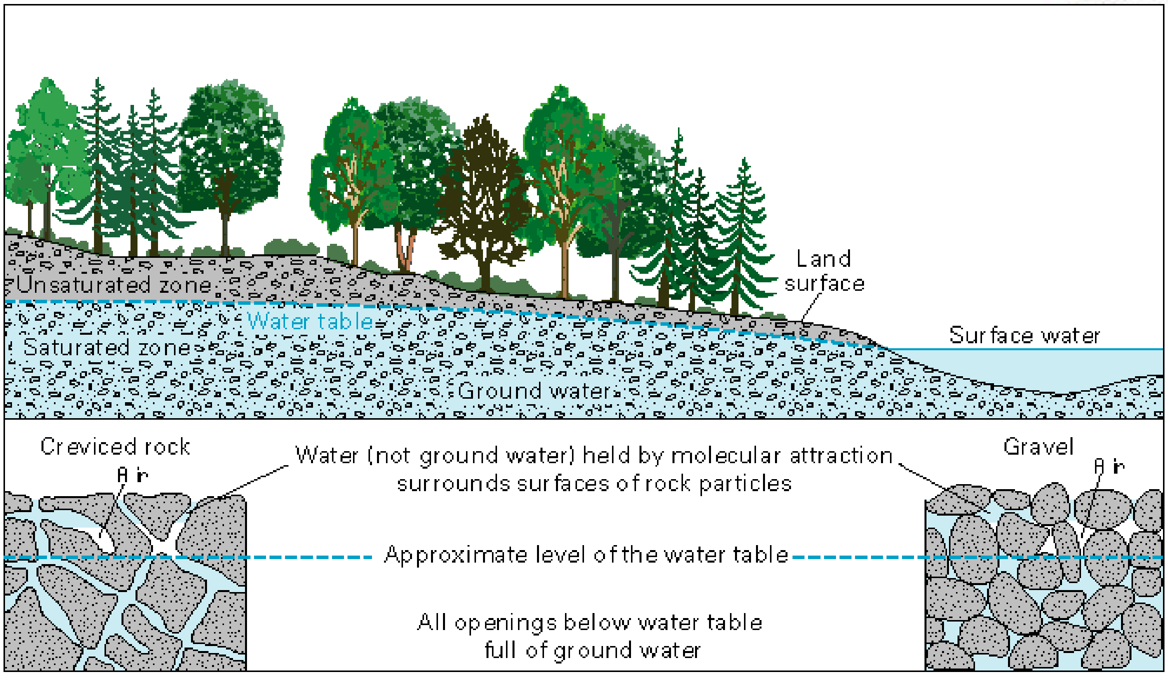
AQUIFERS

Imagine if all of the water that fell onto the location where you lived in a single year stayed right where it landed. Everyone would be wading through water higher than their waists! Fortunately, the precipitation runs into lakes, rivers, oceans, or into underground storage areas called aquifers. As you may have read, most of the void spaces in the rocks below the water table are filled with water. Rocks have different porosity and permeability characteristics, which means that water does not move around the same way in all rocks. When a water-bearing rock readily transmits water to wells and springs, it is called an aquifer. Aquifers are underground reservoirs. Worldwide, 97% of the planet’s liquid fresh water is stored in aquifers. Major aquifers are tapped on every continent, and groundwater is the primary source of drinking water for more than 1.5 billion people worldwide. The aquifer that lies beneath the Huang-Huai-Hai plain in eastern China alone supplies drinking water to nearly 160 million people. Asia, as a whole, relies on its groundwater for nearly one-third of its drinking water supply. Some of the largest cities in the developing world - Jakarta, Dhaka, Lima, and Mexico City, among them - depend on aquifers for almost all their water. In rural areas, where centralized water supply systems are undeveloped, groundwater is typically the source of water. More than 95% of the rural U.S. population depends on groundwater for drinking. Some aquifers extend over long distances and to great depths. Many aquifers are small and localized. An aquifer is often described as a sub-surface geologic formation that contains groundwater in sufficient quantities to be used, or have the potential to be used, for drinking water supply or for commercial, industrial or agricultural purposes. Groundwater is nearly always found when a well is drilled, although in some places there may be a very low rate of flow to the well. How large does a well’s yield have to be to qualify a saturated rock as an aquifer? Half a gallon a minute will provide around 700 gallons a day, but many people would not describe such low yielding rock formations as aquifers. So, by some definitions many low yielding domestic wells are not really in aquifers. All water wells pump groundwater but they don’t all pump from aquifers!

Sometimes an aquifer pops out the side of a hill as a spring. You can think of a spring as a newborn stream. Not many animals live in its water because it doesn't yet contain enough oxygen to support much life. Water mites, scuds or "sideswimmers," black fly or caddis fly larve, and occasionally beetles, snails, and salamanders may live in the cold water. Minks, raccoons, deer mice, and jays use springs as people do, for watering holes.

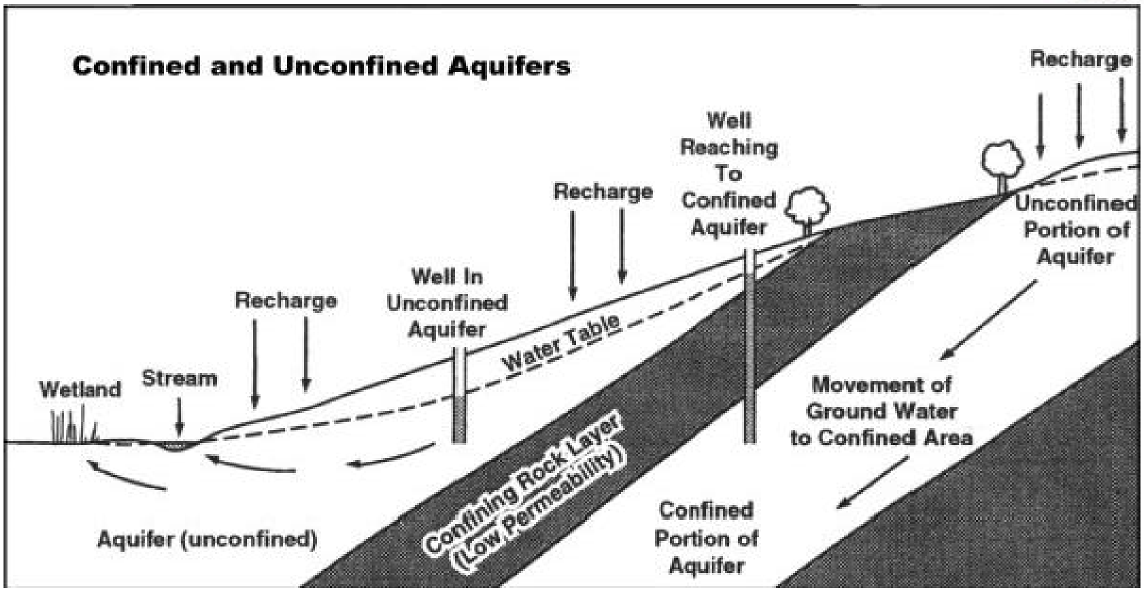
In the diagram below, you can see how the ground below the water table (the blue area) is saturated with water. The "unsaturated zone" above the water table (the greenish area) still contains water (after all, plants' roots live in this area), but it is not totally saturated with water. You can see this in the two drawings at the bottom of the diagram, which show a close-up of how water is stored in between underground rock particles.



Groundwater and the Water Table;
http://ga.water.usgs.gov/edu/earthgwaquifer.html

Sometimes the porous rock layers become tilted in the earth. There might be a confining layer of less porous rock both above and below the porous layer. This is an example of a confined aquifer. In this case, the rocks surrounding the aquifer confines the pressure in the porous rock and its water. If a well is drilled into this "pressurized" aquifer, the internal pressure might (depending on the ability of the rock to transport water) be enough to push the water up the well and up to the surface without the aid of a pump, sometimes completely out of the well. This type of well is called artesian. The pressure of water from an artesian well can be quite dramatic.

In general, there are three main categories of aquifers: unconfined, confined and perched. In reality, there can be a number of combinations and variations.

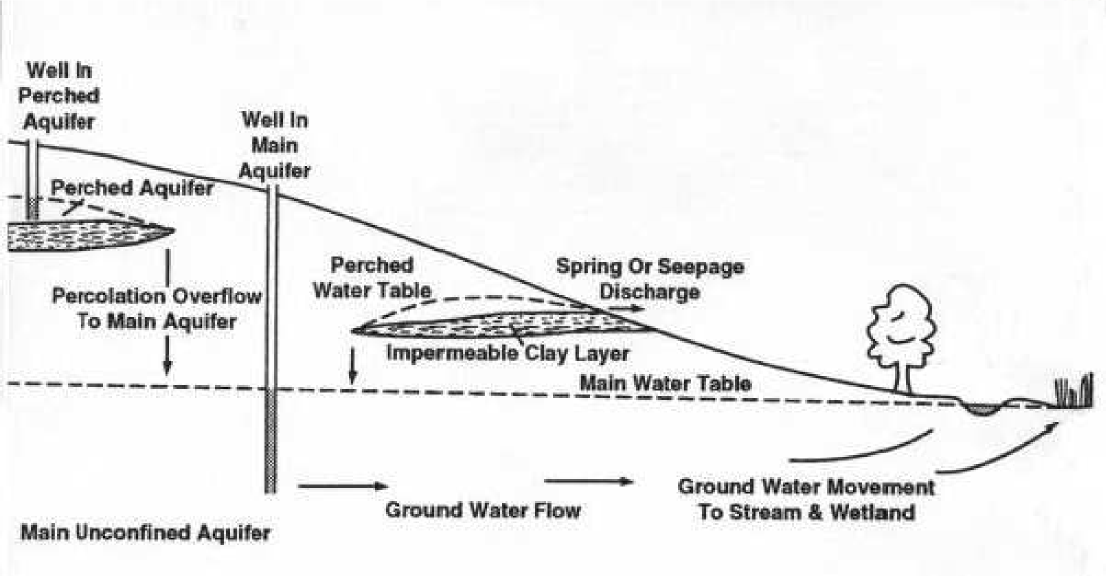


Confined and Unconfined Aquifers

Unconfined aquifers are covered by permeable geologic formations (either solid rock or unconsolidated sediments) and the upper surface where the rock formations are fully saturated is called the water table. These aquifers are also known as water table aquifers. They receive recharge directly from the infiltration of rainfall and surface water.

Confined aquifers are those that are covered (confined) by an impermeable or semi-permeable layer of rock. Confined aquifers are not directly recharged by vertical infiltration. Confined aquifers need to be connected to an unconfined area through which recharge can occur. The confining impermeable layers rarely form a complete barrier to groundwater. There is generally some transfer or flow of groundwater between the confined aquifer and the confining layers.

In confined and unconfined aquifers there may be considerable amounts of groundwater that are stored in impermeable/semi-permeable sediments such as clays. Water from these sediments can reach a well if they are in contact with permeable layers that are intersected by the well. So, although clays are not usually thought of as aquifers, they may be a key part of the storage in an aquifer system.



Perched Aquifers

Perched aquifers occur where groundwater is perched above unsaturated rock formations as a result of a discontinuous impermeable layer. Perched aquifers are fairly common in glacial sediments. They also occur in other sedimentary formations where weathered layers, ancient soils or caliched (a calcareous layer common in semi-arid areas) have created impermeable zones.

The water that reaches these chambers is usually much cleaner than the water of reservoirs at the earth's surface. Almost no bacteria live in aquifers. Many pollutants are filtered out as the water passes through the soil on its way to the aquifer. There is no silty mud to cloud the water, no pollution from boaters, and no evaporation of the water supply by the sun. However, aquifers can become polluted due to human actions and when an aquifer becomes polluted this is very difficult to remedy.

To tap the groundwater in an aquifer, wells are dug until they reach the top layer of the aquifer, the water table. The water table is not flat as its name makes it seem. It has peaks and valleys that echo the shape of the land above it. Further precipitation adds water into the porous rock of the aquifer. The rate of recharge is not the same for all aquifers, though, and that must be considered when pumping water from a well. Pumping too much water too fast draws down the water in the aquifer and eventually causes a well to yield less and less water and even run dry. In fact, pumping your well too fast can even cause your neighbour's well to run dry if you both are pumping from the same aquifer. Water levels in most aquifers vary with the season and during droughts. It is a debatable point whether an “empty” aquifer is still an aquifer and there is no scientific agreement about what to call the permanently depleted portions of overdrafted aquifers. For purposes of wise groundwater protection policy, we should consider as aquifers, the full vertical and horizontal extent of seasonally dewatered or over-pumped rock formations. Water flowing into recharge areas--land covered with soil and trees-- refills the aquifer. Bogs and swamps may absorb and store water that later slowly drains into aquifers. When recharge areas and wetlands are replaced by parking lots and highways, less water reaches the aquifer. Oil and road salt from paved roads may trickle down with rain and snowmelt and pollute an aquifer. High levels of chemical-use and waste generation in recent decades are slowly poisoning supplies of groundwater – the major source of our freshwater needs. It is a silent disaster spreading through many parts of the world. The relentless contamination of groundwater will make the supplies of usable water tighter still.

Our increasing demand on water has made it a resource critical to a degree that even gold and oil have never been. Worldwide, irrigation is by far the biggest drain on freshwater: it accounts for about 70% of the water drawn from rivers and wells each year. Since 1950, there has been a dramatic expansion in irrigated agriculture. In India, the leading country in total irrigated area and the world's third largest grain producer, the number of shallow tubewells used to draw groundwater surged from 3,000 in 1960 to 6 million in 1990. While India doubled the amount of its land irrigated by surface water between 1950 and 1985, it increased the area watered by aquifers 113-fold. Today, aquifers supply water to more than half of India's irrigated land. The United States, with the third highest irrigated areas in the world, used groundwater for 43% of its irrigated farmland. Other industries have been expanding their water use even faster than agriculture - and generating much higher profits in the process. On average, a ton of water used in industry generates roughly $14,000 worth of output - about 70 times as much profit as the same amount of water used to grow grain. Thus as the world has industrialized, substantial amounts of water have been shifted from farms to more lucrative factories. Industry's share of total consumption has reached 19% and is likely to continue rising rapidly. The amount of water available for drinking is thus constrained not only by a limited resource base, but by competition with other, more powerful users. On almost every continent, many major aquifers are being drained faster than their natural rate of recharge. Groundwater depletion is most severe in parts of India, China, the USA, North Africa, and the Middle East. As the competition among factories, farms, and household intensifies, it's easy to overlook the extent to which freshwater is also required for essential ecological services. It is not just rainfall, but groundwater welling from beneath, that replenished rivers, lakes and streams. In a study of 54 streams in different parts of the country, the U.S. geological Survey has found groundwater is the source for more than half the flow, on an average. Groundwater provides the base contribution for the Mississippi, the Niger, the Yangtze, and many more of the world's great rivers - some of which would otherwise not be flowing year-round. Wetlands, important habitats for birds, fish, and other wildlife, are often largely groundwater-fed, created in places where the water table overflows to the surface on a constant basis. While providing surface bodies with enough water to keep them stable, aquifers also help prevent them from flooding: when it rains heavily, aquifers beneath rivers soak up the excess water, preventing the surface flow from rising too rapidly and overflowing onto neighbouring fields and towns. In tropical Asia, where the hot season can last as long as 9 months, and where monsoon rains can be very intense, this dual hydrological service is of critical value.

More than a third of the planet's people live and work in densely settled cities, which occupy just 2% of the Earth's land area. With the labour force thus concentrated, factories and other centres of employment also group together the same urban areas. Aquifers in these areas are beginning to mirror the increasing density and diversity of the human activity above them. Whereas the pollutants emanating from hog farms or copper mines may be quite predictable, the waste streams flowing into the water under the cities contain a witch's brew of contaminants. A major factor in such contamination is that in most places people have learned to dispose of waste - to remove it from sight and smell - so effectively that it is easy to forget that the Earth is a closed ecological system in which nothing permanently disappears. The methods normally used to conceal garbage and other waste -- landfills, septic tanks, and sewers -- become the major conduits of chemical pollution of groundwater. In the United States, businesses drain almost 2 million kilograms of assorted chemicals into septic systems each year, contaminating the drinking water of 1.3 million people. In many parts of the developing world, factories still dump their liquid effluent onto the ground and wait for it to disappear. Even protected landfills can be a potent source of aquifer pollution: the US Environment Protection Agency (EPA) found that a quarter of the landfills in the U.S. State of Maine, for example, had contaminated groundwater. In industrial countries, waste that is too hazardous to landfill is routinely buried in underground tanks but as these caskets age, like gasoline tanks, they eventually spring leaks. In California's Silicon Valley, where electronics industries store assorted waste solvents in underground tanks, local groundwater authorities found that 85% of the tanks they inspected had leaks. Silicon Valley has more Superfund sites - most of them affecting groundwater - than any other area its size in the country and 60% of the United States' liquid hazardous wastes - 34 billion litres of solvents, heavy metals, and radioactive materials - is directly injected into the ground. Although the effluent are injected below the deepest source of drinking water, some of these wastes have entered aquifers used for water supplies in parts of Florida, Texas, Ohio, and Oklahoma. Scores of cities in the developing world, such as Shenyang in China and Jaipur in India have had to seek out alternate supplies of water because their groundwater has become unusable. Santa Cruz, in Bolivia, has also struggled to find clean water, as its shallow aquifer that is the city's main water source has had to soak up the brew of sulphates, nitrates, and chlorides dumped over it but as it has sunk deeper wells in pursuit of pure supplies, the effluent has travelled deeper into the aquifer to replace the water pumped out of it. Some of the greatest shocks may be felt in places where chemical use and disposal has climbed in the last few decades, and where the most basic measures to shield groundwater have not been taken. In India, for example, the Central Pollution Control Board (CPCB) surveyed 22 major industrial zones and found that groundwater in every one of them was unfit for drinking. When aquifers are polluted, it is almost impossible to flush out contaminants from fine-grained clay layers where much of the aquifer’s water may be stored. The rate of groundwater renewal is very slow in comparison with that of surface water. While it is true that some aquifers recharge fairly quickly, the average recycling time for groundwater is estimated at 1,400 years, as opposed to only 20 days for river water and because water in aquifers moves through the Earth with glacial slowness, its pollutants continue to accumulate. Unlike rivers, which flush themselves into the oceans, aquifers become sinks for pollution.

About seventy percent of the earth's surface is covered with water. Only one percent is fresh water, flowing through rivers, lakes, and underground streams. Much of that has already been polluted by humans. That is why aquifers and springs--natural sources of clean water-- are so important. Given how much damage this pollution inflicts on public health, the environment, and the economy once it gets into the water, it's critical that emphasis be shifted from filtering out toxins to not using them in the first place. Prevention is the only credible strategy. This requires looking not just at individual factories, gas stations, cornfield, and dry-cleaning plants, but at the whole social, industrial and agricultural systems of which these businesses are a part. The ecological untenability of these systems is what's really poisoning the world's water. It is the predominant system of high-input agriculture, for example, that not only shrinks biodiversity with its vast monocultures, but also overwhelms the land - and the underlying water - with its massive applications of agricultural chemicals. It's the system of car-dominated, geographically expanding cities that not only generates unsustainable amounts of climate-disrupting greenhouse gases and acid rain causing air pollution, but also overwhelms aquifers and soils with petrochemicals, heavy metals, and sewage. An adequate response will require a thorough overhaul of each of these systems.

Visit: http://www.safewater.org/PDFS/OWF/OWF_Science/OWF_Science_Aquifer.pdf for a lesson that is part of the Operation Water Flow program that teaches students about aquifers. The Safe Drinking Water Foundation has educational programs that can supplement the information found in this fact sheet. Operation Water Drop looks at the chemical contaminants that are found in water; it is designed for a science class. Operation Water Flow looks at how water is used, where it comes from and how much it costs; it has lessons that are designed for Social Studies, Math, Biology, Chemistry and Science classes. Operation Water Spirit presents a First Nations perspective of water and the surrounding issues; it is designed for Native Studies or Social Studies classes. Operation Water Health looks at common health issues surrounding drinking water in Canada and around the world and is designed for a Health, Science and Social Studies collaboration. Operation Water Pollution focuses on how water pollution occurs and how it is cleaned up and has been designed for a Science and Social Studies collaboration. To access more information on these and other educational activities, as well as additional fact sheets, visit the Safe Drinking Water Foundation website at www.safewater.org.

Resources:

American Groundwater Trust. The ABC of Aquifers.
http://ga.water.usgs.gov/edu/earthgwaquifer.html

Gulf of Maine Aquarium. August 17, 1998. Aquifer: Source of Pure Water.
http://www.gma.org/Katahdin/aquifer.html

South-North Development Monitor. 2000. The Covert Ground-water Crisis.
http://www.twnside.org.sg/title/covert.htm

U.S. Geological Survey. August 28, 2006. Ground-water Aquifers.
http://ga.water.usgs.gov/edu/earthgwaquifer.html