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Homework Program

HW 3

Water, Water Wells, and Water Contamination

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Understanding the Hydrologic Cycle

Water is constantly moving. As rain or snow (*precipitation*) falls to earth, some of it collects to form lakes, streams, and other bodies of water. The remaining water enters the soil in a process called *infiltration*. Some of this water evaporates back into the air and some is used by growing plants. The remainder seeps downward through the soil, until it accumulates at some depth and becomes groundwater.

Downward movement of water through the soil is *percolation*. This water eventually makes its way into a zone of soil where the space around each soil particle is completely filled with water (*saturated*). Water in this space is called groundwater, and its upper boundary is called the water table. Groundwater is located in underground formations called *aquifers* at various depths beneath the ground surface, and is generally available for human use. It can move laterally as groundwater flow to replenish surface water supplies. Groundwater constantly moves through the soil and reappears on the lowland surface as lakes, streams, swamps, or springs.

Although water is in constant motion, it seems to be stored in lakes, bays, oceans, and glaciers, as well as in underground supplies as discussed below, because the rate of movement in these vast bodies is relatively slow. Surface waters constantly evaporate into the air and produce clouds and later precipitation. Thus, water changes constantly from precipitation, to surface water, to groundwater, back to surface water, to atmospheric moisture, and back to rain or snow. This cycle of water movement is called the *hydrologic cycle* (Figure 1).

Surface and Groundwater Supplies

What Is Surface Water? Surface supplies of water are quite familiar to most of us. They include rivers and streams, ponds and lakes (reservoirs), and cisterns or other controlled catchments. For purposes of this discussion, springs are also considered surface supplies although, strictly speaking, springs originate from groundwater and occur where the water table intersects the land surface. Each of these sources has different characteristics.

Ponds and lakes occur where nature has created an obstruction to the normal flow

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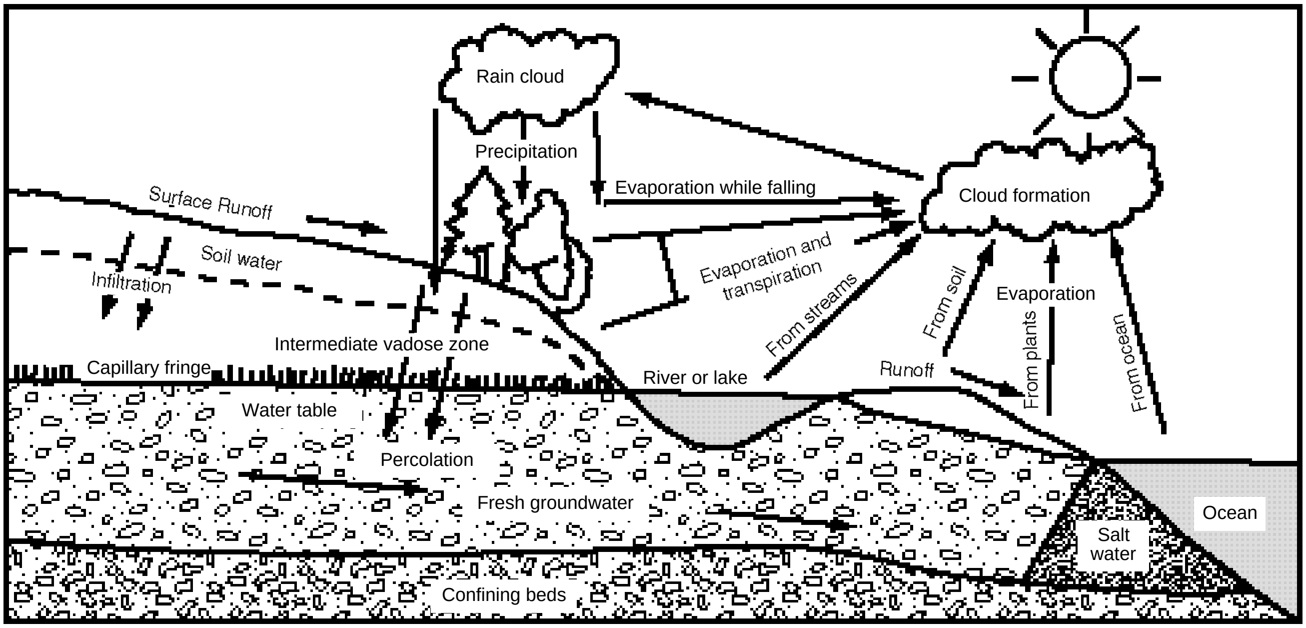


Figure 1. The hydrologic cycle.

of surface runoff or where a natural water-holding depression has formed. People can also create such supplies by building dams.

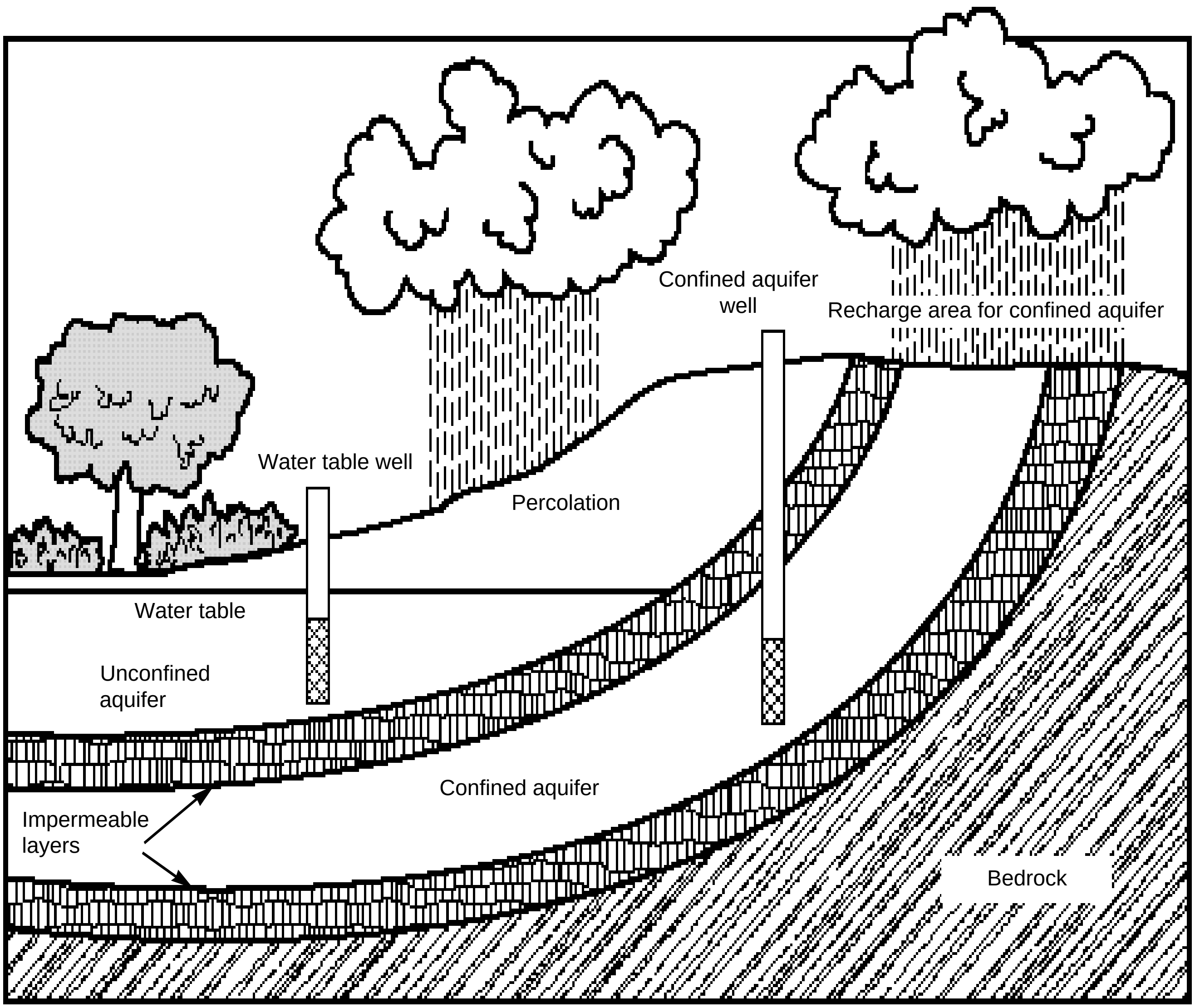
Controlled catchments are areas from which nearly 100 percent of precipitation is collected as runoff. Rooftops are the most easily recognized type of controlled catchment. However, larger areas of land can be manipulated to maximize runoff and subsequent collection (for example, by paving with concrete or asphalt).

Springs and seeps occur at the land surface where water from underground sources appears. Because springs appear at the ground surface, they must be treated differently than groundwater to adequately protect their quality.

What Is Groundwater? Groundwater, water that lies hidden beneath the earth's surface, is an important resource. Although it makes up only 4 percent of the total amount of water on earth, it constitutes 95 percent of the fresh water that is suitable for human consumption. In Maryland, groundwater accounts for only 13 percent of total water usage. Maryland's Eastern Shore, however, depends almost entirely on groundwater for its fresh water supply. Approximately 30 percent (1.5 million people) of the State's population use groundwater.

Groundwater and the way it moves is not as easy to understand or visualize as surface water simply because we cannot see it. People often imagine that groundwater exists in vast buried lakes and rivers. However, only in certain soluble deposits, such as limestone, do water-filled caverns or channels resemble underground lakes and rivers. Unfortunately, the "hidden" nature of groundwater has resulted in a "out of sight, out of mind" sentiment and therefore contributed to its being considered out of danger. We now know that this is not so; too many cases of groundwater pollution are known.

Groundwater occurs beneath the earth's surface in geologic formations called aquifers. In aquifers, all the spaces around individual soil particles and cracks within rocks are completely filled with water. Aquifers can be relatively small in area or they can stretch for several thousand square miles. Aquifers vary in thickness from a few feet to several thousand feet. Unconfined aquifers have no impermeable layers overlaying them and usually are found close to the surface of the land. As shown in Figure 2, precipitation percolates through the soil until it reaches the unconfined aquifer's upper boundary, the water table. Only a very small portion of the water ever filters down to the confined aquifers. Unconfined aquifers, due to their proximity to people's activities on the soil surface, and the fact that the soil material above them transmits water readily, are especially susceptible to pollution. A confined aquifer is bounded on the top and bottom by relatively impermeable layers of clay or solid rock through which only very small amounts of water can pass. Precipitation can enter these deeper aquifers directly through regions called recharge areas where an aquifer is exposed to the earth's surface (Figure 2). In the Coastal Plains especially, several aquifers might overlie each other.



Figur e 2. Confined and unconfined aquifers.

Approximately one-fourth to one-third of Maryland's 37 to 47 inches of annual precipitation filters down to the water table. Only about 1 inch of this precipitation ever reaches the deeper aquifers. Most groundwater is later returned to the surface as *baseflow*, that is, water discharged continuously into perennially flowing streams.

Within an aquifer, groundwater travels along fractures in the rock, through the pores in sand and gravel, or along chan-

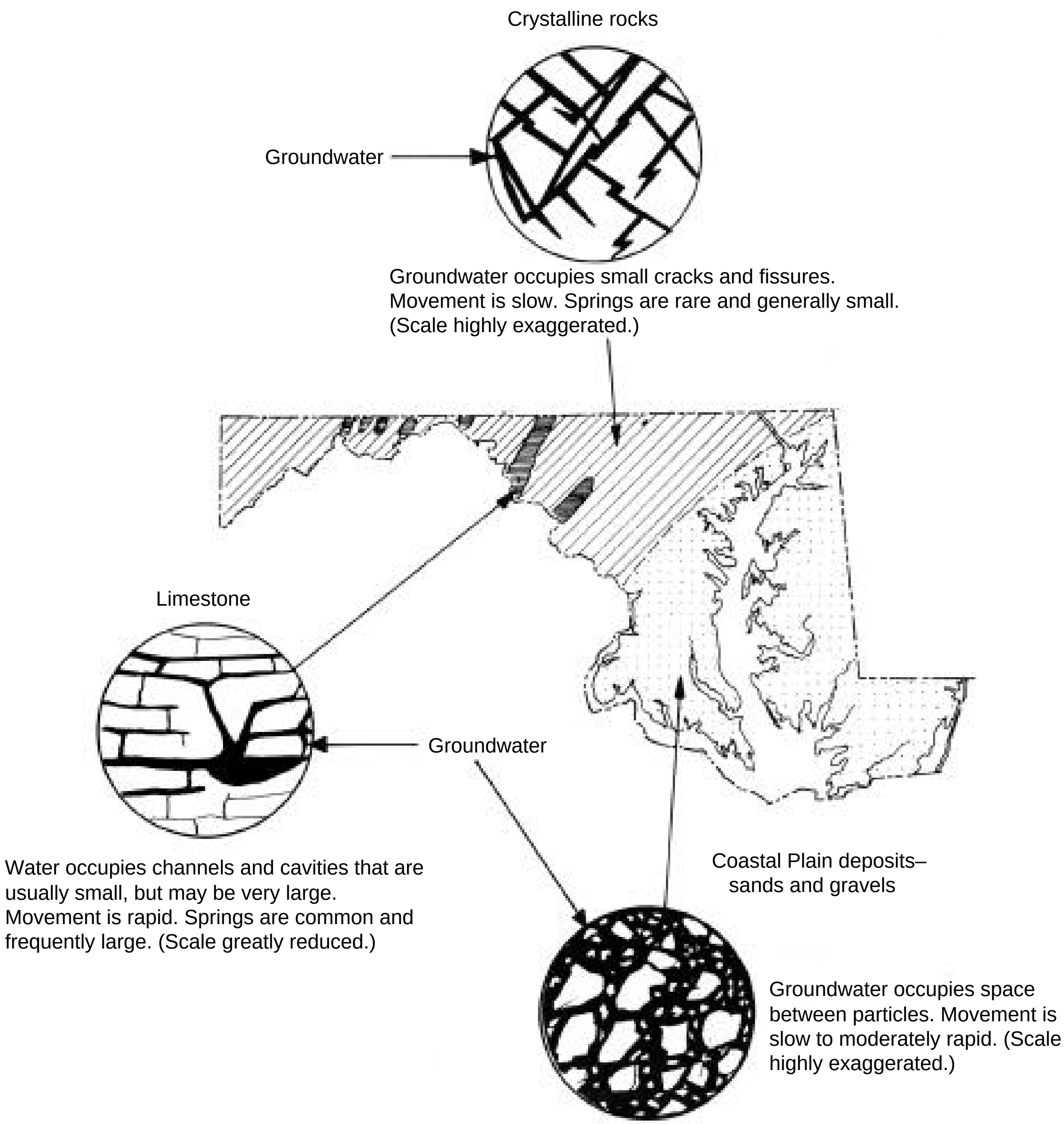


Figure 3. The potential of groundwater as the predominant water resource depends on the aquifer characteristics of the local rocks. Source: *Water in Maryland: A Review of the State's Liquid Assets*, Maryland Geological Survey, Department of Natural Resources.

nels carved out of soluble rock, such as limestone. The direction and rate of this movement are very different from that of surface water. Whereas surface water moves at the rate of tens or even hundreds of feet per minute, groundwater moves at the rate of inches per day or less. Once water enters an aquifer, it can remain there for centuries. Therefore, if contaminated, it might take aquifers just as long to cleanse themselves naturally. Though the soil above aquifers might filter some materials transported by percolating water, these substances can continue to be leached if they are not degraded in the soil by microbial and/or chemical processes.

There are primarily two important and vastly different types of geologic formations in the eastern and northeastern United States where groundwater occurs. The unconsolidated materials in the Coastal Plains were deposited either by glaciers or wind and extend from Florida to New York along the Atlantic Ocean. The other type of formation is fractured bedrock that occurs westward of the Coastal Plain. A simplified representation of the location and type of formations is found in Figure 3.

The Coastal Plain deposits consist mainly of loosely packed gravels and sands, interspersed with layers of silt and clay and can be only a few feet thick or thousands of feet thick. Maryland's Coastal Plain aquifers become deeper as they extend from the northwestern to the southeastern Coastal Plain. Near the Fall Line, where the sediments of the Coastal Plain meet the crystalline rocks of the Piedmont, the consolidated rock beneath these aquifers is just below the ground. Southeast toward Ocean City, this underlying layer of rock dips down to a depth of over 8,000 feet. They vary in the amount of water they can store or deliver (*water-bearing capacity*) from a few gallons per minute to over 1,000 gallons per minute. Depending on the depth of the water table and the type of material above it, pollutants can move into the aquifer from the surface slowly (in a matter of years) or rapidly (in days).

Natural water quality in the Coastal Plain aquifers is generally good, but varies with the type of aquifer material. Some elevation in dissolved mineral content (hardness) is always present, but is elevated in formations derived from fossilized material and limestone. The content of total dissolved solids in Coastal Plain groundwater varies widely, making some groundwater too bitter to drink. And, although iron content is generally low, it can be very high in localized areas.

Fractured bedrock formations present unique problems in both locating and protecting groundwater. Because fractures occur randomly and are generally discontinuous, it is very difficult to predict where adequate supplies of groundwater will be located. Yet, in certain areas, fractures can extend to the soil surface, providing a direct conduit through which pollutants can enter the aquifer. Such problems are prevalent in limestone areas where percolating water has dissolved the limestone, forming caverns underground and, sometimes, sinkholes at the ground surface. Though the cavernous channels can be productive aquifers from a quantity standpoint, they are susceptible to pollution from materials that can enter sinkholes with runoff, or be placed there intentionally by people. Unfortunately, it is still possible to find sinkholes being used as private garbage dumps.

Many contaminants exist that cannot be smelled, seen, or tasted. Some of these substances are believed to be health hazards in very low concentrations, sometimes at levels of a few parts per billion. (One part per billion would be equivalent to one ounce dissolved in a pool of water the size of a football field and 27 feet deep.) Although it might be technologically feasible in some cases to pump and treat contaminated groundwater to remove a pollutant, such a solution could take many years and a great deal of money. Unfortunately, it sometimes takes years to discover that groundwater has become polluted by contamination. All of these facts make it imperative to recognize the importance of groundwater to society, and to understand what it is, how it moves, and how to protect it. Clearly, the wisest and most economical approach is prevention and protection, rather than treatment.

How Are Surface and Groundwater Related?

Groundwater and surface water are intimately connected. Water in streams and lakes is, in most cases, directly linked to groundwater. For example, the surface of water flowing in most streams is actually a continuation of the water table (Figure 1). During drought periods, groundwater moves out of the aquifer and into the stream to supplement stream flow. During floods, water can flow from the stream into the surrounding aquifer. Hence, at times, streams have the potential to pollute groundwater and, at other times, groundwater can pollute surface water.

Water Utilization

Municipal water supplies meet Federal, State, and local guidelines. These requirements vary somewhat both with the size of the municipality and the region. Approximately 50 percent of the State's drinking water is supplied by municipalities. Most of the water on the Eastern Shore and much of the water to many rural homes is supplied by groundwater. If you are on an individual well or one that supplies only a few homes, you are probably responsible for your own water quality. Since you more than likely obtain your water from a well, the following is a discussion of how groundwater is delivered.

Water Well Components

A well consists of two main elements. One element is the hole, or bore, through which water flows upward to the pump intake. This bore is commonly lined with a pipe or casing. The second element is the intake section where water enters the well. The intake usually is a screen at the bottom of the casing in a sand stratum, or it can be the open bore hole in a rock formation.

Well casing. A drilled or driven well in unconsolidated material (such as sands, gravels, and unstable clays) must have a permanent well casing the full depth of the well, and a well screen. In unconsolidated material, soil usually packs tightly against the casing, providing a good seal. Where rock or other stable material overlays water-bearing sand or gravel, the upper part of the well must be sealed artificially on the outside of the casing to prevent contaminated water from moving through this upper layer along the outside of the pipe and down into the aquifer. Sealing usually is done with grout (a cement mix) or other sealants.

Steel pipe has been used extensively for well casing even in soils or waters that are somewhat corrosive. Where abnormally corrosive conditions exist, a casing material of corrosion-resistant metal, such as brass or stainless steel, might be used. Plastic pipe can be used for well casings, but only when special methods can be employed to install the pipe without structural damage.

Well scr een. A well screen fitted to the bottom of the casing allows water to enter the well freely, but prevents the entrance of coarse sand. The selection of the screen material usually is based on the cost of the material and the chemical character of the water. In some instances, where the water-bearing strata contain fine sands or silts, the well can be gravel-packed. The gravel pack acts as a primary filter and is held in place by the screen. Without the gravel pack the bottom of the bore hole would erode and cave in, while continually passing sand and silt to the pump.

Well ter mination . The upper end of the casing pipe of the well can terminate on a pump house floor, platform, or soil surface. The casing should extend at least 8 inches above this surface. The entrance of any pump pipes, cable, air lines, or other device into the well casing must be effectively sealed with an approved sealing device to maintain well sanitation.

Where the pump is mounted directly over the well, a sanitary well seal should be used. If the pump is offset from the well, the seal should consist of a watertight expandable seal that fits into the casing and at the same time seals the drop pipes, cables, and air line. If the pump is offset from the casing with pipes buried below the soil surface, a sealing device, called a pitless adapter, is used. In this case, the top of the casing still projects above the soil level and is fitted with a protective cap.

Water Well Construction Methods

Wells generally are classified according to the method of construction. Wells can be driven or drilled. Older types of wells, such as dug wells, are limited in depth and are subject to contamination from seepage of surface waters. Shallow wells are no longer allowed by many health departments.

A driven well is the quickest and least expensive method of acquiring groundwater. It is most practical where the well depth does not exceed 50 to 60 feet. The driven well is constructed by forcing an assembled length of pipe fitted with a well point and screen through the soil. This process requires porous soil containing no rock.

Drilled wells are installed when greater volume, depth, or diameter is required. Two methods of drilling are the hydraulic rotary method and the cable-tool method. Drilling by the hydraulic rotary method uses a bit attached to the lower end of a vertical shaft consisting of sections of drill pipe that are screwed together. The well casing is placed in the bore hole after the well has been drilled. The complete casing pipe is placed in one operation and then grouted into place.

In cable-tool drilling, a heavy steel bit is suspended on a cable and alternately dropped and picked up to pulverize the earth below it. The steel pipe casing is placed as the well drilling progresses. The casing fits tightly and is driven from time to time to sink in as required. The earth hugs the pipe tightly and grouting generally is not required.

Well Completion. Once the drilling of the well has been completed and the casing and screen, if used, have been placed, the well should be "developed." This process involves pumping to remove all sediment left over from the drilling process. The well is then "surged" using compressed air or washed with a water jet to cause water to move in and out of the sides of the well. A well is developed to clean the water intake spaces and allow the maximum rate of water entry to the well.

The well is then tested for yield. For residential wells, testing usually is done by bailing or with compressed air. This type of test usually is included in the cost of the well. An actual pumping test for capacity in gallons per minute with measurement of water level decline, or "drawdown," costs more, but is justified for irrigation or other wells where reliable high yield is necessary.

Disinfection. For drinking water, the well and pumping equipment should be disinfected before being placed in service. Disinfection should be with a chlorine solution poured into the well at a rate dependent on well size and water storage capacity. After 8 or more hours, the water is then pumped until the amount of chlorine has been reduced sufficiently. This water might burn shrubs and grasses and should be disposed of where damage will be minimal.

Sources of Surface and Groundwater Contamination

There are many sources of contamination for both surface and groundwater. Potentially, any substance that is placed in the air, in surface water, in soil, on the land, or below ground, can become a water pollutant. In addition, substances that occur naturally (such as minerals, soil particles, and decaying leaves) can also contaminate water. Pollutants can originate in both rural and urban settings. In rural, unsewered areas, effluent from septic tank disposal fields can pose a significant threat to groundwater. Bacteria, nitrogen, and other inorganic and organic substances can leach downward to the water table of an unconfined aquifer. Agrochemicals used in food production can pose similar threats to groundwater. In urban areas, pollutants can originate from a variety of sources, such as gasoline service stations, municipal and industrial wastewater treatment facilities, and homeowners' lawns.

Pollutant sources over which people have control, and can manage effectively, include domestic, agricultural, urban, and industrial. Each category can pollute both surface and groundwater. Contaminants include a variety of physical, chemical, and biological substances (such as eroded soil, dissolved nutrients, and bacteria). However, because the soil can physically filter most undissolved substances from percolating water, generally only dissolved contaminants and bacteria actually reach groundwater supplies. Both dissolved and undissolved substances can reach surface supplies.

Domestic Sour ces. Contaminants that originate around the home include chemicals used on lawns and gardens and, conceivably, pesticides used around foundations. Probably the greatest potential domestic source of groundwater contamination is from septic tanks. Though not a surface contaminant, effluent from septic systems can contaminate surface water supplies if improper design and/or maintenance procedures are followed, or if the surface supplies are located too closely to septic systems. Septic systems are used in 20 million (29 percent) households throughout the country. Nitrate from these systems moves readily through soil and can reach groundwater in significant amounts. Nitrate is a major nutrient problem for the Chesapeake Bay.

Household chemicals, such as paints and paint thinner, degreasers, polishes, cleaning solvents, and even waste oil from home car oil changes, are also potential threats to groundwater. Many of these products are disposed of improperly by being flushed down the toilet. If the sewage water goes to a wastewater treatment plant, the pollutants are not removed by the treatment processes.

When poured down the drain, the substances make their way to the drain field of the onsite disposal system, where they can leach into the groundwater. Septic tank cleaners are of particular concern, since many of these contain toxic organic chemicals that can leach through the soil. Household chemicals and waste oil can also move readily through the soil even if they have been spread on the soil surface. In most cases, only small quantities of these materials in a water supply can cause severe contamination.

Fecal wastes from both domestic and wild animals (for example, bird droppings on rooftops) and eroded soil are the major contaminants of surface water.

Agricultural. The major contributors of water pollution from agriculture are eroded soil, animal wastes, fertilizers, and other agrochemicals. By volume, eroded soil is the largest agricultural pollutant of surface water supplies. Nevertheless, pesticides, nutrients (especially phosphorus attached to eroded soil), and animal waste applied to the land can be transported to surface supplies by runoff.

Storage and application of manures and fertilizers also have contributed to increased nitrate levels in groundwater nationwide. In many areas, nitrate levels are above drinking water standards for "safe" water. Improper storage of manures and overapplication of manures and fertilizers have a significant impact especially in areas of the Coastal Plain and in glacial deposits. In these areas, vast acreages could percolate nitrate nitrogen into the groundwater.

Waste storage ponds and lagoons also have the potential to contribute to groundwater pollution. In fractured bedrock and limestone areas with sinkholes and caves (karst formations), these lagoons, if improperly sited, can deliver contaminants directly to groundwater. In karst settings, a pond can empty completely overnight. Careful management and proper siting can greatly alleviate many of the problems associated with these sources of agricultural water pollution.

Urban. Urban areas can contribute the same contaminants to surface runoff as rural domestic areas. In addition, runoff from urbanized areas can carry any number of organic and inorganic chemicals washed from streets and parking lots. These pollutants range from oils and greases to various metals. Construction activities in urban areas contribute large amounts of sediment. Sewage treatment plants discharge treated wastewater directly to rivers and streams.

Urban areas also can contribute to groundwater pollution from landfills, wastewater treatment plants, storm water collection basins, and leaking sewer pipes. A wide variety of pollutants are associated with these activities. Many active and inactive landfills throughout the country are unlined and not monitored to determine if leachate is moving from the landfills. Storm water catchments collect runoff during rainfall events and "dispose" of the runoff by having it infiltrate into the soil. If the storm water contains dissolved contaminants, the soil will provide only slight treatment and the contaminants can percolate to the groundwater supply.

Industrial. Treated industrial wastes are also usually discharged directly to receiving streams. The contaminants such effluents contain depend on the nature of the industry. These can range from easily degraded organic matter to more resistant chemicals and bacteria.

Protecting Surface Water Supplies

Surface water supplies are highly susceptible to contamination. They should be used as a drinking water source only as a last resort, when obtaining groundwater would be technically infeasible or too expensive. If surface supplies become a necessity, they should be sought in the following order of preference: springs, controlled catchments, ponds, and lastly, streams and rivers. In addition, strict attention must be paid to protecting each source from contamination to the maximum extent possible.

Where springs are involved, make sure that the area contributing flow to the spring is safe and that contamination is excluded from the spring where it exits the ground. Springs can occur at relatively shallow depths below the ground surface and are therefore susceptible to contamination by percolating water that has picked up pollutants as it moves through the soil. Thus barnyards, septic systems, trash dumps, underground storage tanks, and the like should not be located on land above the spring. Also, take special care when you use springs in limestone areas. Springs here are often replenished by surface flow into sinkholes that might be long distances from where the spring appears. Very little purification occurs in water flowing in limestone areas, so it is important that you check land use practices in the area surrounding the spring. Springs are almost always high in fecal bacteria contamination.

The immediate area around the spring must be protected from contamination as the water exits the ground. Surface runoff must be diverted from the spring by ditches or by berms. The runoff should be discharged in a safe manner downhill from the spring. Animals should be kept from the spring by a fence at least 100 feet away from the spring. Also essential to proper protection is a properly constructed spring house. Restricted access should be provided to the house and the cover should be locked at all times.

Ponds. Most ponds receive direct surface runoff, although dug ponds can be fed by springs or shallow groundwater. Protecting ponds from contamination chiefly involves keeping the area draining into the pond as free from contamination as possible. To accomplish this, strict control must be exercised over land use in the watershed.

Water quality from forested areas is usually considered to be among the highest that occurs in nature. Runoff from grassed areas is also of relatively high quality. Therefore, the area that contributes water to a pond used for a domestic water supply should be maintained in one of these land uses. Obviously, the watershed should be free of barnyards, septic systems, and other onsite wastewater systems. Fencing should be used to exclude animals from the watershed. Best management practices should be employed to control erosion and loss of nutrients. Agricultural chemicals should not be used in the watershed. These recommendations apply regardless of the type of pond used.

Protecting Groundwater Supplies

The best way to protect groundwater used for human or animal consumption involves proper location of the well, coupled with proper well construction.

All wells should be located safe distances from sources of contamination. However, because many factors affect the movement of contaminants into groundwater, it is impractical to set a fixed distance between well location and contaminant source that would be applicable in all cases. There is NO safe distance between contaminant source and an improperly constructed well.

In general, unconsolidated materials typical of Coastal Plain aquifers provide better "filtration" of percolating water than do consolidated fractured rock aquifers, typical in the central and western part of the State. Most experts agree that even under the best conditions (for example, when soil and aquifer conditions retard the movement of contaminants), the separation distance should be no less than 50 feet. For an added safety measure, many local ordinances often consider 100 feet to be the minimum separation distance.

Since the safety of a groundwater source depends mainly on geological and soil conditions, and well construction practices, these variables must be considered in determining the separation distance between well and contaminant source. Wherever possible, wells should always be placed "up-gradient" of any source of contamination. In many cases, groundwater gradients (tendency for flow) follow surface topography, therefore wells should be located uphill from any contamination source. The direction of groundwater flow does not always follow the slope of the land surface, however. Therefore, well siting should be done by a person with sufficient training and experience to evaluate the various factors involved. Groundwater contamination can continue for long periods before any problem is discovered. The volume of polluted water by then can be large and the source of contamination far removed from the site of the discovery.

What Individuals Can Do

Individuals can help protect our groundwater resources by recognizing that activities on the soil surface and upper profile can, and do, affect groundwater. We need to manage our activities accordingly. Like many public issues, however, awareness of problems and solutions is not enough. Often, we as individuals acknowledge that a problem might exist, but deny that we contribute to it. Even to a greater extent than with surface water, groundwater is shared by all users, and all users similarly share in its contamination.

Here are some key things that individuals can do to protect groundwater:

- Keep a close watch on the inventory of liquids in underground tanks to detect possible losses caused by leakage. If a buried tank is more than 15 years old it has a good chance of leaking. Have it checked.

- Use agrochemicals and lawn and garden chemicals wisely, following recommended application rates, timing, and methods.

- Manage septic tank systems to prolong their life and maximize their efficiency in removing pollutants.

- Support legislation at the local level that will encourage the use of state-of-the-art technology in solid waste management and waste water treatment.

Summary

Individual rural homeowners are often responsible for providing and protecting their own water supplies. Where safety of these sources is concerned, no "short-cuts" can be taken. Protecting the quality of individual water supplies is a combination of controlling land use around the supplies and using proper water treatment techniques where necessary. Rural homeowners must assume responsibility for protecting their families from contaminated drinking water.

Assistance in this regard can be obtained from a number of agencies. Local health authorities can answer questions relating to applicable local regulations, health hazards posed by contaminated water, and suggested procedures for sampling and analyzing drinking water for contaminants. In some cases, local health officials will analyze individuals' water samples for common pollutants at no cost or for a nominal charge. Complete well water analysis is the homeowner's responsibility and is not free.

State regulatory agencies charged with water resource management can answer questions regarding water use. They usually also have information regarding the availability and suitability of water sources in the State. Such agencies usually administer safety regulations for dams as well.