

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.

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



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

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



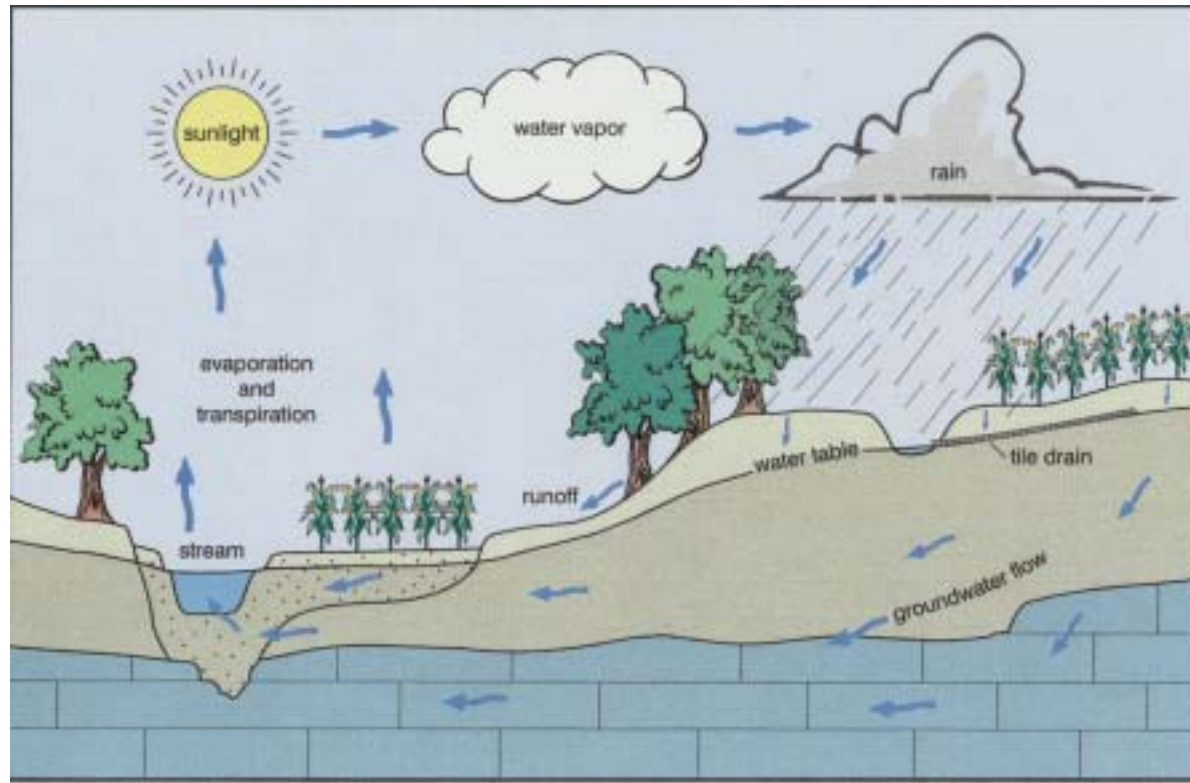
Photographic Services, University of Iowa

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.

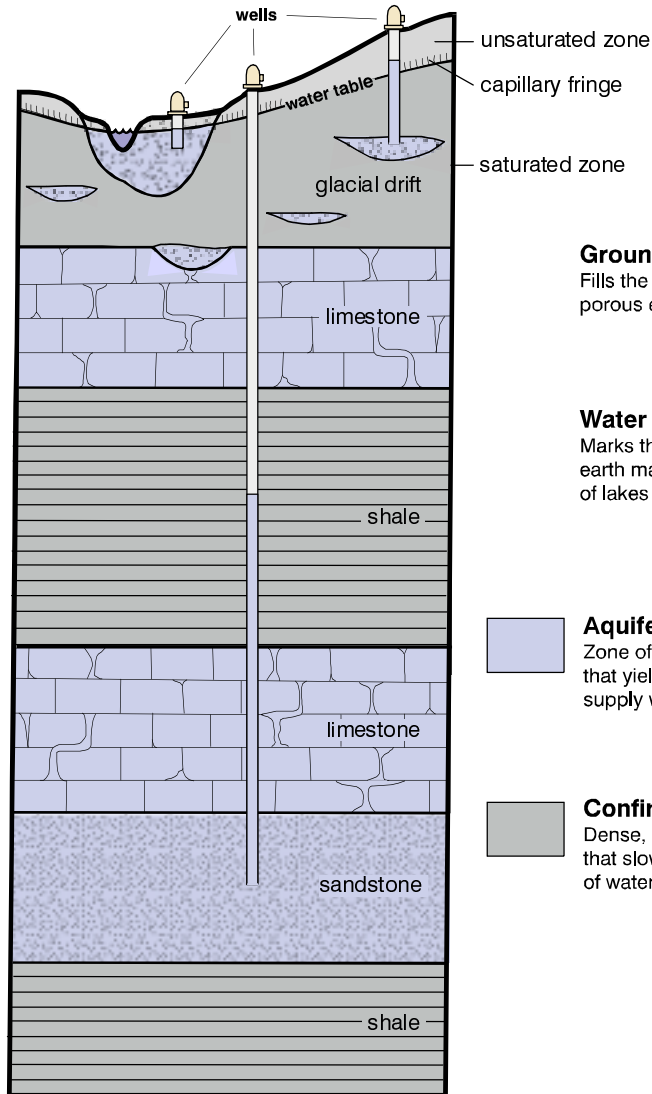
Confined aquifers, on the other hand, are capped by impermeable strata called *aquitards*, or confining beds composed of geologic materials that allow little or no water movement (diagrams, p. 8, 10). These aquitards are an important part of the groundwater system, as they affect water levels, water 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

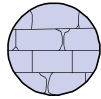


Porosity and Permeability

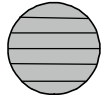
Water is stored and moves easily between grains in sand and gravel.



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.



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

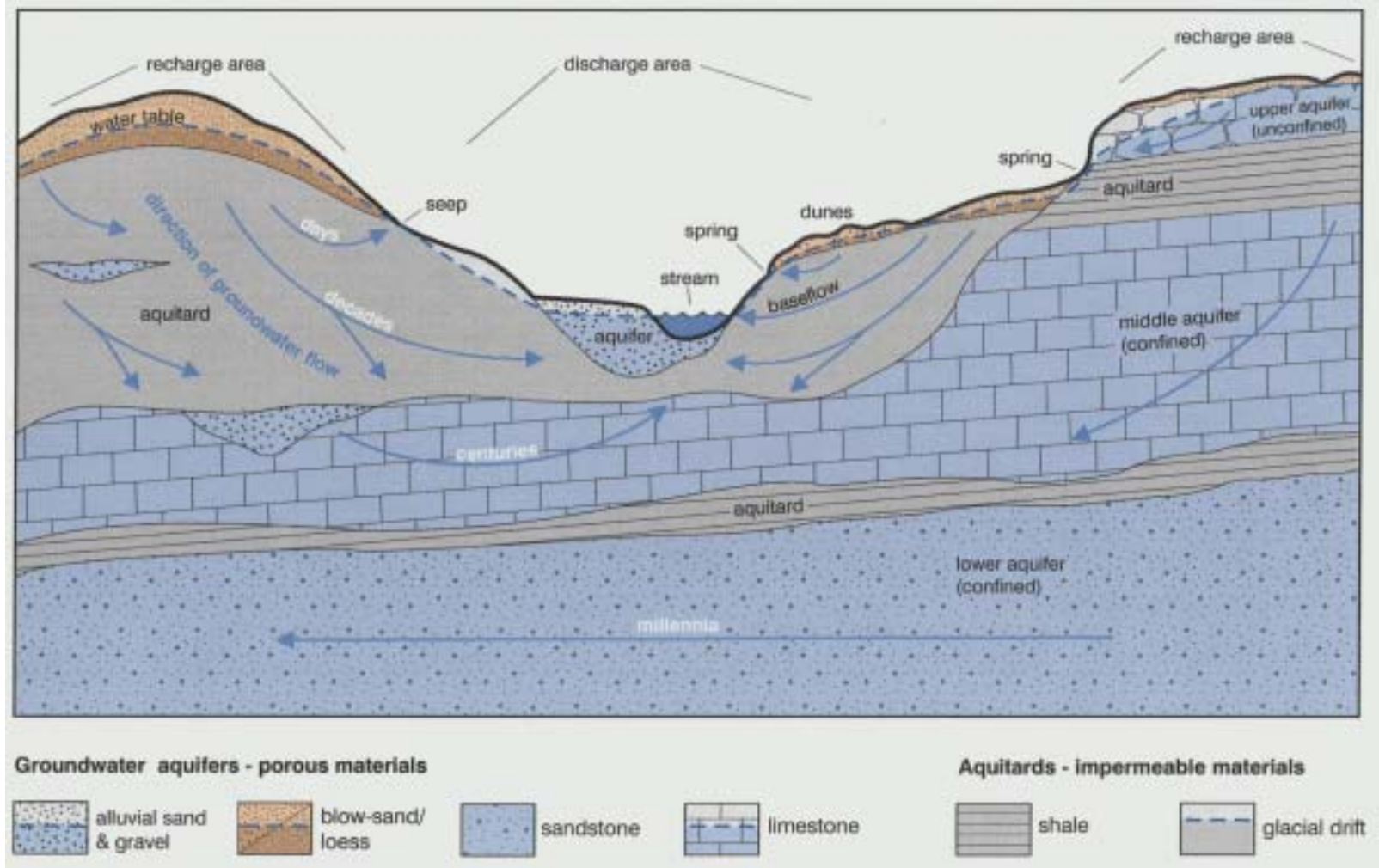
Rick Langel



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).

Ray Anderson

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.