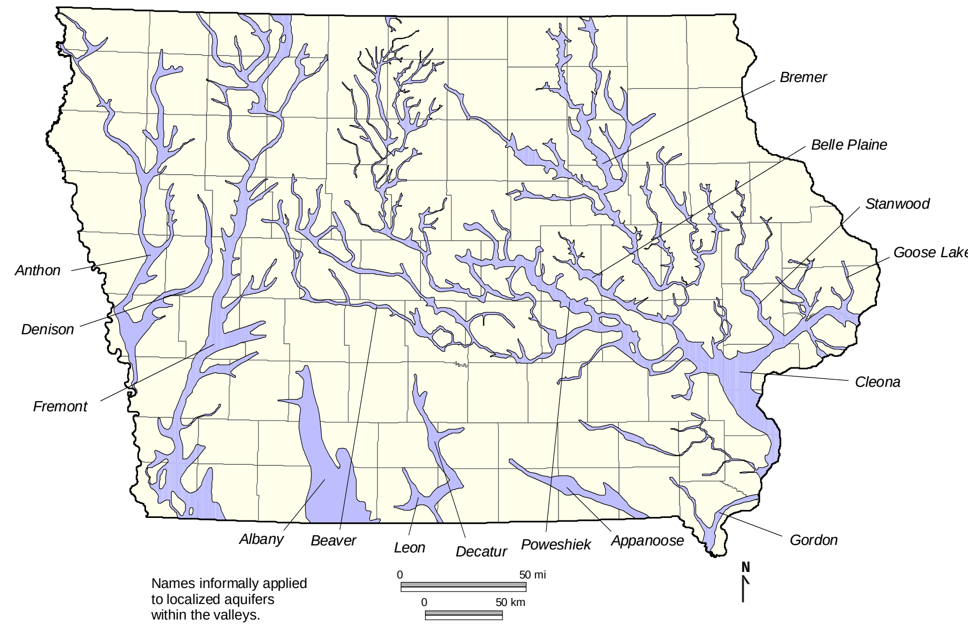
Most of the early Euro-American exploration of Iowa took place along its rivers, and many of Iowa's first settlements were nestled along river banks. Today many of Iowa's major metropolitan centers are along rivers. Consequently, Iowa has numerous municipal wells tapping the alluvial deposits beneath valley landscapes. These provide valuable, as well as vulnerable, water supplies for large numbers of urban-dwelling Iowans. Wells along the Mississippi and Missouri valleys are known to produce 1,000 to 2,000 gallons per minute (gpm) on a sustained basis for municipal, industrial, and irrigation uses. Alluvial aquifers along Iowa's interior streams commonly produce several hundred gallons per minute, with larger yields possible in some localities.

Buried-valley aquifers

A second type of surficial aquifer occurs along ancient river valleys once carved into the underlying bedrock surface across Iowa (map, right). Like alluvial aquifers, these deeper sources are composed of sand and gravel, but they are buried now by younger impermeable glacial tills, thus confining the aquifers and creating artesian pressures. These old valleys were partially filled with *outwash* sand and gravel prior to or between glacial episodes. The presence of these steep-sided valleys is easily recognized on topographic maps of the bedrock surface, but they usually show no visible expression on the modern landscape because they are blanketed by glacial drift. It is worth noting, however, that in places they do influence the routes taken by modern drainage. A number of Iowa rivers have segments that follow the course of one of these deeper buried valleys.

The glacial mantle above most *buried-valley aquifers* also keeps them from being recharged as quickly as the shallow alluvium along modern streams. If these buried valleys are filled with coarse alluvium, it is possible for wells to pump 100 gpm or more. Where the

Buried-Valley Aquifers of Iowa



aquifers occasionally coincide with modern river valley deposits, yields of 500 to 1000 gpm are possible. The most widely used buried-valley aquifers occur in central and southeastern Iowa, while a few others are tapped in the western and southwestern part of the state. Iowa's buried valleys continue to be mapped in better detail as more data from new wells becomes available.

A buried-valley aquifer along the Belle Plaine Channel through Tama, Benton, and Iowa counties made history in 1886. The drilling of a new well for fire protection in Belle Plaine tapped buried sand

and gravel. Flows estimated at 30,000 to 50,000 gallons per minute gushed from the well, nicknamed "Jumbo," hurling chunks of fossil wood, two-pound stones, and tons of sand. Although the flow diminished to about 2,000 gpm after two weeks, efforts to stem the flow ultimately took over 13 months (photo, p.1).

Water quality in buried-valley aquifers is quite variable and is more highly mineralized than in shallow alluvial aquifers. This is because of the longer time that water has been in the ground and often because of its contact with an adjacent bedrock aquifer. Buried-valley aquifers tend to have high concentrations of total dissolved solids, with iron and ammonia being particular problems.

Glacial drift aquifers

A third type of surficial aquifer occurs widely beneath the broad upland landscapes that separate most of Iowa's river valleys. These are known as *glacial drift aquifers*. The term "drift" refers to the glacial deposits that mantle Iowa's deeper bedrock foundation. Though ranging from nearly zero to over 600 feet thick, glacial drift averages about 200 feet in thickness over the state. Drift includes not only pebbly clays known as *glacial till,* but also occasional sand and gravel deposits sandwiched within or at the bottom of these glacial clays. These porous sands and gravels, resulting from episodes of meltwater flow during glacial advances and retreats, tend to be thin, discontinuous, and quite unpredictable in their occurrence.

The suitability of drift aquifers as a source of groundwater varies considerably across the state. Some productive aquifers occur in north-central Iowa, where geologically youthful glacial materials lie at the land surface and contain abundant sand. Wells in this area report yields from less than 10 to over 90 gpm. In contrast, glacial drift is generally absent in the far northeastern Iowa counties. In eastern Iowa, the drift deposits are often bypassed in favor of deeper, more productive bedrock aquifers. In parts of southern and western Iowa, however, where alluvial aquifers may not be available and bedrock aquifers are deep, unproductive, or produce water of poor quality, a good glacial drift aquifer can be a life-saver. Such wells typically range from 50 to 200 feet deep but occasionally reach depths of 400 feet or more. They normally yield only a few gallons per minute, but a respectable 10 to 20 gpm may be obtained from some under favorable conditions. Though water production is low, their widespread potential in the abundant glacial deposits across the state make these aquifers valuable resources, especially for rural homeowners and especially in the western half of Iowa. In terms of natural water quality, shallow drift aquifers are consistently less mineralized than water from either deeper glacial drift aquifers or from the buried valley aquifers.

Falling in a special category are the interesting but enigmatic "salt and pepper" sand deposits known to occur across broad bedrock uplands of western Iowa. The term "salt and pepper" refers to contrasting grains of white quartz and dark volcanic glass, and these sands lie buried beneath 50 to 300 feet of glacial deposits. Although the sands' geological origins are uncertain, they appear to be derived from Rocky Mountain sources and transported to Iowa by eastward flowing ancestors of the Missouri River. The water-bearing potential of these sand deposits is not well known, but locally in northwestern Iowa they do generate moderate amounts of water.

A delicate balance of groundwater seepage from glacial drift

photos by Clay Smith

The permeability of soil and rock affects the movement of groundwater. Slow seepage to the land surface over long periods of geologic time produces fascinating ecological habitats. Hanging Bog State Preserve in Linn County is a forested fen noted for its abundance of heat-generating skunk cabbage (left).

aquifers is one of several hydrologic conditions that give rise to fens, a unique form of wetlands in Iowa (photos above). These spongy, groundwater-saturated peat deposits are only a few acres in size at most, and form low mounds on hill slopes and stream terraces, primarily across the northern portion of the state. Their water is highly mineralized compared to most wetlands, and as a result creates habitats for some of Iowa's rarest plants and insects. The flow of groundwater to the surface must be steady enough to prevent decay of plant material and enable peat accumulation, a process that takes several thousand years. If the flow is too strong, erosion prevails. Rowley Fen in Buchanan County and the Excelsior Fen complex in Dickinson County are fine examples of these groundwater-fed wetland habitats.

All of Iowa's wetlands, whether sustained by groundwater or surface water, are valuable hydrologic features of our landscape. They improve water quality by natural filtration; they reduce flood risks by storing water; they recharge groundwater supplies; and they provide ecological niches for diverse flora and fauna.

Loess-till contact aquifer

In many areas of southern and western Iowa, the surficial aquifers mentioned thus far are not available to residents, and often there are no bedrock aquifer options either. An alternate, but usually meager, water supply can be obtained from large-diameter seepage wells that tap the water table itself. Across this part of Iowa, loess often mantles the glacial till. Loess, being more porous, permits water to percolate easily downward until reaching the less permeable clayey till. Groundwater may be available to a seepage well near this geologic contact either when the water table has risen into the loess, or where groundwater moves easily along the contact's gradient. The availability of this shallow aquifer is affected by landscape position and by position of the seasonal water table.

A large-diameter well (typically 30 to 36 inches) intercepting groundwater near the loess-till contact yields about 1 to 3 gallons per minute. Such wells are most common in upland areas between major stream valleys. Recharge from precipitation and snowmelt occurs quickly to loess-till contact aquifers, and the natural water quality is quite good, given the brief period of contact with surrounding geologic materials. Obviously however, these wells are highly vulnerable to seasonal variations in the precipitation on which they depend, and also to contaminants infiltrating from the land surface.

The loess-till contact (photo, right) is often seen in roadcuts, especially across the southern half of Iowa. Look for places where a uniform-textured silt (loess) lies on top of more dense clayey material, usually with noticeable stones and cobbles mixed in (glacial till). Also, it is not unusual in this region to encounter hillside seeps

Ray Anderson

Infiltration of groundwater is affected by changes in geologic materials. A significant geologic contact in Iowa is shown here between loess (upper brown silt) and underlying glacial till (begins with terra cotta color). The clay-rich till includes numerous pebbles, is strongly rilled, has a paleosol at the top, and contains oxidized (yellow) and unoxidized (grey) zones. (Des Moines County)

These forested bluffs (left horizon) mark the leading edge of the Silurian bedrock aquifer across northeast Iowa. Recharge to this aquifer occurs across broad areas by infiltration through overlying geologic materials. The outcrop belt, known as the Silurian Escarpment, is a discharge zone for local flow systems within the aquifer and includes numerous large springs. (Clayton County)

Paul Horick

or perennial wet spots caused by groundwater movement along the loess-till geologic contact. Such wet, sticky areas are a familiar nuisance to local farmers driving heavy machinery across fields in the spring. Some of these seepage areas are textured with raised grassy tufts and unusual plants, particularly in uncropped fields.

In other places, especially uplands bordering streams and river valleys, the loess may be layered with blow-sand. Such fine-grained sand, carried by the wind, was supplied locally from nearby valleys. Being a highly permeable material in upland landscape positions, blow-sand may also contribute to the presence of hillside groundwater seeps and springs, especially in the southern half of Iowa. Hanging Bog in Linn County is a good example (photo, p.21).

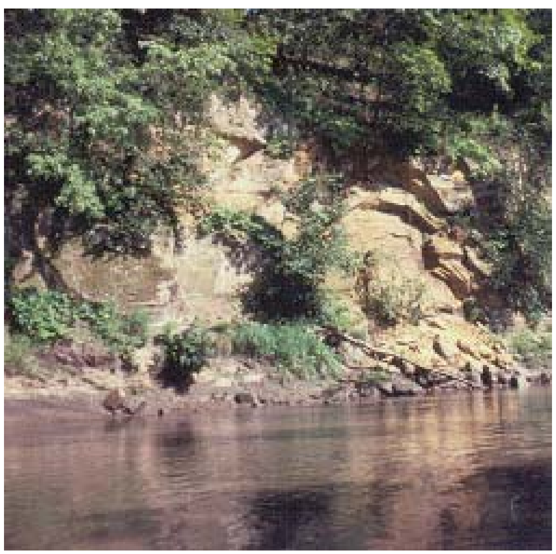
BEDROCK AQUIFERS

Bedrock aquifers are another basic class of Iowa's groundwater resources. Bedrock consists of sedimentary rock layers, primarily limestone and dolomite (carbonate rocks), as well as shale, siltstone, and sandstone. These rocks originated as sediment deposited in ancient seas, rivers, and deltas that occupied Iowa between 75 million years ago (Cretaceous age) and 550 million years ago (Cambrian age). The total thickness of these formations ranges from 5,200 feet in southwest Iowa to about 800 feet in the northeast. This sequence of sedimentary rocks varies widely in its ability to store and transmit water.

Of the state's sedimentary rocks, sandstones and carbonates make the best aquifers. Sandstones often have abundant pore spaces between their grains, so groundwater moves easily following the interconnected openings. Problems with water yields from these

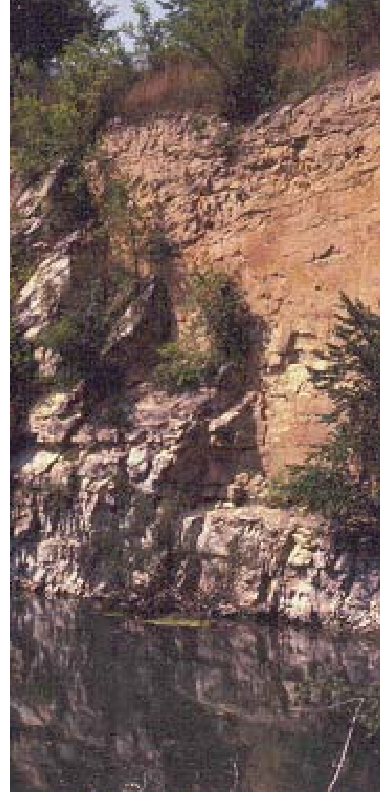
Brian Witzke

Massive dolomite of the Silurian aquifer forms scenic outcrops along the Cedar River at Palisades-Kepler State Park in Linn County.



Brian Witzke

The Dakota Sandstone (Cretaceous aquifer) outcrops along the Middle Raccoon River in Guthrie County.



Brian Witzke

Robert McKay

aquifers occur when there is an increase in mineral cements, which can clog the intergranular pore space. In contrast, carbonate rocks – limestone ($CaCO_3$) and dolomite ($CaMgCO_3$) – are finer grained, and groundwater actually follows vertical fractures, crevices, caves and other solutional openings as well as horizontal bedding planes (thin partings that separate sedimentary rock layers). Groundwater movement along these permeable pathways is especially noticeable at roadcuts in winter, when emerging groundwater forms frozen waterfalls (upper photo, p.9).

Solutional openings are peculiar to lime-rich carbonate rocks and result from the chemical dissolving action of circulating ground-

Middle left: Devonian limestone exposed in this Chickasaw County quarry is part of the Silurian-Devonian aquifer.

Near left: A major unit of the Cambrian-Ordovician aquifer is the colorful Jordan Sandstone, seen in bluffs at McGregor in Clayton County.

Near right: Blackhawk Spring issues from the Mississippian aquifer at Crapo Municipal Park near Burlington.

Far right: Bluffs of Prairie du Chien dolomite in Allamakee County are part of the Cambrian-Ordovician aquifer.

Ray Anderson

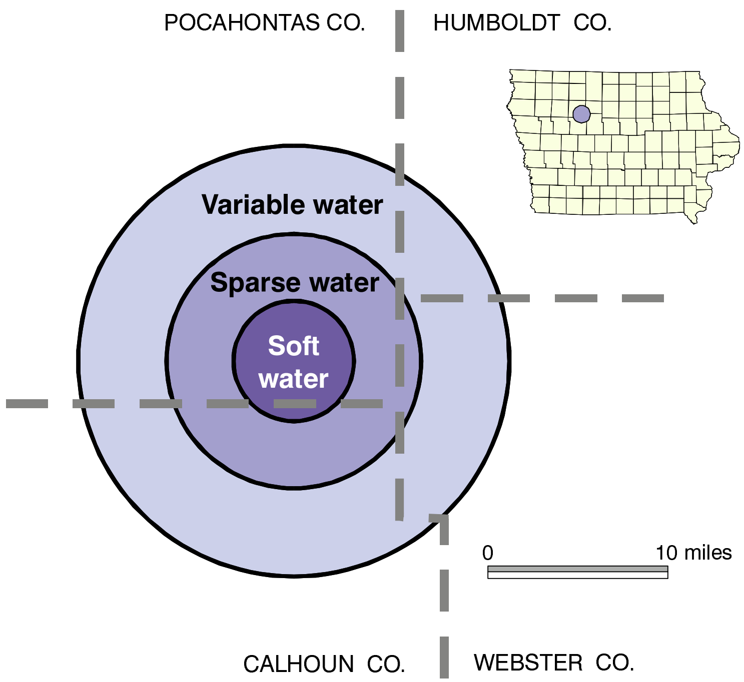
Brian Witzke

water. Such subterranean drainage accounts for sinkholes at the land surface, streams that disappear, caverns underground, and springs on hillsides — landscape features known as *karst* topography (photos, p.2, 3, above, 58). Other types of porosity in Iowa's carbonate rocks occur where fossiliferous zones have been dissolved out, or where the rock has been broken (*brecciated*) in the geologic past, or even between mineral crystals, particularly in the Silurian dolomites. Because these openings in limestone and dolomite are so irregular in occurrence, size, and orientation, yields to wells can be highly variable, even over very short distances.

The distribution of major bedrock aquifers and aquitards beneath Iowa is shown in three different cross-sectional views on pages 27-29. The general slope of these bedrock formations averages 15-18 feet per mile to the southwest, toward geologic basins centered in Kansas and Oklahoma. Note that these inclined strata are beveled by erosion across their upper leading edges, which affects their outcrop patterns across the state's bedrock surface (map, p.40). These conditions are the key to forecasting groundwater availability and quality throughout the range of each aquifer, and to explaining the artesian nature of most bedrock aquifers in Iowa.

For example, where a carbonate bedrock aquifer is the uppermost bedrock unit, natural water quality is at its best. This is where

Groundwater Zones of the Manson Crater



the aquifer received direct precipitation and weathering (prior to glaciation), as well as rapid groundwater circulation and extensive enlargement of rock openings by solutional activity. And now, even with a glacial mantle, the aquifer is still more readily recharged than where it is covered by other bedrock units. The result is much better naturally occurring water quality. The geographic region of greatest use of an aquifer coincides with this outcrop or *subcrop* area.

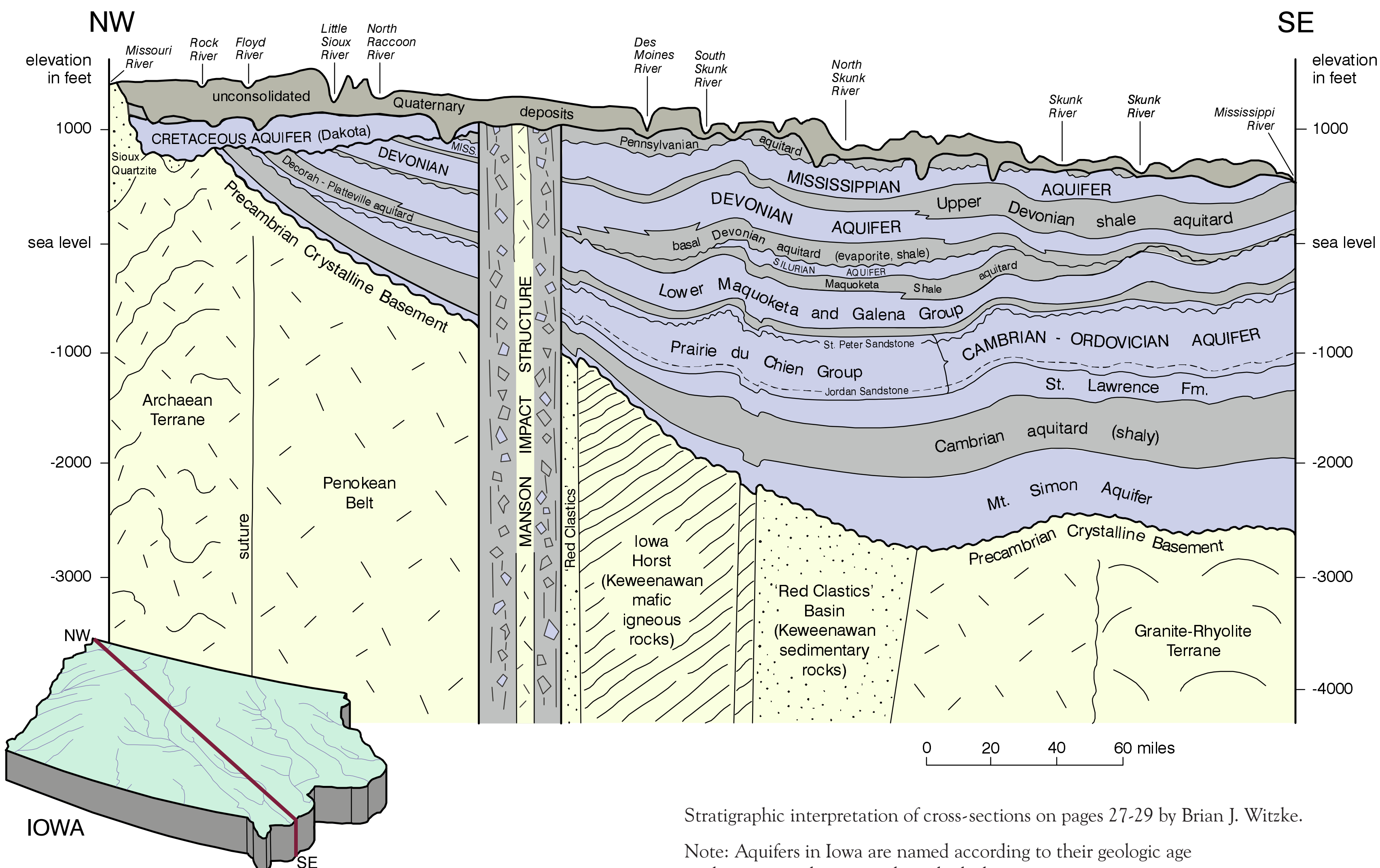
On the other hand, where a bedrock aquifer lies deeper and is overlain by younger bedrock units, natural water quality usually is poorer and use of the aquifer declines. These basic relationships will become more apparent as individual bedrock aquifers are discussed.

Though the deepest groundwater aquifers in the state are contained within this package of sedimentary rocks, the geological story does not end here. Thousands of feet of even more ancient, crystalline rock underlie all of Iowa's sedimentary strata. These so-called basement rocks are 1 to 2 billion-year-old igneous and metamorphic rocks of Precambrian age. In the extreme northwest corner of Iowa, the state's sedimentary rocks end abruptly against an ancient high ground known as the Sioux Ridge, which is composed of 1.6 billion-year-old Sioux Quartzite, a distinctly reddish silica-cemented sandstone. These rocks can be seen at Gitchie Manitou State Preserve in Lyon County.

Another unusual rise of ancient basement rocks in Iowa occurs in Pocahontas and Calhoun counties beneath the Manson Impact Structure (map, left). The sudden impact of a large meteorite 74 million years ago produced massive disruption of the Cretaceous and underlying sedimentary strata, and caused deep-lying igneous and metamorphic basement rocks to rebound to the land surface. The impressive 24-mile wide crater is now concealed from view by 100 to 200 feet of later-arriving glacial deposits. During the early 20^{th} century, water well drillers reported finding unusually soft water from shallow fractured granite, which first brought this fascinating structural feature to geologists' attention. Although good quality water is obtained from the crater's 5-mile-wide granite core, the chaos of deformed strata surrounding it makes finding groundwater in the remainder of the area a "poke and hope" situation at best.

Bedrock Aquifer Systems across Iowa

Northwest to Southeast

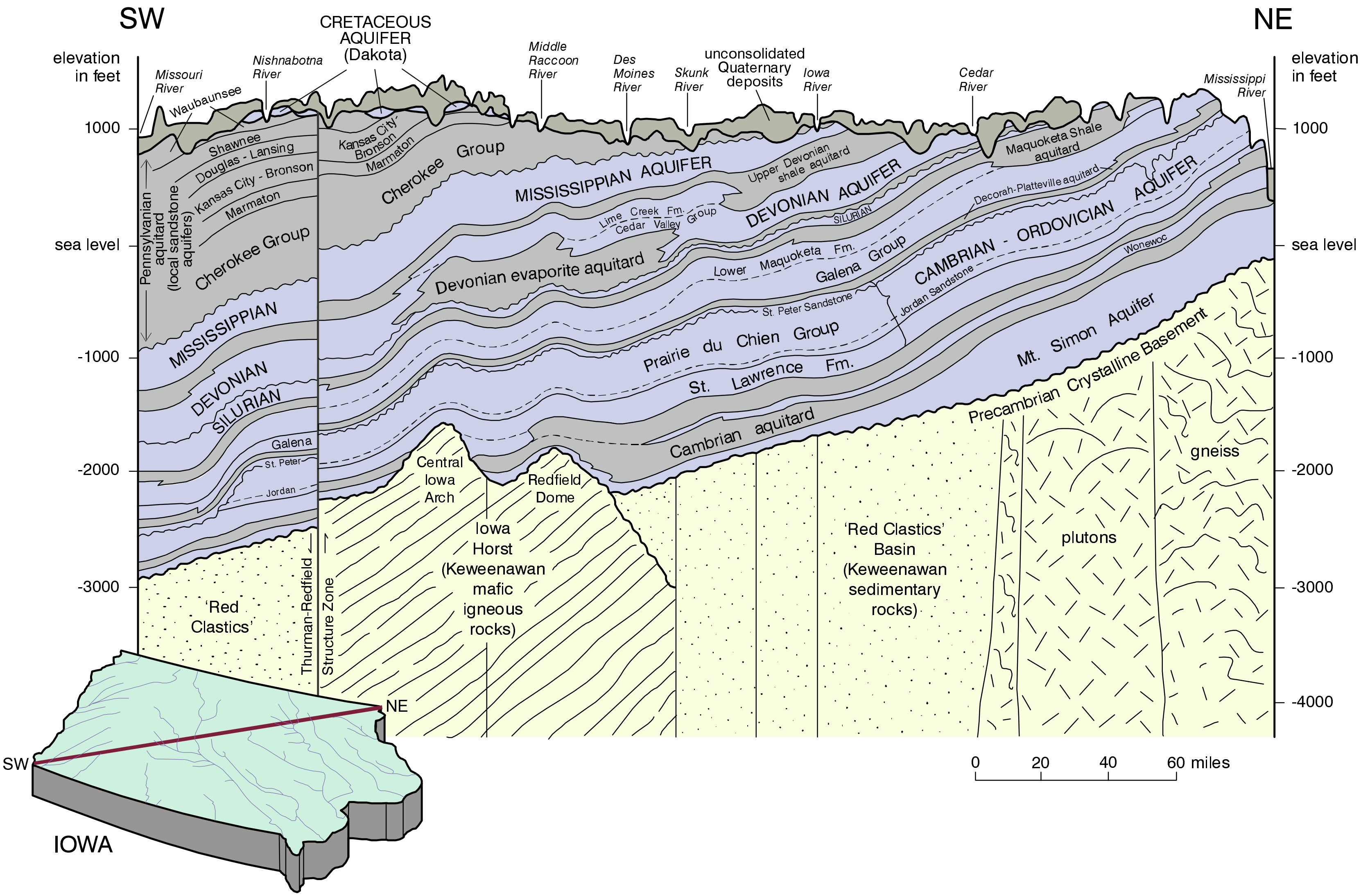


Stratigraphic interpretation of cross-sections on pages 27-29 by Brian J. Witzke.

Note: Aquifers in Iowa are named according to their geologic age or the stratigraphic interval in which they occur.

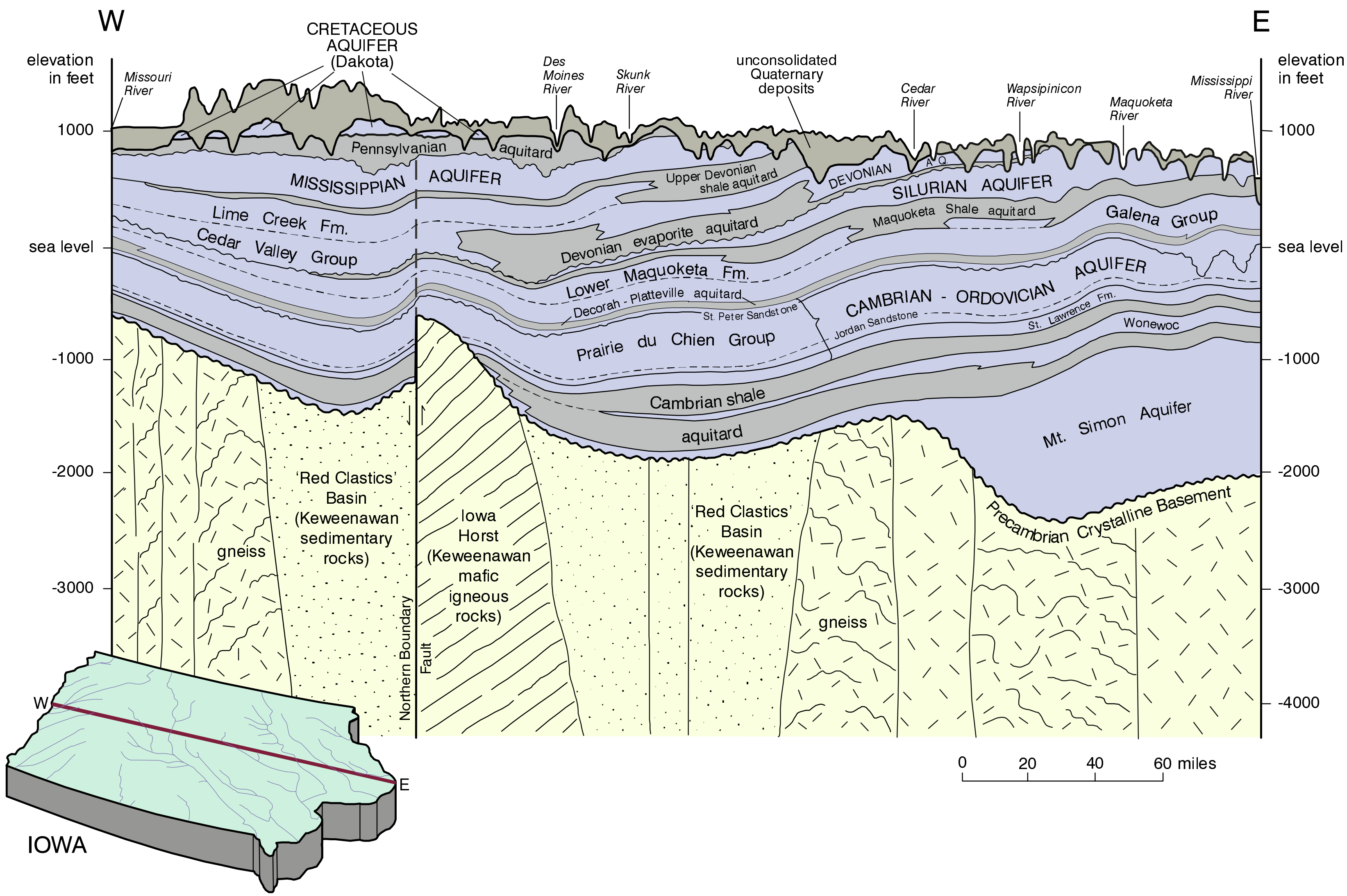
Bedrock Aquifer Systems across Iowa

Southwest to Northeast

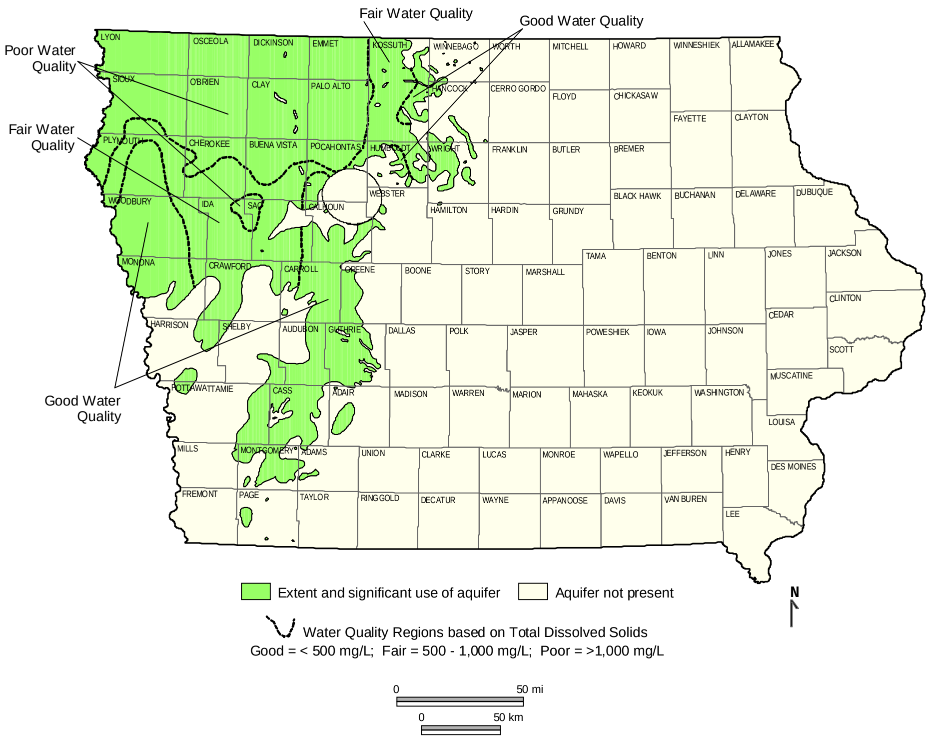


Bedrock Aquifer Systems across Iowa

West to East



Dakota Aquifer of Iowa



Dakota Aquifer (Cretaceous age)

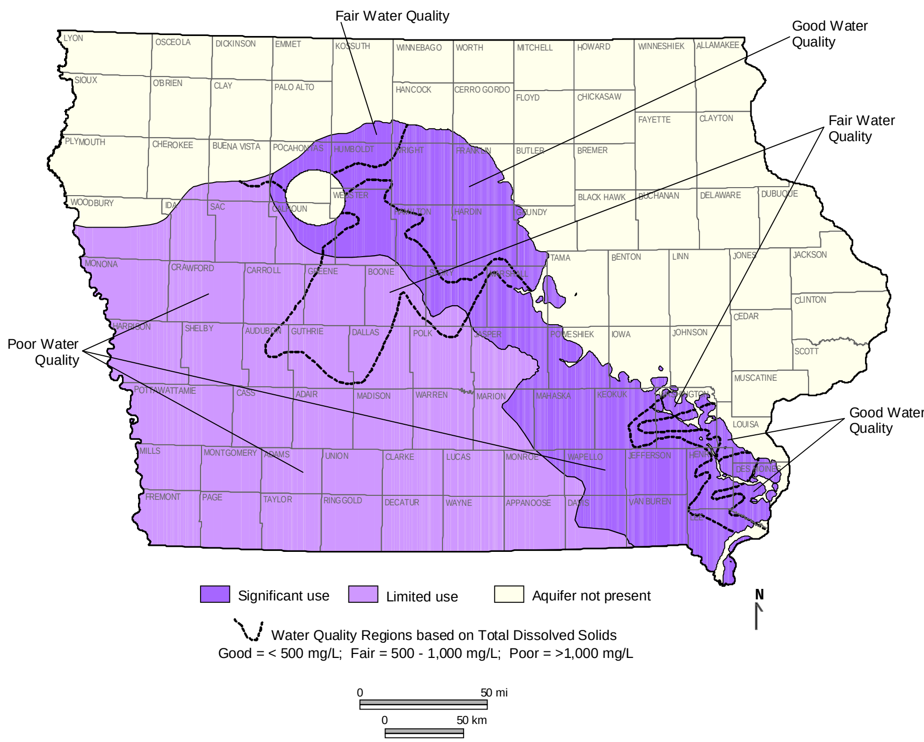
The Dakota aquifer is composed of sandstone deposits 200 to 300 feet in thickness, and provides water for many rural and public water supplies in northwest and west-central Iowa (map, above). This aquifer is composed of the Woodbury and underlying Nishnabotna sandstones, which formed in riverine environments 100 million years ago. The sandstones range in grain-size from very coarse to fine, and they are poorly cemented, providing abundant pore space for groundwater storage. Over 80 percent of the Nishnabotna alone is composed of medium- to coarse-grained quartz sandstone. The sandstones are confined over most of their area by 200 to 400 feet of clay-rich glacial till as well as by thick shale, siltstone, thin chalky limestone, and lignite (low-grade coal).

Wells drilled into the Dakota range from 100 to 600 feet deep and yield 100 to 500 gpm. Some wells can produce as much as 800 to 1,500 gpm. Water quality tends to be fair to poor. The areas of poorer water quality result from high concentrations of dissolved solids (between 500 and 3,000 mg/L), particularly sulfate and calcium carbonate, which are common minerals picked up by groundwater in contact with the confining layers above. Areas of better water quality are found where confining layers are thin and some porous pathways allow for more rapid recharge by unmineralized surface waters. This occurs most notably in the southern area of the aquifer's extent.

The Dakota aquifer in Iowa is recharged by downward percolation through its confining units. Regional groundwater flow is from north to south, and natural discharge from the aquifer occurs into the lower reaches of major rivers in the region.

Views of the Dakota aquifer at the land surface are few and far between. Some of the best, however, are seen in Guthrie County along road cuts and outcroppings in the vicinity of Springbrook State Park and along the Middle Raccoon River valley (photo, p.24). The Dakota sandstone often displays a rust-colored coating formed by oxidation of iron-bearing minerals within the formation.

Mississippian Aquifer of Iowa



Mississippian Aquifer

Productive wells from the Mississippian aquifer supply private and public water supplies for much of the north-central part of the state (map above). The water quality is generally good. In contrast, the same aquifer produces much smaller yields of poorer quality water in central and southeastern Iowa. Throughout its range the aquifer consists of a thick sequence of limestone and dolomite, with thinner deposits of sandstone, shale, the silica-rich mineral chert (flint), and gypsum.

Along the outcrop belt of these rocks, the Mississippian aquifer is overlain by alluvium, loess, and glacial drift, while elsewhere the aquifer is first overlain by thick shale and lesser sandstone units (Pennsylvanian). Since recharge to the aquifer is primarily by infiltration from the land surface, this contrast in materials has a direct effect on the aquifer's water quality. For example, groundwater quality is very good in the north-central *subcrop* area, where dissolved solids concentrations are less than 500 mg/L. Less favorable conditions are present in the central and southeast parts of the area where Mississippian strata have fewer creviced openings and downward recharge is limited by the less permeable Warsaw shale. In these areas, domestic wells may produce only 5 to 10 gpm, and often less than that.

Like the bedrock aquifers beneath it, the entire Mississippian aquifer has a gradual overall slope to the southwest, so that hundreds of feet of younger Pennsylvanian strata and glacial clays overlie the aquifer in south-central and southwestern Iowa. Where these thick Pennsylvanian shales overlie the Mississippian aquifer, high concentrations of sodium, fluoride, and sulfate limit the aquifer's use as a drinking water source, even though yields of 10 to 50 gpm are sometimes possible. In western and southern Iowa the total dissolved solids content ranges from 1,500 to 5,000 mg/L, making the water unsuitable for human and livestock use.

The most productive wells from the Mississippian aquifer are concentrated in north-central Iowa where excellent yields of 500 to

900 gpm are known from municipal wells in Marshall, Story, Hardin, and Wright counties. These high yields coincide with an area of well-developed karst, where the limestone is highly dissolved. Typical well depths range from 100 to 300 feet and commonly yield from 50 to 100 gpm. In central and southeast Iowa, however, yields are as low as 2 to 3 gpm, owing to the scarcity of crevices in the rock formations. Well depths here extend about 100 to 400 feet below land surface.

Regional flow in the Mississippian aquifer is in a southerly direction, and it discharges into the Des Moines and Skunk rivers and their tributaries.

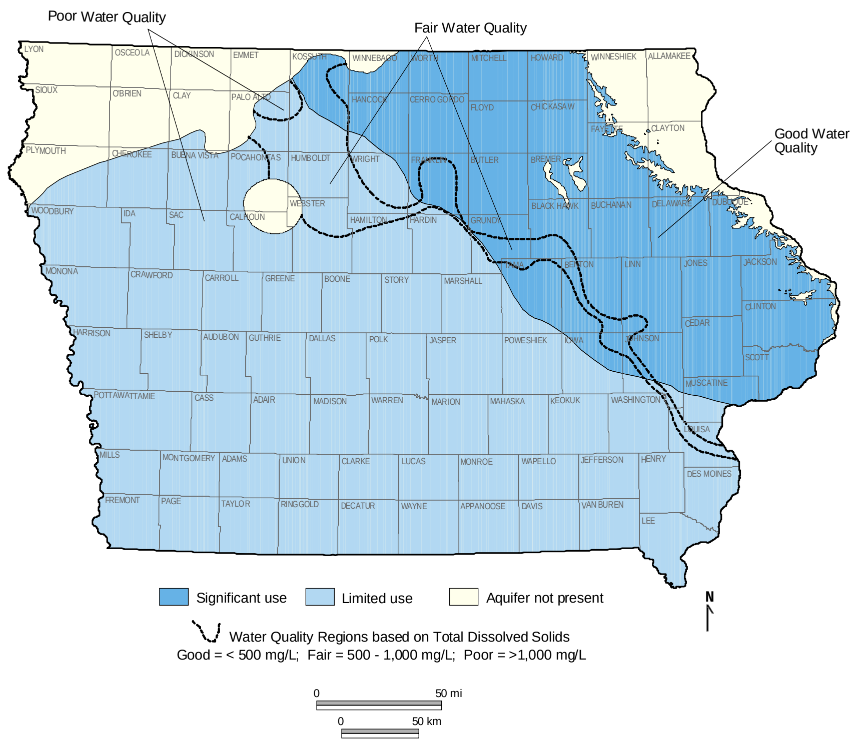
The Mississippian aquifer can be observed as picturesque limestone bluffs along the Mississippi River valley (its namesake), especially between Burlington and Keokuk in southeastern Iowa. In addition, the shallow carbonate aquifer here displays good examples of karst features, including sinkholes within the Burlington city limits, a well-developed solutional cavern at nearby Starr's Cave State Preserve, and Blackhawk Spring at Crapo Park (photo, p.25). Other natural exposures of Mississippian aquifer rocks are seen along river valleys and creek banks as well as roadsides and quarries from Lee, Des Moines, and Louisa counties at the southeast corner of the state to Humboldt and Hancock counties in north-central Iowa. Scenic Lacey-Keosauqua State Park in Van Buren County and Three Bridges County Park along the Iowa River in Marshall County, as well as limestone quarries near Le Grand (famous for their fossil crinoids) are in Mississippian carbonate rocks. Visitors can drink from a flowing artesian well at Benson Park, along Hwy. 3 just west of Clarion in Wright County. This well taps the Mississippian aquifer at a location of considerable artesian pressure. Mineralized groundwater from the Mississippian aquifer at Colfax in Jasper County was thought to have therapeutic effects, and so the ornate Hotel Colfax was built nearby in 1884 as a health spa (photo, p.1).

Silurian-Devonian Aquifer

This aquifer is composed of bedrock units from two major systems of geologic time, the Silurian and the Devonian. They are usually described as a single aquifer package because, regionally, they are composed of similar carbonate rocks that are hydraulically connected and yield similar water quality. Locally, however, there are differences in terms of rock types and water quality, and thus these two units are sometimes considered independently. For example, in eastern Iowa they are two discrete aquifers. In some places, there is no underlying Silurian, and in other places there is no overlying Devonian. And locally, shale and clayey dolomites act as aquicludes, further separating parts of the aquifer system.

This aquifer underlies the entire state except for the northwest and northeast corners (map, right). It is an important source of water primarily in eastern and northern Iowa, serving rural, public, and industrial users. The aquifer is composed mainly of porous dolomites of Silurian age, and limestone and thick shales of Devonian age. As is typical of carbonate rocks, porosity and permeability are dependent on such natural openings as fractures, *brecciated* zones, bedding planes, and solution caverns. These features vary in size, extent, and frequency of occurrence. This aquifer's porosity and permeability are best developed in a broad band about 65 to 70 miles wide and about 200 miles long across the northeastern part of the state (note area of "significant use," above right).

Silurian-Devonian Aquifer of Iowa



The typical thickness of the Silurian-Devonian aquifer in eastern and northern Iowa, its principal area of use, ranges from 200 to 400 feet (diagram, p.29). The aquifer reaches its greatest thickness, 500 to 700 feet, in the southwest part of the state. Most wells tapping the Silurian-Devonian aquifer are 100 to 700 feet deep, and many municipal and industrial wells yield 150 to 400 gpm. Domestic wells can deliver from 10 to 30 gpm, as long as the wells intercept a good fracture system. Interestingly, one of the most productive zones of any bedrock aquifer in Iowa occurs in a narrow zone along the Cedar River valley from Charles City to Waterloo, an area underlain by highly creviced and cavernous Devonian limestones. Yields of 2,000 to 4,000 gpm are known from wells at Cedar Falls, Waterloo, Waverly, and Charles City. The Silurian-Devonian aquifer in parts of this area receives induced recharge from the Cedar River, infiltrating first through a thin layer of alluvial sand and then through cavernous limestone.

Water quality from this aquifer is generally good in eastern and northern areas of the state, with a dissolved solids concentration between 300 and 500 mg/L. This good natural quality, however, decreases rapidly over short distances to the southwest, especially where covered by overlying shales. The aquifer is used much less in the central and southern parts of the state, where it includes thick deposits of gypsum and anhydrite in the Cedar Valley and Wapsipinicon rock units, as well as thick shales. Yields of 20 to 150 gpm can be obtained in these parts of Iowa, but high sulfate concentrations and total dissolved solids as high as 5,000 mg/L make the water unsuitable for human use. In western and southwestern Iowa, the aquifer is deeply buried beneath younger rocks, and the well-developed fracture systems so common in the eastern subcrop area are proportionately fewer and the yields smaller.

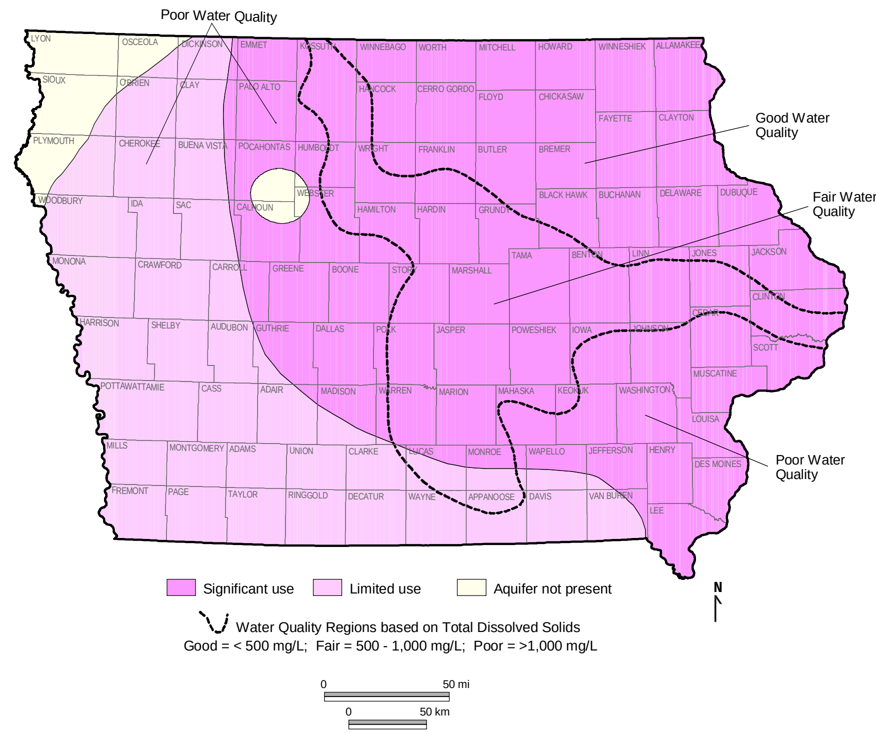
The regional flow of groundwater in the Silurian-Devonian aquifer is to the southeast. Natural discharge from the aquifer toward valleys contributes significantly to the amount of water flowing in the Iowa, Winnebago, Shell Rock, Cedar, and Maquoketa rivers. The aquifer thus serves as an important source of baseflow to these streams.

These river valleys are also good places to observe numerous scenic outcroppings of this aquifer (photo, p.24). Palisades-Kepler State Park in Linn County, Maquoketa Caves State Park in Jones County, and Backbone State Park in Delaware County are excellent and diverse examples of the Silurian aquifer. Fossiliferous Devonian rocks rim the margins of Coralville Lake near Iowa City, and are especially well exposed for visitors at Devonian Fossil Gorge in Johnson County. A portion of the Rockford Fossil and Prairie Center in Floyd County was the former site of the Rockford Brick and Tile quarry, which utilized the thick shale of the Upper Devonian aquitard.

Cambrian-Ordovician Aquifer

This is the only aquifer in Iowa that is widely used even where it is covered by younger bedrock units. The Cambrian-Ordovician aquifer is a widespread and dependable source of water for high-capacity wells, and it is used extensively by municipalities and industries in the eastern half of the state (map, right). The aquifer is composed of three separate formations – the Jordan Sandstone (Cambrian age) at the bottom, dolomite and sandstone of the Prairie du Chien Group in the middle (Ordovician age), and the St. Peter Sandstone at the top (diagrams, p.15, 27-29). All these bedrock units are water-bearing, so they usually are treated as a single aquifer. Wells that require large amounts of water typically tap the full range of the Prairie du Chien and Jordan units, while other wells may tap only the St. Peter or a combination of the St. Peter and upper Prairie du Chien. While often called the "Jordan aquifer," much groundwater also comes from the Prairie du Chien. Thus

Cambrian-Ordovician Aquifer of Iowa



"Cambrian-Ordovician aquifer" is a more accurate term for this water-producing zone.

Typical well depths in this aquifer range from 300 to 2,000 feet, with some over 3,000 feet deep. As noted earlier, bedrock aquifers are inclined in a southwesterly direction toward Kansas and Oklahoma; thus, the deepest wells are in southwest Iowa. This depth range highlights another characteristic of water from this aquifer – its temperature. Since the natural temperature gradient within the earth increases with depth, water temperatures within the Cambrian-Ordovician aquifer range from 60 to 80 degrees F, and reach 85 degrees F in the 3,000-ft wells.

Wells that are properly developed in the Cambrian-Ordovician aquifer yield from several hundred to over 1,000 gpm. As with other sedimentary bedrock aquifers, yields are related to the amount of natural cements filling the pore space in sandstone, and to the presence or absence of fracture openings through denser limestone and dolomite. Water quality is generally good, with the best quality found in northeast Iowa, nearest the areas of outcrop and recharge. In western and southwestern areas, as the aquifer inclines deeper beneath the land surface, the dissolved mineral content increases to undesirable levels, with high sulfate, chloride, and fluoride in particular. In portions of southeast, central, and western Iowa, the aquifer sometimes contains excessive levels of radium and is treated before use in municipal water supplies.

The main area of aquifer recharge is in southern Minnesota and northern Iowa, via vertical leakage from overlying aquifers. Subsurface flow is then to the southeast, with discharge to the Mississippi Valley.

Historical use of the Cambrian-Ordovician aquifer by municipal and industrial pumping centers such as Ft. Dodge, Mason City, Des Moines, Washington, Fairfield, and Ottumwa caused the potentiometric surface of the aquifer to drop between 50 and 150 feet. Sharp recoveries occurred when these wells shut down, but they did not regain their original standing water levels. Despite this drop, the available water is not expected to be exhausted in the near future as the aquifer contains an estimated 80 trillion gallons of water. Local, smaller declines also are noted in the Silurian-Devonian aquifer.

Outcrops of Cambrian-Ordovician rocks produce some of the most spectacular scenery in Iowa, particularly from McGregor northward along the Mississippi Valley (photos, p.24, 25). The 480 to 510 million-year-old dolomites and sandstones that elsewhere comprise this aquifer dominate the landscape at such scenic points as Yellow River State Forest, Effigy Mounds National Monument, and Mt. Hosmer City Park at Lansing, all in Allamakee County.

OTHER GEOLOGIC UNITS

Galena Aquifer

The Galena Group dolomites are a much more restricted source of groundwater used locally in northeastern Iowa, especially in Winneshiek, Clayton, northeastern Fayette, southwestern Allamakee, and the eastern two-thirds of Dubuque counties (photo, p.12). In this area of primary use, the Galena is overlain by the younger Maquoketa Shale which serves to protect the shallow Galena aquifer from surface contamination problems. Most wells in this area yield between 10 and 30 gpm. Just to the east, in the area where the Galena strata are exposed, sinkholes and other karst features are abundant, and contamination from nitrate and bacteria is a significant problem. Locally, iron concentrations also can be a problem. Throughout the aquifer's geographic extent, groundwater flow is generally to the southeast, though local variations occur. Within its outcrop area, recharge occurs across the northeast Iowa uplands, and discharge occurs primarily to the Mississippi, Turkey, Upper Iowa, Volga, and Little Maquoketa rivers.

Brian Witzke

The fine-grained Maple Mill Shale forms part of the Upper Devonian aquitard in Iowa. These exposures occur along the English River in Washington County.

Dresbach Aquifer

Though the Dresbach (Mt. Simon) aquifer is a major water supply for parts of Minnesota, Wisconsin, and Illinois, this deep sandstone aquifer is important to only a few counties bordering the Mississippi River in northeast and east-central Iowa. For example, dependable supplies are tapped at New Albin, Lansing, Marquette, Dubuque, and Clinton. Because it lies beneath the more accessible Cambrian-Ordovician aquifer, it is not used as much, except for large industrial wells. Where tapped, however, it is a prolific source of water, especially near Clinton where pumping rates of 2,500 gpm are known. Quality problems within the aquifer's deep sandstone formations include salty water and high radium concentrations. Little is known about its water quality across the rest of Iowa.

Confining beds: aquitards

Bedrock units in Iowa not specifically highlighted as aquifers are referred to as aquitards and are noted in the tables on pages 14-15 and in the diagrams on pages 27-29. The importance of Iowa's aquitards, or confining beds, cannot be over-estimated. They are what define and separate aquifers from each other, and they provide the stratigraphic seals that place aquifers under artesian pressure. In general, these strata are thick, dense shale or siltstone units that inhibit vertical water movement, though they also may impart poorer water quality to adjacent aquifers. These aquitards include thick Cretaceous shales in western Iowa, Pennsylvanian shales across southern Iowa, Devonian shales in north-central Iowa, and Ordovician shales in northeastern Iowa. Within these broad aquitards, thin interbedded limestone and sandstone units occur and can sometimes be tapped as aquifers for local use. This is particularly true of Pennsylvanian deposits in central and southern Iowa, as well as Ordovician units in northeastern Iowa.

Because aquitards impede downward water movement, groundwater tends to flow laterally, along the paths of least resistance through more permeable aquifer materials. There still remains, however, a vertical component to this flow, and groundwater may very slowly discharge either upward or downward through aquitards, depending on the pressure gradients. This is how poorer natural water quality is imparted to some confined aquifers.

When shallower glacial drift aquifers were described earlier, we noted that their porous sands and gravels occur within more widespread fine-textured glacial till. It is this massive blanket of clayey glacial till that acts as an aquitard over much of Iowa's landscape, separating the land surface from underlying bedrock aquifers. These dense, low-permeability glacial deposits are the first line of defense in protecting Iowa's bedrock aquifers from sources of land surface contamination.

The glacial till aquitard varies considerably in thickness across the state. The thinner it is, the less protection it offers to underlying aquifers. Also, as impermeable as glacial till seems, it is known to be fractured in places. The open vertical "joints" are actually weathering features caused by dessication. These cracks, sometimes occurring in polygonal patterns similar to common mud cracks, formed as the post-glacial land surface was exposed to drying air. Fracture zones occur most often in the oxidized zone of glacial tills, and they can transmit water tens to hundreds of times faster than unfractured materials. In addition, these open pathways allow infiltrating water and contaminants to bypass the clayey matrix, to which some chemicals would otherwise adhere, and move easily through in an unfiltered and undiluted state to an aquifer beneath.

A final comment is warranted about well yields from the various aquifers described in this chapter. The figures given are from wells that are test-pumped in response to a specific, needed pumping rate. The true potential yields from many of these aquifers remain unknown.

IOWA'S GROUNDWATER PROVINCES

"[Groundwater's] importance does not need argument though it may need emphasis."

– Thomas C. Chamberlin
The Requisite and Qualifying Conditions of Artesian Wells, 1885

Brian Witzke

Each region of Iowa has a predictable pattern of available groundwater resources. The state's aquifers are mapped by examining outcrops like these and by studying samples and hydrologic data from drilled wells. (Silurian outcrops, Wapsipinicon River, Linn County)

Iowa's groundwater resources consist of five principal aquifers – four bedrock aquifers and an assortment of shallower sand and gravel deposits that overlie the bedrock and collectively are called surficial aquifers. Widespread confining beds retard movement of groundwater between the bedrock aquifers in particular.

The major bedrock aquifers extend over large geographic areas, well beyond Iowa's borders. These regional aquifers have been introduced as the Dakota (Cretaceous), the Mississippian, the Silurian-Devonian, and the Cambrian-Ordovician ("Jordan") aquifers. Each aquifer system includes several stratigraphic formations and water-bearing zones, as noted in the table on pages 14-15 and in the cross-sections on pages 27-29. Most of the groundwater flow in these aquifers can be described as deep, confined, and relatively unaffected by recharge from the surface. Because of the downward slope of the state's bedrock sequence toward the southwest, however, these aquifers do have areas of local flow where their upper edges lie closer to the land surface and where recharge occurs.

Each of these four bedrock aquifer systems serves as a primary groundwater source over some part of the state, or as a second option in other areas. As already noted, the smaller area of primary aquifer use coincides closely with its area of shallower depth and better natural water quality.

Now, with this overall framework of the bedrock and surficial aquifers in mind, it is possible to look at Iowa statewide and summarize its groundwater resource options as they occur in identifiable groundwater provinces. The general availability of groundwater (how accessible it is), plus its quantity and quality, form the basis for dividing Iowa into three districts: the Northeast, the Northwest, and the Southern Iowa groundwater provinces.

Northeast Iowa Groundwater Province

The Northeast Iowa Groundwater Province is rich in water resources and thus can be described as “good” (map, p.40). This region has several options for groundwater sources. Depending on location within the province, these options include the Mississippian aquifer, the Silurian-Devonian aquifer, and the Cambrian-Ordovician aquifer. Locally, the more restricted Galena and Dresbach (Mt. Simon) aquifers are also available.

Both glacial drift and river valley alluvium are often bypassed in favor of the relatively shallow and more productive underlying bedrock aquifers. Deposits of glacial drift are thin or absent in far northeast Iowa, but thicken to about 300 feet in the southern or western parts of the province. Alluvial aquifers are utilized along the larger rivers that cross the province in a northwest-to-southeast direction, especially the Iowa, Cedar, and Wapsipinicon.

The Mississippian aquifer is used primarily along its narrow outcrop belt that stretches from north-central to southeast Iowa. Where the Mississippian is absent, the Silurian-Devonian aquifer provides abundant water. Water quality in both these regional bedrock aquifers is generally good, but is typically hard because of dissolved minerals from the carbonate rocks and is occasionally prone to taste and odor problems. These naturally occurring quality problems increase in a westerly direction across the province.

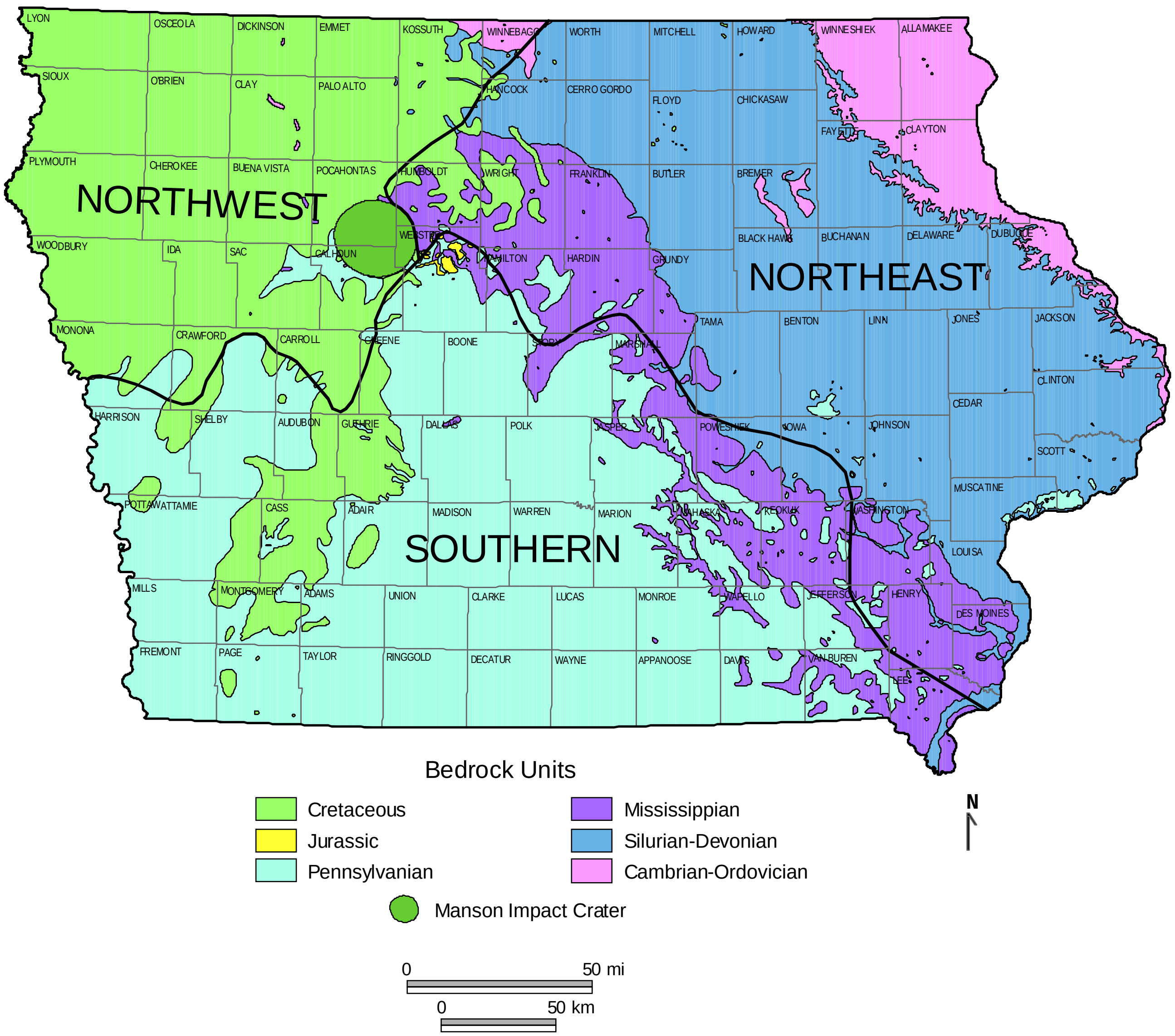
In extreme northeast Iowa, both the Mississippian and Silurian-Devonian rocks are absent, having been removed by erosion in the geologic past. Here, the Cambrian-Ordovician aquifer is the most reliable groundwater source. A few counties in northeastern Iowa also use the Galena aquifer, a shallower Ordovician water-bearing formation. Use of the deep Dresbach aquifer is confined to a few Mississippi River counties, specifically eastern Allamakee, Clayton, Winneshiek, Dubuque, Jackson, Clinton, and Scott.

In parts of northeastern Iowa, the bedrock aquifers are highly susceptible to contamination, especially where they lie at or near the land surface and where the karst conditions described earlier are present. Newer wells frequently are drilled to greater depths to avoid these known contamination problems. Aquifers in the central and east-central portions of the province have a thicker cover of glacial drift, making them less susceptible to contamination problems from surface sources. Major aquitards in this region include the clay-rich glacial drift and the Maquoketa Shale.

Northwest Iowa Groundwater Province

Northwest Iowa can be characterized as “fair” in terms of groundwater availability, quantity, and quality. This area has fewer options for groundwater than northeast Iowa. The Dakota Sandstone, or Cretaceous aquifer, is the primary groundwater source because of the relatively shallow depth, generally good yields, and fair water quality of its sandstone units (except for local areas of exceptionally high sulfate). Regional bedrock aquifers lying below the Dakota Sandstone are very high in total dissolved solids and are unsuited for human or livestock use. Alluvial aquifers, on the other hand, are extensively used along major valleys, especially those of

Groundwater Provinces of Iowa



the Floyd, Rock, Little Sioux, Big Sioux, and Missouri rivers.

Buried valley aquifers are quite productive in certain locales of northwest Iowa (map, p.19). Glacial drift aquifers, while not as productive, are sufficient for many private and small public water supplies. The "salt and pepper" sands also occur within or at the base of the glacial tills in western Iowa, and locally these sand deposits produce moderate amounts of water.

The circular Manson Impact Structure in parts of Calhoun and Pocahontas counties features a massive disruption of the normal bedrock sequence, and finding groundwater within its boundaries can be difficult (map, p.26). Test holes are needed to search for water, and once found, the supply may not last long because the rocks often are no longer connected to the aquifers surrounding the meteor impact structure.

Northwest Iowa has substantial amounts of loess and glacial drift (an aquitard) covering the bedrock aquifers, thus protecting them from surface contamination. The major contamination issue in this province is the vulnerability of the widely used alluvial aquifers.

Southern Iowa Groundwater Province

The search for groundwater in southern Iowa can be challenging. Consequently this province is generally classified as a "poor" or difficult area in terms of finding water of sufficient quantity and quality. Pennsylvanian strata are the uppermost bedrock across large expanses of southern Iowa. These rock units, generally regarded as an aquitard, can sometimes be pressed into service if local occurrences of limestone and sandstone are favorable.

Three major bedrock aquifers are used in southern Iowa, the Mississippian carbonate as well as the Dakota and Cambrian-Ordovician sandstone aquifers. The Mississippian carbonate aquifer is used in areas where the Pennsylvanian bedrock is relatively thin or absent. The Dakota sandstone aquifer extends from northwest Iowa into several southwestern Iowa counties. The Cambrian-Ordovician aquifer has been relied on for decades in central and southeast Iowa as the only source of an adequate and reliable volume of water for towns and industries in particular. The introduction of Rural Water Districts has reduced or eliminated that reliance. Elsewhere, water in the deep regional bedrock aquifers is generally unusable because of very high levels of total dissolved solids.

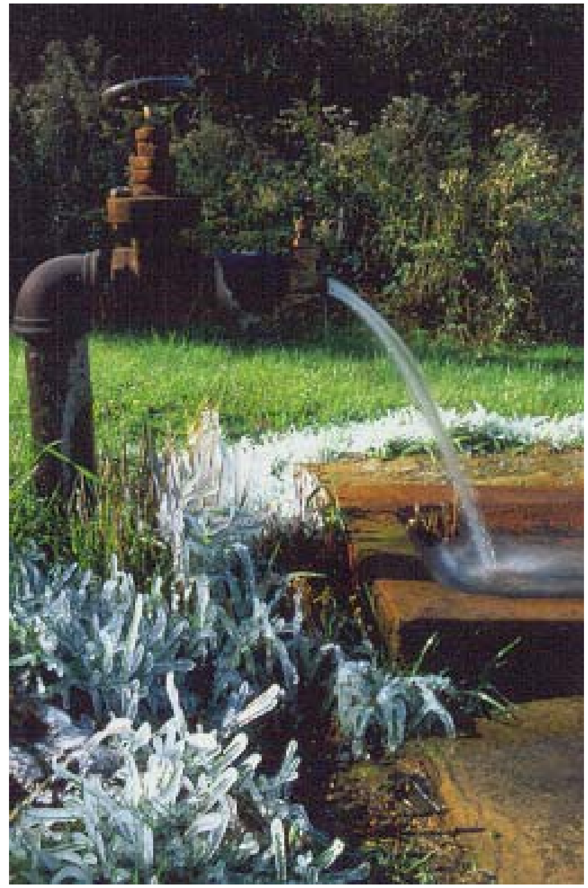
For these reasons, both glacial drift aquifers and buried valley aquifers assume a more important role in providing water in southern Iowa. Alluvial aquifers also are valuable here, especially along the Skunk, Des Moines, and Nishnabotna rivers. These shallow sources are vulnerable to contamination problems from the land surface and present the most serious contamination issues in the province. The steeply rolling, well drained topography across much of southern Iowa is well suited to the installation of ponds and reservoirs, many of which are used to augment water supplies for both people and livestock.

Most areas of southern Iowa have a thick covering of glacial materials that keep surface contaminants from entering bedrock aquifers. The main exception is an outcrop area of the Mississippian aquifer in far southeastern Iowa, especially Des Moines County, where limestone is exposed near the land surface and local karst conditions are present.

WELLS
GETTING WATER from the GROUND

"The strata penetrated, the depth of water horizons, almost all the facts of use in artesian investigations must be gathered while the boring of any well is in progress, or not at all."

– William Harmon Norton
Artesian Wells of Iowa, 1897



Clay Smith

The internal pressure that causes artesian wells to flow comes from the arrangement of rock layers beneath the ground. (Black Hawk Bluff, Allamakee County)

Water flows from an aquifer into your drinking glass by means of a well. Techniques for well drilling and construction vary with aquifer depth, aquifer rock type, other strata encountered above the aquifer, and the amount of water needed. In Iowa, three major types of wells are used to produce groundwater: sandpoints, bored wells, and drilled wells. Common to most of them is a cylindrical hole excavated into the ground, a column of pipe or *casing* to keep the hole from collapsing, grout to seal the space between the hole and the casing, and a pump to lift the water to the surface.

The oldest method of obtaining groundwater is to dig a hole by hand to some depth below the water table. Historically such dug wells were lined with stones, bricks, or tiles and covered with a cap of wood, stone, or concrete. Modern versions of these dug wells are large-diameter seepage wells that are mechanically bored with power equipment. These wells usually range from 30 to 36 inches in diameter, and they are intended to expose a large surface area to slowly infiltrating groundwater. Such bored wells are useful in tapping shallow water-table conditions, often in fine-grained, slowly permeable materials such as loess (silt) or glacial till (clay).

Sandpoint wells, or "driven wells" as they are sometimes called, are small-diameter pipes (about two inches) pushed into the ground to tap shallow water-bearing sand or gravel. These pipes are usually fitted with a pointed screen at the bottom. Like the dug and bored wells, these shallow wells are typically less than 50 feet deep, and they go dry when the water table drops below the bottom of the well. They are also highly vulnerable to contamination sources originating at the land surface (diagram, p.45).

Most deeper wells today are constructed by truck-mounted, rotary drill rigs (photos, p.46). After a drill hole is completed, permanent steel or plastic casing is inserted. Typically the casing extends from just above ground level through the relatively soft glacial materials and into bedrock, usually several feet into the major water-bearing bedrock aquifer. The drilled hole below the casing is left exposed to provide water to the well (diagram, p.44). Wells drilled into shallower sand and gravel require casing plus an attached well screen to prevent the hole from collapsing and to keep fine sediment from entering the well and damaging the pump or clogging the pipe. When an aquifer consists of very fine sand, a gravel pack is added around the screen to prevent sand from entering the well. This technique allows use of larger slot openings in the screen, thus enabling increased water yields. Wells drilled into loosely cemented sandstone bedrock sometime need screens too. When the aquifer is in carbonate rocks, screens are unnecessary because groundwater movement is along fractures and bedding planes, and usually there is little sand or silt present.

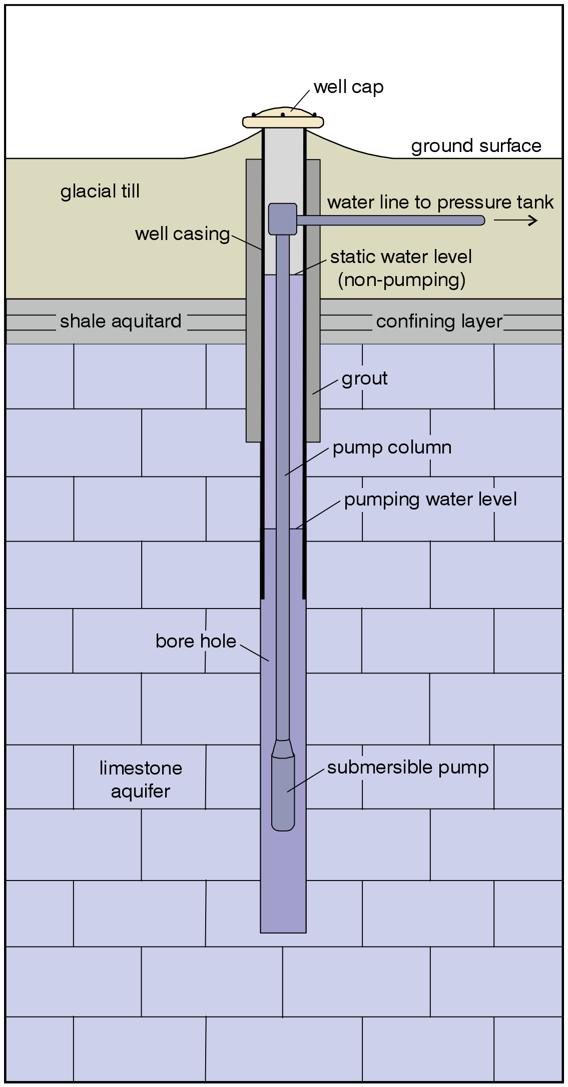
Once the well casing is in place, grout is used to seal the *annular space* between the borehole and well casing. *Grout* is a slurry mixture of cement or *bentonite* and water that sets up to form an effective seal. This prevents surface water from draining down the outside of the casing and into the well and also prevents the movement of water between aquifers. In addition, grout seals off openings to undesirable formations and helps to prevent corrosion of the well casing (diagram, p. 44).

Modern wells are constructed in accordance with rules found in the *Iowa Administrative Code*. These rules fit the various well construction methods used in Iowa – drilled wells in unconsolidated (glacial) materials, drilled wells in bedrock materials, and bored and augered wells in unconsolidated materials (diagram p.45).

Most wells drilled in Iowa are for groundwater supplies. The deepest water well record on file at the Iowa Geological Survey in Iowa City is the 3,467-foot Greenfield Municipal Well #1 in Adair County drilled in 1929. Other wells are drilled to test for water-bearing conditions, to monitor aquifer conditions, and to explore for minerals, oil and gas (or its underground storage), and, historically, to drain wet ground (*ag-drainage wells*). For many years, the deepest well drilled in Iowa for any purpose was a 5,305-foot oil test in Page County completed in 1930. Then in 1987, an exploratory oil test hole in Carroll County near Halbur was drilled to a depth of 17,851 feet. This remains the deepest well drilled in Iowa to date.

Often wells are "developed" by drillers to increase the amount of water produced in a new well or to improve the performance of an older well. *Well development* may be as simple as the vigorous pumping of a new well to remove excess drilling mud and other fine sediments. At other times a solution of dilute hydrochloric acid may be pumped into a new well to enlarge openings in carbonate rock formations (called "acidizing") or into an older well to remove encrusting deposits of lime. The addition of polyphosphates, followed by vigorous surging of a well, is used to disperse silts and clays and remove oxides of iron and manganese.

Components of a Water Well

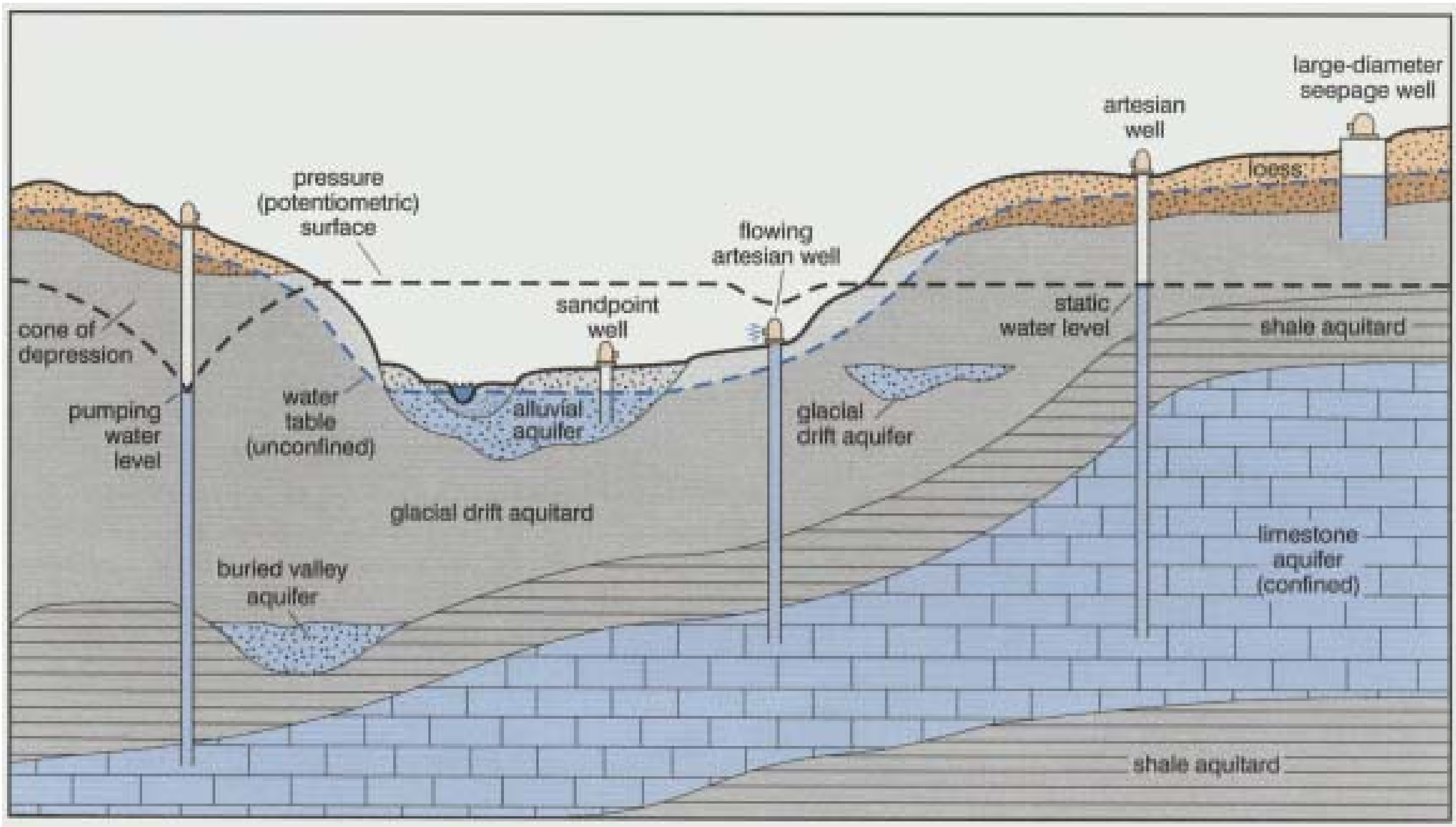


Yields from wells depend largely on the ability of an aquifer to store and transmit water. When water is pumped, water levels in the aquifer decline. The maximum decline occurs at the pumping well itself, and the decline, or *drawdown*, radiates from there, decreasing with increasing distance from the pumped well. In three dimensions, the drawdown is generally cone-shaped and therefore referred to as the well's *drawdown cone*, or *cone of depression* (diagram, right). In an unconfined aquifer, the drawdown cone reflects lowering of the water table. In a confined aquifer, it reflects lowering of the potentiometric (artesian pressure) surface around the well.

When a well no longer produces water or functions as a standby supply in good repair, then it should be properly plugged. Deteriorating wells become direct conduits for contaminants from the land surface to reach an aquifer and for cross-contamination to occur between different aquifers. Since 1987, about 44,000 abandoned wells in rural Iowa have been plugged, assisted by a Grants-to-Counties program funded by the Iowa Department of Natural Resources. The key aspects of proper well closure are to isolate the aquifers penetrated by a well from each other and from the land surface using impermeable filling material such as bentonite.

Since a well owner can't examine the inside of a well to troubleshoot problems, it is important to maintain basic information about its construction, performance, and water quality. Starting with construction records provided by the well drilling contractor, keep all records about a well's performance, routine pump maintenance, and needed repairs or remediation measures. Careful documentation of a well's history can be invaluable to diagnosing future well problems, suggesting appropriate treatment, and predicting the useful life of the well. Basic information about a well should include

Wells and Aquifers in Iowa



its precise location on a map (¼, ¼, ¼, ¼, Section, Township, and Range), well depth, *static water level*, pumping water level, estimated yield, and basic water quality.

A drilled well in Iowa can yield much more than water. Since the late 1800s, the Iowa Geological Survey has routinely archived well samples from cooperating drillers around the state. This library

Wells were drilled at Briggs Woods Park in Hamilton County to test aquifer characteristics in the surficial and Mississippian aquifers. These nested wells enable water levels and quality of the groundwater supplies to be monitored over the long term.

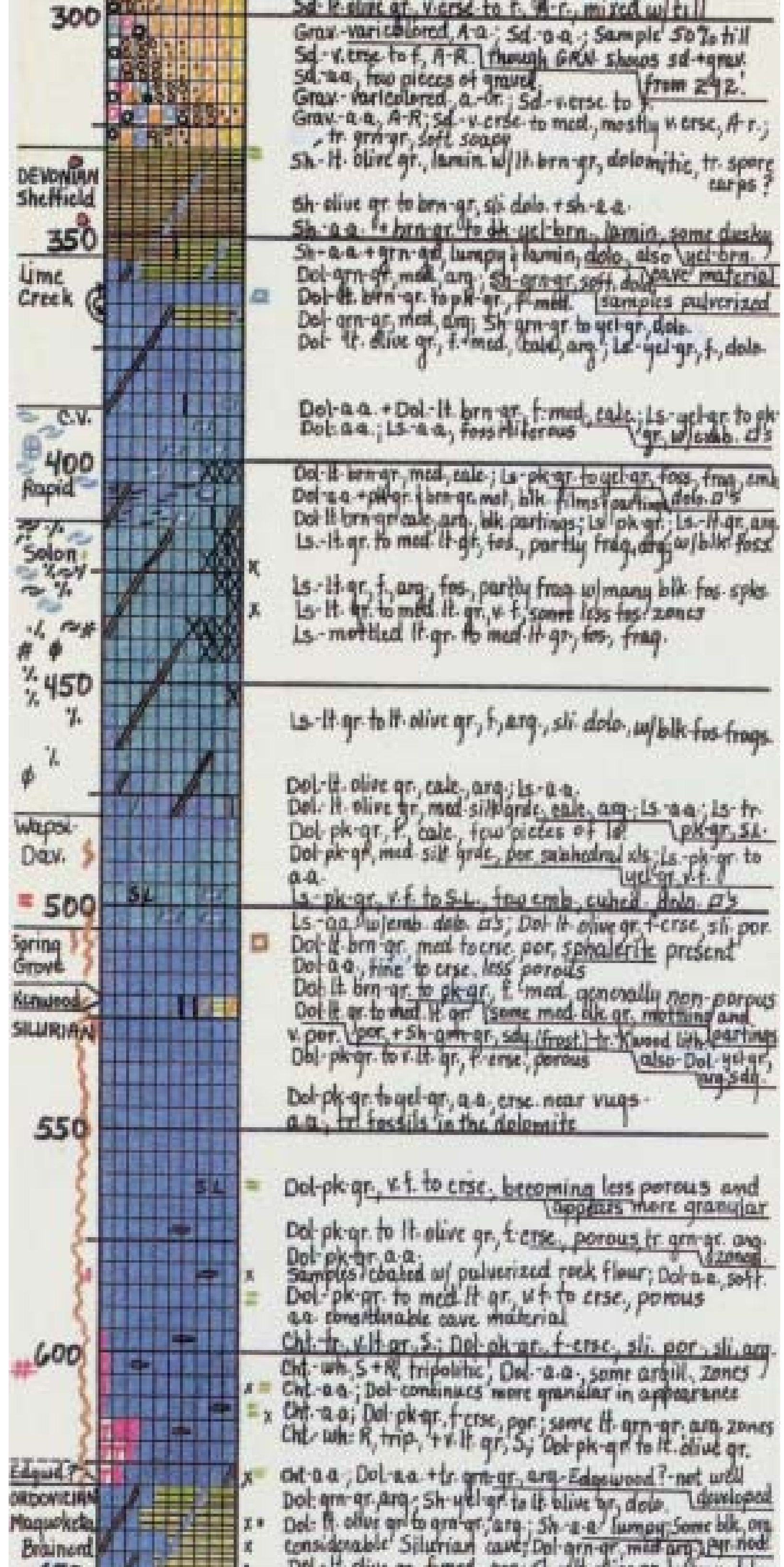
photos by Clay Smith

of 36,000 sets of drill chips and some 900 cores (solid cylinders of rock), totaling over 400,000 feet, account for over 90 percent of the information used to interpret the state's subsurface environments and their groundwater resources. Logs prepared from these samples are invaluable as baseline records of well conditions at the time of drilling (photo, right). They are solid pieces of geologic and hydrologic data to be used many times over as information to forecast conditions at prospective drilling sites or any site having engineering or contamination problems. When combined with sample sets from other wells, they become part of a database that is essential for both immediate and long-range use in solving the underground puzzles of Iowa's geologic strata and their associated groundwater resources.

Wells also reveal much about the health of an aquifer. By sampling well water periodically, changes can be noted in its quality and in the presence or absence of annoying or harmful contaminants. Also, keeping records of water levels can identify long-term trends in whether groundwater is being used faster than it is being naturally replenished. Such monitoring activities are valuable in identifying potential problems, tracking the geographic extent and depth of contaminant plumes, and supplying basic information about individual aquifers and how they differ from one another (photos, left).

One of the most interesting effects on water levels in Iowa wells occurred on March 27, 1964, following the Great Alaskan Earthquake, some 3,000 miles away. This earthquake, one of the largest

Logs of wells are prepared from microscopic study of samples collected during drilling. Details of soil and rock materials are keys to understanding the occurrence of groundwater resources in Iowa and to predicting conditions in untested areas.



ever recorded on the North American continent, disturbed water levels in all of Iowa's major aquifers. The effect in some wells was noted as sharp fluctuations in water levels on recorder charts. In other wells and in some springs, the water became turbid for a short time from disturbed silt and clay in the aquifer. Still other wells showed a permanent rise or fall in the water level of the aquifer, likely because the earthquake caused either compression or expansion of the porosity within the aquifer.

Then on the afternoon of November 3, 2002, another strong earthquake in central Alaska had noticeable repercussions in Iowa wells. The 7.9 Richter Scale quake along the Denali Fault struck at 4:12 p.m. Iowa time, and by 6:00 p.m. reports of discolored water in northeast Iowa started coming into local and state offices. Over the next two days, owners of limestone wells throughout northeastern Iowa reported water that ranged from lime-green to almost black (photo, p.51). Shock waves from the quake caused groundwater in Iowa's aquifers to slosh. This agitation stirred up fine sediment lying along rock fractures and in the bottoms of wells, and loosened the buildup of iron and manganese on submerged well pipes, casing, and pumps, contributing to the temporary discoloration of the water.

Water quality is a major factor in the development of a water

Significance of Commonly Occurring Constituents in Drinking Water

Constituent	Maximum contaminant level (MCL) for public water supplies	Recommended maximum level	Naturally occurring	Comments
Microorganisms				
Total coliform bacteria	No bacteria in 95% of samples collected		✓	Indicates pathway for potentially harmful microorganisms; inadequate well condition
Inorganic chemicals				
Arsenic (As)	0.01 mg/L		✓	Adverse health effects; carcinogenic
Chloride (Cl)		250 mg/L	✓	Salty taste when sodium present; corrosion of pipes
Fluoride (F)	4.0 mg/L	2.0 mg/L	✓	Affects dental health
Hardness: calcium (Ca) and magnesium (Mg) ($CaCO_3$)			✓	Limits lathering ability of soap; causes scale buildup
Iron (Fe)		0.3 mg/L	✓	Objectionable taste; stains laundry and porcelain
Manganese (Mn)		0.05 mg/L	✓	Objectionable taste; stains laundry and porcelain
Nitrate: as N as NO_3	10 mg/L 45 mg/L		✓	Land-applied fertilizer; leaching from septic tanks and sewage; adverse health effects; causes “blue baby syndrome” in infants
Sodium (Na) and potassium (K)			✓	Salty taste when combined with chloride

Sulfate (SO_4)		250 mg/L	✓	Objectionable taste; laxative effects; forms scale when combined with calcium
Total dissolved solids (TDS)		500 mg/L	✓	Refers to all material in solution; limits lathering of soap; objectionable taste
Suspended sediment			✓	Gives water a muddy or turbid appearance; pump wear
Dissolved gases				
Hydrogen sulfide (H_2S)			✓	Odor; corrosion of pipes, casing, and pumps
Methane (CH_4)			✓	Explosive
Organic chemicals	Atrazine 0.003 mg/L			
Pesticides	Alachlor 0.002 mg/L			Land-applied herbicides; adverse health effects
Benzene	0.005 mg/L			Leaking gasoline storage tanks; adverse health effects
Trichloroethylene (TCE)	0.005 mg/L			Industrial solvent and degreaser; adverse health effects
Radionuclides				
Gross alpha particles	15 pCi/L		✓	Formed by decay of radioactive elements; adverse health effects
Beta particles	4 millirems per year		✓	Formed by decay of radioactive elements; adverse health effects
Radium 226 & 228 (Ra)	5 pCi/L (combined)		✓	Formed by decay of radioactive elements; adverse health effects
Radon 222 (Rn)	4000 pCi/L (in review)		✓	Colorless gas formed by decay of radium; adverse health effects

mg/L = milligrams per liter; equivalent to parts per million (ppm)   pCi/L = picocuries per liter

Lowell Washburn

Abandoned wells are direct pathways for contaminants from the land surface to reach underground aquifers. Proper closure of these wells is essential to maintaining groundwater quality.

supply and problems can arise from a multitude of sources. As already noted, groundwater moving through soil and rock dissolves minerals, and these naturally occurring constituents can present health concerns and cause economic problems. In addition to mineral content, bacterial and chemical contamination can also affect water quality. Contaminants affecting health include bacteria, nitrate, pesticides, radionuclides, organic chemicals, arsenic, and lead. Contaminants that do not affect health, at least in small quantities, include sulfate, total dissolved solids, calcium and magnesium, hydrogen sulfide, iron, manganese, and iron bacteria.

The table on page 48-49 summarizes commonly occurring constituents that can cause problems in Iowa drinking water supplies, as well as those that are regulated and nonregulated ("recommended") for public water supplies.

Total *coliform bacteria*, which includes both fecal and non-fecal bacteria, is the most commonly reported health-related water quality problem in Iowa. Water containing coliform bacteria should not be consumed unless properly disinfected by boiling or chemical treatment.

Nitrate occurs naturally in soil, but concentrations exceeding 10 mg/L as NO_3-N often indicate pollution from sources of nitrogen such as fertilized cropland or human or animal waste-disposal sites.

Agricultural pesticides have been detected in Iowa groundwater since 1964. The U.S. Environmental Protection Agency (EPA) has established maximum contaminant levels (MCLs) for many commonly used pesticides. Two of those used in Iowa, atrazine and alachlor, have MCLs of 0.003 mg/L and 0.002 mg/L respectively.

Total dissolved solids are all the materials in water that are in solution. Water with less than 500 mg/L is considered excellent; 500 to 1,000 mg/L is good; 1,000 to 1,500 mg/L is fair; and greater than 1,500 mg/L is considered poor.

Calcium and magnesium are the primary cause of "hardness" and scale-forming properties in plumbing, and they also reduce the lathering ability of soap. Hardness is reported in terms of an equivalent amount of calcium carbonate ($CaCO_3$). Water is considered "soft" when the hardness is below 100 mg/L. Commercial water softening companies often use "grains per gallon" to report hardness. One "grain" equals 17.1 mg/L (or parts per million). "Very hard water" is reported as anything over 10.5 grains per gallon.

Adapted from photo by Michael Wade

Water discolored by suspended sediment appeared in northeast Iowa wells just hours after a major earthquake in central Alaska. Water in left jar from a 600 ft. well; water in right jar from a 200 ft. well.

Hydrogen sulfide (H_2S) is a dissolved gas that imparts a "rotten egg" odor to water and accelerates the corrosion of steel pipes, casing, and pumps. It is commonly produced by sulfate-reducing bacteria that live in aquifers or water distribution systems. Elimination of hydrogen sulfide odors in wells can be accomplished through aeration or chemical oxidation.

Following exposure to oxygen or chemical oxidizing agents, ferrous iron (soluble) is converted to ferric iron (insoluble), which imparts a yellow or reddish color to water. Iron concentrations exceeding 0.3 mg/L often will stain laundry or plumbing fixtures and can affect the taste of water. The accumulation of insoluble iron often causes deterioration of softening capacity and plugging of water softeners. Manganese concentrations exceeding 0.05 mg/L also cause brown stains on laundry and plumbing fixtures.

A common problem in Iowa is the clogging of well screens or pump components with iron bacteria. This nuisance aquatic bacteria, in the presence of dissolved oxygen, will precipitate an insoluble iron-oxide slime that can plug water distribution systems and impart an unpleasant odor to drinking water. Shock-chlorination can be effective in loosening such bacterial growths, though this procedure may have to be repeated on a regular basis. To distinguish whether the rusty color in water is caused by iron bacteria or simply the oxidation of dissolved iron, microscopic examination of the water is necessary.

Radioactivity is another natural contaminant in groundwater, derived from contact with rocks where the water is stored. While generally not excessive, it is highest in deep bedrock aquifers, especially in central and southeast Iowa, where it often exceeds drinking water standards.

After constructing a well, the water should be tested. In most areas the county health or sanitation department will work with well owners to test their water.

Good sources of information about well construction, maintenance, remediation, and abandonment include local well-drilling contractors, the Iowa Department of Natural Resources (IDNR) Water Supply Section, and county sanitarians. Publications about these topics are available from the U.S. Environmental Protection Agency and the U.S. Geological Survey. A local library can be another good source of water well information. The Iowa Geological Survey will provide individual well forecasts to landowners to help them estimate drilling depths, yields, and quality of water-bearing units beneath their property.

GROUNDWATER USE in IOWA

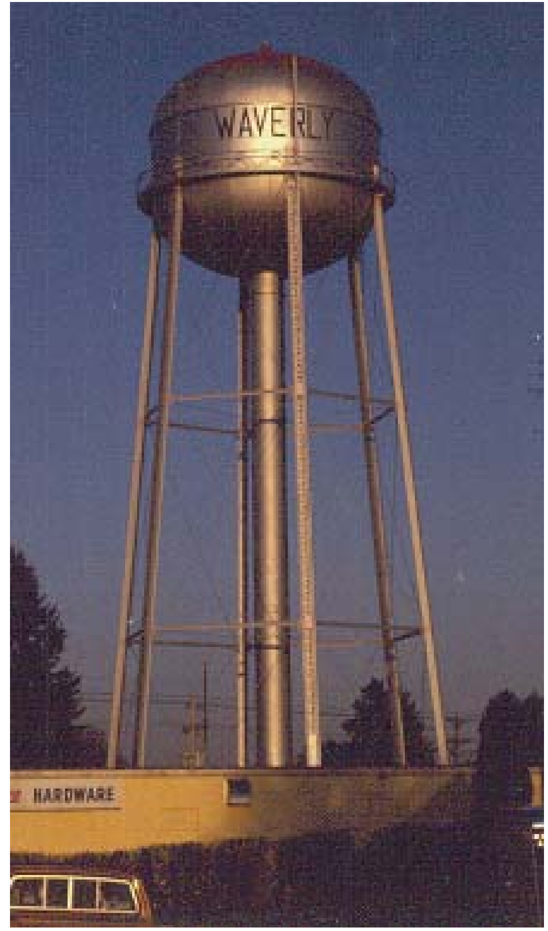
"Liquid Assets: A History of New York City's Water System."

– Diane Galusha, Communication Director for the Catskill Watershed Corporation, Walton, NY, 2002.

The book title above captures the value of water resources to any community today – they are indeed, "liquid assets." It is interesting to note that in 1870, not a single community water works existed in the state of Iowa. By the end of 1880, 16 community water systems were in operation, and that number had increased to 40 by the end of 1885. The *Manual of American Water Works* for 1890 and 1891 listed 85 Iowa towns as having a community water supply. Currently about 1,200 community supplies exist in Iowa, of which over 800 are municipal water supplies, 40 are rural water associations, and about 400 are unincorporated supplies, such as housing developments and mobile home parks. To understand something about the demand placed on Iowa's available water resources, it is helpful to take a look at how the resources are used.

Water use in Iowa includes both groundwater and surface water resources for a variety of purposes, including agriculture, commercial, domestic, industrial, irrigation, mining, power generation, and public water supplies. In these so-called "off-stream" uses, water is actually withdrawn or diverted from a groundwater or surface water source. This does not include such water uses as barge transportation, recreation, or fish hatcheries. The upper table on page 54 shows how groundwater and surface water withdrawals in Iowa compare for these various uses.

Information about water use usually is separated into water withdrawn and water consumed. Consumptive use is that part of water withdrawal that is removed from the environment by people



Paul VanDorpe

Groundwater pumped from aquifers supplies drinking water to many Iowa communities.

or livestock, by incorporation into manufactured products, by evaporation, or transpiration by crops and other vegetation. This water is no longer available for future use. Estimates indicate, for example, that less than 1 percent of the water used for power plant cooling is lost through evaporation, while nearly 100 percent of water used by agriculture and irrigation is consumed. Overall, only about 13 percent of the water withdrawn for use in Iowa is considered to be consumed. Note that groundwater accounts for about two-thirds of the water consumed in Iowa (lower table, p.54).

The largest amount of water used in Iowa is for power generation. A little over two-thirds of the state's total water withdrawn is for production of steam and for cooling of equipment in thermoelectric power plants. Almost 99 percent of this cooling water comes from surface sources such as the Mississippi and Missouri rivers, as well as larger interior streams such as the Des Moines and Cedar rivers.

Public water supplies account for the second largest amount of water withdrawn in Iowa. These include cities, towns, mobile home parks, housing developments, and rural water associations. On average, Iowans use about 1,100 gallons of water every day if indirect sources such as manufactured products, food production, and energy generation are included. Individually, however, we actually use about 100 gallons per day for drinking, food preparation, laundry, washing, and waste water. Nearly 70 percent of the water used by public water supplies in Iowa comes from groundwater. When the rural population on privately owned wells is added in, nearly 80 percent of Iowans depend on groundwater for their drinking water supplies.

Other major uses of groundwater in Iowa include irrigation, with over 90 percent of needed water coming from groundwater sources, and livestock and poultry production, with 75 percent of their total withdrawals being from groundwater.

Tim Kemmis

Deposits of sand and gravel often occur below the water table and are excavated by dredge and dragline operations. Materials are washed and sorted into different sizes for various uses, with little water being consumed. (Worth County)

Sand and gravel production and limestone quarrying dominate mining activities in Iowa, and are one of the smaller categories of water use with less than 2 percent of the total. Most of the water withdrawn is for dewatering quarries and for washing aggregate products. The water consumed by these processes is negligible.

Which aquifers in Iowa supply the groundwater for each of the

Water Withdrawn in Iowa

Purpose	Groundwater withdrawals (Mgal/d)	Surface water withdrawals (Mgal/d)	Total withdrawals (Mgal/d)
Agriculture (livestock)	82	27	110
Commercial	18	25	43
Domestic	45	0	45
Industrial	74	184	258
Irrigation	35	4	39
Mining	1	42	43
Power generation	15	2110	2120
Public water supplies	257	116	373
Total water withdrawn	528	2510	3030

Mgal/d = million gallons per day

Source: *Estimated Use of Water in the United States in 1995*. U.S. Geological Survey Circular 1200, 1998.

Water Consumed in Iowa

Purpose	Groundwater consumed (Mgal/d)	Surface water consumed (Mgal/d)	Total consumed (Mgal/d)
Agriculture (livestock)	82	27	110
Commercial	6	8	14
Domestic	73	0	73
Industrial	12	41	53
Irrigation	35	4	39
Mining	<1	<1	<1
Power generation	<1	10	10
Public water supplies	52	36	89
Total consumptive use	261	127	388

Mgal/d = million gallons per day

Source: U.S. Geological Survey estimated water use in Iowa, 1995, unpublished data.

Figures above may not add to totals because of independent rounding.

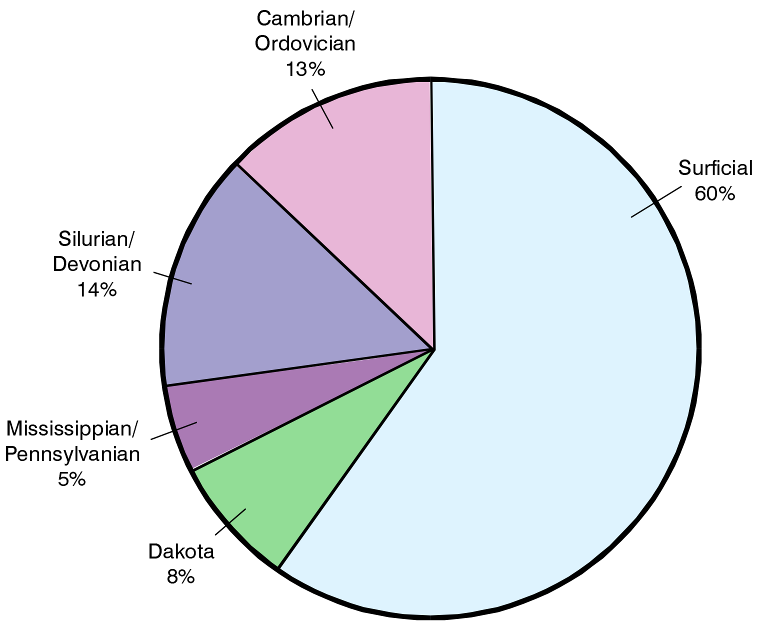
various uses? The U.S. Geological Survey compiled figures for 1985 estimating the contribution for total groundwater withdrawals from each of the state's major aquifers. The left pie chart on page 55 totals these estimates, and we see that Iowa's relatively shallow surficial aquifers led the way in supplying 60 percent of the groundwater withdrawals in Iowa.

Another question often asked is, "Where does our drinking water come from?" In town or country, Iowans obtain their drinking water from ten major hydrogeologic sources as seen in the right pie chart on page 55. Taken together, wells drilled into bedrock aquifers supply about 40 percent of Iowa's drinking water, with wells completed in the shallower surficial aquifers accounting for another 40 percent, and surface water sources making up the remaining 20 percent.

Keep in mind that the numbers reported here for various aquifers and use categories change from year to year, and precise water use data are difficult to get a handle on over the entire state for any single year. While these collected data may reflect a span of several years, they still are useful in providing a perspective on the sources and use of water in Iowa.

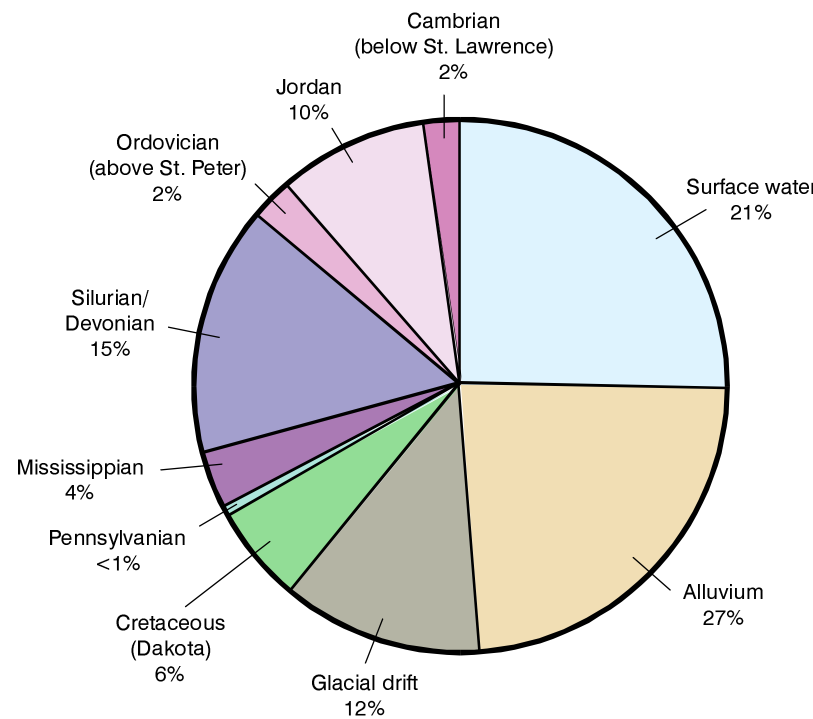
In addition to the groundwater that society uses or consumes, there is another important aspect of this resource that is often overlooked. Throughout the Iowa landscape groundwater is constantly replenishing rivers, lakes, springs, and wetlands. In fact, this natural groundwater input, known as baseflow, accounts for about 50 percent of the total flow of Iowa's rivers and streams. The amount of baseflow varies across the state from 30 to 70 percent depending on whether the rivers and streams are cut into geologic materials having high or low permeability, as well as on the amount

Groundwater Withdrawals by Aquifer Source



Source: U.S. Geological Survey, 1988.
Estimated Water Use in Iowa, USGS
Open File Report 87-704, p.11.

Drinking Water Supplies by Source



Source: Iowa Geological Survey
(Unpublished data)


Clay Smith

Groundwater is used for irrigation of general farm crops and for orchards, nurseries, and golf courses. (Monona County)


J.R. Olson

A stream continues to flow during extended dry periods because of groundwater seepage into its channel. Known as baseflow, this condition affects water temperature, aquatic life, and delivery of pollutants to streams (obvious livestock sources notwithstanding).

of recharge to the groundwater system. During extended dry periods, groundwater may be the only contributor to a stream's flow (photo, bottom left).

A look at long-term trends in surface-water discharge reveals that baseflow contributes a greater percentage of water to rivers in the northeast and eastern parts of Iowa, compared to rivers in western and southern Iowa. Approximately 11.3 billion gallons are discharged every day to Iowa's surface waters from groundwater; that is about 3.5 times what we use and about 29 times what we consume. Without baseflow to sustain our streams, Iowa would not always be "the land between two rivers."

Studies at the Iowa Geological Survey show significant increases in baseflow to major Iowa rivers between 1940 and 2000. More of the precipitation falling across the Iowa landscape is infiltrating and being routed into streams as baseflow than is being shed as overland stormflow. This baseflow gain in the state's rivers are attributed to several causes: the effects of increased row-crop production and tile drainage, improved land management and conservation practices that increase absorption of surface water runoff, and the widespread down-cutting of streams below the water table during the post-settlement period in Iowa. A strong correlation exists between the significant increases in baseflow and the increasing nitrate concentrations in Iowa streams.

Another factor affecting the baseflow gains in Iowa streams is an increase in precipitation rates. The Environmental Protection Agency reports a 5 to 10 percent increase in precipitation over Iowa and the rest of the United States during the past century. Iowa's baseflow gain in the past 60 years, however, is greater than that accounted for by precipitation alone.

Electric generating plants are among the largest users of water in Iowa. Most of the water needed for steam production and cooling equipment comes from surface water sources along the state's major rivers, and most of this use is non-consumptive. Plant operations may be supplemented by groundwater from alluvial wells. (Allamakee County)

Paul Horick

This interaction between underground aquifers and surface water is a dynamic part of the hydrologic cycle. Groundwater aquifers should not be viewed as end points in the hydrologic cycle. Rather, they are connected and contribute in a major way to water bodies on the land surface and to the water quality of those waters as well. It is increasingly important to assess water above and below ground as a single resource.

GROUNDWATER ISSUES
and PROTECTION STRATEGIES

"By the Way, You'll Need Water"

– Donivan Gordon
Iowa Geology 1981

Funnel shaped sinkholes at the land surface indicate shallow limestone and subterranean groundwater flow. Shallow aquifers are highly vulnerable to contamination problems in this geologic setting. (Clayton County)

Groundwater is usually out of sight, and for many people this keeps it "out of mind" as well. In many places, this attitude is understandable as good quality groundwater is in plentiful supply. At other locales, however, this is not the case. Numerous factors can affect the utility of groundwater as a water supply. Most important are the quality of water and the quantity that can be withdrawn, and these characteristics vary widely across the state depending on geological conditions.

In addition, different uses of water have different requirements for the quantity needed and the quality desired. For example, water for crop or turf-grass irrigation typically demands high yields, often in excess of several hundred gallons per minute. Water quality usually is not an issue. In contrast, a well producing just a few gallons per minute may be adequate for a household supply. Because the water is for human consumption, the home user has concerns about quality that the irrigator does not have. The water supply for a town or city must be adequate in terms of both quality and quantity. Water for some industrial and agricultural uses will have still other quality constraints. While many aspects of groundwater availability and quality are geologically controlled, society's needs and activities also have an impact.

Yields from wells depend largely upon the ability of the source aquifer to store and transmit water. These hydrogeological factors are fairly predictable for many aquifers in Iowa. The amount of groundwater any well can produce, however, may be affected by the presence of other nearby water wells. When two or more pumped wells are sufficiently close, their drawdown cones may intersect, causing further lowering of water levels – a condition commonly termed *well interference*. When interference is great, the pumping from one well can effectively render another well unusable. Therefore, the presence of other wells and the amount of drawdown they cause are factors that impact the quantity of water a new well can produce. How closely wells should be spaced to minimize this interference is a site-specific question because of the variable nature of aquifers.

Quarries and mines are often dewatered so that earth materials can be extracted more easily. Large volumes of water are pumped during these dewatering operations. A pumped quarry acts like a very large well, and therefore causes a drawdown of the water table in the surrounding area. Impacts on neighboring wells need to be evaluated before dewatering proceeds.

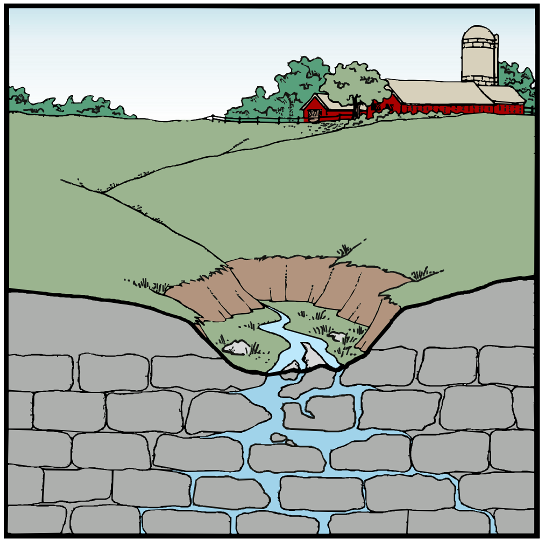
Typically, water level declines caused by pumping wells (or quarries) are relatively localized occurrences. Where numerous wells withdraw large volumes of groundwater over time, however, regional declines in water levels may occur. In Iowa, the most widespread of these declines has occurred in the extensive Cambrian-Ordovician aquifer. Regional water levels have dropped about 100 feet in this aquifer since use began in the late 1800s, with the greatest lowering of water-levels near major pumping centers. Other declines of a more local nature have occurred, such as those in the Cedar Rapids and Iowa City areas where the Silurian aquifer is heavily used.

Extended drought conditions can also impact groundwater levels and well yields. This effect is most significant in shallow water-table aquifers that recharge and discharge rapidly, and that supply similarly shallow wells. In Iowa, drought effects often hit hardest in the shallow alluvial aquifers of western Iowa, which are valuable sources of groundwater for many community supplies. The pinch is also felt in the shallow seepage wells that tap the water table in western and southern Iowa. Such wells supply many rural residents. Water levels in the shallow, fractured bedrock aquifers of northeast Iowa also can fall significantly during extended dry periods. These very permeable aquifers are deeply cut by river valleys that drain the fractured rocks and drop water levels during drought conditions.

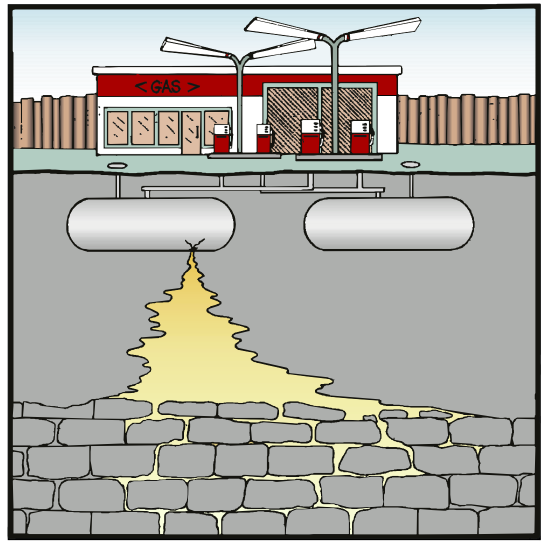
Gary Hightshoe, Iowa State University

Contour farming, strip cropping, and grassed waterways are land management strategies to slow runoff from sloping land and to allow greater infiltration of water. (Near Iowa-Poweshiek County line)

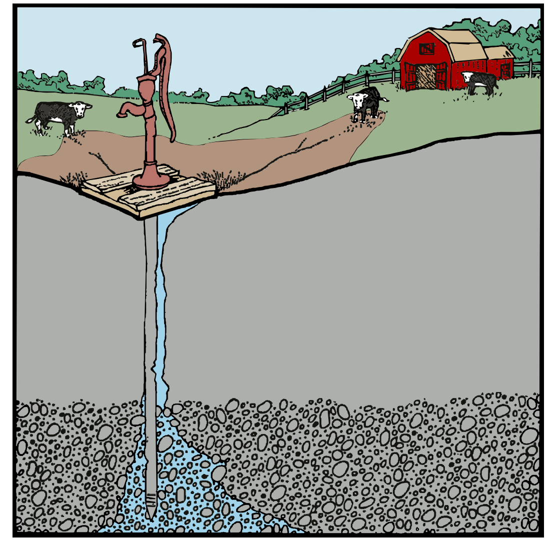
The quality of groundwater also affects its value for different water needs. The natural water quality in an aquifer results from interaction with rocks and minerals comprising the aquifer. Water slowly dissolves soluble minerals adding to the water's concentration



Sinkholes provide direct paths for silt, bacteria, and land-applied chemicals to reach shallow bedrock aquifers. Groundwater flow is rapid and undiluted in such karst areas. These natural circular pits should be cleaned of waste materials and buffered from cultivated land and surface runoff by permanent vegetation. Over 12,700 sinkholes have been mapped in northeast Iowa.

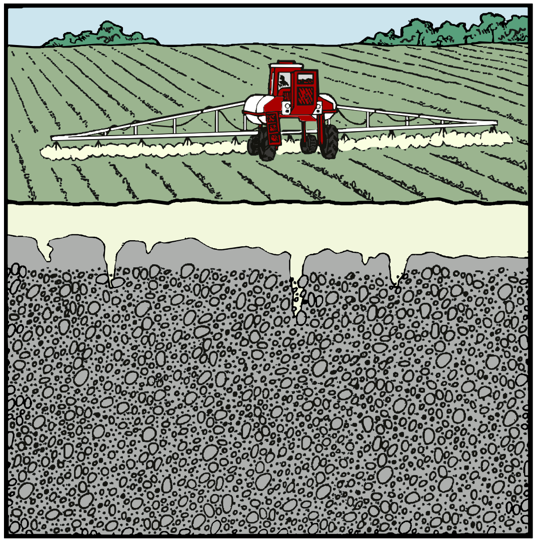


Underground tanks that store gasoline or diesel fuel are a risk to groundwater supplies. They lie near the water table; their metal corrodes with age; and leaks are hard to detect. Registration of tanks, new construction standards, early detection of leaks, and site cleanup are underway. Monitoring wells are used to determine product loss and establish flow direction and dimensions of a contaminant plume.

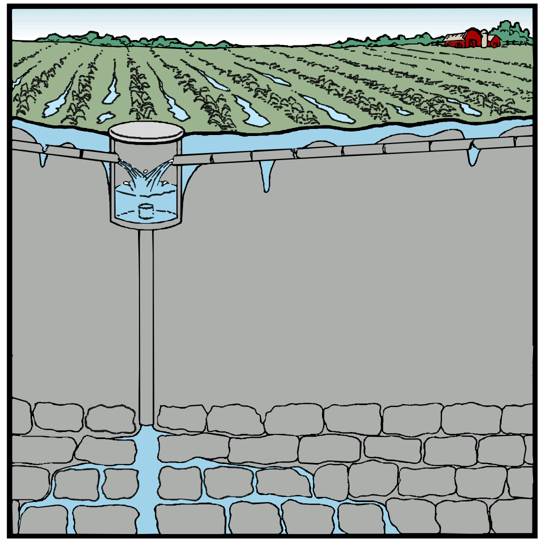


Old wells in disrepair or no longer in service provide direct pathways for contaminants to reach groundwater aquifers. If more than one aquifer is tapped, unwanted mixing of poor quality water with good water can occur. Finding and properly plugging and sealing the state's thousands of abandoned wells are important to maintaining groundwater quality.

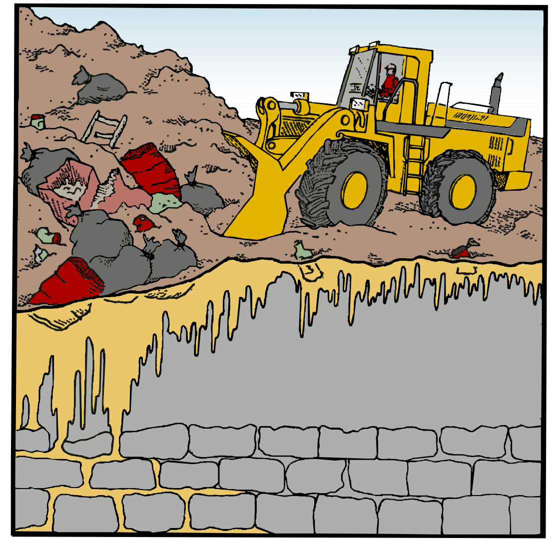
of total dissolved solids, which is used as a general indicator of natural water quality. High concentrations impart a salty taste to water, and are usually associated with significant amounts of other constituents, such as sulfate and hardness, which may affect utility of the groundwater for some uses. High dissolved solids occur in aquifers that contain significant amounts of soluble minerals and have sluggish rates of groundwater movement. The table on pages 48-49 lists some of the more common troublesome constituents found in groundwater and the maximum concentrations allowable in public water supplies.



Widespread application of nitrogen fertilizer and pesticides to farm fields and their subsequent movement through soil to groundwater is an economic loss to farmers as well as an environmental loss to groundwater quality. More efficient use of these chemicals and best management practices on the land can help reduce these losses. Urban use of these materials is also a concern.



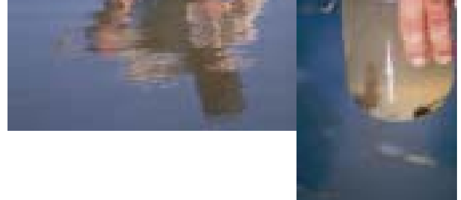
Agricultural drainage wells were intended to funnel excess surface water and tile-drainage deeper into the ground in poorly drained areas of north-central Iowa. Consequently they deliver sediment and land-applied chemicals directly into aquifers used for drinking water supplies. Some of Iowa's estimated 400 ag-drainage wells are being closed and sealed, with documented improvement in water quality.



Many kinds of waste have been buried in Iowa's land in the past, including toxic industrial wastes. Leachate carrying pathogens, heavy metals, and organic compounds still threaten groundwater supplies. Modern landfills must be sited in less vulnerable geologic settings, and monitoring of groundwater is required at all permitted sites to check for seepage. Recycling and composting can help reduce the volume of landfill waste.

Other natural constituents, such as hydrogen-sulfide, iron, manganese, ammonia, arsenic, and radioactive substances may also impair use. While some of these constituents tend to occur in groundwaters with high total dissolved-solids concentrations, they may also occur in less mineralized groundwater.

Groundwater quality can also be affected by society's day-to-day activities, many of which have the potential to release contaminants into the environment (illustrations, left and above). These include: nutrients, particularly nitrate, from fertilizers as well as animal and human wastes; pesticides, from agricultural, urban, and other uses;



photos by Clay Smith

Volunteers across Iowa are being trained to test streams and lakes for chemicals, aquatic organisms, and suspended sediment. The IOWATER monitoring program enables Iowa citizens to take an active role in protecting and restoring the state's waters.

road salts; diesel and gasoline-related petroleum compounds from leaking storage tanks and spills; and other organic chemicals and metals from industrial activities, waste storage, septic systems, and landfills.

The potential for a contaminant to affect groundwater at any given location depends, in part, on properties of the contaminant itself. These include: the chemical's mobility, or how likely the chemical is to attach to soil particles; the rate at which the chemical degrades to less harmful compounds; and the amount of the compound involved. As an example, consider nitrate nitrogen. It has virtually no tendency to attach to soil. In many important groundwater environments, it does not degrade. Large quantities are widely applied to row-crop lands in the form of fertilizers and manure. These factors, acting together, allow nitrate to be the most common contaminant in Iowa's groundwater. In contrast, many organic chemicals adhere tightly to soils and/or degrade quickly in the soil environment. The movement of significant amounts of such chemicals to groundwater is not likely unless large-scale, concentrated leaks or spills occur.

The sanitary condition of water from wells is another important consideration for drinking water supplies. Bacteria and other potential disease-causing agents may be present in shallow groundwater, but often are adsorbed and filtered out of the water before it travels far in the subsurface. Bacteria typically enter wells through defects in the casing or grouting of a well, rather than travelling with the groundwater itself. Wells are often tested for the presence of coliform bacteria. These bacteria are not necessarily a health concern; however, they show that bacteria are able to move from the land surface into a well. This is an indication that more harmful bacteria or other agents, if present, have the opportunity to do the same. Wells that produce water with coliform bacteria are sometimes tested for the presence of fecal coliforms, an indicator that water once in contact with human or animal waste has reached a well.

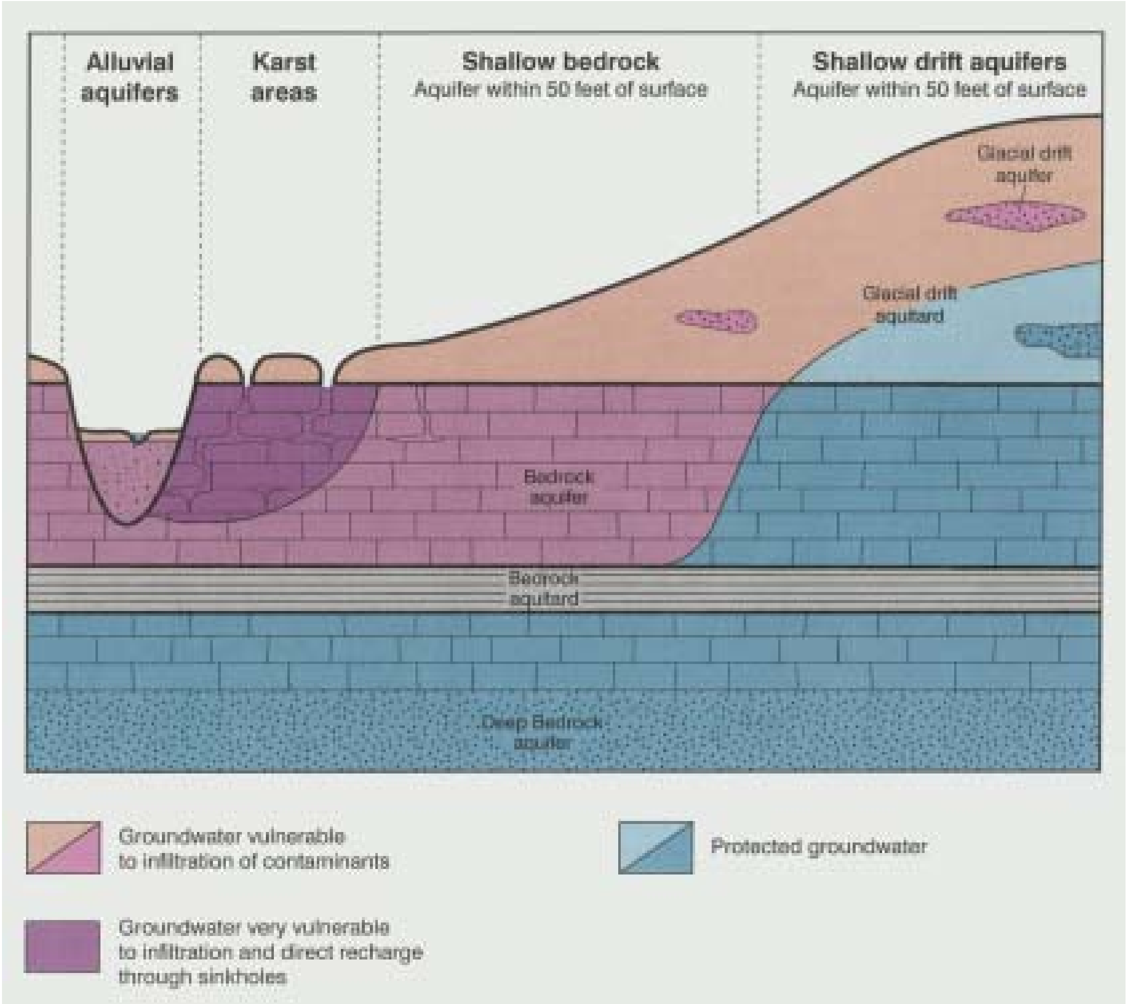
Along with contaminants present at the land surface, the potential for groundwater contamination is a function of the geologic setting of a given locale. The degree of vulnerability will always be a function of the enclosing earth materials and their hydrologic conditions. Much of Iowa's land surface is covered with a variable thickness of fine-textured glacial deposits. These deposits typically are slowly permeable, forming an aquitard. Where sufficiently thick, and if unfractured, they act as a protective blanket for underlying aquifers, limiting the downward movement of groundwater and contaminants. The diagram on page 64 summarizes common geological settings across Iowa and the relative protection provided to various groundwater aquifers.

Numerous studies in Iowa and adjacent states indicate that where an aquifer is covered by 50 feet or more of glacial deposits, the groundwater in the aquifer is usually free of contaminants from the surface. In many settings, the groundwater in these protected aquifers fell as rain and interacted with the land surface decades to hundreds of years ago, when contamination sources were considerably more scarce than today. The slow travel time of water through the glacial materials also allows for significant degradation and adsorption of some contaminants. In these areas, artificial pathways such as improperly constructed or abandoned wells, agricultural drainage wells, and underground mines may allow water and surficial contaminants to bypass the natural cover and reach otherwise protected aquifers.

Paul VanDorpe

Long-term protection of a community's water supply includes the inventory of potential contaminant sites within the areas affecting their aquifer source.

Geological Conditions and Groundwater Vulnerability

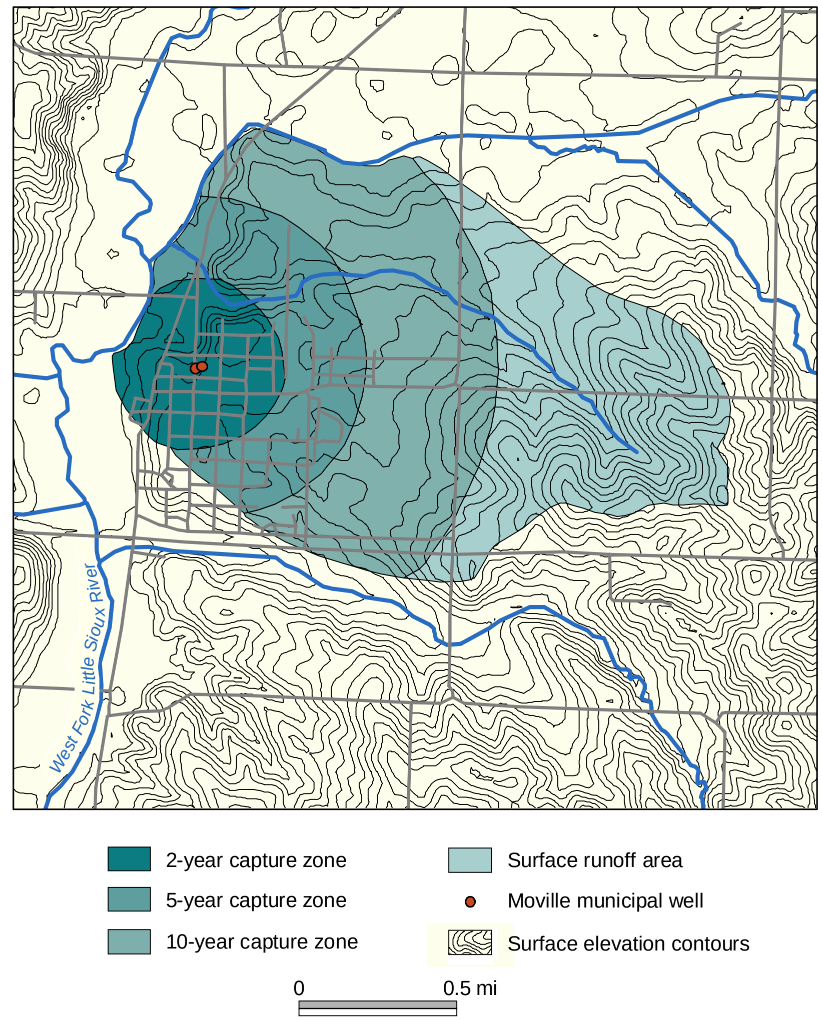


In contrast, aquifers with a thin protective cover are readily recharged by more recent water and contaminants. In particular, precipitation may infiltrate the land surface, mobilize contaminants, and enter alluvial aquifers, bedrock aquifers with less than 25 feet of glacial cover, and karst areas with sinkholes and fractured limestone on time-frames of hours to months, rather than many years. In addition, very shallow rock aquifers, very coarse-grained alluvium, or the presence of artificial pathways increase the potential for groundwater to carry bacteria and other biological contaminants into the subsurface. Extra precautions, planning, and management of contaminants are needed in these vulnerable areas.

With an improved understanding of groundwater vulnerability conditions, protection strategies today are aimed at finding and eliminating older existing sources of contamination. For example, *abandoned wells* need to be located and plugged with impermeable clay. Sinkholes need to be cleaned out and buffered from cultivated land with permanent vegetation. Other protection strategies aim to decrease and manage the contaminant sources that continue to enter our hydrogeologic environment. This means keeping a guardian eye on resource characteristics, gathering information, and watching for changes through long-term monitoring of all the aquifers that Iowans depend upon.

The value of monitoring wells installed in aquifers lies in the building of a long-term record whose value grows with the passage of time. If the usual patterns of water levels and water quality are known, then detection of something new provides a first alert. This protection strategy works just as effectively for an individual private well on a rural acreage as for a large operating farm well, a suburban housing development, or a major municipal or industrial well. It is

Sourcewater Delineation Map for Moville, Iowa

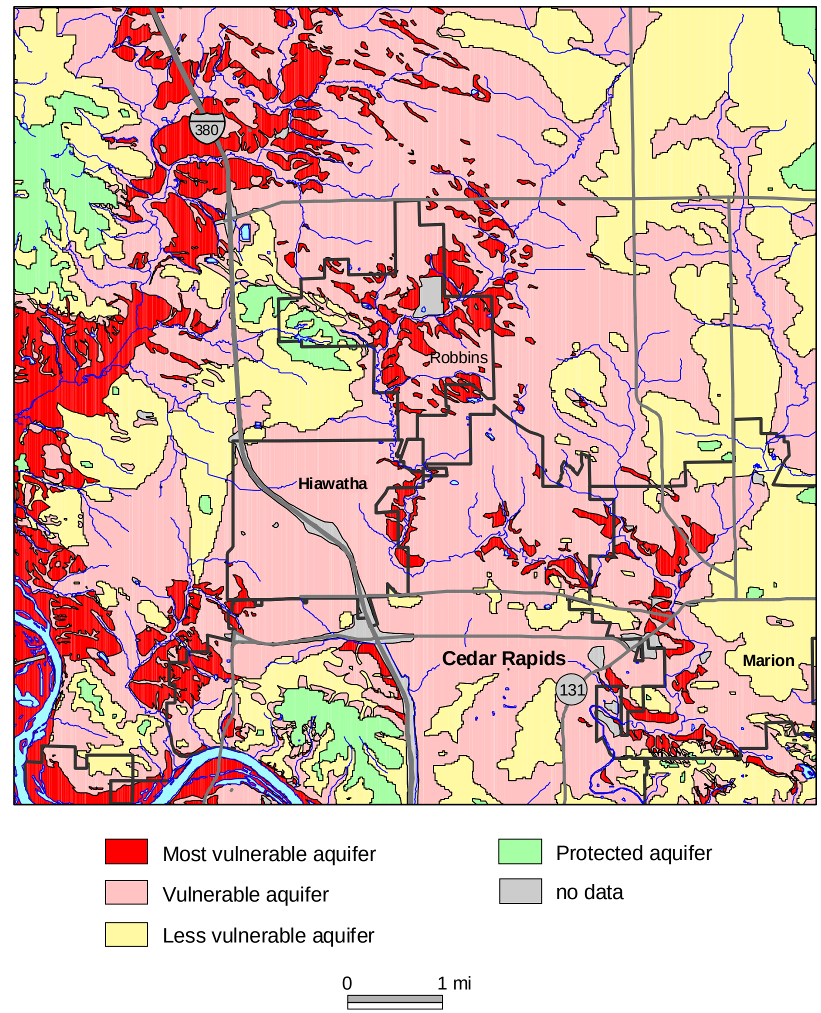


just a matter of scale; and whether small scale or large scale, monitoring data can build a valuable record and prompt action when necessary.

Contaminant sources in Iowa often stem from the long-term, widespread, commonly accepted practices of farmers, businesses, and homeowners. And once beneath the ground, the true extent of a problem is difficult to identify; it is often too late to apply corrective measures; and it takes a long time (if ever) for contaminants to be flushed from an aquifer. Thus, education and prevention are effective strategies to deal with both *point source* and *non-point source contamination* problems. Iowa's landmark Groundwater Protection Act of 1987 was significant for addressing growing evidence of groundwater degradation and public concern, and for focusing on solutions. It provided initiatives not only to deal with specific sources of contamination, but set out goals for long-term water monitoring, relevant research, and public education and action.

Federal government funding of the *Source Water Assessment and Protection* program in Iowa is prompting state action to delineate protection areas around community wells that tap various aquifers in Iowa. The idea is to preempt contamination problems and costly remediation procedures. This plan for long-term water supply protection includes identifying aquifer sources, examining their vulnerability to contamination, predicting the time-of-travel for contaminants moving in the groundwater flow system, and instructing the communities themselves on how to inventory contamination threats within areas needing protection (photo, p. 63). The map for the Woodbury County town of Moville on page 65 defines protection areas (capture zones) around the town's municipal wells based on the time-of-travel of water and direction of groundwater flow

Groundwater Vulnerability Map of the Cedar Rapids Area



within the source aquifer. Defining these capture zones around a public water supply helps the community focus future source water protection efforts.

Many of the groundwater issues prompting these government actions will continue to be with us far into the future. They all involve use of Iowa's land. Our approach to safeguarding groundwater resources must always take into account their degree of vulnerability, which will always remain a function of the surrounding earth materials and the dynamic hydrologic conditions. Thus it is important to continue to investigate Iowa's geologic realms, to bring the most accurate and up-to-date information to bear on these issues as they arise at different times in different parts of the state.

In recognition of the key role of earth materials and their characteristics in groundwater contamination issues, the Iowa Geological Survey published a map depicting groundwater vulnerability regions of Iowa in 1991. It provides a regional summary of geologic conditions that affect aquifer recharge and contaminant transport, and it synthesized a long period of geologic research and record-keeping.

More detailed geologic mapping of shallow subsurface materials is underway in areas of the state experiencing rapid urban expansion and associated land use changes. Maps derived from this basic geologic mapping are available for use by local community leaders as well as the private sector to improve decisions on economic development, natural resource management, and environmental protection. An example of the varying susceptibility of aquifers to contamination from near-surface sources in part of Linn County is shown on page 66. The most vulnerable areas (red) are underlain by sandy alluvial aquifers, areas where bedrock aquifers lie near the land surface, and areas characterized by karst features such as sinkholes. In contrast, aquifers in protected areas (green) are overlain by 100 feet or more of slowly permeable glacial deposits, and are largely protected from surface-related contamination. This mapping effort is a direct spin-off from the U.S. Geological Survey funded STATEMAP program in Iowa.

To be effective, groundwater protection needs not only on-going monitoring and research efforts, but needs to include public action. Education is one of the most valuable tools to improve groundwater protection. Just as human activity on the land surface can be detrimental to the quality of underground waters, so it is possible for an informed public to intervene, both through individual efforts and teamed with government action, as seen with voluntary best management practices and with water monitor training programs, such as IOWATER (photos, p.62). Society must make the effort to control and manage potential sources of contamination.

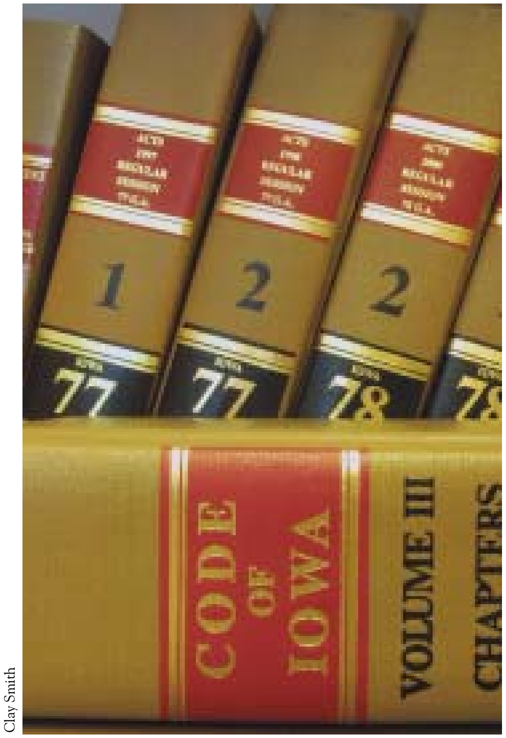
Large quantities of groundwater are needed to support our modern society, as we have seen. At the same time, human activity can contaminate both surface water and groundwater. Agriculture, industry, urban development, and recreation can degrade groundwater quality. Unmanaged groundwater withdrawals can alter aquifers, damage wells, destroy wetlands, cause land subsidence, and change natural hydrologic flow conditions. Proper management of groundwater resources is essential to ensure that no one is without a useable supply of water. As long as Iowans rely on water from the ground, the discussion of protection issues and strategies must be underlain by an informed understanding of the hydrogeological dynamics of our groundwater resources.

GROUNDWATER
LEGAL and REGULATORY ASPECTS

The Missouri is a river " . . . that goes traveling sidewise, that interferes in politics, rearranges geography, and dabbles in real estate. It cuts corners, runs around at night, lunches on levees, and swallows islands and small villages for dessert."

– G. Fitch, 1907, as quoted in *Missouri River News,* January 2001, article by Ryan Roenfeld

The importance of water resources in Iowa has led to passage of laws to protect and regulate its use. The Iowa Code [section 455B.171] defines "water of the state" to mean: " . . . any stream, lake, pond, marsh, watercourse, waterway, well, spring, reservoir, aquifer, irrigation system, drainage system, and any other body or accumulation of water, surface or underground, natural or artificial, public or private, which are contained within, flow through or border upon the state or any portion thereof." Jurisdiction to prevent, abate, or control water pollution and to conduct the public water supply program is given to the Iowa Department of Natural Resources. The IDNR carries out responsibilities of the state related to public and private water supplies and sewage disposal systems for the protection of the environment and the health and safety of Iowa citizens. County boards of health adopt standards at least as stringent as those of the state and regulate both private water supplies and sewage disposal systems.



Clay Smith

The IDNR protects our water supplies through a set of environmental rules, the *Iowa Administrative Code* (IAC), Part 567. Some rules address drinking water quality concerns, including construction standards for private wells (567 IAC 38, 49), well plugging requirements (567 IAC 39), public water-supply design and operation (567 IAC 40, 41, 42, 43), the drinking-water revolving fund (567 IAC 44), whereby low-interest loans are made available to certain public drinking-water supplies for facility improvements, and the grants-to-counties program (567 IAC 47), whereby funds are made available for testing, rehabilitation, and closing of private wells. Other rules address water quantity concerns, including water withdrawals, water diversion, water storage, and water rights (567 IAC 50, 51, 52, 53, 54, 55). Protecting our water supplies also extends to how we handle wastewater effluent, wastewater plant construction and operation, septic tanks, wastewater treatment limitations and prohibitions, manure, land application of sewage sludge, and the application of aquatic pesticides to waters (567 IAC

Title IV). Rules are in place for certification of public water-supply operators, wastewater treatment plant operators, well contractors, and water-testing laboratories (567 IAC Title VI). Solid waste, land application of sludge and solid waste, spills and hazardous conditions, and hazardous waste are also regulated (567 IAC Title VIII, Title IX, Title X, Title XI).

Other rules enable the IDNR to assure that Iowa's water resources are put to beneficial use, that the resource is not used indiscriminately (567 IAC 50, 51, 52), and that conservation and protection are maintained. For example, users of large volumes of water (greater than 25,000 gallons per day) need a water withdrawal permit, regardless of the intended use and regardless of whether it is surface water or groundwater. Construction standards for private water wells insure that individual water supplies are safe from contamination and that aquifers are protected from contamination, thereby protecting public health. Certain criteria also apply to groundwater withdrawals. For example, wells in alluvial aquifers adjacent to streams with drainage areas of less than 50 square miles are not allowed to pump in excess of 200 gallons per minute (gpm). Wells close to such streams may not pump when stream flow falls below a protected flow threshold.

Additionally, two of the state's major sandstone aquifers are protected from overuse (567 IAC 52). Withdrawals from the Cambrian-Ordovician aquifer are limited to 200 gpm for new irrigation, recreational, and aesthetic-use permits. New permits for industrial and power generation are limited to less than 2,000 gpm. Also, the maximum allowable decline in the potentiometric level of the Cambrian-Ordovician aquifer is 200 feet from a 1977 baseline map. The Dakota aquifer is likewise protected from excessive use. For withdrawal rates in excess of 200 gpm, permit holders must monitor water levels within the aquifer using monitoring wells. If water level declines are a serious threat, then certain types of groundwater use have priority, for example public water supplies.

Though seldom used, a defined geographic area may be designated as " a protected source area" (567 IAC 53). Such areas are designated on a case-by-case basis to preserve water availability for beneficial use, to minimize migration of a contaminant plume in a groundwater aquifer, to maintain surface-water quality, or to preserve surface-water flow. Withdrawal of groundwater from a protected source area by non-regulated wells (e.g., private wells) can be restricted or denied, if necessary.

Private well construction permits are issued by individual counties (567 IAC 38), and well construction standards are set forth in 567 IAC 49. Construction standards notwithstanding, occasionally conflicts arise from well interference problems caused by simultaneous pumping of two or more nearby wells. 567 IAC 54 is used to resolve situations where a permitted use causes interference in a non-regulated well. Of course, this assumes that there was an adequate water supply for the non-regulated user prior to the well interference claim. Problems are resolved by modifying the affected well or by changing the conditions of permitted use.

The rules outlined here cover a wide range of activities related to specific uses of the state's groundwater, with other regulations designed for protection of the resource. One of the best ways that individual well owners can help protect the state's groundwater resources is by making sure that all abandoned wells on their property are properly plugged, thereby permanently sealing off contamination to individual aquifers (567 IAC 39).

Silver Lake, Dickinson County. Photo by Clay Smith.

EPILOGUE

" . . . blues would become the underground aquifer that would feed all the streams of American music, including jazz."

– Ken Burns, Iowa Public Television documentary film on *"Jazz"* (2001)

Groundwater surfaces to feed our lives in many ways, including its apt use in the metaphor above. To be fully appreciated, groundwater must be viewed as a vital natural resource, as a dynamic geologic process, and as a fundamental element of the natural environment. Groundwater influences the quality of our lakes and streams, the supply of our aquifers, the depth and purity of our well water, the appearance of our landscape, the sites of our cities and towns, and the ability of wetland habitats to sustain native forms of life. It has value both when extracted from the ground and when left in place.

The need for water resources drawn from wells has long been the essential motivation for groundwater studies in Iowa. The fact that nearly 80 percent of Iowans depend on groundwater for their drinking water supplies emphasizes this point. Many Iowa communities initially put down their roots along river valleys because of easy access to abundant shallow groundwater. Today, our ability to produce reliable forecasts of the availability, quantity, and quality of this resource for new wells requires increasingly accurate and detailed views of the geological conditions beneath Iowa's land. Similarly, as demand increases for larger capacity wells, information is needed to minimize the impact of such pumping on existing wells and to resolve conflicts among water users. If groundwater is to continue its essential role in Iowa's water resources picture, then it also needs protection from threats of contamination originating in both the past and present, from both point and non-point sources. The ability to forecast extends to identifying vulnerable groundwater aquifers and the geologic conditions that put them at risk from human activity.

With today's improved awareness and recognition of problems, and with more effective regulations in place, we are moving into an era that emphasizes contaminant prevention, in addition to after-the-fact cleanup and remediation. We must continue to investigate the diversity of geologic settings across Iowa and the complexities of groundwater travel through three-dimensional configurations of soil and rock in order to meet the demand for more detailed information about potential contaminant risk to groundwater resources.

In addition, groundwater is a slow but effective geologic agent currently shaping Iowa's landscape. The natural erosion of hillsides and stream banks is closely tied to subtle but persistent fluctuations of groundwater flow through time. The shifting intersection of water table with land slope contributes to slumps, collapse, and larger landslides. In fact, our own awareness of groundwater tends to fluctuate with the water table. Only when it rises well above its normal range, and floodwaters spread into our lives, do we take active notice of its presence. During the Flood of 1993 for example, many people found the water table rising into their basements to be as serious a problem as overland flooding was to others. Groundwater can be notorious during another extreme condition – when it's absent. During periods of drought, the water table falls and water disappears from creeks, river beds, and the reach of shallow wells. Still other expressions of groundwater as a geologic agent are the presence of solutional cave and karst features below ground, and springs and sinkholes at the land surface.

The movement of groundwater is a major contributor to natural hazards in Iowa. Such events occur when normal geologic processes are speeded up. For example, in the shallow limestone terrain of northeastern Iowa, underground flow systems persisting through time can result in the sudden collapse of land into a sinkhole. In western Iowa, groundwater saturation of the steep loess bluffs near the Missouri River creates slope instability that leads to landslides and other serious engineering problems.

Finally, groundwater is an important element of Iowa's natural environment. It is part of the dynamic hydrologic cycle, one of Earth's most fundamental and vital natural systems. Understanding the role of groundwater in this cycle is essential to interdisciplinary, regional, watershed-based, and site-specific assessments of biological habitats as well as environmental issues. Water-based habitats such as rivers, lakes, sloughs, springs, hillside seeps, and fens in Iowa are dependent in varying degrees on groundwater flow and replenishment. Distinct plant and animal communities reside in these ecological niches, and their long-term protection is dependent on maintenance of both the physical flow and chemical quality of the groundwater feeding them. The role of groundwater needs to be recognized and integrated into efforts to maintain and restore these habitats.

Watersheds are a keystone of natural resource management today. To improve the quality of a single body of water requires a combined, long-term effort over its entire watershed, a large, sometimes diverse drainage area where numerous individual decisions affect how land is used. Keep in mind that watersheds are more than three-dimensional features of the land surface. They extend below the ground and include the movement of groundwater through time. These added groundwater and time dimensions of watersheds in Iowa are essential to understanding the movement of contaminants below ground and their eventual delivery back to our surface streams and lakes.

Understanding the fundamentals of groundwater in its geologic realm provides valuable information and insight for the use, protection, and sustainable development of Iowa's land and waters.

GLOSSARY

abandoned well – a water well that is no longer in use or is in such a state of disrepair that continued use is unsafe or impractical.

ag(ricultural) drainage well – a drilled shaft that drains excess water into underlying bedrock; upper parts are often cistern-like structures that form a discharge point for tile-drainage lines.

alluvial aquifer – sand and gravel deposits that fill valleys along rivers and streams; important for public, industrial, and agricultural water supplies along large rivers.

alluvium – gravel, sand, silt, or clay deposited by flowing water.

annular space – the ring-shaped space between a borehole and the casing set within it.

aquifer – a body of earth materials that yields groundwater to wells or springs; a water-bearing formation.

aquitard (or aquiclude) – a body of earth materials capable of absorbing water but not transmitting it in sufficient quantities to supply a well; functions as the upper or lower boundary of an aquifer.

artesian – describes groundwater under pressure from the weight of water at higher elevations in a *confined aquifer*.

baseflow – that portion of stream flow originating from groundwater discharge into the stream channel.

bedrock – solid rock that underlies soil or other unconsolidated surficial materials.

bentonite – naturally occurring clays that swell greatly in volume as water is absorbed; used as an impermeable seal in well construction and abandonment.

brecciated – said of rock composed of broken, angular fragments.

buried-valley ("channel") aquifers – sand and gravel deposits along ancient river valleys, often carved into bedrock, and buried beneath other sediments.

capillary fringe – a zone in which water is drawn upward immediately above the *water table*, held by surface tension within tiny pores.

casing – the tubular steel or plastic lining of a well, installed to support the well opening and keep fluids and earth materials out.

coliform bacteria – a group of bacteria whose presence in well water indicates a direct path for potential contaminants from the land surface.

cone of depression (drawdown cone) – a conical depression in the *water table* or the *potentiometric surface* that forms in response to pumping groundwater from a well.

confined aquifer – an aquifer bounded above and below by impermeable strata and under *artesian* pressure.

discharge – the outflow of water from a stream or groundwater aquifer; opposite of *recharge;* also, outflow from a pumping well.

drawdown – the difference between water levels in a well before pumping and during pumping.

evapotranspiration – process by which water moves into the atmosphere by evaporation from land and water and by transpiration from plants.

fen – a special type of wetland sustained by mineralized groundwater flow and including saturated peat deposits, often in mounded positions on hill slopes.

floodplain – the relatively level land that lies adjacent to a river channel and periodically is covered with flood water.

geothermal gradient – the rate of increase in temperature with depth within the Earth.

glacial drift aquifers – pockets of water-bearing sand and gravel within pebbly clay material left by glacial and associated meltwater activity; their configurations are irregular and locations are often unpredictable.

glacial till – an unsorted and unstratified mixture of clay, silt, sand, gravel, and boulders deposited directly by a glacier without subsequent reworking by meltwater.

groundwater – subsurface water that occupies pores, fractures, or other openings within earth materials.

grout – slurry mixture of cement or bentonite and water that can be pumped through a pipe and placed as a protective fill or seal during well construction.

hydraulic conductivity – the capacity of porous earth materials to transmit groundwater; the rate is determined by size and shape of the pore spaces and their degree of interconnection.

hydraulic head – the pressure of groundwater at a given point caused by the height of groundwater higher in the aquifer; represented by the elevation to which water will rise in a well.

hydrogeology – the study of groundwater and its relationship to the geologic environment.

hydrologic cycle (water cycle) – the continuous circulation of water from the atmosphere to earth and into the ground by precipitation and infiltration, and its eventual return to the atmosphere from land and water surfaces by evaporation and *transpiration*.

impermeable – describes earth materials that will not readily transmit water.

infiltration – the downward movement of water into the ground; percolation.

karst – describes topography formed by the dissolving action of groundwater on underlying carbonate bedrock and characterized by sinkholes, caves, underground drainage, and springs.

leachate – a solution formed by groundwater percolating through shallow materials containing soluble minerals or chemicals.

loess – wind-blown silt, usually porous and friable, deposited as a by-product of glacial and meltwater activity.

mafic – describes igneous rocks composed mainly of dark-colored minerals (ferromagnesian).

nonpoint-source contamination – pollution stemming from diffuse, widespread sources such as runoff and percolation from agricultural or urban areas.

outwash – sand and gravel carried by glacial meltwater and deposited beyond the ice margin.

paleosol – a soil formed in the geologic past and buried by younger materials.

perched water table – the mounding of water above a low permeability material located above the water table.

permeable/permeability – the capacity of earth materials to allow free passage of water; a measure of the interconnectedness of porous openings in rock, sediment, or soil.

pluton – an intrusion of igneous rock formed at great depth.

point-source contamination – pollution stemming from a single, identifiable source, such as a drainpipe, sewer, ditch, or underground container.

porosity – a measure of the open spaces in a deposit of earth materials; capacity to store water.

potentiometric (or pressure) surface – an imaginary surface defined by the level to which water will rise in a well.

recharge – the replenishment of groundwater supplies by infiltrating precipitation and surface water.

recharge area – a portion of the land surface over which infiltrating water eventually reaches an aquifer.

runoff – precipitation that flows over land until it reaches surface water, infiltrates into the ground, or evaporates.

saturated zone (phreatic zone) – that portion of earth materials in which all subsurface openings are filled with water; the upper surface of this zone is the *water table*.

Source Water Assessment and Protection – a program to determine susceptibility of public water supplies to contamination; key components are defining the hydrogeologic area (source) that contributes to a water supply, and then assessing land surface contaminant sources in order to minimize risk.

spring – natural discharge of groundwater to the land surface or into a lake, stream, or wetland.

static water level – the standing water level in a well that is not being pumped.

subcrop – (in Iowa) an occurrence of bedrock lying directly beneath the much younger mantle of glacial deposits; a "subsurface outcrop."

surficial aquifer – occurs in earth materials lying above bedrock; typically includes alluvial, glacial drift, and buried valley groundwater sources.

total dissolved solids – the combination of all dissolved mineral constituents in groundwater.

transpiration – the process by which plants evaporate water into the atmosphere.

unconfined aquifer – an aquifer having a freely fluctuating water table, open to atmospheric pressure; not confined beneath *impermeable* strata.

unsaturated zone (zone of aeration; vadose zone) – an underground area where pore or fracture openings contain both air and water; lies between the land surface and the *water table*.

watershed – the land area drained by a stream; a drainage basin.

water table – the top (upper boundary) of the saturated zone in an *unconfined aquifer*.

well – a cylindrical hole drilled or excavated into a water-bearing zone so that water can be pumped or will flow to the land surface.

well development – a process to increase water yield by enlarging voids and flushing sediment from a well.

wellhead protection – a program that encourages communities to determine groundwater sources for and contamination threats to their public water wells; protection of well sources including the surface and subsurface area through which contaminants could move toward a well or well field.

well interference – when the *cone-of-depression* of one well overlaps with that of another well pumping from the same aquifer.

wetlands – lands where water-saturation during all or part of the year determines soil types and plant and animal communities.

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Sources of Additional Information

Certified Well Contractors – The Iowa Department of Natural Resources will provide a list of certified well contractors in your area. The Iowa Water Well Association (515) 243-1558 will also provide information on well contractors in your area.

Iowa Department of Natural Resources – For information about state regulations, well permits, and a listing of certified well contractors call (515) 725-0275 or *www.iowadnr.com/.* For forecasts on well depth, water availability and quality, contact the Iowa Geological Survey at (319) 335-1575 *or www.igsb.uiowa.edu*.

Iowa Department of Public Health – For information about health effects of contaminants found in drinking water and regulations regarding the sale of water treatment systems in Iowa call (515) 281-7726 or *www.idph.state.ia.us*.

Local health departments (county sanitarians) – Information about local regulations for water well construction, water testing, well plugging, and well inspection services.

Local Iowa State University Extension offices – Publications about water testing and well construction.

U.S. Geological Survey – Information on surface water resources in Iowa and water level records from groundwater monitoring networks; District Office in Iowa City at (319) 337-4191 or *http://ia.usgs.gov.*

University of Iowa Hygienic Laboratory – For information about testing your water, the interpretation of test results, and water treatment systems, call (319) 335-4500 or *www.uhl.uiowa.edu*.

Understanding the fundamentals of groundwater in its geologic realm provides valuable information & insight for the use, protection, & sustainable development of Iowa's land & waters.

Iowa Department of Natural Resources