Groundwater:
A Primer for Pennsylvanians

“Give me the good old well water anytime,” said the teenager as he watched the backflushing of a sandfilter while touring a water treatment plant.

True, the junk coming off the sand filter was pretty unappetizing stuff, even though the stream the water plant drew from was high in the mountains of eastern Pennsylvania. But, unfortunately, the young man’s faith in “good old well water” may not be — in fact, is increasingly not — justified.

Pennsylvania’s groundwater supplies are at risk from a variety of human activities that can negatively affect both groundwater quantity and quality. Furthermore, this threat to our groundwater comes at a time when we in Pennsylvania are becoming more dependent on this resource for several reasons. Although the state has experienced only minimal population growth during the past two decades, there has been a steady migration of people and industry from the cities to more rural settings. This has resulted in the development of groundwater resources at a rate three times that of surface water. The development of groundwater resources has also accelerated due to concern about the quality of surface water and to the expense of new federal regulations requiring increased filtration of surface water used for drinking.

Although the public has become used to seeing the federal and state governments take the lead in environmental protection, when it comes to groundwater protection, the initiative and responsibility in Pennsylvania lies with local communities and their leaders. Therefore, as the threat to groundwater grows along with our dependence on it, protecting our valuable groundwater supplies must become a priority for local governments.

This booklet is intended to provide the background information necessary for local leaders to understand this resource, what and how human activities can harm it, and what can be done to protect it.

Groundwater and the Hydrologic Cycle

Groundwater is water at one stage of a cycle, called the **hydrologic cycle,** that all water moves through: rain and snow fall on the land surface and infiltrate the soil or run off the land into streams, lakes, and oceans evaporation and transpiration (release of water through the leaves of plants) carry the water back into the atmosphere) where it condenses and again falls to earth.

The water that filters through the soil and is not taken in by plants (and then transpired into the atmosphere becomes groundwater. It does not remain in the ground, however, sooner or later it surfaces at an area of discharge -- spring, stream, lake, or wetlands--and eventually evaporates back into the atmosphere.

See Illustration 1— Hydrologic cycle, water is constantly on the move.

A Closer Look at Groundwater

Water filtering through the soil moves first through an **unsaturated zone** where the spaces (pores) between solid particles or rocks contain both air and water. At this stage water is called **soil water** and some of it will be taken up by plants. The rest of it continues, pulled by gravity, in a generally downward path and eventually reaches the **zone of saturation.** Here the pore spaces are completely filled with water; this is **groundwater.**

The top of the zone of saturation is called the **water table.** Rock or soil layers within the zone that can readily store and transmit usable amounts of water are called aquifers. Aquifers may be as large as several states combined or as small as a few acres and may be found a few feet or hundreds of feet below the surface. The vertical thickness may vary from a few feet to hundreds of feet.

See Illustration 2—Groundwater is the water that fills all the spaces in the saturated zone.

Several different aquifers yielding varying amounts of water can exist within the zone of saturation, separated by **aquitards.** These geological formations are layers comprised either of clay with tiny, poorly connected pores or of nonporous rock, and they restrict the flow of water from one aquifer to another. An aquifer that has an aquitard located both below and above it is called a **confined or artesian aquifer** and very often is under pressure. If such an aquifer is tapped with a well, artesian pressure forces the trapped water to rise in the well to an elevation higher than the aquifer water level. An aquifer with no aquitard above it is an **unconfined aquifer.** In wells penetrating this type of aquifer, the water level in the well and the aquifer are the same.

See Illustration 3—Aquifers can be composed of a variety of rock types with different water-bearing properties

Aquifers are classified into two general categories. Consolidated aquifers-consisting of limestone, sandstone, granite or other rock hold water in interconnected fractures, small cracks, pore spaces, spaces between rock layers, and/or solution channel openings. Unconsolidated aquifers-consisting of rock debris or weathered bedrock, i.e., soil particles hold water in spaces between the particles. In Pennsylvania, most aquifers are consolidated.

How much water is contained in an aquifer and how fast it moves depends on the type of soil or rock comprising the aquifer. Clay, fine-grained sand, and silt hold a lot of water and release it very slowly, while coarse-grained sand and gravel hold somewhat less water but the water moves more freely. The amount of water held and yielded by consolidated aquifers depends on the size of the rock's openings and cracks. Limestone aquifers yield substantial amounts of water; sandstone aquifers, moderate amounts; and granite aquifers, small amounts.

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See Illustration 4—A confined aquifer is trapped beneath an impermeable layer of clay or rock and is often under pressure.

How Groundwater Moves

Groundwater, like surface water, is constantly on the move. However, groundwater moves much slower --at rates ranging from feet per day to inches per year depending on the type of soil or rock through which it is moving. The natural movement of groundwater is from upland recharge areas to lowland discharge areas —points where the water table meets the land surface, such as springs, lakes, streams, and wetlands. Most water seeping into the soil moves only a few miles to the point where it is discharged; in most instances it stays within the same watershed.

See Illustration 5—Groundwater generally flows from upland recharge areas to lowland discharge areas.

Groundwater discharging into streams provides the water that keeps streams flowing year round. Except for a short time during and after rain storms and snow melt, all the water in a stream is provided by groundwater seeping through stream banks and stream beds. This is called **base flow.**

From points of recharge to points of discharge, groundwater moves slowly through small openings in rocks and soil and usually in parallel paths (i.e., layers). Generally there is little mixing of the water in these layers because the slow movement of groundwater does not create sufficient turbulence for mixing to occur. As a result, when groundwater becomes contaminated, the contaminants stay in fairly confined plumes which may take hundreds of years to reach a discharge point and which may be very difficult to detect in the ground.

See Illustration 6 - Groundwater moves in parallell paths or layers with little mixing between layers.

When wells are drilled, the flow of groundwater changes. Pumping water from a well pulls groundwater toward the well creating an area called the **cone of depression** where the water table is lowered due to the pumping. If the cone of depression from a pumping well extends to a nearby stream or lake, the stream or lake will then lose water to the groundwater. This is called **induced recharge**. Streams and wetlands can be completely dried up by induced recharge from well pumping.

See Illustration 7—Pumping from a well lowers the water table near the well creating a cone of depression.

The Hydrologic Cycle in Pennsylvania

Each year on an average, 41 inches of precipitation falls in Pennsylvania. Six inches of that enters streams and lakes directly either as surface runoff or as flow that enters streams from the unsaturated zone under the land surface. Twenty inches returns to the atmosphere through evaporation and transpiration. The remaining fifteen inches infiltrates the soil and moves downward to the zone of saturation to recharge groundwater.

Groundwater Recharge

Since all groundwater eventually surfaces, the water in the ground must be periodically recharged. Most groundwater recharge occurs in the spring when there is plenty of water from rain and melting snow, plants are not actively growing and are not taking water from the soil, and the amount of sunlight is less so evaporation is less. Following the spring recharge the water table usually lowers steadily during the summer, fall, and winter. Recharge, or infiltration, rates also vary with the type of land cover. For example, infiltration is higher in forested areas where the soil seldom freezes so some recharge continues to occur in winter months. Furthermore, since overland flow is rare in forested areas, this recharge water is clean.

Natural Groundwater Quality in Pennsylvania

The natural constituents of water that may affect its suitability for drinking and other purposes and that most commonly are found in Pennsylvania groundwater are dissolved solids, calcium carbonate, and iron. Concentrations of chlorides and nitrates can also restrict use of water. These constituents enter water by leaching from rocks as water moves through them. Drinking water standards specify maximum concentrations of 500 milligrains per liter (mg/1) for dissolved solids, 250 mg/l for chloride, and 300 micrograms per liter (ug/1) for iron. A limit of 150 mg/l of hardness is recommended but is not a legal standard. Hardness is a property of water, usually measured by the concentration of calcium carbonate, which increases the amount of soap needed to produce a lather.

In general, Pennsylvania's aquifers yield water that is within these limits. Iron exceeds the maximum allowable concentration in a significant number of wells in sand and gravel aquifers and to a lesser extent in sandstone and shale aquifers. Water in carbonate aquifers frequently exceeds the recommended level of 150 mg/1 of calcium carbonate.

Radon, a naturally occurring radioactive gas formed from decaying uranium or radium deposits, is a natural contaminant of increasing concern. Where radon is present in bedrock it can dissolve in groundwater and become a health hazard both when consumed or when the gas escapes into the air during showering, cooking, and laundering. No official standard has yet been set; a standard of 300 picocuries per liter is being considered.

Hydrogen sulfide is an infrequent natural contaminant of groundwater caused by water storage in certain types of shale rock. It imparts a characteristic rotten egg odor to the water, but is not seen as a health threat at the levels at which it makes water unpalatable.

Corrosive groundwater is common in Pennsylvania. Corrosivity involves many factors including high acidity and low concentrations of calcium carbonate. In a recent Penn State survey of groundwater in private wells, 60% had corrosive water. Corrosive water dissolves lead and copper from pipes and plumbing fixtures thus causing a health risk.

We Depend on Groundwater

About four and a half million Pennsylvanians (37 percent of the population) use groundwater from wells and springs for their drinking water and other domestic uses. In rural areas most people depend on groundwater; in some of the densely populated suburban areas around Philadelphia, 60% of the population uses groundwater. Almost half the groundwater used in Pennsylvania is used for domestic water supply. Industry uses another 26%; mining, 17%; and agriculture, 10%.

Water supplied by a public water systern is tested and treated so users can be assured that their water is safe. Rural homeowners with their own wells are responsible for the safety of their own water supply. More than 2.6 million Pennsylvanians use drinking water that is not regularly tested for contaminants.

Effects of Land Use on Our Groundwater

Many human activities can negatively affect groundwater quality as well as quantity. For many years it was generally believed that the filtering capabilities of the soil protected groundwater from contamination by human But with the discovery in the 1970s of human-made organic chemicals in groundwater, we began to realize how extensively our activities can affect groundwater. In fact, in a nationwide study commissioned by the U.S. Environmental Protection Agency 65% of the private wells tested failed to meet at least one drinking water standard.

Those activities that can have a negative impact on groundwater can be categorized in four groups: waste disposal, resource extraction, agricultural practices, and urbanization.
activities on the surface.

See Illustration 8—Groundwater contamination may come from a variety of sources.

Waste Disposal The best known source of groundwater contamination is waste disposal sites, both municipal and industrial, that were in existence before new regulations went into effect in 1988. Of 160 major Pennsylvania waste disposal facilities for which comprehensive data has been analyzed and for which groundwater monitoring data is available, 79 show contamination of groundwater. In addition, the Department of Defense (DOD) has scheduled 68 DOD sites for cleanup through a Cooperative Multi-Site Agreement with DEP. Cleanup is expected to be completed by 2010.

Septic systems are another potential source for groundwater contamination. If septic systems are improperly installed or maintained, bacteria, viruses, nitrate, phosphorus, chlorides and the organic solvents that are found in many household cleaners as well as products sold to "clean" septic systems can all make their way into groundwater. As a result of poor construction or maintenance of their septic systems, rural homeowners are frequently the cause of contamination of their own wells.

Resource Extraction Coal mining, both deep and surface, causes changes in groundwater quantity and quality. As mines intersect aquifers and collect water, they interfere with groundwater storage and can lead to lowered water levels in wells. Moreover, the sulfur in coal reacts with oxygen and water to form sulfuric acid. The resulting acid mine drainage degrades water quality as it infiltrates aquifers or discharges into streams. Increased concentrations of iron manganese, sulfate, and dissolved solids in groundwater can result. Many aquifers in coal mining regions of Pennsylvania can no longer be used for drinking water supplies as a result of contamination from mining.

Oil and gas drilling, located primarily in northwestern Pennsylvania, also has had a detrimental effect on groundwater. Oil wells produce brine which is separated from the oil and stored in surface lagoons. If not properly lined these lagoons can leak and release brine to groundwater. Methane can migrate from gas wells that are under pressure and has been found in private water wells.

Abandoned unsealed oil and gas wells call also be a source of contamination of groundwater. An uncapped well is an inviting illegal disposal spot for waste. Improper casing and grouting or deteriorated casings can cause contaminants to be spread between aquifers.

Agriculture Common agricultural practices such as fertilizing and applying pesticides are coming under increased scrutiny because groundwater samples have revealed nitrates and, in some cases, pesticides. The most prevalent problem is high levels of nitrate from overapplication of manure and fertilizer. The maximum allowable level for nitrate in public water supply wells is 10 mg/l. Samples in Lancaster County have reached as high as 40 mg/I and in one case, 130 mg/l. Nitrate is especially harmful to babies, interfering with the blood's ability to transport oxygen which causes the baby to suffocate ("blue baby" disease).

Pennsylvania's most productive agricultural land is generally in areas with carbonate aquifers which allow rapid movement of groundwater and pollutants with it. This makes water supplies in areas in south-central Pennsylvania particularly vulnerable to contamination from agricultural practices. DEP has found that fifty percent of Pennsylvania's community water supplies that exceed maximum levels for nitrates are located in Lancaster County. The same soil and geological properties also pose a hazard for groundwater when this land is developed for residential or industrial use.

Illustration 9—Animal manure is a common cause of groundwater contamination by nitrates, bacteria, and viruses.

Urbanization Many human activities and land use practices, which proliferate with urbanization, can negatively affect groundwater. Even cemeteries, for example, can contaminate groundwater.

One effect of urbanization is recharge diversion. Soils that have been covered with impervious surfaces -- roofs, parking lots, or streets -- obviously cannot absorb precipitation. Nor can soils that have been compacted by heavy machinery. As a result much of the water from rain and snow melt goes directly into streams and is never available to recharge groundwater.

Large concentrations of people can also lead to overpumping of aquifers. This can result in significant aquifier drawdown which in turn reduces the quantity of streamflow. Stream water quality then suffers due to higher concentrations of sewage treatment plant effluent. Intensive pumping in coastal areas can cause salt water to be drawn into aquifers and wells. Polluted stream water can also be drawn into drinking water wells.

With increased population comes industrialization and an increase in the amount and variety of industrial activities, many of which can potentially contaminate groundwater. Leaking storage tanks at both industrial sites and gas stations have contaminated groundwater in many instances. DEP has documented over 13,000 storage tank releases in Pennsylvania. However, throughout the state, old tanks are being replaced by new tanks under stricter regulation. Other industrial activities in the more populated areas of the state have led to contamination by synthetic organic chemicals such as trichloroethylene (TCE) and percloroethylene (PCE), solvents commonly used as cleaners and degreasers. These have infiltrated groundwater as the result of poorly constructed and maintained landfills as well as spills or improper handling at industrial sites and small neighborhood businesses such as gas stations, dry cleaners, and machine shops. A 1982 groundwater study in the middle Delaware River Basin found that 84% of documented contamination cases were caused by hydrocarbons or organic chemicals. One-third of these were caused by TCE and PCE.

Pipelines that bring oil and gas from wellfields to Pennsylvania industries and homes are another source of contamination. About 50% of the pipeline compressor stations which have been monitored in Pennsylvania have contaminated groundwater.

Individual homeowners also impact groundwater through a number of activities. These include improper disposal of used oil and overapplication of fertilizer and pesticides on lawns and gardens. Homeowners use four to eight times the amount of fertilizers and pesticides per acre than farms. Golf courses are another potential source of groundwater contamination from overuse of fertilizers and pesticides.

Illustration 10—Groundwater can be contaminated by various substances that can be spilled while in transport as well as by deicing salts.

Detecting Contamination

Detecting and assessing contamination can be very difficult. Since groundwater cannot be seen from the surface, usually the first we know about any contamination is when it appears in water from springs or existing wells. However, because existing wells were located to provide a water supply and not to investigate groundwater conditions, even then we may not know the extent of contamination or what groundwater conditions are really like. Drilling new monitoring wells and analyzing the data gathered may give us a better idea of what is happening in the aquifers but such intensive investigations are very expensive and may still miss pockets of contamination.

Locating the source of contamination may also be very difficult, particularly if there are several potential sources nearby. It is especially difficult when a contaminant plume affects a well temporarily and then moves past the well. This could happen where there has been an isolated spill of a substance that does not linger in the soil and the groundwater is moving fairly rapidly.

Illustration 11—The density of a contaminant determines whether it is a “floater,” “mixer,” or “sinker” and affects how quickly or easily it is

Detection of contamination is also affected by the density of contaminants which affects how they move in the ground. Gasoline, for example, is lighter than water and so floats on the top of the water table, just as it floats on the top of a lake. Therefore, gasoline is difficult to detect since it may not appear in water being drawn by a well until the water table drops to the level at which the water is being drawn. Based on their density, contaminants are sometimes characterized as “floaters,” “mixers,” or “sinkers.”

Cleaning up Groundwater

Once contaminated, groundwater is very costly and difficult to clean up. One technique is pumping contaminated water, treating it with carbon filtration, and recharging it to the aquifer. Wells can also be used to redirect the flow of groundwater, pulling the contaminated water into the well to keep it from spreading. Underground barriers can be constructed to isolate contaminants and prevent further movement of pollutants in the aquifer. However, unless an impermeable barrier prevents new water, including rainfall, from flowing into the contaminated area, the groundwater and contaminants will find a new flow path around the underground barrier. Even under ideal conditions it is unlikely that groundwater treatment will restore groundwater to its original quality

Prevention is the Solution

Since groundwater contamination is so difficult and costly to detect and cleanup, the best approach to maintaining groundwater quality is to prevent contamination in the first place.

Several state and federal laws deal with some of the activities that can pollute groundwater. However, neither the state nor the federal government has any law specifically focused on management of the quality or quantity of groundwater.

Most regulatory programs that control potential sources of contamination of groundwater are the responsibility of the Pennsylvania Department of Environmental Protection. DEP has adopted “Principles for Groundwater Pollution, Prevention and Remediation” to guide Department programs that impact groundwater. The Principles set an ultimate goal of prevention of contamination whenever possible. Standards for clean-up of contaminated groundwater are drawn from Pennsylvania’s Land Recycling and Environmental Remediation Standards Act (Act 2, “Brownfields legislation”) which sets a variety of clean-up standards depending on the future use of the contaminated site.

Threats to groundwater from leaking storage tanks have been lessened by new storage tank regulations adopted in 1991 which set tighter standards for tank construction, installation and leak detection as well as require replacement of older tanks.

The Pennsylvania Department of Agriculture completed its "Pesticides and Ground Water Strategy" in January 1998. This strategy provides a framework for managing specific pesticides through prevention activities, groundwater monitoring and plans for response to detection of contaminants.

In the 1990s, DEP developed a Wellhead Protection Program (WHPP) to meet requirements of the federal Safe Drinking Water Act (SDWA). The WHPP, which is voluntary for existing and mandatory for new or expanded public water supply wells, sets standards for protection activities in areas surrounding a well, the wellhead protection area. The purpose of this program is to enhance local efforts to prevent contamination of recharge areas around public water supply wells and wellfields. In 1999**,** of approximately 2000 community water systems that rely solely on groundwater, over 150 have developed a wellhead protection program.

Since so many of the potential sources of groundwater contamination are related to local land use decision, local governments and citizens have a vital role to play in protecting groundwater. Unfortunately, few communities have taken steps to do so. There are several reasons for this, including that it has become clear only fairly recently that land use and groundwater quality are connected. In addition, the cooperation between municipalities that is necessary when aquifers cross municipal boundaries may be difficult to achieve. Also, some programs require accurate technical data. And perhaps most significant, local officials have not been informed that they must or should enact policies to protect groundwater or even that groundwater needs to be protected.

However, the need for local action to protect groundwater cannot be ignored any longer, and the information and resources necessary can be obtained. Local protection programs can range from public education to change individual habits to land use controls to protect aquifers. Some possible protection programs are:

- wellhead protection programs to protect the recharge areas for public water supply wells and wellfields
- design standards for structures in the recharge area
- operating standards for activities in the recharge area
- education programs to assist homeowners and businesses in making informed decisions about activities that impact groundwater
- septic management districts to better control installation and maintenance of septic systems
- land use regulations to protect aquifer recharge areas
- household hazardous waste collection programs to remove harmful substances from the waste stream
- groundwater monitoring to determine water quality or movement of a contaminant plume
- well construction and siting standards for private wells
- water conservation programs to reduce stress on septic systems and/or reduce contamination from saltwater intrusion in coastal areas.

The Future

Many technical questions remain about how contaminants affect groundwater and how groundwater once contaminated can be restored. On the basis of recent cleanup efforts, some experts are beginning to think that, once contaminated, aquifers cannot be restored with present technology to original purity.

Many of the problems we are now discovering with groundwater are the result of past practices and activities. As we have learned more about groundwater problems, some of these practices have been discontinued or altered. However, some still continue. Furthermore, there is little awareness on the part of the public and local officials of how individual activities and uses of land can be detrimental to groundwater.

The future availability and viability of Pennsylvania's groundwater depends on what we do today to protect this resource. Much of the initiative and responsibility for that rests with local communities. Their efforts should be directed to developing local policies that effectively manage or control potential sources of groundwater contamination. In addition, public education has a vital role to play in protecting groundwater. Groundwater protection must become a priority for Pennsylvania residents if we are to continue to have the supplies necessary to meet our needs.

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This pamphlet is designed to be a tool for citizens and community leaders interested in learning more about groundwater. Readers are urged to get involved in their communities to inform residents and leaders about the need for groundwater protection and to help develop groundwater protection programs.

THE PA WREN Project publishes a newsletter, *Water Policy News,* which reports on community-based water resources protection activities throughout Pennsylvania. To be placed on the mailing list, obtain additional copies of this publication and to learn about other resource materials available from WREN, call the WREN Resource Center at 1-800-692-7281. Or visit the WREN website at: http://pa.lwv.org/wren/

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