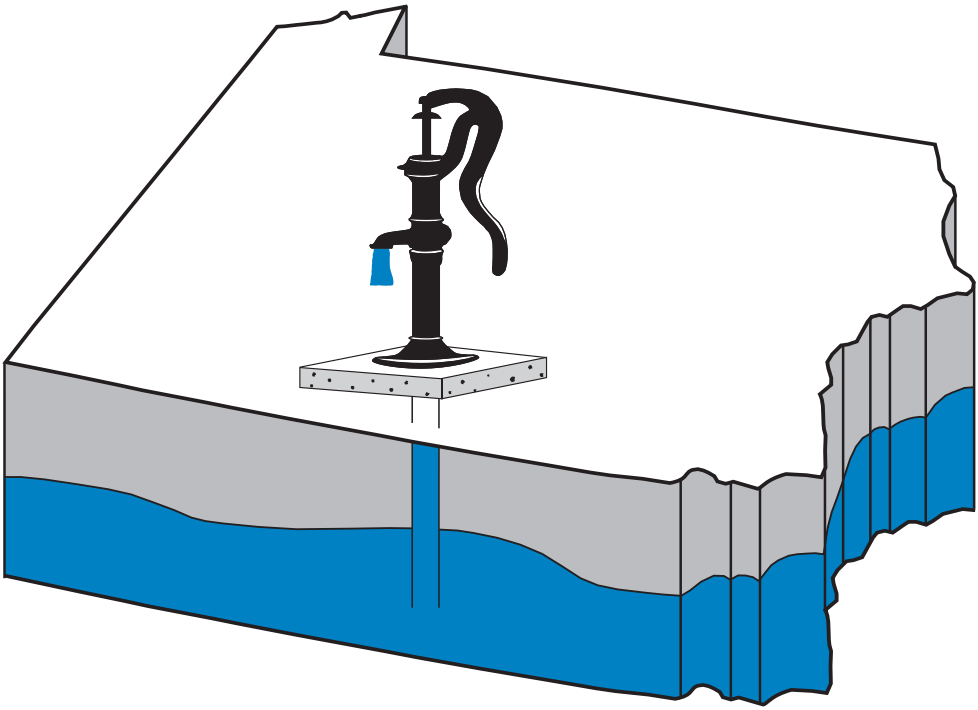
Educational Series 3

THE GEOLOGY OF PENNSYLVANIA'S GROUNDWATER



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Educational Series 3

The Geology of Pennsylvania's Groundwater

by Gary M. Fleeger

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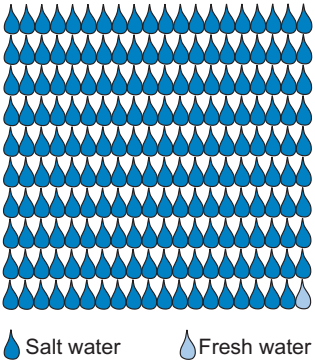
THE GEOLOGY OF PENNSYLVANIA'S GROUNDWATER

by Gary M. Fleeger

What is groundwater?

Water is present almost everywhere in, on, and above the earth. We can readily see ***surface water,*** such as oceans, lakes, and rivers, and ***atmospheric water,*** such as clouds, fog, and precipitation. What we cannot normally see is ***groundwater,*** which is found below the surface of the earth.



Amount of salt water compared to amount of fresh water.

Of all of the earth's water, we are able to drink only the 0.5 percent that is ***fresh water.*** The rest is ***salt water,*** which contains too much dissolved salt and other minerals to be drinkable. Fresh water is abundant in Pennsylvania, which has more miles of streams per square mile of area than most other states. All of the water that we can see, however, is just a fraction of the fresh water available in the state. There is a *lot* more fresh water under the ground than on the ground in Pennsylvania.

Just about anywhere in Pennsylvania, salt water can be found beneath fresh groundwater at depths ranging from about 200 feet to over 1,000 feet. This salty groundwater, called ***brine,*** contains much more salt than seawater. Brine has probably been under the ground since the rocks were formed hundreds of millions of years ago. Because we use mainly fresh groundwater, we will focus on fresh groundwater in this book.

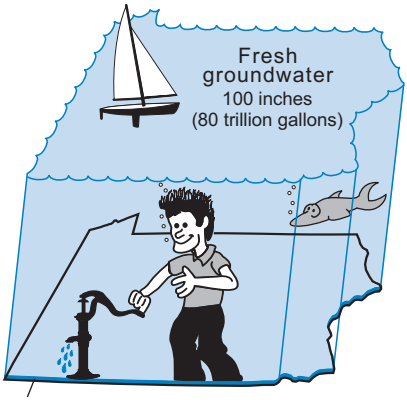
Every day, groundwater is taken from wells and springs to meet our household, agricultural, and industrial needs. Unfortunately, we cannot always find enough groundwater for a particular need, and sometimes the groundwater we find cannot be used because of its quality. To avoid these problems as much as possible, we need to understand some basic concepts about groundwater, specifically about groundwater in Pennsylvania.

The geology and landscape of Pennsylvania vary, and the variations affect the movement and quality of groundwater. Throughout this book,

we will relate basic concepts of groundwater flow and development to the different rock types and landscapes of Pennsylvania. We will start by reviewing our need for groundwater. Then we will look at groundwater from a large scale (the movement of water from the atmosphere, to the land surface, underground, and back to the atmosphere) to a more detailed scale (how water is stored in and flows under the ground). We will learn what effects human activity has on groundwater in Pennsylvania. Finally, we will discuss the ways in which Pennsylvanians obtain groundwater.

How much groundwater do we have?

Most people are surprised to learn that *almost all of the world's unfrozen fresh water exists under the ground*. Pennsylvania, having a humid climate, has a lot of water in streams, lakes, and wetlands. But Pennsylvania has much more fresh groundwater than surface water—more than *thirty* times as much. Pumping all of Pennsylvania's fresh groundwater onto the surface would cover the entire state with more than 8 feet of water!



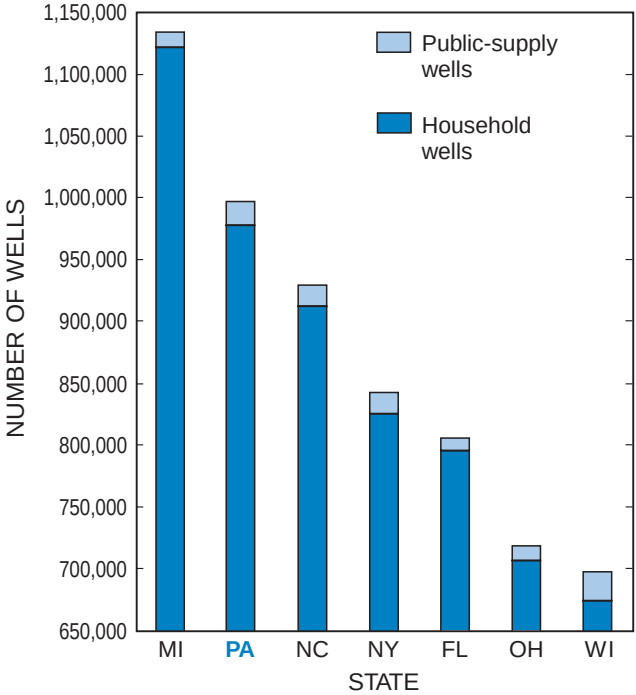
Surface water—3 inches (2.5 trillion gallons)

Who uses groundwater?

All Pennsylvanians ultimately depend on groundwater for drinking water. Public water companies use wells and springs to supply almost one million Pennsylvania households with at least part of their water. Add to that almost one million homes that use private wells and springs, and about half of Pennsylvania's 12 million residents get at least part of their drinking water *directly* from groundwater. Nationally, Pennsylvania ranks second (after Michigan) for total number of wells, second (after Michigan) for number of household wells, and third (after Wisconsin and New York) for number of public-water-supply wells.

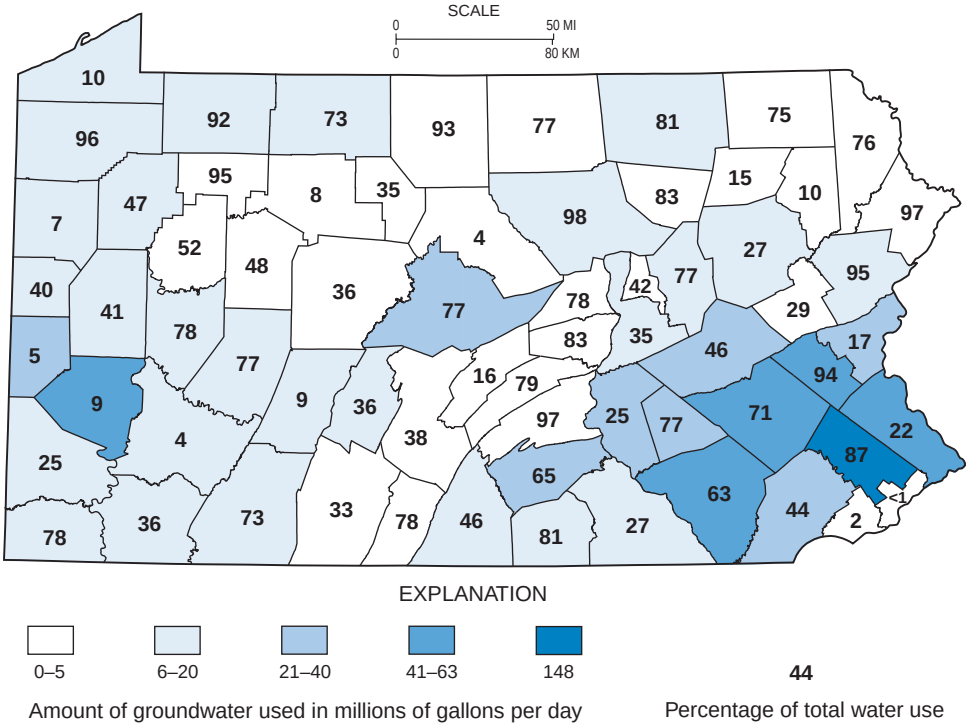
Perhaps you are one of the 6 million Pennsylvanians whose drinking water is provided by a public supplier who uses only water from streams

and lakes. You would have little reason to be concerned about groundwater. Right? You may be surprised to find out that most of your water also comes from groundwater. Groundwater provides two thirds of the water to our streams, lakes, and wetlands. As a result, what we do to the groundwater affects the quality of our surface water. It does not matter if you get your water from a well, spring, river, or lake—you still depend on groundwater.



Top seven states in terms of water-supply wells.

In addition to 30 percent (568 mgal/d (million gallons of water per day)) of Pennsylvania's domestic water use, groundwater contributes 74 percent (50 mgal/d) of the water used for agriculture, 10 percent (180 mgal/d) of the water used for industry, 84 percent (210 mgal/d) of the water used for mining, and 58 percent (14 mgal/d) of the water used for commercial purposes. In all, Pennsylvanians use over 1 billion gallons of groundwater per day. This is equivalent to the amount of water in the second largest natural lake in Pennsylvania, Lake Canadohta in Crawford County.

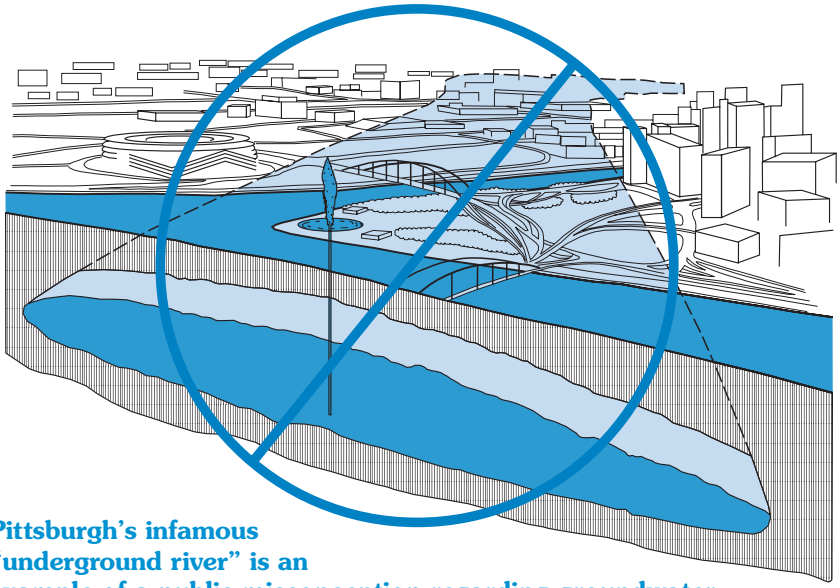


Percentage of total water use that is from groundwater and amount of groundwater used in Pennsylvania, by county, in 1990.

Why is groundwater so misunderstood?

People often have trouble understanding things that they cannot see, such as groundwater. The public has many misconceptions regarding groundwater, the most common probably being that groundwater normally flows in veins or in large open cavities in the earth. The misconceptions are not surprising because some children's books about water either do not mention groundwater or mistakenly indicate that it exists in lakes and rivers under the ground. Our mistaken ideas about groundwater start at an early age, and it becomes difficult to dispel these ideas.

Because groundwater generally cannot be observed directly, scientists called ***hydrogeologists*** use indirect methods, such as measurements in wells, to study groundwater. They have learned that the same scientific principles that control surface water affect groundwater movement and quality, but that groundwater is also affected by other factors. Superstitions,



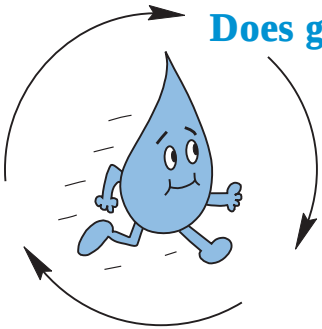
Pittsburgh's infamous "underground river" is an example of a public misconception regarding groundwater.

such as water witching (also called divining or dowsing), play no role in understanding or finding groundwater. The apparent success of dowsers results from the fact that a well drilled almost anywhere in Pennsylvania would be likely to yield some water.

Where did the earth's water come from?

The origin of water in, on, and above the earth is uncertain. One widely accepted theory is that water originated through volcanic eruptions early in the history of the planet. These eruptions released hydrogen and oxygen that combined in the atmosphere to form water. If the volcanic eruptions were the sole source, then the amount of water would have been fairly constant for the past 500 million years. The water in yesterday's rain, in the stream that you canoed last week, or that came from your well today may be the same water that a dinosaur drank 70 million years ago.

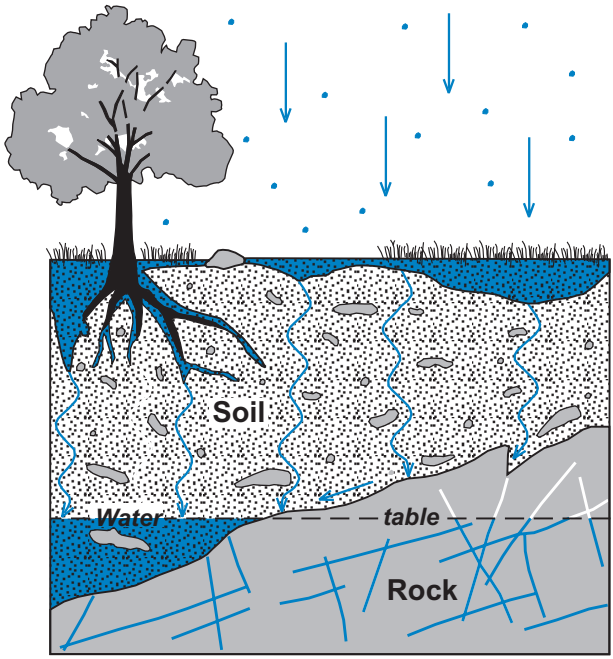
Another theory is that some or much of the earth's water could have originated through "cosmic snowballs" (small comets of ice), which have probably bombarded our atmosphere for 4.5 billion years. If this is the case, then the amount of water is continually increasing.



Does groundwater stay underground?

Regardless of its origin, water moves between the subsurface, surface, and atmosphere via the earth's recycling machine known as the ***water*** (or hydrologic) ***cycle***. Although this book focuses on groundwater, we will briefly discuss atmospheric and surface water, because eventually all water spends time in all three environments.

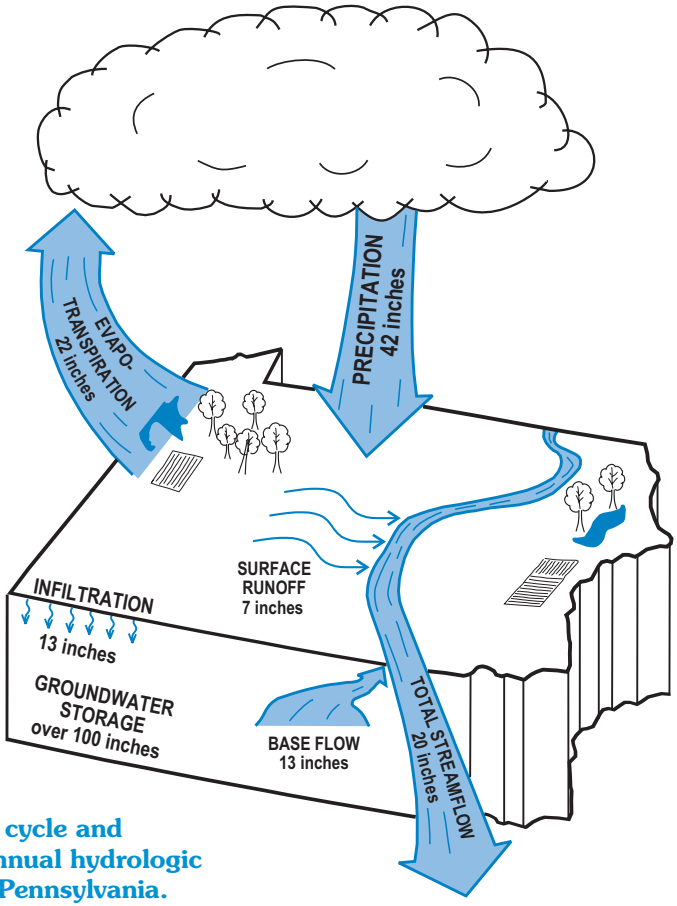
The water cycle is continuous. There is no starting or ending point. Precipitation returns atmospheric water to the surface of Pennsylvania. Some of the water flows on the surface as ***surface runoff*** to Pennsylvania's streams, lakes, and wetlands. Most of the precipitation *evaporates* back into the atmosphere from the ground surface. The remainder of the precipitation infiltrates into the ground. Once water penetrates the ground surface, some of it is taken up by plant roots and *transpired* (transpiration and evaporation combined is ***evapotranspiration***) back into the atmosphere. The remaining water filters downward through a zone where the soil, sediment, and rock are only partly saturated. Eventually, this water



Infiltration of water into the ground replenishes the groundwater supply.

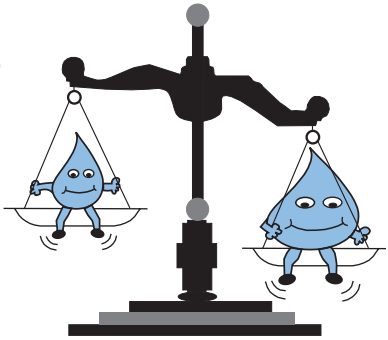
reaches the ***water table,*** the boundary below which all of the spaces and cracks in the soil or rock are filled with water. Water below the water table is in ***groundwater storage.*** Water that filters through the ground to the water table ***recharges*** the groundwater system.

The depth to the water table varies with topography: it is generally farther beneath the surface under hills and closer to the surface under valleys. Streams, lakes, and wetlands occur where the water table intersects the land surface (see, for example, the cross section of the Allegheny and Monongahela Rivers on page 19). At these places, groundwater ***discharges*** out of groundwater storage and becomes surface water. Groundwater that discharges to surface water is called ***base flow.*** The water cycle is complete when evaporation from the surface returns this water back to the atmosphere as water vapor.



The water cycle and average annual hydrologic budget in Pennsylvania.

Does the amount of groundwater in Pennsylvania change?



The amount of water in atmospheric, surface, and groundwater environments varies from place to place. How the water is distributed between these environments is largely controlled by climate. For example, a desert has very little atmospheric and surface water. Most of its water is groundwater. Pennsylvania's humid continental climate results in relatively abundant water in all three environments. Although there are seasonal weather fluctuations, the average amount of water in each environment is fairly constant over time (decades to centuries).

Scientists can measure the amounts of precipitation, streamflow, evapotranspiration, and groundwater. Evaluating all of these measurements helps determine the ***hydrologic budget*** (or balance) for Pennsylvania. The hydrologic budget tells scientists how much water we have and whether we will have enough in the future.

The hydrologic budget can be compared to the way you budget your money. Precipitation is income, the source of all of our water. Surface runoff and evapotranspiration are expenses. Groundwater storage is the bank balance, and infiltration represents a deposit to the bank account. Base flow is a bank withdrawal. To maintain your bank balance (groundwater storage), all the money that you withdraw (through base flow) must be replaced by deposits (infiltration).

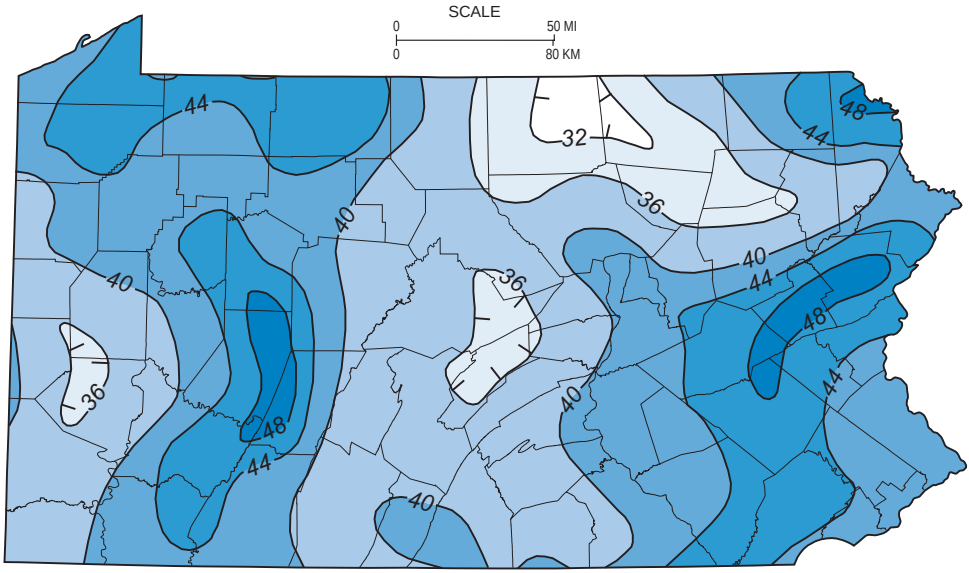
You are probably familiar with weather forecasters reporting rainfall in inches. The other parts of the hydrologic budget are also measured in inches. For example, a measurement of 13 inches of base flow in Pennsylvania per year means that if the amount of groundwater that discharges into Pennsylvania streams each year were spread out over the state, this water would be 13 inches deep.

During short periods of time (months to years), it is not unusual for the amount of water entering groundwater storage to be more or less than the amount leaving. During droughts, more water leaves groundwater storage than enters it and groundwater levels drop. Lower water levels in wells and reduced streamflows indicate lower groundwater levels. If the water table drops below a streambed, that streambed will be dry. Flooding, a common situation in Pennsylvania, is not related to high groundwater levels but, rather, is caused by high amounts of surface runoff.

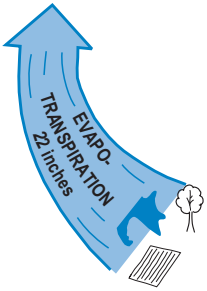
Humans do many things to alter the hydrologic budget. Buildings and pavement increase surface runoff to streams and reduce the amount of infiltration. Converting from on-lot septic systems to public-sewage-treatment systems also diverts to the surface water that once entered the groundwater system. These changes increase the amount of water bypassing the groundwater part of the cycle.

Extracting more groundwater than is naturally replaced also reduces the amount of water in groundwater storage. This practice of ***groundwater mining*** is more of a problem in the arid western states, but it has occurred locally in southeastern Pennsylvania. There, urbanization has increased surface runoff (decreasing infiltration), while the growing population has increased the demand for water. As a result, pumping has exceeded replenishment of the groundwater in that heavily populated region.

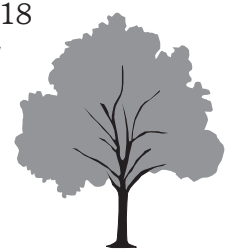
Components of the hydrologic budget vary somewhat across the state. The average annual precipitation ranges from a minimum of 32 inches in Tioga and Bradford Counties (in north-central Pennsylvania) to a maximum of almost 50 inches in Indiana and Cambria Counties (in western Pennsylvania) and Carbon and Monroe Counties (in eastern Pennsylvania). Precipitation is fairly evenly distributed throughout the year, but it is slightly greater during May, June, and July.

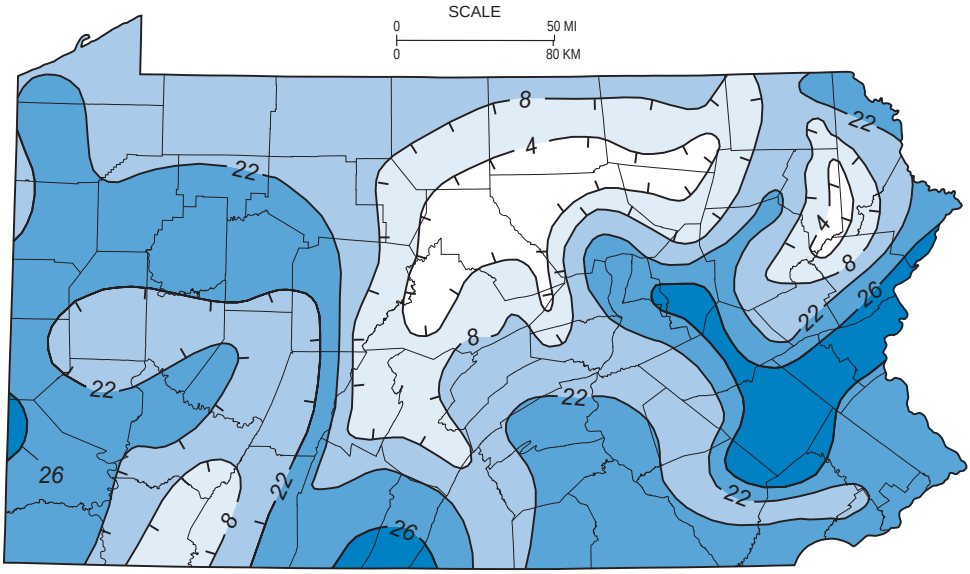


Average annual precipitation in Pennsylvania in inches.

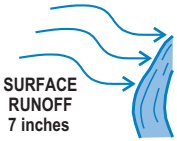


The highest annual evapotranspiration (as much as 28 inches) occurs in east-central Pennsylvania. The higher elevations of northeastern (Pocono Plateau), north-central, and southwestern (Laurel Highlands) Pennsylvania, where temperatures are lower, have the lowest annual evapotranspiration (from less than 14 inches to 18 inches). Evapotranspiration occurs unevenly throughout the year, increasing during the warm summer months when temperatures are higher (increasing evaporation) and the deciduous trees have leaves (increasing transpiration).

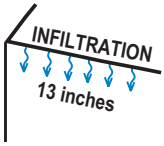




Average annual evapotranspiration in Pennsylvania in inches.

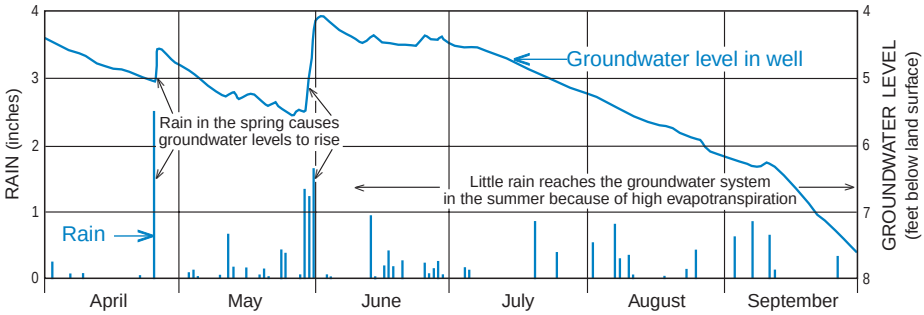


The amount of surface runoff also varies throughout the year. It is greatest during the early spring when snowmelt is occurring and the ground is still frozen, preventing infiltration. Surface runoff is also significant during intense rainfall, when the ground cannot absorb the rain as fast as it falls.

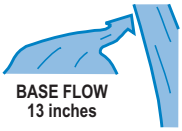


Precipitation (amount and rate), temperature, and soil conditions control the amount of water that infiltrates and becomes groundwater. The maximum amount of infiltration and groundwater recharge normally occurs during the spring

and fall when the ground is not frozen, there is sufficient rain, and evapotranspiration is low. The effect of precipitation and seasons on the groundwater system is illustrated in the graph below.



Relationship between groundwater level, precipitation, and season near Allentown, Pa., in 1968.

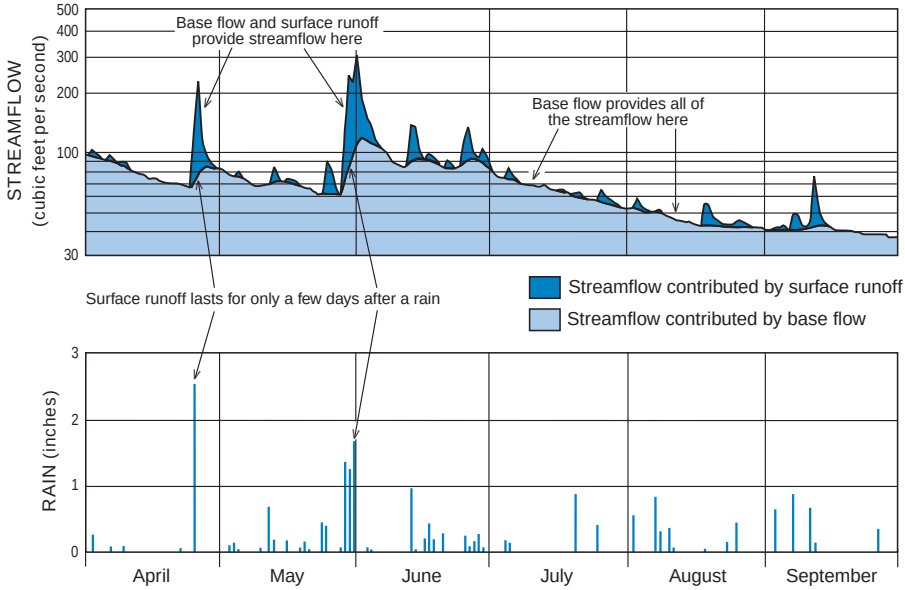


Groundwater naturally discharges from springs and seeps. Over a long period of time (decades to centuries) and under natural conditions, the average amount of base flow equals the average amount of recharge. However, withdrawing groundwater through wells reduces base flow. The water that would have discharged to springs and streams as base flow is removed from groundwater storage before reaching the springs or streams. Again, this is more of a problem in the Great Plains states, where groundwater mining for irrigation has dried up many streams. In Pennsylvania, most streamflow reduction due to well pumping is negligible.

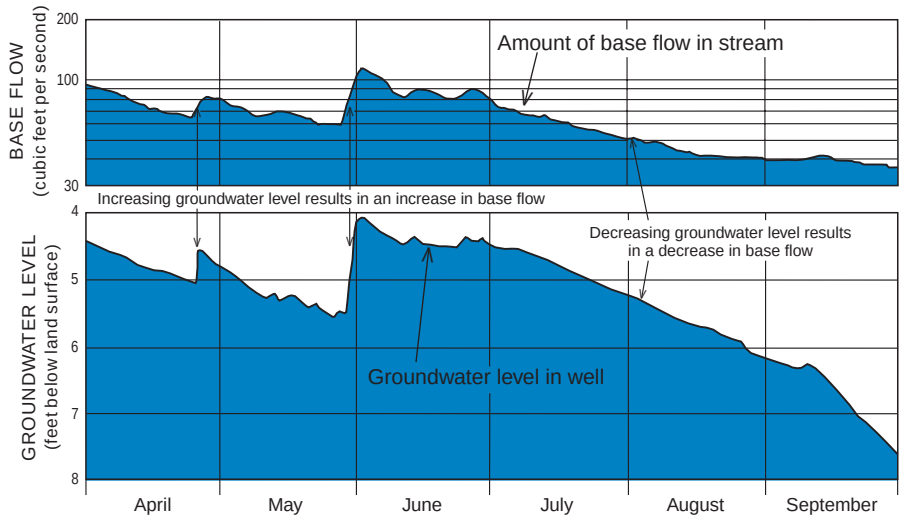
Other than those short periods after a rain when surface runoff also contributes to streamflow, base flow provides all of the water to streams (see the graph near the top of the next page for an example). That is why streams continue to flow even during long periods without rain. Base flow contributes to streamflow throughout the year.

The hydrologic budget also includes another component not indicated on the diagram on page 7. An additional 6 inches of streamflow enters Pennsylvania from neighboring states. However, most of this streamflow simply passes through the state and does not really factor into Pennsylvania's groundwater story. The 20 inches of streamflow shown leaving Pennsylvania in the diagram includes only that portion of the flow originating as surface runoff and base flow within the state.

Now that we have looked at Pennsylvania's water cycle and hydrologic budget, let us look at an example of the interaction between surface water and groundwater. The graphs at the bottom of this page show a rela-



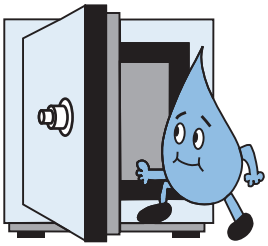
Relationship between streamflow and precipitation near Allentown, Pa., in 1968.



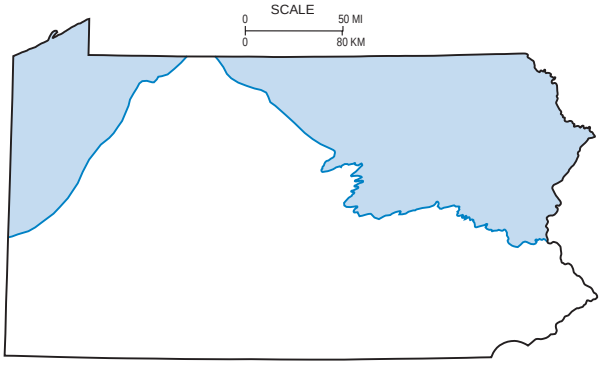
Relationship between base flow and groundwater level near Allentown, Pa., in 1968.

tionship between the water in those two settings. The groundwater levels change through time, just as stream levels do. You can see how what we do to groundwater is important, not only to those who use groundwater directly, but also to those who use surface water. The groundwater that is being affected will one day be surface water again.

How is water stored in the ground?



Groundwater is found in ***unconsolidated*** (loose) sediments, such as sand, and in ***consolidated*** (solid) rocks, such as sandstone. Unconsolidated sediments are composed of individual particles, or grains, some of which may not be visible without a magnifying glass or microscope. Groundwater can be stored in the ***pores*** (empty spaces) between the grains. Unconsolidated sediments have a lot of pore space. In Pennsylvania, unconsolidated sediments are common along major stream valleys. They are also common in the northeastern and northwestern regions of the state, which were covered with glaciers during the Ice Age. Unconsolidated sediments below the water table store a large amount of water.



Areas of Pennsylvania that were covered by glaciers during the Ice Age.

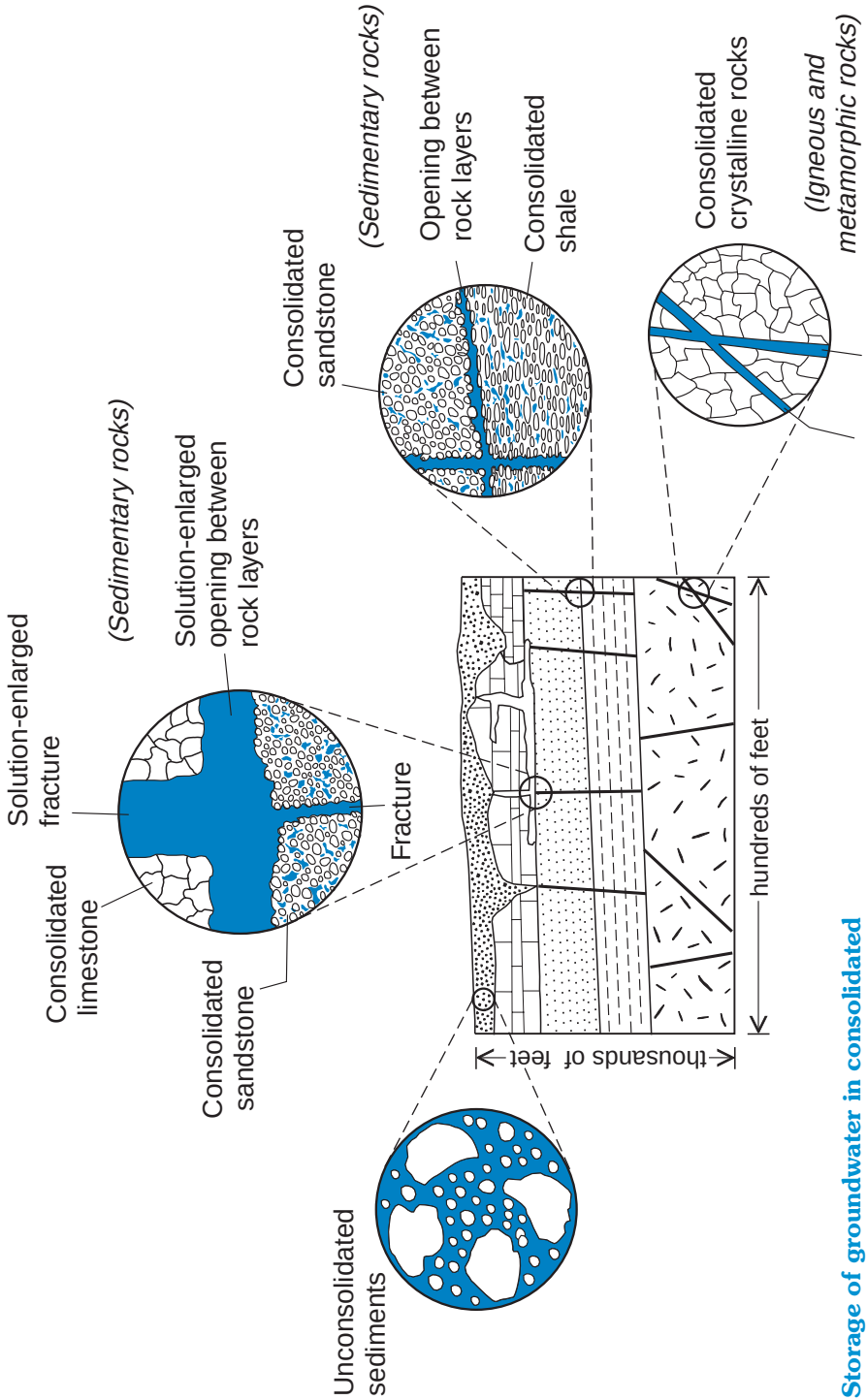
Water can exist between the grains of unconsolidated sediments, but how does water exist in consolidated rock? A rock (or bedrock) is also composed of grains, but its grains have been cemented together. Most rocks in Pennsylvania have very little pore space. Water in consolidated rocks is mainly stored in openings between rock layers and in fractures that cut through the rocks. It is common to see water coming out of rock

openings where they are exposed at the surface. Farther from the surface, however, these fractures and openings between rock layers are normally only millimeters in width and, compared to the pores in unconsolidated sediments, hold only a small amount of water.

Ice accumulated from the slow discharge of groundwater from openings between layers of rock in Lawrence County.

Exceptions occur in limestone and dolomite, common types of rock in central and southeastern Pennsylvania (see the map on page 23) and found locally in western Pennsylvania. Groundwater gradually dissolves these two rock types, causing openings within the rocks to widen, eventually becoming caves. Caves can hold considerably more water than the fractures and pores in most rocks, but they are rare.

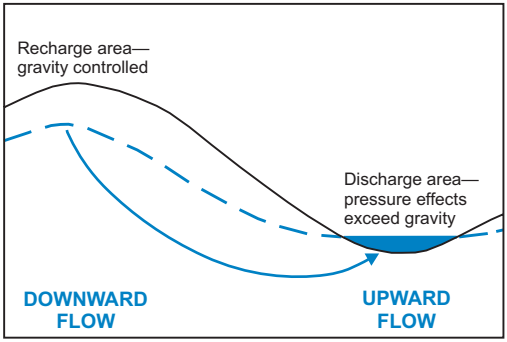
The total amount of open spaces in rocks or unconsolidated sediments is called ***porosity.*** The spaces may be pores, openings between rock layers, fractures, or caves. All are potential sites for groundwater.



Storage of groundwater in consolidated rocks and in unconsolidated sediments.

What causes groundwater to flow?

Water is not just stored in the ground. It flows around grains and through the cracks within and the spaces between rock layers. What forces cause groundwater to move through rocks and sediments? The main force causing groundwater to flow is the same force that causes surface water to flow—***gravity.*** Groundwater *always* flows downward from recharge areas on hills toward discharge areas in valleys. The water that you see in a stream came from a higher elevation, either from surface water upstream or from groundwater that recharged at a higher elevation.

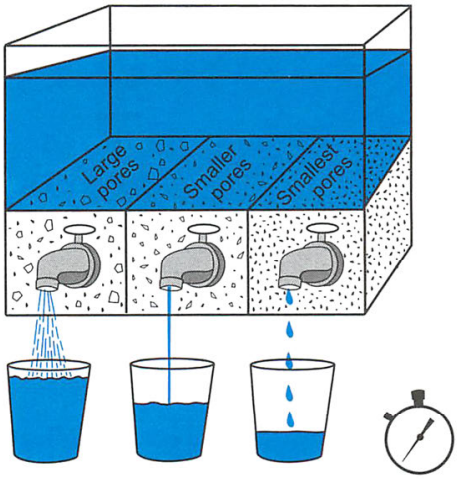


There is an additional force on groundwater, however, that does not exist for surface water. Once groundwater has flowed down from a recharge area and entered a discharge area, ***pressure*** caused by the weight of the water above can cause water within the discharge area to flow upward. This means that, unlike surface water, groundwater can sometimes flow from a lower to a higher elevation. The pressure is always greater below the water table than it is at the water table. If the pressure difference is large enough, which happens only in discharge areas, groundwater may flow up into a stream from below. Gravity is the main influence on groundwater flow, but within some discharge areas, pressure can be great enough to overcome gravity.

How fast does groundwater flow?

The difference in elevation and pressure between two points controls the speed at which groundwater flows: the greater the combined difference in elevation and pressure between the two points, the faster the groundwater will flow between those points. The rocks or sediments containing the water also control the rate of flow. As water flows through a deposit of sediments or a rock, friction between the water and the sediment

Pore sizes affect groundwater flow rates.

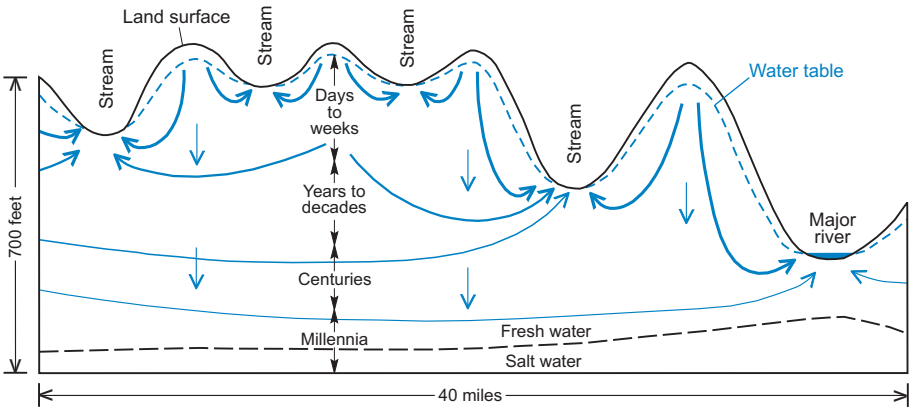


grains or rock slows the water down. If the pores, fractures, and openings between rock layers are small, friction can slow the water down quite a bit. If the pores are not connected to each other, or the fractures and openings do not intersect each other, the groundwater cannot flow. The ease with which groundwater can flow through rocks or sediments is a measure of their ***permeability.*** It depends on the size of the pores, fractures, and openings between rock layers, and on the degree to which the pores are connected and the fractures and openings intersect. Compared to surface water, most groundwater flows very slowly, on the order of feet per day.

How far does groundwater flow and how long does it take?

Nearly all water entering the groundwater system in Pennsylvania flows from a hilltop to the nearest stream. Because of the large number of streams in Pennsylvania, shallow groundwater never has far to go. Almost all shallow groundwater in Pennsylvania reaches a stream within days, weeks, or months after the water enters the groundwater system.

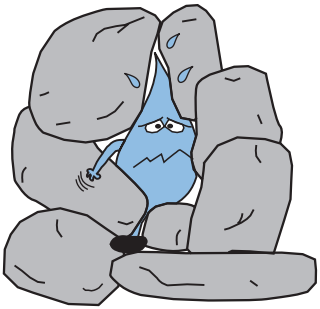
A small amount of shallow groundwater does not discharge into the nearest stream. Instead, this groundwater moves deeper into the earth, passes beneath the adjacent stream, and continues toward deeper stream valleys. Not only does deep groundwater travel farther than shallow groundwater, but it travels slower. Permeability decreases with depth because the weight of the overlying rocks causes the pores, fractures, and openings between rock layers to be smaller. Deep groundwater is almost stagnant compared to shallow groundwater. The deepest groundwater discharging directly into one of Pennsylvania's major rivers (Ohio, Susquehanna, or Delaware) has probably been underground for hundreds or thousands of years.



Groundwater flow paths (indicated by the blue arrows). The thickness of the lines reflect the relative amount of groundwater flowing through the groundwater system.

In rugged, hilly landscapes, such as in north-central and central Pennsylvania, a larger portion of the shallow groundwater discharges to the nearest stream valley than is the case in gentler, flatter landscapes, such as in southeastern Pennsylvania and in the glaciated regions of northwestern and northeastern Pennsylvania. However, even in the gentler landscapes, most shallow groundwater in Pennsylvania never penetrates to great depth but flows to the nearest stream.

Does groundwater flow through all rocks?



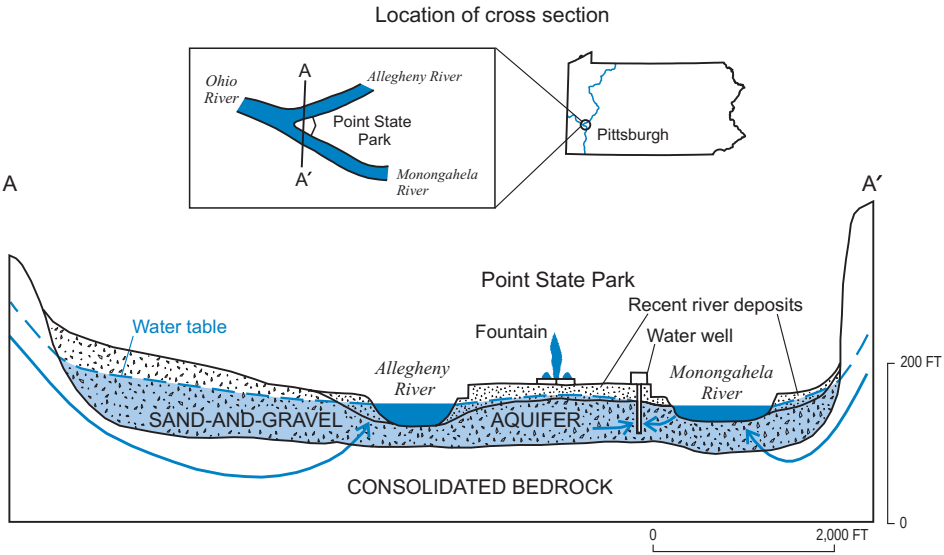
Groundwater flows through almost *all* rocks and sediments below the water table. Because some are less permeable than others, water flows through different rocks and sediments at different speeds. ***Aquifers*** are the rocks and sediments that not only contain significant quantities of groundwater but also have sufficient permeability to allow the groundwater to flow at a speed that can supply enough water to your home.

In the western United States, some geologic units serve as aquifers over hundreds of square miles. In Pennsylvania, the permeability of the rocks and sediments changes over short distances. As a result, most aqui-

fers in Pennsylvania are local. A particular rock layer may serve as an aquifer in one location but not in another.

Unconsolidated sediments having significant porosity and permeability, mainly sand and gravel, make some of the best aquifers in Pennsylvania, producing large amounts of water. These aquifers are limited mostly to major stream valleys in Pennsylvania, especially those that drain areas that were covered by glaciers during the Ice Age (see the map on page 13). The sand and gravel were deposited by water from melting glaciers, which carried great loads of sediments. Other aquifers in unconsolidated sediments are found near Lake Erie along the northwestern border of Pennsylvania and in the Atlantic Coastal Plain area along the southeastern border of Pennsylvania.

A good example of an aquifer in unconsolidated sediments that produces an abundant amount of water can be found in Pittsburgh. For years, it has been reported in many popular publications and newspapers that an "underground river" flows beneath Pittsburgh in a cavity wider than the downtown area (see the sketch on page 5). This "river" was credited with supplying the water for the fountain at Point State Park. These reports are false. In reality, the water for the fountain at Point State Park comes from a sand-and-gravel aquifer in the Allegheny and Ohio River valleys.



Cross section of the Allegheny and Monongahela River valleys at Point State Park, Pittsburgh. The vertical scale is greatly exaggerated to show detail.

A well drilled into the sand-and-gravel aquifer near the fountain provides more than enough water to replace any that is lost to evaporation or blown out of the fountain by the wind.

A number of Pennsylvania communities along major rivers use similar sand-and-gravel aquifers for their water supplies. If the wells in a particular sand-and-gravel aquifer, such as the one at Point State Park, pump more water than is replaced by normal groundwater flow toward the river, then river water will be pulled into the aquifer. As long as the river valley contains water, there will be water in the sand-and-gravel aquifer, making it seem as though the wells are tapping an underground river.

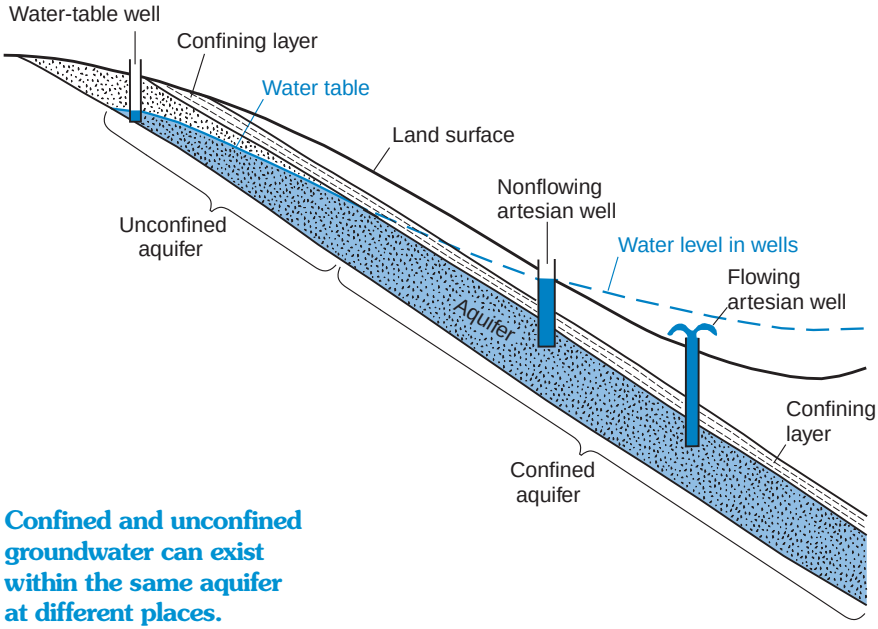
Not all unconsolidated sediments are aquifers. Fine-grained sediments (silt and clay) may have high porosity but low permeability. These types of deposits can store large quantities of water, but their pores are too small for the water to move through quickly.

Water flowing through caves in limestone and dolomite forms the only true underground streams in Pennsylvania. However, such streams are rare and typically small. Most are not capable of producing the large amount of groundwater that is popularly associated with the mythical "underground rivers."

Groundwater flowing from a small cave (arrow) in Lycoming County.

Why do some wells flow and others need to be pumped?

Aquifers can be divided into two types: ***confined*** and ***unconfined.*** Confined aquifers are overlain by a layer of low-permeability rock ***(confining layer).*** Because of the variability of rock types in Pennsylvania, deeper aquifers almost always have a confining layer above them. Groundwater will flow through confining layers but much more slowly than in the adjacent aquifers. Unconfined aquifers either have a water table within them or do not have a low-permeability layer above them restricting flow into or out of the aquifer.



Confined and unconfined groundwater can exist within the same aquifer at different places.

Groundwater in a confined aquifer is under pressure and is referred to as ***artesian*** water. The pressure in artesian aquifers will cause the water in wells drilled into them to overcome gravity and rise above the top of the aquifer. Some artesian aquifers are under enough pressure that wells drilled into them will flow without being pumped. Artesian aquifers need not be confined. As mentioned before, the pressure may be great enough in a discharge area to cause upward flow, perhaps even great enough to allow wells to flow.

A flowing well in Jefferson County.

Contrary to some advertising campaigns, the term "artesian" has nothing to do with water quality. Making a product using water from a confined aquifer will not improve the quality of the product.

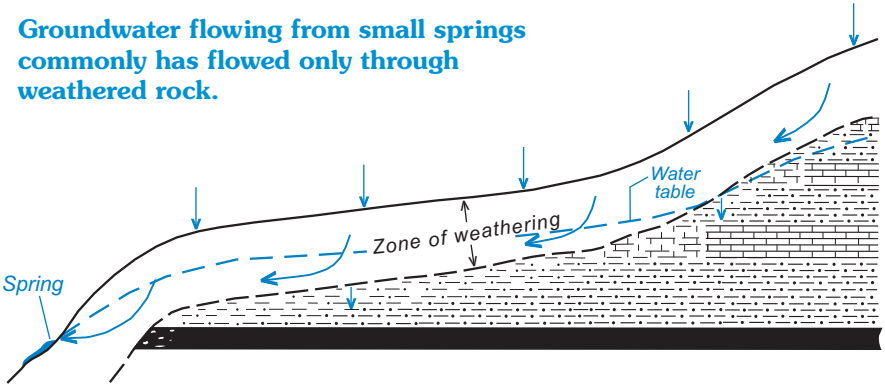
Is groundwater different than surface or atmospheric water?

The natural chemistry of groundwater varies from place to place. It is controlled by two factors: (1) the minerals with which the water comes in contact, and (2) how long the water is in the groundwater system.

As groundwater flows, it dissolves minerals in the soil and rock, and its chemistry changes. Some minerals dissolve more easily than others. This results in groundwater having various amounts of ***dissolved solids.*** The quantity of dissolved solids in water is measured in milligrams per liter of water (mg/L). A milligram is the weight of about 10 grains of table salt. A liter is slightly more than a quart. The geology of Pennsylvania varies, and the groundwater composition varies depending on the type of rock or sediment through which it moves.

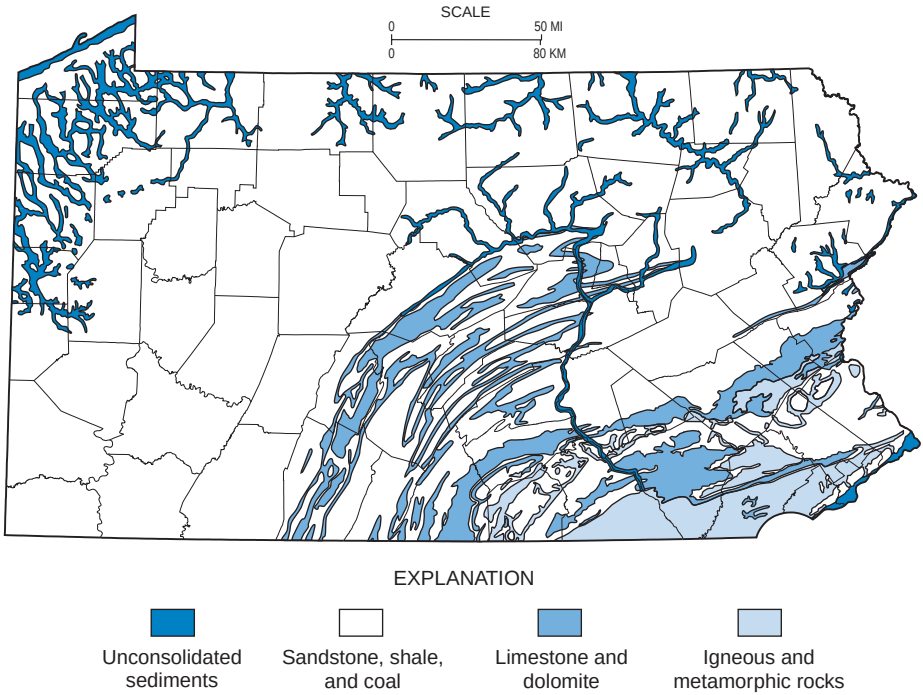
Over most of Pennsylvania, there is a surface layer of soil and weathered rock that ranges from a few inches to tens of feet in thickness. Most of the minerals that easily dissolve have already been dissolved from this

Groundwater flowing from small springs commonly has flowed only through weathered rock.



layer. Water from most small springs has flowed only through this layer of weathered material. The composition of spring water, therefore, may not be much different than that of rainwater.

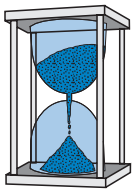
Unconsolidated sediments vary widely in composition and, consequently, have a large range of associated groundwater chemistries. Limestone and dolomite, common in many of the valleys of central and south-



Distribution of rocks and sediments in Pennsylvania.

eastern Pennsylvania, are composed of minerals that easily dissolve in groundwater. Igneous and metamorphic rocks, common in other parts of southeastern Pennsylvania, generally contain small quantities of soluble minerals. Sandstone, shale, and coal have few soluble minerals, but they have more soluble minerals than igneous and metamorphic rocks.

The dissolution of minerals in rocks occurs very slowly. The longer the groundwater flows through the rocks ***(residence time),*** the more time it has to dissolve minerals. Deep groundwater, which has been in the groundwater system longer than most shallow groundwater, is more likely to be higher in dissolved solids. Most spring water has not had enough residence time to dissolve any minerals still present in the rocks.



Mineralization of Water by Depth[1]

Source	Dissolved solids, median (mg/L)[2]	Number of samples
Springs	150	50
Shallow wells[3]	253	59
Deep wells[4]	277	179

[1]Groundwater samples were taken from all types of rocks and sediments and included naturally occurring groundwater and groundwater altered by human influence.
[2]Midway value of all samples.
[3]Less than 80 feet deep.
[4]Greater than 80 feet deep.

Poor water quality is not always the result of degradation from human activities. Depending on what minerals are dissolved from the rocks and sediments, natural groundwater quality may be unacceptable in some areas. Probably the most common problem is hardness, which results from high concentrations of calcium. High amounts of dissolved solids, iron, and hydrogen sulfide (which has a rotten-egg odor) are examples of other water-quality problems that occur naturally.

The quantity of dissolved solids in groundwater is lowest in north-central Pennsylvania. Because of the rugged landscape, little groundwater penetrates to deep levels in that area, resulting in a short residence time. The main rock types are sandstone and shale, which are made of rela-

tively insoluble minerals. Other areas of Pennsylvania have more rock that is soluble and/or more of the groundwater penetrates to deeper levels, increasing residence time.

Mineralization of Water and Water-Quality Problems by Type of Rock or Sediment

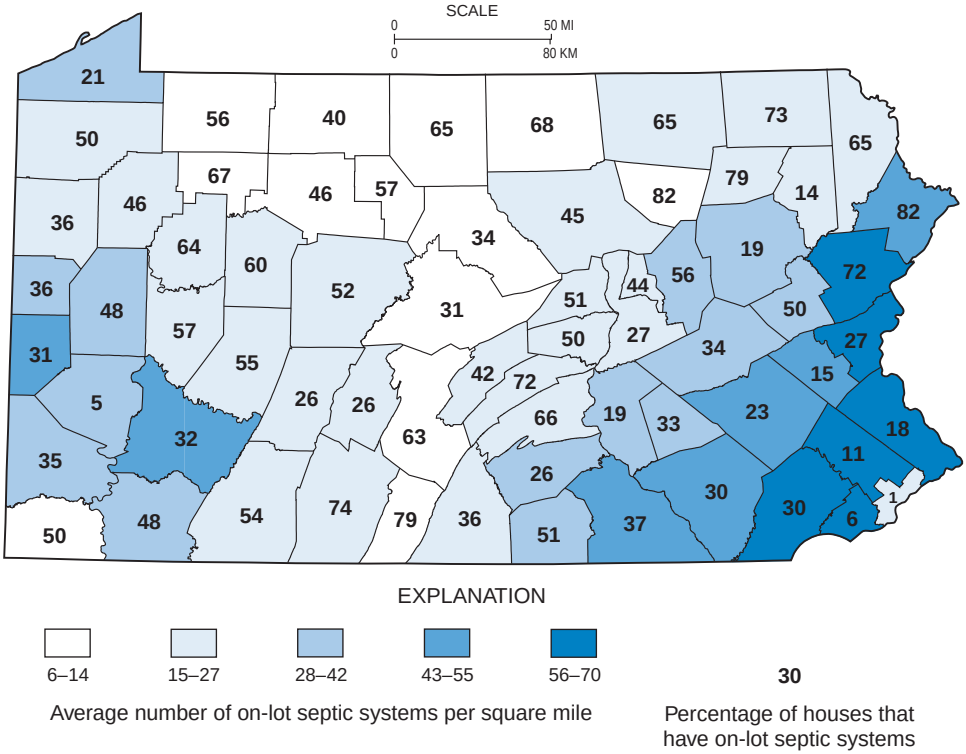
Rock or sediment type	Dissolved solids, median (mg/L)[2]	Number of samples	Quality problems[1]	
			Natural	Human-caused
Sediments				
Glacial and river	255	256	Iron; hardness	Iron; salt water
Atlantic Coastal Plain	423	123	Unknown[3]	Iron; salt water
Sedimentary rocks				
Limestone and dolomite	323	464	Hardness	Nitrates
Sandstone and shale	182	1,067	Iron	Salt water
Coal-bearing rocks	253	386	Iron	Acid mine drainage
Igneous and metamorphic rocks	129	340	Iron	Nitrates

[1] Only the most common problems are listed.
[2] Midway value of all samples. Samples included naturally occurring groundwater and groundwater altered by human influence. Typically, dissolved solids concentrations vary by several hundred milligrams per liter across the state for any given rock or sediment type.
[3] Groundwater chemistry has been altered so much by humans, it is no longer possible to determine the natural quality of the groundwater.

Have humans affected groundwater quality?

Activities of humans can cause changes to the chemistry of groundwater in a variety of ways. Many types of pollutants can get into the groundwater system from the surface. Most homes in rural areas use on-lot septic systems for sewage disposal. If septic systems are not properly installed and maintained, they can be a source of pollution. Nitrates and bacteria from sewage, as well as household chemicals that are dumped into septic systems, can contaminate groundwater. This is probably more of a problem in Pennsylvania than elsewhere in the United States because

Pennsylvania has more rural residents than any other state (3.7 million in the 1990 census). As of 1990, 1.2 million Pennsylvania homes (one fourth of all of the homes in the state) used on-lot septic systems. As a result of extensive rural home development in the Poconos (Wayne, Monroe, and Pike Counties), about 84,000 (or three fourths) of the homes in that area used on-lot septic systems for sewage disposal.

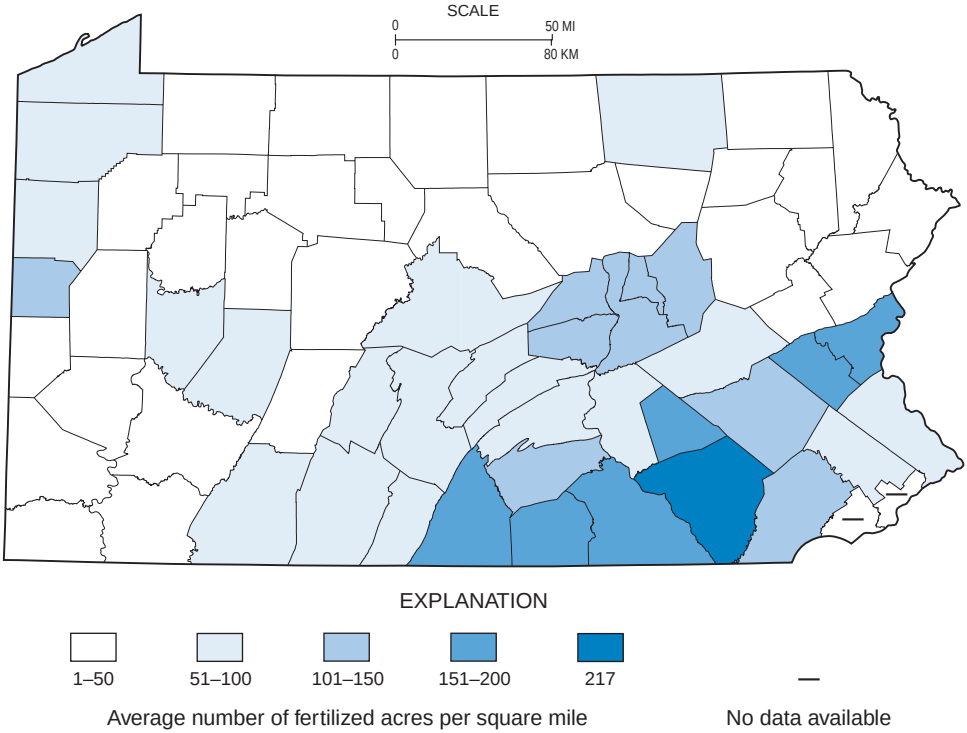


Percentage of homes using on-lot septic systems and average density of on-lot septic systems in Pennsylvania, by county, in 1990.

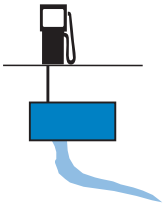
Bacterial contamination of well water may indicate contamination of the well from a direct flow path from the surface (often around improperly installed casing) and not necessarily contamination of the groundwater in the aquifer. As might be expected, this type of contamination happens most often in the more heavily populated areas.

Pesticides and fertilizers applied to fields and lawns, and nitrates, bacteria, and viruses from animal wastes, are agricultural sources of ground-

water contamination. These problems are more significant in southeastern Pennsylvania because of the concentration of farms there.

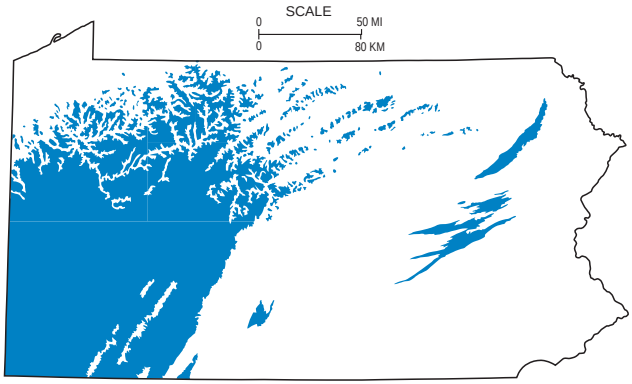


Average number of fertilized acres per square mile in Pennsylvania, by county, in 1992.



Other surface sources of contaminants include highway salt application and storage piles, leaking storage tanks, landfills, and chemical spills.

It is not necessary to add contaminants to the subsurface to cause a change in groundwater quality. Excavations beneath the weathered zone can change the chemistry of groundwater without adding new substances underground. The breaking up of rocks during excavations exposes more of the rocks to air (above the water table) and groundwater (below the water table). This allows more minerals in the rocks to react with the air and to dissolve in the groundwater, resulting in a change in the chemistry of the groundwater. If limestone or dolomite

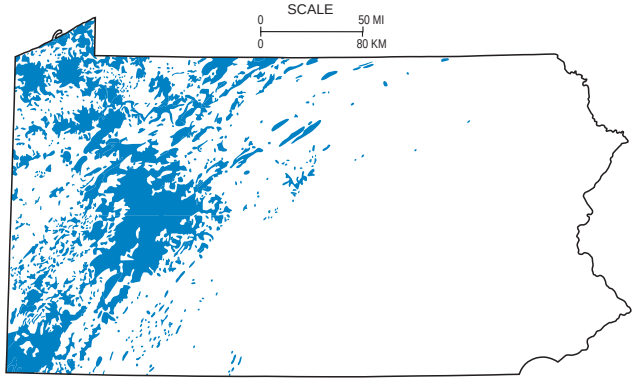


Coal fields of Pennsylvania.

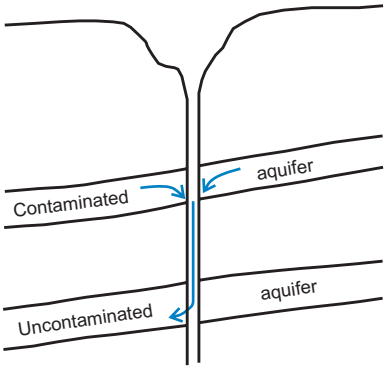
is disturbed, higher pH (alkaline) water may result. If iron and sulfur minerals are present in the rocks, acid drainage, which is characterized by low pH and high levels of metals and sulfates, may develop. In Pennsylvania, coal mining is the major cause of acid drainage.

In southeastern Pennsylvania near sea level, and in other parts of Pennsylvania where brine is at shallow depths, pumping more water from wells than is recharged into the groundwater system may draw the salty groundwater into the fresh groundwater, thereby contaminating the groundwater flow system. In the oil- and gas-producing regions of western Pennsylvania, unplugged, abandoned oil and gas wells provide pathways for oil, natural gas, and salty groundwater to migrate into the fresh groundwater flow system, and vice versa. This problem occurs more frequently in older parts of the oil and gas fields, which have many oil and gas wells that were abandoned prior to the implementation of modern well-plugging methods.

Oil and gas fields of Pennsylvania.



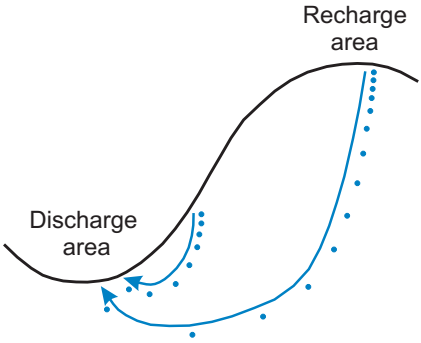
Migration of groundwater through an abandoned, unplugged well.



All abandoned wells, whether water, oil, or gas, should be plugged (filled) with impermeable material. This eliminates the physical hazard of the hole in the ground and prevents water in one aquifer from migrating to another aquifer.

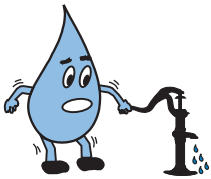
In the mining, well-pumping, and unplugged-wells examples, no new materials were added to the subsurface. The chemistry of the groundwater changed because the groundwater flow pattern changed. Pennsylvania has developed a wellhead protection program to protect the quality of water in public-supply wells and springs. Under this program, the recharge areas for the wells and springs are identified, and measures are put into place to protect those areas from the introduction of contaminants into the groundwater system.

Because groundwater contributes most of the flow to streams in Pennsylvania, groundwater contamination can affect the quality of surface water. A pollutant introduced to the groundwater system near a discharge area is more likely to affect the water quality of the associated stream than the same pollutant introduced in that stream's recharge area. Pollution originating in the recharge area will be more dilute by the time the groundwater is discharged to the surface. Many industrial sites are located in stream valleys; therefore, any pollution to groundwater from these sites is likely to also cause surface-water pollution.



Concentration of pollutants (represented by dots) diminishes with increasing distance from the point of introduction.

How do we get groundwater out of the ground?



Groundwater has many advantages over surface water, but it is not as easy to get. All groundwater in Pennsylvania comes from either wells or springs. Most supplies are from wells.

Advantages of Using Groundwater and Surface Water for Water Supplies

Groundwater		Surface water
Low development costs	Constant chemical quality	Predictable yield
Low treatment costs	Constant low temperature	High yield
Low cost of expanding yield	Sediment-free supply	Easily accessible
Relatively constant yield	No evaporation losses	Easier to clean if contaminated
Natural filtration	Development uses small land area	

Wells

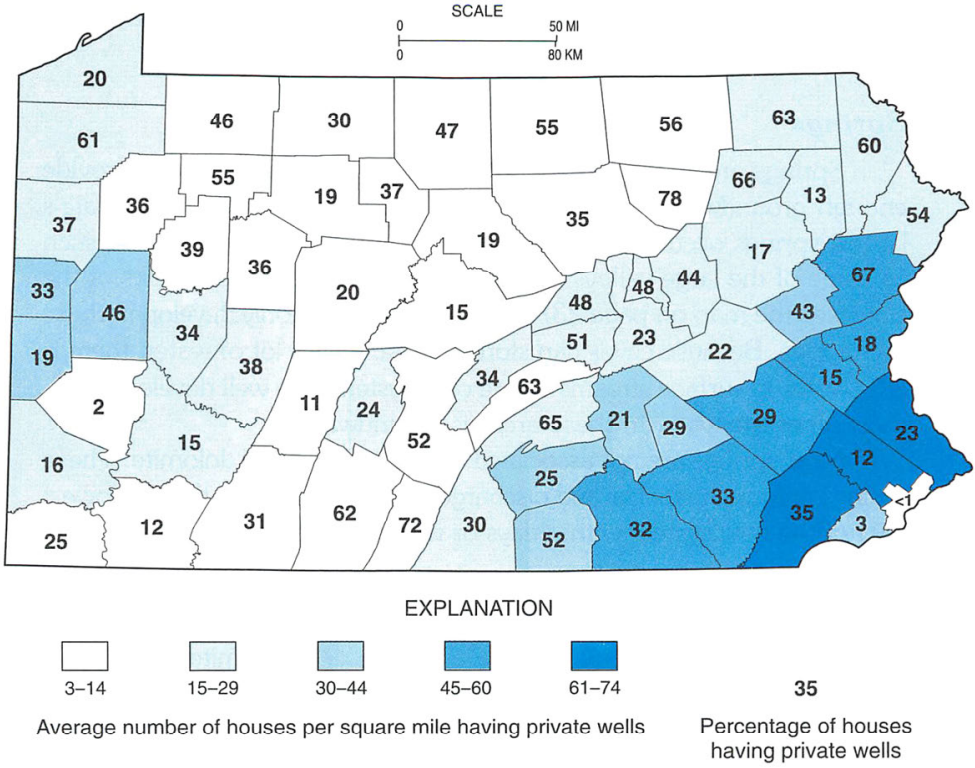
In 1990, Pennsylvanians used about 1 million water wells for domestic purposes. These wells included private wells and wells owned by public suppliers.

Wells capable of supplying enough water for household use can be drilled almost anywhere in Pennsylvania. However, in determining the best location for a well, there are several factors to consider.

The type of sediment or rock available for well development is a primary concern. Different sediments and rocks have different characteristics that make some of them better aquifers than others. In many places, only one sediment or rock type is reasonably available to use for a water supply, particularly for a private supply.

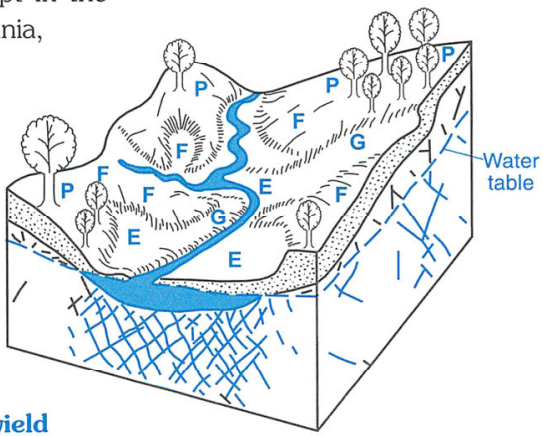
Because most groundwater in bedrock flows through fractures and openings between rock layers, locating a well where rocks have a high density of fractures may result in a higher yield. The more fractures that a well intersects, the better its chance of receiving an adequate supply of water.

Determining the fracture density requires that the person selecting the well site has some geological knowledge. A simple way for anyone to increase the likelihood of a good yield is to locate a well in a valley. Other things being equal, wells drilled in valleys yield more water than



Percentage of homes having private wells and average density of private wells in Pennsylvania, by county, in 1990.

those drilled on hillsides or hilltops. Valleys exist where rocks are more easily eroded; they indicate zones of weakness. The source of that weakness in most of the state, except in the major valleys of central Pennsylvania, may be a concentration of fractures. The rocks beneath a valley are more likely to be highly fractured than the rocks beneath a hillside or hilltop. Also, most valleys are discharge areas, and



How topography reflects well-yield potential: E, excellent; G, good; F, fair; and P, poor.

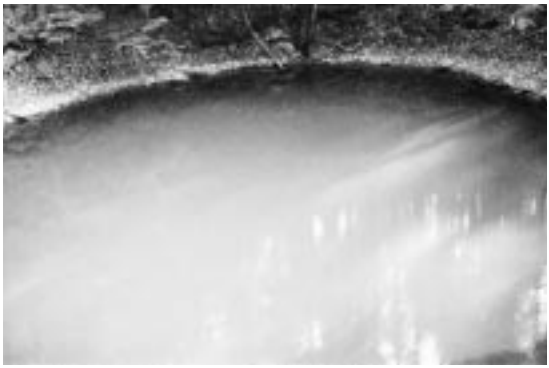
a larger recharge area is available for valley wells than for hillside or hilltop wells.

Springs

Springs are found throughout Pennsylvania. Some springs provide enough groundwater for public and private water supplies. The state's largest springs occur in areas underlain by limestone and dolomite, such as some of the large valleys in the central and southeastern parts of the state (see the map on page 23). Cave systems commonly develop in these rock types. Because caves can store and transmit a lot of water, there is little water in surface streams where cave systems are well developed. Almost all of the water in these areas is groundwater.

Most springs are not associated with limestone and dolomite. These springs are much smaller and discharge groundwater from the shallowest part of the flow system within days or weeks of its recharge. As a result,

Big Spring, Bellefonte's water supply, is located in a large limestone valley in central Pennsylvania.



Nippono Spring in Lycoming County is the largest spring in Pennsylvania. It discharges about 18,000 gallons of water per minute, draining an extensive cave system.

discharge quickly increases after a rain and quickly decreases a short time later. Also, spring water is commonly much lower in dissolved solids than well water (see pages 22–25). Many people prefer the taste of spring water to well water. However, this lack of ability to chemically alter the groundwater because of the short residence time also means that any contaminants introduced to the groundwater will more likely be reflected in the quality of the spring water. No water source should be used without first determining that the water quality is good.

People filling bottles with untested water at a roadside spring.

Some springs are warmer and/or more highly mineralized than most. The water feeding warm springs has penetrated deep beneath the surface, where the temperature is higher. Pennsylvania has few warm springs. Warm Springs in Perry County is the best known. Its temperature is only 10 to 15 degrees Fahrenheit warmer than surrounding groundwater. Warm and hot springs are more common in the western United States, where underground temperatures are higher.

The temperature of groundwater fluctuates considerably less than air temperature because groundwater is insulated from surface-temperature extremes. Groundwater temperatures remain fairly constant throughout the year. This property makes groundwater useful for heating and cooling systems. Groundwater is warmer than the air in the winter and cooler than the air in the summer.

Mineral springs, those with large amounts of dissolved solids (minerals), are more common than warm springs in Pennsylvania. In the past, many, such as Bedford Springs, have had resorts developed around them

because of the perceived health benefits of the more highly mineralized water. Water from these springs has been underground for a long time and/or has flowed through rocks with easily dissolved minerals.

Hopefully, you now have a better understanding of groundwater, in general, and of groundwater in Pennsylvania, in particular. It is important to remember how much groundwater there is, and that groundwater and surface water are *not* separate entities. Your increased understanding may allow you to better appreciate the abundant water resources that we have in Pennsylvania. *All* Pennsylvanians depend on groundwater.

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