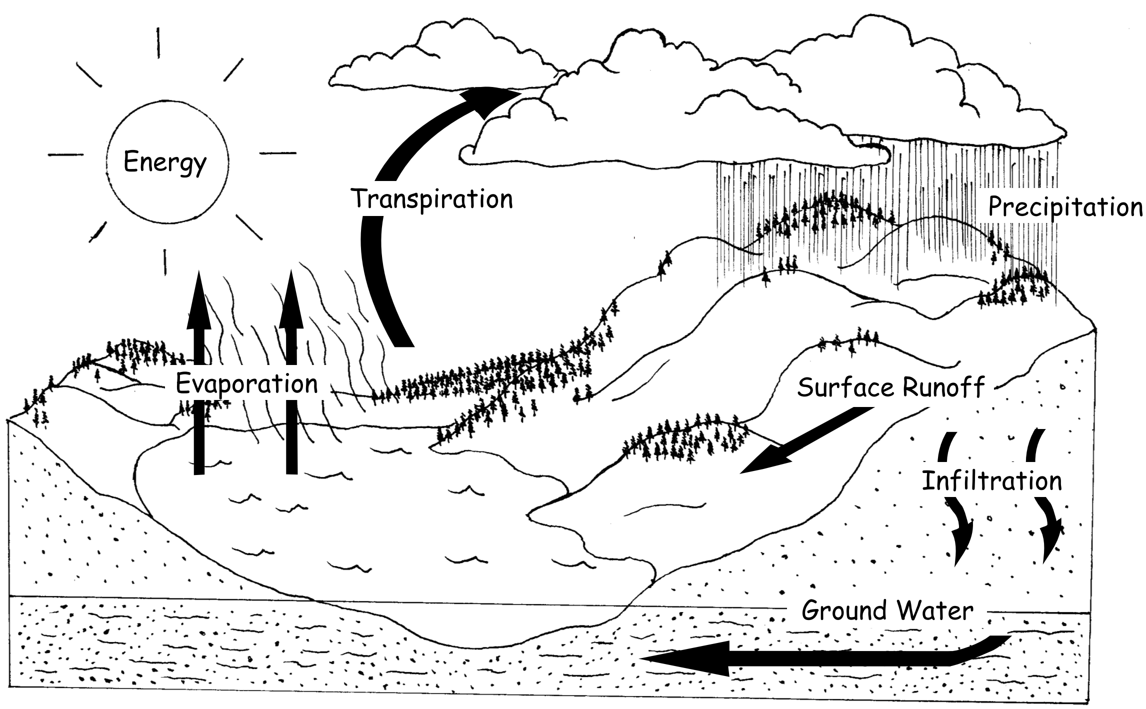
The Importance of Groundwater

Do you drink groundwater? In Virginia, chances are about 80% that the water you and your students drink and use everyday is partly or wholly from groundwater. Ninety-five percent of Virginians in rural areas are dependent on their own wells to provide all their water needs. Many town and city dwellers also drink groundwater, as the vast majority of public water supply systems (2,300 out of 2,500) use groundwater too. In fact, 38 of Virginia's 95 counties are completely dependent on groundwater for public water supplies according to the U.S. Census (1990). Fifty-five counties draw half or more of their public water supplies from groundwater.

In addition to rural households and public water supplies that depend on wells and groundwater, farmers too use groundwater for irrigating crops and for their animals. Many commercial businesses and industries in Virginia also depend on groundwater for their processes and operations. In fact, the largest users of groundwater in the Commonwealth are paper companies in Franklin and West Point. Other industries rely on clean groundwater for the production of electric power, food, beverages, and material production. In all, almost 50 billion gallons of groundwater are used each year in Virginia by farms, public water supplies, companies, and families with wells.



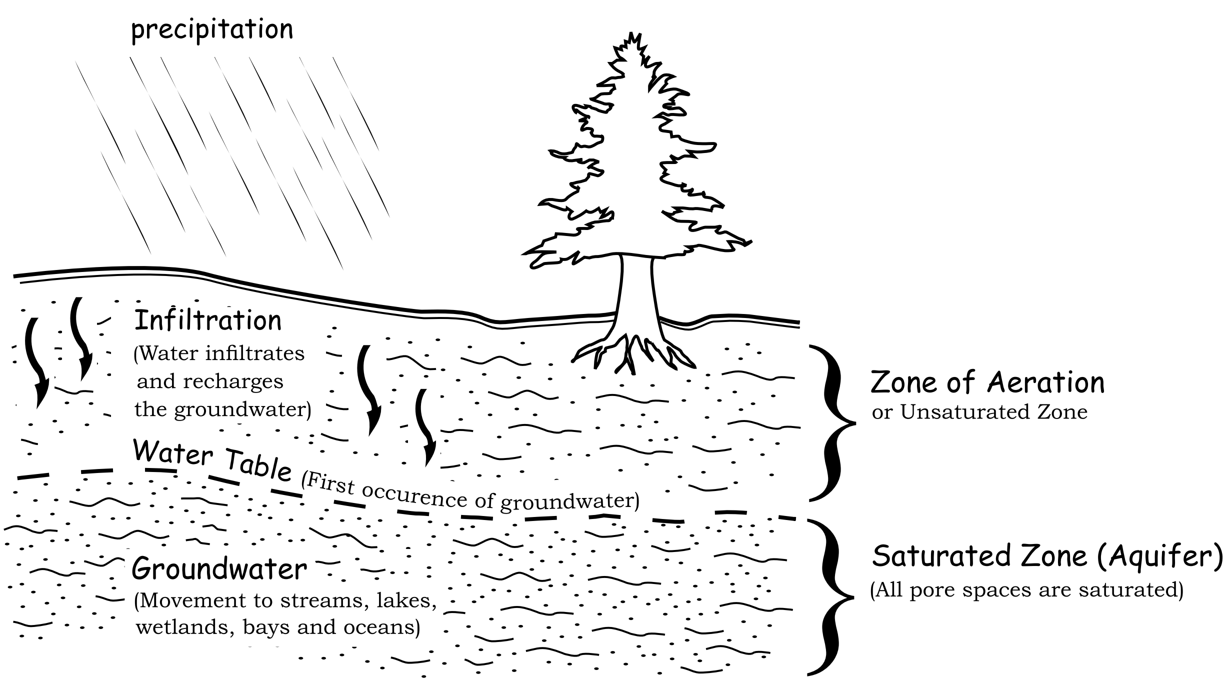
Groundwater is also very important as it supplies springs, and much of the water in our ponds, marshland, swamps, streams, rivers and bays. Although it is "out of sight," it is critical that we learn about groundwater, how it is part of the water cycle, and the importance of protecting and maintaining the quality and quantity of this water resource.

UNDERSTANDING GROUNDWATER

As part of the water cycle, some precipitation infiltrates the ground and percolates down until it reaches a depth where all the fractures, crevices and pore spaces are saturated with water. In this **saturated zone** – called an aquifer – the water is called groundwater. The upper surface of a zone of saturation is the water table. In other words, the **water table** is the first occurrence of groundwater. Above the water table is the **zone of aeration** (also called the unsaturated zone). There is some water in the zone of aeration, but it will not flow into a well. So successful wells need to be deeper than the water table.

GROUNDWATER -- ONE WORD OR TWO?

Most dictionaries indicate that the term for underground water can be written as one word, "groundwater" or as two, "ground water." Some editors prefer that the single word "groundwater" be used when it modifies the next word. For example, "groundwater quality." "Ground water," then, is written as two words when it is not a modifier. For example, "What is the quality of the ground water?" But, more and more ecologists, hydrologists, and hydrogeologists are using the single word "groundwater" in all applications as it represents a technical term. In this chapter, we will use the compound word "groundwater."



Aquifers are geologic formations – layers of sand, gravel and rock – where significant amounts of water can be stored, transported or supplied to well or a spring. They are irregular in shape, and can be close to the surface, or very deep. Under your home, there may be several aquifers layered one on top of another. Because of this, neighboring homes potentially can have their wells in different aquifers and experience different water quality.

There are two types of aquifers: confined and unconfined. **Unconfined aquifers,** generally located near the land surface, have no layers of clay (or other impermeable geologic material) above their water table, although they do lie above relatively impermeable clay beds. The upper limit of groundwater within an unconfined aquifer is the water table. In many places, the water table is actually above the surface of land. Wetlands are a great example of where groundwater becomes surface water. Groundwater in an unconfined aquifer (sometimes called a "water table aquifer") is more vulnerable to contamination from surface pollution than a confined aquifer because pollutants on the land surface can enter the unconfined aquifer as water infiltrates the soil.

Confined aquifers, on the other hand, have layers of impermeable material above and below them – so they are contained within these layers. The geologic barriers cause the water to be under pressure.

Fractures, or cracks, in bedrock also are capable of bearing water. In Virginia's counties with **Karst terrain** (see list on page 4/13), the bedrock aquifers can have large openings where groundwater has dissolved some of the rock. These openings can store large amounts of water, accounting for the high yields of wells in this area.

Do Water Tables Move?

Yes-the level of water tables does change over time. For instance, in the summer of 2002, after three years of below average precipitation, thousands of wells failed due to dropped water tables across Virginia. People who had shallow wells that were dug or bored were the first to see the effects of a falling water table as water table levels dropped below the pump intake level. Many streams and rivers were also drying up as the prolonged drought lowered the water table. In addition to droughts, water tables and aquifers canalso be negatively impacted when we pump groundwater out of the earth at a rate faster than it is replenished.

Groundwater flows vertically and horizontally through the aquifers at rates that are influenced by gravity and the geologic formations of the area. Groundwater can remain in an aquifer for a short period measured in days, or for many centuries. In fact, the deep aquifers under parts of Virginia's Coastal Plain are considered "fossil aquifers" as the water in them has been there for more than 10,000 years.

How Long Does It Take for an Aquifer to Recharge?

The rate of water inflow into an aquifer (called the recharge rate), varies greatly across the state because Virginia has relatively complicated geology. Factors that influence the recharge rate are:

- Climate
- Terrain or topographic relief
- Geology
- Type and amount of vegetative ground cover

Climate includes the amount of local precipitation. Lower precipitation means less water is available for recharging groundwater levels, while more precipitation means more water is available. The terrain, or topographic relief, will impact the rate of runoff. Rapid runoff doesn't allow percolation, while standing water allows more percolation. Geology and the amount of vegetative ground cover will influence the capacity of the land surface to accept infiltrating water. Types of rocks or sediment (including presence of Karst terrain and fractured rocks) also impact the recharge rate, as does the amount of land that has impervious surfaces (i.e., paved surfaces and roof tops). In areas with many paved surfaces, the soil is effectively "sealed off" from precipitation. This means that water cannot enter the soil, nor percolate through the soil to reach the water table.

By one estimate, the annual recharge to the groundwater system in the western counties of Virginia is approximately 8 inches, and in the Coastal Plain it is approximately 10 inches. Other experts argue that the actual recharge rates are significantly less. The size of the recharge area for any given well depends on the depth of the well, and the factors listed above.

According to the Virginia Ground Water Protection Steering Committee's web site (*www.deq.state.va.us/gwpsc/faq.html*),

> "Throughout Virginia's five major physiographic provinces, shallow dug or bored wells are not much deeper than the water table and usually obtain water that infiltrated relatively nearby, typically less than a mile. Recharge areas for deeper wells are more variable. Recharge to wells drilled into rocks in the Piedmont and Blue Ridge also is fairly localized. Wells drilled into rocks in the Valley and Ridge sometimes intercept water that has traveled as far as several miles, particularly in limestone areas with large cave systems. In the Coastal Plain, wells drilled into deep sand layers can intercept water that traveled several tens of miles, from recharge areas that may be several counties away."

How Groundwater Interacts with Surface Water

Surface water and groundwater are intimately linked to each other within the hydrologic cycle. Groundwater is an important source of water for Virginia's streams, rivers, lakes, wetlands and bays. According to the Virginia Department of Environmental Quality, about 30 percent of stream flow is from groundwater, although it may reach 100 percent during droughts. Springs, where groundwater becomes surface water, are present where the water table intersects the land surface.

Virginia has thousands of springs – a point where groundwater discharge becomes surface water. Most of Virginia's largest springs are found in the counties with Karst terrain. While some streams and rivers gain water from groundwater, other streams help recharge groundwater. This occurs when water from a stream infiltrates into the ground. The rate of recharge from streams varies greatly depending on the season, amounts of precipitation, and other factors. Because of these interactions, the quality of groundwater and surface waters are linked. In fact, studies by the U.S. Geological Survey have found that groundwater discharge is a significant source of nitrate load to tidal creeks, coastal estuaries, and the Chesapeake Bay.

If we pump too much groundwater, the flow of water in springs can be decreased, thus affecting the receiving waterbody and the plants and animals that use the spring-fed habitat. For example, a stream that flows year-round due to groundwater could become an intermittent or ephemeral stream that flows only a few weeks or months a year.

How We Affect Groundwater Quantity

Overuse of groundwater for urban, rural and industrial uses can cause temporary or permanent declines in the quantity of available groundwater. Overuse can also cause subsidence, where the land sinks. To learn more about subsidence, see the U.S. Geological Survey's web site at *http://water.usgs.gov/ogw/subsidence.html.* In coastal areas, when fresh groundwater is withdrawn at a faster rate than it can be replenished, saltwater from the ocean can intrude into the aquifer. This process, known as saltwater intrusion, has occurred in aquifers along the Atlantic and Gulf coasts. The result is that fresh water supplies become contaminated with saltwater.

Another related problem concerns changes we make in the recharge rate. When recharge areas are paved with roads and parking lots or are covered with impervious surfaces such as rooftops, water cannot soak into the ground and replenish the groundwater supplies. Adding to the problem, paved surfaces collect oils, salts, animal waste, antifreeze, and other pollutants. When it rains, these pollutants become part of the storm water runoff. So it is an important lesson – if we want clean groundwater and surface water, we need to prevent all possible pollutants from being poured on the ground or spilled onto our parking lots and roads.

Many solutions exist, like using gravel or paving stones instead of concrete for parking lots. Communities can preserve open space in urban areas where rainwater can percolate into the ground. Homeowners, schools and businesses can also create "rain gardens" (also known as "bioretention basins"), a man-made depression in the ground that collects runoff water and stores it, permitting it to slowly percolate into the soil. Schools interested in creating a rain garden can learn more by visiting *www.dof.state.va.us/rfb/raingadens.shtml*

See the Appendices section of this packet for information about applying for grant support to fund the creation of a rain garden on your school grounds.

Groundwater in Virginia by Region

A map showing the physiographic provinces of Virginia can be found at: http://www.deq.state.va.us/gwpsc/geol.html

Appalachian Plateaus

The Appalachian Plateaus (which contains a portion of the Cumberland Plateau) has deep narrow valleys and steep, rugged mountainsides under which are formations of sandstone, shale, and economically-important coalbeds. The quality of well water in this area depends on how deep the wells are, and where they are located. According to the Virginia Ground Water Protection Steering Committee (GWPSC), "the first 100 feet of rock below stream level is often of poor quality, tending to be sulfurous and iron-rich, and naturally saline waters occur at depths greater than 300 feet. Better quality water can be found at depths of 150 to 300 feet below stream level, however. In coal mining areas, some groundwater has become acidic due to mine drainage and is usually unsuitable for most uses."

Valley & Ridge

This physiographic province is characterized by Karst terrain, where sedimentary carbonate rocks including limestone and dolomite have been dissolved over the years by groundwater to form underground cavities. Because these cavities can hold large amounts of water, wells in this area can be very productive, yielding large amounts of groundwater. See section "Karst, Sinkholes and Groundwater" for more information about this type of terrain, and how pollution potential is higher than in other parts of the state. The geology of the Valley and Ridge province is complicated, so in some areas of this region, wells may yield enough water for rural homes, but are not as productive as other wells in the province.

Blue Ridge

This physiographic province has some of the highest elevation mountains in the state. It has thin soil, impervious rocks and steep terrain, leading to rapid run-off of storm water, and a low groundwater recharge rate. Because of the relatively impervious rocks, water is contained mainly in joints, fractures and faults, so wells tend to yield fewer gallons per minute than Virginia's other provinces. Springs are common, and often are used to provide drinking water for homes. The potential for pollution reaching the groundwater is high in this province.

Piedmont

The Piedmont is the largest physiographic province in Virginia, and has great diversity in its subsurface geology. Because of this diversity, the groundwater quality and availability in this physiographic province varies greatly. According to the GWPSC: "The size and number of fractures and faults in the bedrock which store and transmit groundwater decrease with depth, so most significant water supplies are found within a few hundred feet of the surface. Fairly large yields of water can be obtained where fracture and fault systems are extensive, as in the Western Piedmont along the base of the Blue Ridge Mountains." The pollution potential in the Piedmont province is low to moderate.

Coastal Plain

The Coastal Plain region has more groundwater than Virginia's other provinces thanks to its geology. The very permeable materials present in alternating layers of sand, gravel, shell rock, silt, and clay hold large amounts of groundwater. This region also has a high population density, many farms, and some water-intense industries, so it has high groundwater withdrawals too. The Coastal Plain has two groundwater systems that provide water. One is a shallow unconfined aquifer, and the other is a series of deeper confined aquifers. Many wells are in the uppermost unconfined aquifer. As discussed earlier, unconfined aquifers are more susceptible to pollution. According to the GWPSC, "…the principal source of major groundwater withdrawals is a deeper system of confined aquifers."

The pollution potential in this province is high due to geology, the high population density, and the amount of agricultural activities in the area. While the natural water quality in the Coastal Plain aquifers is generally good, some of the deep aquifers on much of the lower York-James Peninsula and the Norfolk-Virginia Beach area generally contain water too salty for domestic use without treatment. This wedge of salty groundwater in the Hampton Roads area is thought to be a remnant of a comet/meteorite collision 35 million years ago. Scientists studying the Chesapeake Bay impact crater now theorize that the slightly salty to brackish groundwater that occurs in the aquifers beneath the lower portions of the York-James and Middle peninsulas is due to the crater. To learn more, see the U.S. Geological Survey's report at: *http://meteor.pwnet.org/impact_event/impact_crater.htm*

Virginia Counties with Karst Terrain

In Virginia's counties that have Karst terrain, the groundwater is especially vulnerable to contamination from the surface because of the speed of the infiltration pathways.

Alleghany	Pulaski
Augusta	Roanoke
Bath	Rockbridge
Bland	Rockingham
Botetourt	Russell
Clarke	Scott
Craig	Shenandoah
Frederick	Smyth
Giles	Tazewell
Highland	Warren
Lee	Washington
Montgomery	Wise
Page	Wythe

Contaminants in Groundwater — Natural Sources

In nature, even the cleanest water contains some impurities that come from the erosion of natural rock formations. Water dissolves and absorbs substances that it touches, including calcium, magnesium, silica, and fluoride from dozens of naturally occurring minerals.

So, the chemistry of water is influenced as it flows downward through soil and the unsaturated zone. Because groundwater is in contact with soil as it moves down to the aquifer, dissolved minerals are picked up by the water, leading to a higher mineral content than surface water. At low levels, most of these dissolved minerals do not cause health problems,

Karst, Sinkholes and Groundwater

***Karst** – A land area that includes sinkholes, springs, sinking streams and caves. This landscape features underground streams and aquifers that supply the wells and springs communities use for drinking water.*

– From Project Underground

Counties in the western portion of Virginia share distinctive topography called Karst terrain or topography. These counties, located mainly in the Valley and Ridge physiographic province, have underlying rock of sedimentary carbonate rocks (limestone and dolostone) and other soluble rock. Approximately 20 percent of the United States has Karst topography, where ancient seas retreated millions of years ago, leaving seashells and calcium crystals which compacted into hard limestone. The USGS has a map showing Karst topography in the United States: *http://water.usgs.gov/ogw/karst/*

As rain falls through the sky, it becomes slightly acidic as it absorbs carbon dioxide. Because of this, unpolluted precipitation in the U.S. has a pH of 5.0 to 5.6. Limestone dissolves relatively rapidly when exposed to the weakly acidic groundwater, forming elaborate networks of underground caves and tunnels. When the roof of an underground cave collapses, a **sinkhole** forms. Sometimes, a sinkhole will "swallow" a building, road or parking lot. The formation of sinkholes is a natural process that results in basin-like, funnel-shaped, or vertical-sided depressions in the land surface.

In Karst terrain, streams may sink into the ground, making surface water less common than in other regions of the state. Karst topography truly has a unique water cycle with its sinkholes, sinking streams, springs, and caves.

Karst and Groundwater Pollution

Groundwater flow in areas with Karst terrain is very different than in other parts of the state, presenting unique environmental problems. Groundwater in areas with Karst is more sensitive to the effects of pollutants because the groundwater generally flows faster than in other areas. A pollutant spilled into a sinkhole can have consequences miles away in just a few hours. Since surface water can quickly enter the groundwater system through sinkholes, people living in areas with Karst must be extra careful to protect groundwater from pollution. Land use management is an important tool in these areas to prevent pollutants from reaching the groundwater.

and can even give water an appealing taste. Some of these minerals determine how “soft’ or "hard" our water is, and some may produce an unpleasant odor or taste. At higher levels, minerals can be considered contaminants, and like man-made chemicals, can make water unpalatable or unsafe to drink. In some areas, iron, manganese, and sulfate occur locally in objectionable concentrations. For example, large amounts of iron in the rock in some areas, particularly the Piedmont and Blue Ridge, result in iron "staining" of toilet bowls and sinks. Sulfide in groundwater in parts of the Valley and Ridge where coal or natural gas is present can produce an obnoxious odor.

Naturally occurring soil bacteria can also be found in groundwater, and may cause odor, taste, and discoloration problems. It is not unusual for a well in Virginia to have sulfur, iron, or manganese bacteria.

Karst, Sinkholes and Groundwater Continued…

Great Tool for Virginia's Teachers

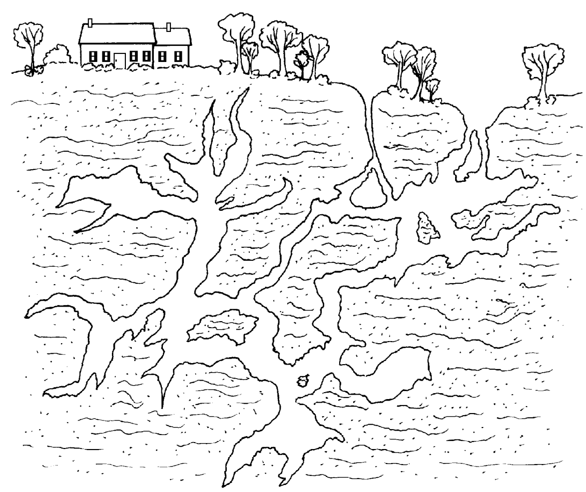
The Virginia Department of Conservation and Recreation has Project Underground, an environmental education program designed to promote better understanding of caves and Karstlands. The purpose of Project Underground is to create and build awareness of and responsible attitudes toward Karst and cave resources and their management needs. It is a supplemental program for use by K – 12 educators. During Project Underground workshops, teachers participate in hands-on, interactive activities, learning more about the geology and hydrology of caves, Karst ecology, historical uses of caves, and the biodiversity of Virginia's Karst lands (including bat, salamander, insect, spider, millipede, and crustacean species). Learn more about this program at: *www.dcr.state.va.us/underground.htm* or contact the Karst Education Coordinator at 540-831-4057.

Also, explore the Virginia Cave Board's web site (*www.dcr.state.va.us/dnh/vcbintro.htm*) and the Karst Waters Institute (*www.karstwaters.org*) for photos, maps, lesson plans, posters, and other resources about caves and Karst terrain.

CONTAMINANTS IN GROUNDWATER FROM HUMAN ACTIVITIES

Most groundwater contamination is the result of human activity. Just as our surface freshwater resources (i.e., rivers, wetlands) are influenced by geologic processes and the activities of humans, so too is groundwater.

Contaminants can seep into groundwater from leaking underground tanks, cesspools, septic tanks, and landfills. Pesticides and fertilizers used on farmlands and lawns can find their



way into groundwater, as can substances discharged from factories. Common pollutants include bacteria from septic systems, and nitrates from fertilizer applications and from septic systems. Other possible contaminates include petroleum products, pesticides, detergents, hazardous chemicals and polluted runoff from paved surfaces. Sources of contaminants can be very close to a well, or miles away. Since contaminants that reach the groundwater generally move very slowly, continued leakage in one spot will lead to gradually increasing levels of contaminants.

Nitrate

At high-enough levels, some pollutants found in groundwater are harmful to human health. For example, well water with more than 10 parts per million nitrate-nitrogen should not be ingested by babies, as it can cause "blue baby syndrome." There are also health risks for adults associated with excessive nitrate consumption. Boiling water will not correct this problem, as boiling will increase the concentration of nitrates. The Virginia Department of Health recommends that private wells be tested annually for nitrate-nitrogen to detect contamination. See the lesson in this packet "Nitrate Levels in Wells" for information on this common groundwater pollutant, and how students can investigate this issue in your area.

Fecal Coliform Bacteria

According to the U.S. Environmental Protection Agency's website on drinking water, "*…the presence of coliform bacteria indicates that the water is potentially dangerous and should not be consumed unless boiled.*" Fecal coliform bacteria (including *E. coli*) originate in the intestinal tract of humans and warm-blooded animals including cattle, swine, poultry, dogs, deer, and geese. Fecal coliform and *E. coli* are not usually health threats in themselves; they are used to indicate whether other potentially harmful bacteria or viruses may be present. Their presence in wells shows that the well casing is not correctly sealed, the well is improperly constructed, or the on-site sewage disposal system (usually a septic tank and drain field) has failed. The U.S. EPA's standard for coliform in drinking water is zero. Fecal coliform bacterial contamination is also the main reason that Virginia's surface waters are found to be polluted or impaired.

The Virginia Department of Health recommends that private wells be tested annually for coliform bacteria to detect contamination. This is the responsibility of the well owner. Technical advice is available from the Virginia Water Resource Research Center (*http://www.vwrrc.vt.edu/*) or local health departments. According to studies conducted by the Virginia Cooperative Extension's Rural Household Water Quality Education Program, bacterial contamination is the most widespread problem in the wells they tested. Older, shallower wells that were dug or bored had higher incidences of bacterial contamination, while newer drilled wells, which tend to be deeper, had a lower incidence of contamination when the wells were correctly constructed to seal off the water table aquifer.

For more information on groundwater quality, see the resources at the end of this chapter.

Protecting Groundwater

While groundwater is an immensely important resource, it will become even more so as the state's population continues to grow. Groundwater, although separated from the land's surface by dozens, hundreds, or thousands of feet, is still susceptible to pollution and excessive withdrawals, and therefore must be protected and managed.

For farmers, landowners, businesses and local governments to wisely manage this critical resource, we must understand the flow, storage and quality of groundwater in Virginia. Unfortunately, there is much we need to learn about these aspects of our groundwater, as well as how contaminants get to and travel through aquifers. Like many other states, Virginia has not had a long-term, sustained program of monitoring the quality of its groundwater, so we do not have a complete understanding of the condition of our groundwater resources. Monitoring, mapping, and testing groundwater for contamination is more expensive and complicated than testing surface waters, as pollutants might be found in one part of an aquifer, and not in others.

Groundwater Management in Virginia

Under the Ground Water Management Act of 1992, Virginia manages groundwater through a program regulating the withdrawals in certain areas called groundwater management areas. Those wishing to withdraw 300,000 gallons per month or more must apply for and receive a groundwater withdrawal permit. Currently, there are two Ground Water Management Areas in the state: the Eastern Shore and eastern Virginia.

Preventing Pollution

All Virginians have a role in determining how clean our water will be. Ensuring that our groundwater stays free of man-made contaminants requires us to understand how water and pollutants enter aquifers. We are responsible for protecting this and Virginia's other water resources. Like other forms of pollution, prevention is the best policy. Preventing pollutants from reaching groundwater is cost-effective and demonstrates good stewardship. Removing pollutants from groundwater is extremely expensive, and often the water cannot be restored to drinking water quality.

Proper storage and disposal of potential pollutants, proper land use management, and protection measures around wellheads and sinkholes, will prevent groundwater contamination. Federal and state regulations have been developed to control "contaminants of concern" and potential contamination sources, and localities have responsibilities for land use management decisions to protect water quality. But it is up to all citizens to help keep our groundwater resources clean.

What you can do

- Determine the source of your drinking water. If your water is supplied by a public water treatment plant, ask if they use surface water (streams, rivers, reservoirs) or groundwater as their source.
- If you have a well, create a file with test results, maintenance history, depth, construction method and other information.
- If you have a septic system, make sure it is inspected and your tank is pumped on a regular basis. Do not use septic tank additives, and do not pour harmful chemicals down any drain in your house.
- Never pour motor oil or any other pollutant on the ground.
- As your class learns about groundwater, they can build a "rain garden" on your school grounds, or test local well water for the presence of nitrates (see the lesson Nitrate Levels in Wells).
- Learn from local well-drilling companies how deep wells are in your area.
- Schedule a field trip to see a septic tank and drain field as they are being installed.
- Your class can meet with local government employees or someone from your local Soil and Water Conservation District to learn about local efforts to protect water quality.

Resources

American Ground Water Trust: *www.privatwater.com*

Arsenic in Groundwater: *http://co.water.usgs.gov/trace/arsenic/*

http://co.water.usgs.gov/trace/pubs/geo_v46n11/fig2.html

http://co.water.usgs.gov/trace/pubs/geo_v46n11/fig1.html

Atlas of Groundwater in Virginia: *http://capp.water.usgs.gov/gwa/ch_l/index.html*

Bacteriological Contamination of Drinking Water: *http://www.dnr.state.wi.us/org/water/dwg/BACTI.HTM#results*

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Geology of Virginia. Virginia Department of Mines, Minerals and Energy (1999-2001) CD-ROM

Groundwater Foundation. *http://www.groundwater.org/*

Groundwater Pollution Primer. Virginia Tech. *www.cee.vt.edu/program_areas/environmetal/teach/gwprimer/gwprimer.html*

Groundwater Shock: The Polluting of the World's Major Freshwater Stores. Sampat, P. World Watch, January/February 2000.

Karst Waters Institute. *http://www.karst waters.org/*

Major aquifers in North America: *http:// www-atlas.usgs.gov/Images/20maquifer.gif*

Nitrates in Groundwater. Canter, L. W. (1997). Boca Raton, FL: CRC Press, Inc.

Project Underground: *www.dcr.state.va.us/ underground.htm* or contact the Karst Education Coordinator at 540-831-4057

Understanding Groundwater. Schwalbaum, W.J. (1997). Commack, NY: Nova Science Publishers, Inc.

U.S. Environmental Protection Agency sites:

- Drinking water activities for kids *www.epa.gov/ogwdw/kids*
- Office of Ground Water and Drinking Water *www.epa.gov/ogwdw/index.html*
- Private Drinking Water *www.epa.gov/OGWDW/pwells1.html*

U.S. Geological Survey sites:

- USGS Water Science for Schools web sit *http://ga.water.usgs.gov/edu/*
- Ground Water Atlas Of The United States *http://capp.water.usgs.gov/gwa/ch_l/L-text4.html*
- Ground Water Information Pages (maps, photos, lesson plans and more) *http://water.usgs.gov/ogw/karst/*
- Effects Of Groundwater Development On Groundwater Flow To And From Surface-Water Bodies *http://water.usgs.gov/pubs/circ/circ1186/html/gw_effect.html#springs*
- Chesapeake Bay Impact Crater *http://metor.pwnet.org/impact_event/impact_crater.htm#3*

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van der Leeden, Fritz. 1998. The Environmental Almanac of Virginia. Lexington, VA: Tennyson Press, ISBN: 0-9638711-0-2. 540-463-2599

Virginia Cave Board: *www.dcr.state.va.us/ dnh/vcbintro.htm*

Virginia Ground Water Protection Steering Committee (GWPSC). *http://www.deq.state.va.us/gwpsc/*

Virginia Water Resource Research Center (septic systems, wells, testing water, protecting groundwater) *www.vwrrc.vt.edu/advisor/ water.htm*

Water, Rivers and Creeks. Leopold, L.B. (1997). Sausalito, CA: University Science Books